A. Sopwith, Photo. Dawsons. Ph. Sc.

A TEXT-BOOK

OF

COAL-MINING.

FOR THE USE OF COLLIERY MANAGERS
AND OTHERS.

BY

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FIFTH EDITION.

THOROUGHLY REVISED, ENLARGED, AND IN PART RE-WRITTEN.

With Four Plates and 690 Figures in the Text.

LONDON:
CHARLES GRIFFIN AND COMPANY, LIMITED;
EXETER STREET, STRAND.
1904.

PREFATORY NOTE TO THE FIFTH EDITION.

THIS Edition has been thoroughly revised, and the size of the book has been considerably increased by the introduction of additional matter dealing more especially with the use of compound and electrical winding engines, and with the application of central condensation stations. Nearly two hundred figures were added to the fourth edition to illustrate, as far as possible, the most recent appliances, and the opinions that have attracted attention during the last half decade. These have been retained, and additional ones inserted in the present issue.

Year by year the more easily worked coal deposits become scarcer, and operations have to be carried on in deeper areas, or in seams presenting difficulties that have hitherto hindered their development. The mining engineer of the future will have to deal with commercial and technical problems that will tax his resources to the utmost. There is, too, little doubt that labour will also claim a greater proportion of the profit than it has in the past. The influence of this factor on the prosperity of the mining industry can be minimised only by the introduction of labour-saving appliances, by increased knowledge on the part of the engineer, and by a readiness to avail himself of improvements, which his own ingenuity, or that of his fellow-workers, may suggest. It is hoped that the information contained in this volume may help to remove local prejudices and to suggest ways in which the experience gained in other districts may advantageously be applied.

I have to thank Mr. G. Stephen Corlett for revising the electrical portion of the work, and I am again indebted to Mr. Bennett H. Brough and Mr. H. G. Graves for valuable suggestions.

H. W. H.

DUDLEY, *February*, 1904.

PREFACE.

In the preparation of this volume my aim has been to supply a text-book of moderate dimensions, giving all the information with which the student and the practical miner should be familiar. In order, however, to economise space, I have had to omit reference to many appliances which have become obsolete from their antiquity, or by reason of their failure in practice.

Although it is impossible within the limits of the book to furnish exhaustive descriptions on all points, yet the details of general colliery work have been fully described, on the ground that collieries are more often made remunerative by perfection in small matters, than by bold strokes of engineering. All modern collieries are practically identical so far as general machinery and arrangements are concerned; nevertheless, it frequently happens, in particular localities, that the adoption of a combination of small improvements any one of which viewed separately may be of apparently little value, turns an unprofitable concern into a paying one.

At the end of each chapter will be found a carefully selected list of Memoirs in which fuller information can be sought. This will, it is hoped, prove a novel and useful feature in a treatise on coal-mining, for, scattered through the pages of the Transactions of the Mining Institutes, numerous valuable papers exist; but, owing to the lack of general indexes, they are unfortunately not consulted so much as they deserve to be.

All the figures elucidating the text have been specially drawn for this work, the majority having been reduced from original working drawings.

In conclusion, I have to express my cordial thanks to the many friends who have rendered valuable help in the preparation of the work. Especially, I am indebted to Mr. B. H. Brough, Assoc. R.S.M., F.G.S., Mr. H. G. Graves, Assoc. R.S.M., and Mr. H. F. Bulman, for important suggestions and able assistance while the volume was passing through the press.

HERBERT W. HUGHES.

CONEYGRE COLLIERY,
DUDLEY, *September*, 1892.

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ABBREVIATIONS.

The following abbreviations have been used to denote the publications most frequently quoted in this work.

The Roman numerals designate the volume, and the ordinary figures the page. For. Abs. = Foreign Abstracts.

So. Wales Inst. .	Transactions of the South Wales Institute of Engineers.
Soc. Ind. Min. . .	Bulletin de la Société de l'Industrie Minérale de Saint Etienne.
Ches. Inst. . .	Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Fed. Inst. . . .	Transactions of the Federated Institution of Mining Engineers. Title altered to "The Institution of Mining Engineers," July, 1898.
Brit. Soc. Min. Stud.	Journal of the British Society of Mining Students.
N. E. I. . . .	Transactions of the North of England Institute of Mining and Mechanical Engineers.
N. Staff. Inst. . .	Transactions of the North Staffordshire Institute of Mining and Mechanical Engineers.
Inst. C. E. . . .	Minutes of Proceedings of the Institution of Civil Engineers.
Amer. Inst. M. E. .	Transactions of the American Institute of Mining Engineers.
Man. Geo. Soc. . .	Transactions of the Manchester Geological Society.
Eng. and Min. Journ.	The Engineering and Mining Journal, New York.
So. Staff. Inst. . .	Transactions of the South Staffordshire and East Worcestershire Institute of Mining Engineers.
Rev. Univ. . . .	Revue Universelle des Mines.
Min. Inst. Scot. .	Transactions of the Mining Institute of Scotland.
Mid. Inst. . . .	Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Ann. des Mines .	Annales des Mines.
Coll. Guard. . .	The Colliery Guardian, London.

TEXT-BOOK OF COAL-MINING.

CHAPTER I.

THE OCCURRENCE AND COMPOSITION OF COAL.

Preliminary.—Although some knowledge of geology is absolutely essential in the search for coal and in the working of the deposits, it is impossible in a text-book on coal-mining to deal usefully with so comprehensive a subject, or even to find space for a consideration of the salient points with which the mining student should be familiar. He is, therefore, referred to the standard treatises on geology. A few brief notes are here given to recall to his mind the order of succession of the beds of which the earth's crust is composed, and the meaning of the geological terms frequently used in describing the methods of winning and working coal seams.

The order of geological succession has been divided into four great divisions—(1) archæan; (2) palæozoic, or primary; (3) mesozoic, or secondary; and (4) cainozoic, or tertiary; to which is sometimes added the quaternary, or recent. These divisions are split up into systems, each system into formations, which usually receive the name of places where they are well developed, and, finally, the formations are subdivided into beds, characterised in many instances by certain fossils being always associated with them.

The following summary shows the classification at present adopted:—

CAINOZOIC, OR TERTIARY.	Post-pliocene.	
	Pliocene.	
	Miocene.	
	Oligocene.	
	Eocene.	
MESOZOIC, OR SECONDARY.	Cretaceous.	
	Jurassic.	
	Triassic.	
PALÆOZOIC, OR PRIMARY.	Permian, or dyas.	
	Carboniferous.	Upper, middle, and lower coal measures. Millstone grit. Carboniferous limestone.
	Devonian.	
	Upper Silurian.	
	Lower Silurian.	
	Cambrian.	

ARCHÆAN.—Crystalline rocks, schists, &c.

It must be observed, that these formations rarely succeed each other in the regular order given; breaks occur, caused by metamorphism and denudation, or by original non-deposition owing to local circumstances, and only by observations at numerous places has the order of succession been established.

The coal-miner is more interested in the carboniferous formation, that being the one in which beds of coal occur to the greatest extent all over the globe. In Great Britain, with one or two small and rare exceptions, the whole of the coal mined is extracted from beds of the carboniferous strata. The coal measures of Europe and the United States mostly belong to the carboniferous system, but in the latter country large deposits of coal occur in the cretaceous formation, and in the Pacific States (California, Washington, and Oregon) in the eocene formation, while much of the New South Wales coal belongs to the triassic.

Inclination of Strata.—Generally speaking, strata were laid down in a horizontal position, this being shown by the lie of pebbles in rocks, and by the position of fossil trees. It is, however, very rare to find the beds retaining this position, though the folding may be of the slightest. If a bed is at all inclined, it must reach the surface somewhere, and the space where this happens is said to be the *outcrop* of the bed. The nature of the outcrop and its width depend on the thickness of the bed and the degree of inclination; it cannot be less than the thickness of the bed, and is wider, the smaller the angle of inclination.

In order to define a bed, two things must be known—first, the direction in which the inclined bed reaches the surface, and the inclination of the bed. The angle which beds make with the horizon is called the *dip*, and the line in a horizontal plane, the *strike*, the latter necessarily being at right angles to the dip. When the surface of the ground is horizontal, the lines of outcrop and strike coincide, but, if the strata are inclined, the outcrop is inclined also; the strike is always horizontal. Angles of dip are usually measured by an instrument called a clinometer, but, in doing this, care must be taken to distinguish between the true and apparent inclination; the latter can never be greater than the former, but it may be less to any amount.

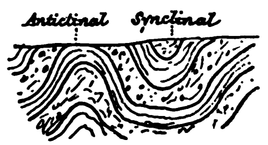

Fig. 1.

When the strata are bent in arches they are said to have a synclinal fold, when the arch is downwards; an anticlinal, when the arch is upwards (Fig. 1); when the folds are small, they are called troughs and saddles respectively.

Faults.—When the pressure is too great, or is applied suddenly, or if the rock refuses to yield, and then breaks, instead of bending, a dislocation is obtained; the divided segments are thrown out of level, and do not fit, one side being higher than the other. This is called a fault. In mining districts such term is applied loosely to anything which interferes with the seams that are being worked. Generally speaking, when contortions of the strata are numerous, faults are few; and *vice versâ*. The position of every fault is defined by two directions, as in the case of beds: the strike of a fault is spoken of, but, in the place of the word "dip," the term *hade* is employed, this being, however, the inclination measured from the *vertical*. To determine a fault accurately, it is necessary to know two other things—(1) which side is thrown up, and which is thrown down; (2) the amount of displacement. The former is in the majority of instances easily determined, as faults usually hade or incline towards the down-throw, so that in driving roads under ground, if the fault is first met with in the roof it is a down-throw, while, if struck on the floor first, it is an up-throw. Again, rocks before breaking usually yield to bending a little, and such signs are very useful to the miner, especially where the hade of fault is nearly vertical (Fig. 2). No rule can give the amount of displacement, as sometimes, when the hade is small, the throw is large, and at other times, with a similar hade, the displacement is small. The throw of faults is always measured vertically, and may be variable at different points, often changing from a few feet at one end to hundreds of yards at the other. In addition, there is often a variation in the throw of the same fault at different levels. When the amount is small, they are called hitches, troubles, or slips.

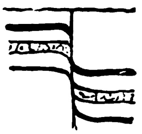

Fig. 2.

Fig 3.

Reversed Faults.—It has been observed above that ordinary faults incline to the down-throw, but in some instances they incline towards the up-throw, and are then said to be overlap or reversed faults (Fig. 3). The most noteworthy of this class in Great Britain is the overlap fault of the Somerset coal-field, which occurs in the Countess Waldegrave's colliery at Radstock; by it, the seams of coal are doubled for a breadth of about 150 yards, the alteration in level amounting to 44 yards.

The dislocated walls of a fault are often in contact with each other, but frequently, especially when the beds are of varying hardness, spaces are left between filled with broken fragments which have been removed from the adjoining rocks. The distance across a fault may therefore vary from a few feet to many yards.

When the rocks are very hard and the fault is a clean-cut one, we get a remarkable polishing of the sides known as "slickensides," caused by the enormous pressure of the rocks on each other during the displacement of the beds.

Trough Faults.—These are caused by two faults, each having a down-throw towards the other. A very good example of this is the Dudley Port Trough Fault, of the South Staffordshire coal-field (Fig. 4). Here two faults are separated from each other by half a mile—one a down-throw to the south, and the other a down-throw to the north. Each hades towards the other, so that they meet at no great depth, and, as the throw is equal and opposite at the point of meeting, no dislocation takes place.

Conformable and Unconformable Strata.—Subsidence has taken place in all times, but when this action was uniform, bed succeeded bed in regular order, and produced what are called conformable strata (Fig. 5). When, however, the beds were tilted up before the succeeding layer was deposited on them, or, as in many instances, the older beds were in addition denuded or worn away, the strata are said to be unconformable to each other (Fig. 6).

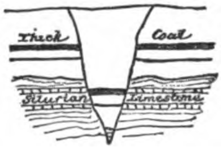

Fig. 4.

Fig. 5.

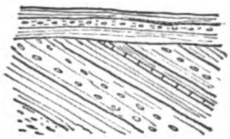

Fig. 6.

Carboniferous System in Britain.—This is divided into the following members:—(1) The *Coal Measures*, consisting of beds of shale and sandstone varying in thickness from 200 to 1200 feet, and containing numerous beds of coal. The coal measures proper may be further subdivided into upper, middle, and lower divisions, each of which possesses characters more or less peculiar to it; no sharp line of demarcation has, however, been yet satisfactorily established between them, each passing insensibly into the other. One peculiarity of the upper coal measures is worth noticing—namely, the occurrence in them of thin beds of a fresh-water limestone, containing immense numbers of a small shell called the *Spirorbis carbonarius*, from which the beds are called spirorbis limestone. (2) The *Millstone Grit*, consisting of coarse sandstones. This received, in the South of England, the name of the "farewell rock," as it contains no coal seams in that part of the country. This rule, however, does not apply to every district, as, in the North of England and in Scotland, beds of coal and shale are found. (3) The *Carboniferous Limestone* contains in Scotland thin beds of coal. This portion of the carboniferous system is built up of thick beds of limestone of marine origin, full of the remains of animal life.

Fossils.—The coal measures contain in varied abundance the remains of luxuriant vegetation. As an example, may be cited the occurrence of the plant known to the geologist as *Lepidodendron*, which attained dimensions of from 40 to 60 feet high, and several feet diameter. This plant is allied to the lowly club-moss of the present time, whose height does not exceed a few inches. Another example that may be referred to is the jointed and fluted stems called *Calamites*, represented in our fields and marshes by the *Equisetum*, or *horse-tails*. Portions of ferns are very abundant, some of which attained enormous dimensions. Remains of the stalks (rachis) of ferns have been met with, measuring in their compressed state 5 feet across, and Grand 'Eury describes the frond of a fern measuring 16 feet long. The classification of these ferns has always presented difficulties to the botanist, owing to the fragmentary manner in which they are found, but recent researches of Williamson and Kidston in Great Britain, Grand 'Eury, Schimper, Zeiller, and Stur in Europe, and Dawson and Lesquereux in America, have greatly extended our knowledge of a most fascinating branch of geology, and one in which the mining student is most directly interested. A knowledge of the flora of the coal measures is essential to any one searching unknown districts for indications as to coal-bearing rocks, and it is not too much to say that vast sums of money have been thrown away in fruitless attempts to prove coal to exist, where a little knowledge of the fossils of the carboniferous formation would have at once shown the uselessness of any search. The classification of these ferns has until lately been quite arbitrary, form of leaf and arrangement of nerves being the points usually relied on. Living ferns are referred to their several classes by the arrangement of their fructifications, which are usually borne in small rounded dots, called sori, on the back of the leaflets. Much knowledge has recently been gained of the fructifications of fossil plants, and hence a more reliable classification is the result.

Definition of Coal.—The question, "What is coal?" appears a very simple one to answer, but that such is not the case was proved by the now historical lawsuit over the Torbane Hill mineral in 1853. The owners of the Torbane Hill estate had leased all coal contained in it, and, in the course of working, the lessees extracted a combustible material containing a large amount of gas. The lessor claimed that this mineral was not coal, and disputed the right of the lessees to work it. A trial resulted, and geologists, chemists, and gas engineers gave evidence on both sides. In summing up, the judge remarked that "to find a scientific definition, after what has been brought to light within the last few days, is impossible." For our purpose, coal may be defined as a solid stratified substance, capable of undergoing combustion in contact with oxygen, not containing sufficient earthy impurities to prevent its being applied as a source of heat in furnaces and fireplaces, and varying in colour from brown to black.

Formation of Coal.—However much geologists may differ as to the question whether coal was formed on the spot on which the forests that produced it grew, or whether it resulted from the accumulation of drift, every one agrees that it results from the decomposition of vegetable matter. The hypothesis generally accepted is the former, although it seems perfectly clear that in some instances areas of coal have been formed by organic matter drifted into deltas. The common-sense view, that the land became submerged at intervals, and that the underclays of coal seams form the beds on which the plants originally grew, is the great argument in favour of the *in situ* theory, as it is an everyday occurrence to find the roots of trees firmly embedded in the underclay. On the other hand, trees and their rootlets are found in a horizontal position, and even inverted, while it is difficult to understand how the alternate rising and lowering of the ground could have so rapidly taken place, as would be necessary to account for the alternate layers of thin coal and shale so often found in coal seams.

Exposed to the action of the atmosphere, vegetation decays and goes to enrich the soil, but supposing that the organic material fell into water, decay is incomplete, layer would be deposited on layer, and under pressure deposits of coal are formed. In peat bogs, for instance, living plants are found at the surface, lower down the forms of plants are still recognisable, while the bottom portion is very compact, and vegetable structure can scarcely be distinguished; as we go deeper in the mass the quantity of carbon increases. The conversion of woody tissue into coal takes place by the elimination of oxygen, which combines with carbon to form carbonic acid gas and by the separation of carburetted hydrogen ("fire damp" of the miner) and water. To illustrate the gradual change in composition in passing from wood to anthracite coal, Dr. Percy* gives the following table, the proportion of carbon being estimated at the constant amount of 100 :—

Substance.	Carbon.	Hydrogen.	Oxygen.	Disposable† Hydrogen.
Wood (the mean of several analyses),	100	12·18	83·07	1·80
Peat ,, ,, ,, ,,	100	9·85	55·67	2·89
Lignite ,, ,, 15 varieties, . .	100	8·37	42·42	3·07
Ten-yard coal of South Staffordshire,	100	6·12	21·23	3·47
Steam coal from the Tyne, ...	100	5·91	18·32	3·62
Anthracite from Pennsylvania, U.S.A.,	100	2·84	1·74	2·63

Note.—All bodies existing in Nature consist of substances that cannot be resolved into any simpler form, these being called *elements* by chemists, and designated by symbolic abbreviations. The smallest indivisible parts of these elements are called atoms, and these, by combination with each other, form the substances occurring in Nature. The number of atoms of each element comprised in any substance is shown in chemical formulæ by a number following the symbol of each element. Thus, water contains one atom of oxygen and two of hydrogen, its chemical symbol being H_2O.

Classification of Coals.—The classification of the various coals occurring in the sedimentary rocks is best done by dividing them into heads according to the relation between the proportions of carbon and oxygen. In this manner is obtained (1) Lignite, (2) Bituminous Coal, (3) Steam Coal, (4) Cannel, (5) Anthracite.

1. *Lignite.*—Found in our own country at Bovey Tracey, in Devonshire. Some varieties show distinct woody texture, while others are structureless. They contain a large proportion of water, burn with a disagreeable odour, and are brown in colour. Lignite coal contains about 67 per cent. of carbon and 26 per cent. of oxygen. A subdivision of the class is sometimes made, called *brown coal*, which contains a larger proportion of carbon and less oxygen than the true lignite. It occurs in large quantities on the Continent and in some of our colonies, an analysis of brown coal from New Zealand showing, carbon 72·2, oxygen 22·4, hydrogen 5·4.

2. *Bituminous Coal.*—The proportion of carbon in this class varies from 75 to 90, and the oxygen from 6 to 19. They burn with a more or less smoky flame, and are largely used for household purposes. As the proportion of oxygen decreases, the coal gets blacker and less sonorous, and the friability increases. The bituminous class of coals may be further subdivided into non-caking and caking varieties; the former, when burnt, split up into fragments, while the latter soften on the fire and swell up, the particles bind together, and form a pasty mass. This property is an extremely valuable one, and from this class of coal are made great quantities of coke. The small pieces are heated together in a suitable oven to a certain temperature, and when the mass is withdrawn and cooled, a hard glistening mass is obtained, in which all form of the original particles is lost. It has never been

* *Metallurgy* (*Fuel*), &c., 1875, p. 208. † For definition, see p. 9.

established to what this property of caking is due, but it is certain that ultimate analysis forms no guide. Mr. Gruner gives the following analyses of two coals:—

	(a)	(b)
Carbon,	75·2	76
Hydrogen,	4	4·3
Oxygen,	16	16
Ash,	3	3·3
Water,	6·3	5·4

These coals are nearly identical in composition, but while (*a*) cakes, (*b*) does not. Chemists can determine the amounts of the various elements present in coal, but are quite unable to say how these elements are combined amongst themselves, these internal combinations being the probable explanation of the different behaviours of coals of the same ultimate analysis. For commercial purposes, proximate analysis is all that is required, this giving us the amount of fixed carbon (coke), volatile matters, and the amount of impurities. There appears to be no rule for determining the caking qualities of a coal, except actual experiment, as this property is possessed by coals differing widely in composition. It appears to be influenced by the method of conducting the experiment; thus, in some cases rapid heating will cake a non-caking coal. The amount of ash present does not seem to influence the result, as examples are known of a caking coal containing 20 per cent. of ash. On the other hand, many coals lose their power of caking by long exposure to the air.

3. *Steam Coals.*—These are principally worked in the South Wales and North of England coal-fields. As their name denotes, they are mainly used for the production of steam; their evaporative power is high, and they give off scarcely any smoke in burning, while, on account of their structure, they burn more readily than anthracite.

4. *Cannel Coal.*—The chief deposits of this class occur in the Lancashire and Scotch coal-fields. Cannel is very rich in hydrogen, and is mainly used for the production of gas, as it yields by destructive distillation about 40 per cent. of volatile matters. It is very hard, dense, and structureless, and is sometimes used for the manufacture of ornaments. In this division of coals may be included certain shales, containing large quantities of bituminous matters, which on distillation yield liquid and solid paraffin. The Boghead cannel, over which the celebrated trial took place, may be considered the representative of this type.

5. *Anthracite.*—The darker and denser varieties of ordinary coal gradually pass into the anthracite varieties, which are characterised by the large amount of carbon they contain. They do not soil the fingers, are very hard, and break with a conchoidal fracture. The formation of anthracite has probably been effected by the alteration of bituminous coals under heat and pressure. In the South Wales coal-field the same seam of coal, which is of the ordinary bituminous variety in the eastern district, passes by gradations into steam coal in the middle of the coal-field, while in the western district it is changed into anthracite. Enormous deposits of this class of coal are met with in Pennsylvania, our own store being confined to South Wales. Anthracite contains from 93 to 95 per cent. carbon, 4 to 2 per cent. hydrogen, and 3 per cent. oxygen. It is practically smokeless when

No. of Sample.	Nature of Coal.	Locality.	Specific Gravity.	Composition per Cent.							Coke.
				Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Water.	
1.	Lignite, .	Bovey Tracey, Devonshire, . . .	1·129	66·31	5·63	22·86	0·57	2·36	2·27	34·66	30·79
2.	" .	Bodonspatak, Hungary, ...	1·327	55·94	4·26	33·23	...	4·27	3·30	10·84	52·60
3.	" .	Auckland, New Zealand, ...	...	55·57	4·13	15·67	1·15	0·36	9·00	14·12	...
4.	Bituminous,	Thick coal, Wolverhampton, S. Staffs.,	1·278	78·57	5·29	12·88	1·84	0·39	1·03	11·29	57·21
5.	" .	Arley coal, Bolton, Lancashire, . .	...	80·32	5·33	7·47	...	2·13	2·87	1·88	63·32
6.	" .	Northumberland, ...	1·276	81·41	5·83	7·90	2·05	0·74	2·07	1·35	66·70
7.	" .	Aberdare, South Wales, ...	...	85·74	4·54	3·57	...	0·81	4·64	0·70	76·10
8.	Steam, .	Merthyr, South Wales, ...	...	86·80	4·25	3·06	...	0·83	4·40	0·66	84·42
9.	" .	Llwynypia, South Wales, . . .	1·310	90·55	4·14	2·35	1·26	0·45	0·67	0·58	85·68
10.	" .	Pontypool, Monmouthshire, . .	...	90·63	4·11	2·53	...	0·48	1·65	0·60	88·35
11.	" .	Aix-la-Chapelle, ...	1·343	91·45	4·18	2·12	...	...	2·25	...	89·40
12.	Cannel, .	Wigan, ...	1·276	80·07	5·53	8·08	2·12	1·50	2·70	0·91	...
13.	" .	Lesmahagow, Scotland, ...	1·251	73·44	7·62	11·76	...	1·14	6·03	...	43·30
14.	" .	"Boghead," Edinburgh, ...	...	63·10	8·91	7·25	...	0·96	19·78	...	19·78
15.	Anthracite,	South Wales, ...	1·392	90·39	3·28	2·98	0·83	0·91	1·61	2·00	...
16.	" .	South Wales, near Swansea, . . .	1·348	92·56	3·33	2·53	...	...	1·58	...	...
17.	" .	Pennsylvania, ...	1·462	90·45	2·43	2·45	...	...	4·67	...	...

The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

The composition per cent. is calculated on dry samples in Nos. 1, 2, 4, 6, 11, 12, 13, 14, 15, 16, and 17, and water is included in Nos. 3, 5, 7, 8, 9, 10.

burning, and is much used where such a property is valuable, as, for instance, in malt-drying and in some metallurgical operations. The coke is brittle.

The table* (p. 8) shows the percentage composition of different classes of coal.

Commercial Value of Coals.—The value of coal as fuel depends chiefly on the *Calorific Power*, which is the total heat developed by combustion, expressed either in units of heat or of evaporation, and by the amount of ash and impurities present.

In determining the calorific power of fuels, the same difficulty is met with as in judging of the caking properties. The composition, and the units of heat developed by the combustion of each component of the coal, being known, the theoretical calorific power can be easily determined, but, as before, we neither know how the various elements are combined together, nor what quantities of heat appear or disappear during the breaking up of the complicated compounds of which coals are composed. Direct experiment is resorted to for ascertaining the actual calorific power, the operation being performed in an instrument called a *calorimeter*. The most convenient of these for practical purposes is the one designed by Mr. Lewis Thompson, which consists of a glass vessel (*a*, Fig. 7) containing a known quantity of water. A weighed invariable quantity of the coal to be experimented with is intimately mixed in a mortar with about ten times its weight of a mixture of three parts potassic chlorate and one of potassic nitrate. This mixture is placed in a small copper cylinder *b*, which in its turn is covered with another copper vessel *c*, furnished with a tube and stopcock *d* on the upper side, and pierced with holes *e* on the lower end. A fuse is placed in the smaller cylinder containing the mixture, this is lighted, the stopcock closed, and the apparatus let down to the bottom of the graduated flask containing the water. When combustion has ceased, the stopcock is opened and the apparatus is moved gently up and down, care being taken not to raise it out of the water. The temperature is noted at the beginning and end of the experiment, and from a table supplied with each instrument the calorific power is found. The rise of the temperature, plus 10 per cent. of this rise, will give the number of lbs. of water which 1 lb. of coal will convert into steam from and at 212° F. The importance of calorific power is not at all understood by consumers. One coal may be obtained for a less price than another, but if the lower-priced coal has less calorific power than the other one, the consumer may not be obtaining the best value for his money. Coals rich in oxygen never have such high calorific powers as those containing a smaller amount, as the quantity of hydrogen available for heating purposes in any fuel is not the total amount of that element present, but only that portion of it (called *disposable* hydrogen) which is in excess of the quantity required to form water with the oxygen contained in the coal. The amount of disposable hydrogen in any coal can be ascertained, when its composition is known, by dividing the quantity of oxygen present

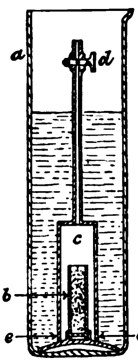

Fig. 7.

* Compiled from Dr. Percy's *Metallurgy* (*Fuel, &c.*), London, 1875.

by 8 and subtracting the result obtained from the total quantity of hydrogen present, the remainder being the disposable hydrogen. Calorific powers of a few coals are given in the following table *:—

Locality.	Nature of Coal.	Calorific Power (in heat units), of dry Coal free from Ash.
Toula, Russia,	Lignite	13,837
Manosque, Basses Alpes,	,,	12,584
France and Germany,	Brown coal	11,340-14,220
England,	Caking coal	15,804
,,	,, ,,	16,108
Basin of Donetz, Russia,	,, ,,	15,651
Le Creusot, France,	,, ,,	17,319
,, ,,	Anthracite	17,021
Basin of Donetz, Russia,	,,	14,866

The ash of coals is the substance remaining when total combustion has been effected. It is composed of the earthy impurities originally present in the coal, and may be easily determined by burning a weighed quantity of coal in a porcelain crucible, either over a Bunsen gas-burner, or in a muffle. It is important that not only the *quantity* of ash should be determined, but also its *nature*. Some ashes tend to fuse together and form "clinker," which is very objectionable; more attention is required from the stoker, as he has to be continually stirring up the fire, and even when this is done thoroughly, the draught is materially interfered with, and imperfect combustion is likely to take place. Coal may contain such a large proportion of ash as to be practically worthless as a fuel. The amount of iron pyrites present has also a great effect on the nature of ash, as fusion is assisted and a tendency to form clinker results. Sulphur, too, which is contained in pyrites, is very objectionable in some metallurgical operations.

Gases occluded in Coal.—The majority of coals contain various gases, which are given off when exposed to the atmosphere. Generally this takes place slowly, and may be observed by the singing noted at the working places in fiery seams of coal, or by the sudden outbursts of gas which are known to the miner by the name of "blowers." Certain coals of a porous structure readily yield up the gases contained in them, while others of a denser character, although containing even more gas stored in them, do not discharge it in such quantities. In vacuo, and under the influence of a gentle heat, coals readily discharge the gases they contain. Mr. J. W. Thomas † has made a series of experiments on this subject which throw a great deal of light on the question. He finds that the gases occluded from bituminous coals consist mainly of carbonic acid, and that the quantity yielded is very much smaller than that given off by the steam and anthracitic varieties. Steam coals evolve a large quantity of gas, the chief component of which is marsh gas, which in some instances reaches as high as 87 per cent. Anthracites yield by far the largest volume of gas, with a composition closely resembling that from steam coal. The following

* *Coal, its History and Uses*, 1878, p. 250.
† *Coal, Mine Gases and Ventilation*, 1878.

table* shows the quantities of gas evolved from coal at 100° C. (212° F.) in vacuo, and its percentage composition :—

No. of Sample.	Nature of Coal.	Gas evolved by 100 grammes of coal at 100° C. *in vacuo.*	Composition of Gases.			
			Carbonic Acid.	Oxygen.	Marsh Gas.	Nitrogen.
		c.c.				
1	Bituminous, .	55·9	36·42	0·80	...	62·78
3	,,	55·1	5·44	1·05	63 76	29·75
3*a*	Semi-bituminous,	73·6	12·34	0·64	72·51	14·51
4	Steam, . .	194·8	5·04	0·33	87·30	7·33
5	,, . .	250·1	13·21	0·49	81·64	4·66
8	,, . .	375·4	9·25	0·34	86·92	3·49
9	,, . .	149·3	11·35	0·56	73·47	14·62
13	Anthracite, .	555·5	2·62	...	93·13	4·25
14	,, .	600·6	14·72	...	84·18	1·10

Mr. Thomas points out, that these results were obtained in a laboratory, and that it must not be supposed that coals which contain the greatest quantity of gas in their pores are the most dangerous to work, the rate of discharge being controlled, as has been before pointed out, by the structure of the coal. Anthracites, for instance, although holding large quantities of marsh gas, are by no means dangerous to work, as only small quantities of gas are discharged at the working face owing to the jet-like nature of these coals, such structure being eminently favourable to the retention of gas. On the other hand, steam coals, although containing a smaller quantity of gas, readily give it up, owing to their porous nature, and the quantity of gas evolved at the face of the workings in some of these coals is enormous. From these results we are able to see where the explosive gases in mines are obtained, and can readily understand that mine-gases and the gases occluded in the coal stand in definite and fixed relationship. Mr. Thomas experimented in this direction, and the results he obtained are summarised in the following table :—

No. of Sample.	Whether a Blower or obtained by boring into Coal.	Composition of the Gas.			
		Marsh Gas.	Carbonic Acid.	Oxygen.	Nitrogen.
1	Blower, ...	97·65	0·50	...	1·85
2	Boring, ...	97·31	0·38	...	2·31
3	Blower, ...	96·74	0·47	...	2·79
4	Boring, ...	96·54	0·44	...	3·02
5	,, ...	74·86	0·15	4·69	20·30
8	Blower, ...	94·84	0·10	...	5·06
10	,, ...	47·37	0·90	10·15	41·58
14	,, ...	95·56	0·35	0·11	3·98

The enormous pressure under which these gases are contained in the coal will be realised when it is stated that in the 4-feet seam of the Harris Navigation Colliery, at a depth of 700 yards from the surface, and with a bore-hole put 30 feet into the face of the coal, the

* *Op. cit.*, p. 345.

pressure was 143 lbs. per square inch; while a bore-hole 50 feet deep, in the 4-foot seam at Merthyr Vale Colliery, at a depth of 450 yards from the surface, registered 280 lbs. per square inch pressure of gas; it may be further added that these pressures are by no means the maximum ones that have been obtained in different collieries.*

"Blowers" of small dimensions usually follow the face, and as this proceeds the older ones die out and newer ones take their place. A thin seam of coal overlying the bed worked is very favourable for supporting this action. By the sinking of the strata, cavities are formed in the measures above the roof, and these are filled with accumulations of gas; a crack is by some means formed, and an outburst of gas results. This action is guarded against in some collieries by a regular system of putting bore-holes up in the roof, and thereby gradually draining all the gas from the measures. In driving exploring works, large blowers are frequently met with which yield enormous volumes of gas, sometimes for long periods of time, and sometimes for smaller ones. In the former case the gases are conveyed to the surface through pipes and burnt; while in the latter the district has to be temporarily abandoned until the outburst has exhausted itself.

The World's Production of Coal.—The world's annual production of coal and lignite now amounts to about 780,000,000 tons. The production of the coal-producing countries in 1901, expressed in tons, was as follows:—United Kingdom, 219,046,945; Australasia—New South Wales, 5,968,426; New Zealand, 1,239,686; Queensland, 497,132; Tasmania, 43,000; Victoria, 209,000. Austria, 11,738,839 coal and 22,473,500 lignite; Hungary, 1,367,189 coal and 5,130,077 lignite; Belgium, 23,462,800; Borneo, 35,360; Bosnia, 445,000; Canada, 5,613,690; Cape Colony, 198,450; France, 31,613,000; Germany, 108,417,000 coal and 44,211,900 lignite; Greece, 9,720; Holland, 320,220; India, 6,635,700; Italy, 425,610; Japan, 7,429,450; Mexico, 38,670; Natal, 569,200; Peru, 47,500; Portugal, 22,200; Russia, 15,652,480; Servia, 192,800; Spain, 2,514,500; Sweden, 271,500; Transvaal (1898), 1,953,000; United States, 260,929,248.

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CHAPTER II

SEARCH FOR COAL.

Prospecting.—The preliminary operations in searching for coal in new districts, consist in carefully examining surface indications to determine the nature and position of the beds exposed in the area under examination. A knowledge of geology is indispensable for such work. The banks of streams and cuttings should be closely examined, and all outcrops noted and laid down on a rough sketch-map. Rocks and fossils of Carboniferous age afford the best indication of the probable existence of coal, but it is not absolutely necessary that such should be found at the surface, nor is it certain that when they are found coal surely exists beneath. For instance, in England, the greater part of the Somerset coal-field is covered with rocks of newer formations (Lias and New Red Sandstone); while in the north of France and Belgium, thick deposits of the Cretaceous formation are passed through before reaching the Coal Measures. Perhaps the most remarkable instance of the reversal of strata is afforded at Drocourt, in the Pas de Calais, where, after sinking through the Cretaceous, they passed at a depth of 413 feet into the Devonian; and after sinking in this formation to a depth of 958 feet from the surface, met with very disturbed Coal Measures, and beds of coal, which were worked for a considerable period. The shaft was sunk deeper and deeper, until at 1886 feet a fault was reached. On passing through this, the *ordinary* Coal Measures of the district were met with, and are now being worked. The Devonian and first portion of the Coal Measures met with had evidently been bent completely over before the Cretaceous was deposited.

Boring.—Even after the examination above referred to, from which the probable existence of minerals may be reasonably inferred, further proofs have to be obtained. If outcrops of actual seams have been found, a great deal can be done by sinking shallow pits or by driving levels. Indications at small depths are, however, seldom conclusive, especially as regards the quality of the coal seams, and the operation of boring is generally resorted to.

Choice of Site.—For proving considerable areas several holes may be required, the sites of which are determined by the extent, location, and general features of the land to be developed. The preliminary survey decides these general features, but consideration has also to be given to the suitability of the spot for the erection of the drilling apparatus and for carrying on the work.

Various Appliances used in Boring—(*a*) *Bits.*—For shallow holes in soft ground the borer consists of some heavy instrument of the "scoop" kind, the general form being a cylinder, the cutting edge having a slit up its side like a gimlet. In soft, loose ground, pipes furnished with a cutting edge can be driven down by blows of a heavy wood block dropped through a considerable height. A second pipe of smaller diameter is lowered inside the drive-pipe, and through it a strong stream of water is forced. This second pipe follows the cutting-shoe, and stirs up the loose material and washes it to the surface.

This method is largely used in America, up to 300 feet of gravel being easily got through. The pressure of water is sufficient to force up gravel of about ½ inch diameter, but if larger pieces than this are encountered they must be chopped to pieces.

For harder ground bits of chisel-shape have to be employed. These are suspended from rods, which are raised up and dropped down, thereby chipping off small quantities of rock. The rods are rotated after every blow, so that the tool drops in a different place each time.

The general form of chisel employed is that having a straight edge (Fig. 8). The angle enclosed by the cutting edges is variable, depending on the nature of the rock. For hard rocks, a chisel with an acute edge is too likely to break; the angle should not exceed 70°. The size of the chisel should be carefully measured before it is lowered into the hole, as if it is too wide it will jam, while if too small the hole will get too narrow. As with all tools, the chisel was formerly made of wrought iron tipped with steel, but is now universally constructed of steel throughout. For very hard rocks a V-shaped chisel is sometimes employed. Various other shapes have been tried from time to time, but abandoned, owing to the difficulty of sharpening.

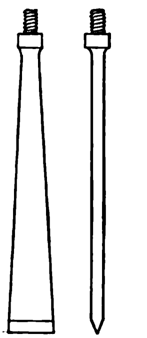


Fig. 8.

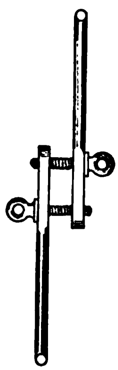


Fig. 9.

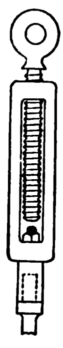


Fig. 10.

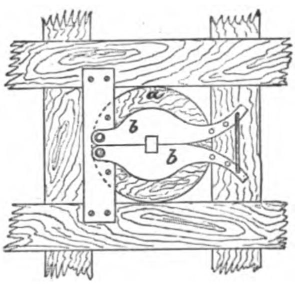


Fig. 11.

(*b*) *Rods.*—These may be either of wood or iron, the latter being most common. Their usual size is about 1 inch square, and from 28 feet to 36 feet long. Shorter pieces for making up lengths are also used. As the hole gets deeper the thickness of rods has to be increased. The rods are provided with screwed and socket ends, and as the portion on which the screw is cut should be the same size as the rod itself, the metal is thickened out at the joints, forming a shoulder, to which the tools for supporting the rods during changing operations can be conveniently attached. The common triangular screw thread is generally employed, and the socket made deeper than the screw, in order that the shoulders of two successive rods should bear firmly against each other, thereby preventing the risk of stripping the thread. All the joints should be identical, made to gauge, and be well fitting, or the liability to accident is great. Splitting the socket is perhaps the commonest failing, and may be minimised by exercising care in preventing the vibration of the rods. The rods should always be rotated in the same direction as they are screwed up together, and when the threads begin to wear they should be broken off and fresh end pieces welded on.

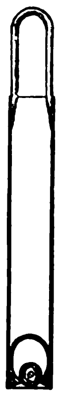
After each blow the rods and chisel are turned through a small angle by the "tiller" (Fig. 9), which is attached at the surface. To enable this operation to be easily carried out, a swivel joint is introduced. As the depth of the hole slowly increases the rods necessarily descend, being allowed to do so by the use of an instrument called the "stirrup" (Fig. 10), which consists of a collar gradually working down a long screw. When the limit of travel of this instrument is reached, it is detached, the screw run back into the position shown in the illustration, and a short length of rod inserted between it and the main length attached to the tool. This operation is repeated until sufficient distance has been bored to allow of the insertion of an ordinary length of rod, the smaller making-up pieces being then removed. For unscrewing, an ordinary spanner key is employed.

(c) *Guides.*—To keep the hole vertical a guide-block is fixed at the surface. This generally consists of a block of wood (*a*, Fig. 11) about 9 feet long, through the centre of which passes a hole of the same diameter as the bore-hole. It is fixed truly vertical, and secured by four pieces of wood arranged in the form of a square. Its upper end is furnished with two stops (*b*, *b*) turning around pins. A piece is cut out of each shutter, leaving an opening central with the hole, and of a size slightly larger than the rods, so that when the latter are in position the space is filled in. This shutter really fills two purposes, as it prevents anything falling down the bore-hole, and also suspends the rods during the operation of unscrewing, the hole through it being large enough to allow the rods to pass, but not a joint.

In deep holes other guides are inserted in the rods at regular intervals. A common form is that shown by Fig. 12, which readily passes through water. Discs and other shapes have been abandoned, as even where water-ways are left through them, they set up eddies in the water filling the bore-hole, wearing away the sides, and causing them to fall in, if the rock is at all soft.

(*d*) *Clearing Instruments.*—When a sufficient amount of cutting has been done, the débris which has accumulated at the bottom of the hole is removed by the "sludger" (Fig. 13), which consists of a tube from 4 to 6 feet long, having a valve at the bottom, either of the ball or flap-door type. The removal is usually done with a rope, sometimes a few lengths of rods being added to give weight. When the sludger reaches the bottom, it should be picked up and dropped several times before raising to the surface. For deep and large bore-holes a superior class of sludger is employed, having, in addition to the valve at the bottom, a piston working in the barrel portion. When this piston is drawn up it sucks-in the slime.

(*e*) *Levers.*—The most general way of working the rods in percussive boring is to attach them to the shorter arm of a lever (Fig. 14), the longer end of which receives an up-and-down motion; as previously mentioned, the rods are suspended by a swivel, and are turned by the bore-master after each blow. Where manual labour is employed two or more smooth cross-bars are attached to the longer arm of the lever, so that more men are able to work at it. With cross-pieces 8 feet long, six men can work on each side. For deep holes manual labour is quite out of place, and the long end of the lever is depressed at intervals, either by large teeth on a revolving wheel driven by steam, or, preferably, by directly connecting it with the piston-rod of a cylinder.



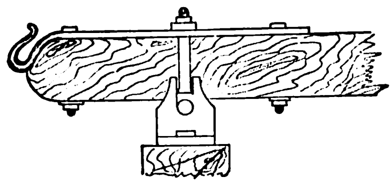
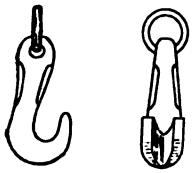


Fig. 14.

Fig. 12. Fig. 13. Fig. 15.

(*f*) *Spring Pole.*—In our coal districts the vibratory movement is often given to the rods by the use of the spring bar, which consists of a wooden pole having one end fixed to the ground, a fulcrum placed further on, and the rods attached to the other end. The blow is struck by depressing the beam, the rods being raised by the elasticity of it. The lengths of the parts on each side of fulcrum are usually 1 : 3 or 5. For shallow holes the axis may be fixed, but for deeper ones it must be movable. An elaboration of this method consists in the employment of two spring poles. The first is from 60 to 70 feet long, fastened at one end (Fig. 15), and at $\frac{2}{3}$ of its length from the fixed point it rests on an upright. To the other end are fixed two cross-bars which the workmen press down on to a second spring pole, thus producing a dancing movement. Between the upright and the cross beams is attached a hook, from which the boring tools are hung in the usual manner.

(*g*) *Frames.*—In order to enable the rods to be raised perpendicularly, a frame of three shear legs is erected at the surface, to which a pulley is attached at the top, one of the shear legs having steps on it so that this may be easily reached. For shallow holes a windlass supplies motive power, but in larger holes a steam engine and drum is employed. To save labour in unscrewing the rods, it is advisable that the frame should be made as high as possible, so that a long length of rods may be raised at a time. This is done in the following manner:—The stops (*h*, Fig. 11) are opened, and a hook (Figs. 16 and 17) at the end of the rope is placed beneath a joint in the rods, these being then detached from the end of the lever. The rope is then hoisted up until the limit in height is reached, when the stops are closed beneath the nearest joint, and the rods above that joint unscrewed and removed. This operation is repeated until all are withdrawn. The sludger is then lowered, either by the same rope, or, if the boring is a large one, by a second one passing over another pulley lower down the frame. After clearing out the débris the rods are replaced by a reversal of these operations. One point must be specially noted: the rods when not in use should never be stood on end, but always suspended.



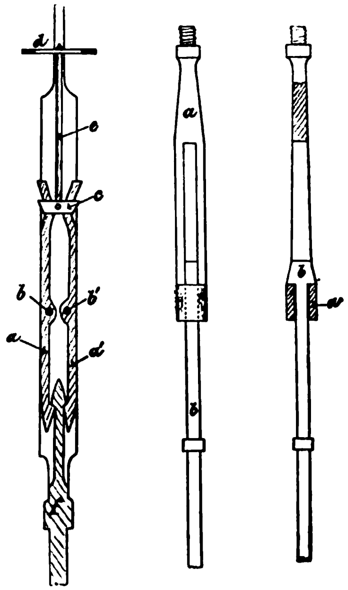
Figs. 16 and 17.

Devices employed to meet Difficulties of Deep Boring.—As the depth of holes increases a large number of difficulties arise, the greatest one being the weight of the rods themselves. Rods 1 inch square weigh about 1 ton for every 200 yards. In deep holes not only does this great weight injure the screw joints, alter the structure of the iron, and break the tool which receives the blow, but it sets up excessive vibration in the rods, injures the sides of the hole, and accumulates a mass of broken material above the tool which often leads to rupture when an attempt is made to withdraw it. To overcome these disadvantages several methods are employed.

(*a*) *Lighter Rods.*—Hollow iron rods were first suggested, the weight of these for the same strength as solid ones being in the ratio of 1 to 1·35. They were, however, found to be too expensive. Wooden rods were then introduced. They possess certain advantages over iron, as not only are they specifically lighter, but, when the bore-hole contains water, as their size is also greater, a larger volume of water is displaced. They also fit the hole tightly, and do not rattle about from side to side like iron ones. When a rupture occurs with iron rods, the large weight dropping down causes other breakages and the bending of rods in the hole, often rendering it a most difficult matter to get them out. On the other hand, when a breakdown occurs with wooden rods, there is generally only one fracture. The great objection, however, to their employment is the large diameter of hole required, owing to the necessity of using rods 2 to 3 inches square for shallow depths. For larger and deeper holes this objection is removed, and such rods have been largely employed in Canada and on the Continent.

(*b*) *Free-falling Cutters.*—The greatest advance made in percussive boring, was undoubtedly the introduction of what are known as "free-falling cutters." By their use, vibration and shocks in main rods are practically avoided, the only portion of the apparatus that is really let fall being the boring tool itself, and as much of the apparatus as is necessary to give weight to the blow.

The tool designed by Kind has been largely employed. It consists of two fangs or pincers (*a*, *a*′, Fig. 18), working about centres *b*, *b*′. These fangs are enclosed at their upper extremity by a collar *c*, connected to a circular disc of leather *d*, through a rod *e*; at their lower end they grip, during certain stages of the operation, that part, *f*, of the rods to which the tool is attached. As shown in the illustration, the rods are making their upward stroke, and the pressure of water in the bore-hole depresses the leather disc, pushes the collar c down on the tangs, and causes them to retain their hold of the lower part of the rods carrying the tool. When the limit of the up stroke is reached, a sudden change of motion takes place in the opposite direction, causing the pressure of water on the underside of disc d to lift the collar, thus opening the fangs. The tool and lower rods fall quickly and deliver their blow, while the long length of upper rods follow at a slower speed. When this has descended to the proper point, a slight upward motion, producing pressure on the upper side of the leather disc, causes it to descend with the rod e and collar c, and so close the fangs.



Figs. 18, 19, 20.

The above apparatus reduced in a marked manner the breakages of tools and rods, and consequently the cost of boring. It is, however, inapplicable in dry and narrow holes, is somewhat complicated, and causes the water to form streams, whilst the slime from the hole collects on the disc, and prevents it from acting.

Numerous other complicated appliances have been used from time to time, but practically have all given way to the sliding joint invented by Œynhausen. As before, the rods are divided into two lengths, but a sliding joint forms the connection between them. The two lengths a and b (Figs. 19 and 20) are raised together and also fall together, until the lower part b, to which the tool is attached, strikes on the bottom of the hole, when its motion is arrested. The upper part, however, continues its downward movement (the collar sliding over the stationary lower rods), and is gradually brought to rest within the limit of length of the slide by an elastic stop placed beneath the rocking lever at the surface. By this means, the shocks received by the tool and lower rods do not reach the upper part.

Mr. W. Wolski* is of opinion that the consideration of the proper length of the stroke of boring rods has been neglected as it has a great effect on the boring. After considering the matter in its several bearings he draws the conclusion that the efficiency of boring increases as the square root of the length of the stroke (the maximum limit is fixed at 6½ feet), but lighter blows may be used with soft rock, and some clays cannot be treated otherwise. In all other cases, especially with hard rock, the heaviest blows and the greatest length of stroke are essential. A short thick rod is preferable to a long thin rod of the same weight.

* *Fed. Inst.*, xiii., 646.

Obtaining Cores.—It is of the greatest importance that satisfactory samples of the strata cut through should be obtained. With the tools already described, everything is chopped to small pieces, and it is necessary to examine the contents of the sludger very closely, to determine what material the hole is passing through. In order to obtain more definite results with percussive boring, a tool is put down consisting of four or five chisels, arranged round a cylinder (Fig. 21), which cuts away an annular space, leaving a central core. A second tool is then lowered down to the bottom of the hole, and a cutting tooth at the base is pressed inwards by means of a spring. This tool is revolved several times, until the greater part of the foundation of the core is cut away, and then by a sharp jerk the whole is detached, and brought carefully to the surface.


Fig. 21.

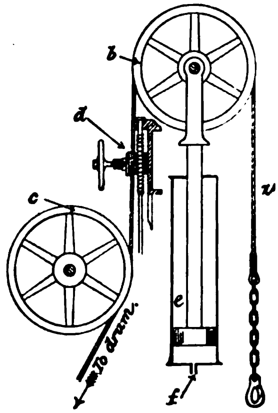


Fig. 22.

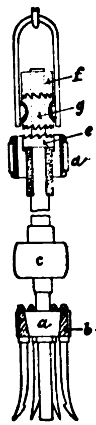


Fig. 23.

Special Methods of Boring.—The greatest change which has taken place in percussive boring is that due to suspending the tools by a rope, in place of the rigid bar. To the Chinese belongs the credit of first employing this means. The shank of the tool consists of a heavy cylinder of iron attached to a rope of bamboo fibres, the torsion of which is sufficient to rotate the tool after each blow. Motion is communicated at the surface by means of a spring pole.

(*a*) *Mather and Platt's System.*—In this method,* the tool is suspended from a flat hempen rope, but the system differs from all others in the measures employed for rotating the tool, and giving it the necessary percussive action. The rope to which the tool is attached (*a*, Fig. 22) passes over a pulley *b*, over the hole, and thence is directed by a guide pulley *c* to the drum of a winding engine worked by steam power. This rope can be clamped at an intermediate point by means of the clutch *d*. The up and down motion is obtained by connecting the pulley *b* to the piston-rod of a small vertical cylinder *e*. As the rope is clamped on one side at the point *d*, when the piston moves upwards it carries the tool and rope hanging in the

* "Well Boring." F. Mather, *Proc. Inst. Mec. Eng.*, 1869, 278.

hole with it, and allows it to fall on the return stroke. As the hole deepens, the rope on the drum is gradually let out. A self-acting valve motion, worked by tappets moved by the piston-rod, is employed, and the length of stroke can be varied by altering the position of the tappets. Before the valves can be opened, it is necessary that the piston-rod should move; a small quantity of steam is therefore kept continually blowing on to the underside of the piston, through the small port *f*. As the exhaust port is situated a little higher up the cylinder, this really serves an additional purpose, as it interposes a cushion of steam between the piston and bottom of cylinder, preventing any chance of the latter receiving a blow on the return stroke.

The boring head (Fig. 23) consists of an iron bar about 8 feet long, having a cast-iron boss *a* at the bottom, into which the cutting tools are secured with taper shanks *b*, so as to be firm in working, but easily taken out for sharpening. Two guides are employed to keep the tool perpendicular; one, *c*, being a plain cylinder, the other, *d*, having ribs of saw-tooth form arranged round its circumference. These ribs have a long pitch, and as they bear against the sides of the bore-hole assist in turning the tool. Each alternate plate has the ribs inclined in opposite directions, so that one-half are acting to turn the bar in rising, and the other half to turn it in the same direction in falling. The definite rotation of the tool is effected by keying two cast-iron collars, *e* and *f*, on to the bar, about 12 inches apart. The top side of the lower collar, and the bottom side of the upper collar, have deep ratchet teeth cut on them. Intermediate between these two, and sliding freely on the bar, is a third collar *g*, having ratchet teeth cut on both its faces, but those on the upper side are set half a tooth *in advance* of those on the lower side. A wrought-iron hoop is attached to this third collar, through which the bore-head is attached to the hook and shackle shown in Fig. 22. When the tool is dropped and the blow delivered, the teeth of the collar *g* fall on to those of the bottom collar *e*, and, through the teeth not being opposite each other, receive half a twist backwards; on commencing to lift again, immediately *g* engages with *f*, a further twist backwards of half a tooth takes place, so that the flat rope is actually twisted through the space of one tooth. As soon as the lift takes place it untwists itself, and so rotates the tool.

The sludger is furnished with a clack at the bottom, and inside is fitted a bucket having an indiarubber valve on the top side.

The boring head can be lowered at a speed of 500 feet per minute, and raised at the rate of 300 feet per minute. The percussive action gives 24 blows per minute, and if this rate be continued in New Red Sandstone, or similar strata, about 6 inches will be drilled in ten minutes, when it becomes necessary to send down the sludger, which is effected at the same speed as the tool, but it only remains down about two minutes.

(*b*) *Raky Boring Apparatus.**—The rods consist of Mannesmann steel tubes, 2 inches diameter, in 16 feet lengths, which are connected together by loose collars and screw threads. The chief peculiarity consists in the method of mounting the walking beam, which is supported on a bearing resting on a cross-beam, between which and a

* *Coll. Guard.*, lxxvii, 60.

second cross-beam, also mounted on a frame, are arranged from 30 to 40 strong steel spiral springs, thus rendering the bearing elastic, and counteracting the disadvantage of rigid boring rods.

The rods are attached to the walking beam by a conical turned gland provided with a clamp and screws for fixing the rod in any position. Above this clamp is a second one, which rests on the first by means of 4 studs or pins projecting $\frac{3}{8}$ inch and pushed outwards by spiral springs situated in the inside. At the outset the rods are so arranged that the boring bit does not quite touch the bottom of the hole, but when the walking beam begins to vibrate the recoil increases with the speed through the action of the springs, and when a speed of from 80 to 100 strokes per minute is reached, the bit strikes against the rock every time. The contact between the bit and the rock is very short, the recoil of the former being very rapid.

The following advantages are said to be obtained :—Quicker speed, large number of strokes per minute, absence of complications in the apparatus, no "jars" or sliding joints.

(*c*) *American System.*—The development of the oil industry in the United States required rapid boring, and considerable improvements under this head have been effected. The whole operation has been elaborately described by Mr. J. F. Carll.* The success of the operation seems to be due more to the perfection of small details than to any startling novelty. The first thing done is to erect shear legs and fix the wooden conductor box previously described, this being set truly perpendicular, and carried down a few inches into the bed rock to fasten it securely. Should the bed rock lie at a considerable depth beneath the surface, the wooden conductor is replaced by a wrought-iron stand pipe, which is carried down by the method already alluded to. The engine furnishing power is regulated and controlled from the boring stage. The tools are attached to a rope, and an instrument called a "temper screw" (*a*, Fig. 24) connects the rope to the lever through the "stirrup" *b*. The lever receives an oscillating movement from a connecting-rod and crank turned by the band wheel. The length of stroke can be varied by adjusting a collar-pin in any one of several holes placed in the crank at different distances from the centre of its shaft. Separate drums are provided both for winding out the drilling rope and the sludger, these being driven by gearing thrown in and out by clutches. The effective cutting blow of the tools is given by the weight of the chisel, the auger stem, and the lower link of the "jars." The jars is a modification of Œynhausen's slide, arranged in such a manner that the auger stem and bit are given a decided jar on the *up stroke*, so that the bit is loosened in case it has a tendency to wedge fast in the hole. As the tools rise and fall with the rocking lever, they are constantly rotated by hand by a short lever inserted in the rings of the temper screw, and as the hole deepens and the screw of the stirrup reaches its limit, the clamps (*c*) of the temper screw are slacked, and a short length of rope payed out.

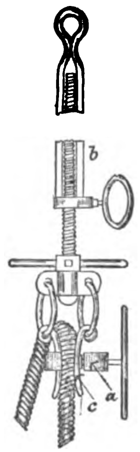


Fig. 24.

* *Second Geo. Survey of Pennsylvania, Report I*[3].

The withdrawing of tools is carried out by first taking up all the slack rope, then loosing the clamps, throwing the connecting-rod out of gear with the band wheel, and lifting up the lever out of the way. The tools are then run up, but are stopped when the bit reaches the level of boring-floor, where it is loosened by large wrenches. The tools are then lifted up clear of the hole, and the rope disconnected from the steam engine, the bit being removed and replaced by a sharp one. While this has been going on, the sand pump, or sludger, has been run up and down once or twice by the friction gear, &c., already described.

The first 60 feet cannot be drilled in the ordinary way just described this being done by the method called "spudding." The auger stem and bit are attached by the rope socket to a short piece of cable (150 to 160 feet long), the other end being passed over the pulley at the top of the frame, round another wheel, and then a few turns taken round one of the drum shafts. The engine is started, and one of the drillers takes his stand near the drum with the loose end of the cable in his hands. A slight pull on this tightens the loose coils on the drum shaft, which is rapidly revolving; the tools are raised, the rope is immediately slackened, and the tools drop in the hole; another slight pull is given, and so on until sufficient depth is attained to enable the drillers to replace this motion by that of the rocking lever.

This method has been introduced into England, and was used in September 1886 for boring for salt in the neighbourhood of Middlesbrough. Mr. J. Daglish* stated that it proved exceedingly satisfactory, the progress having been remarkably rapid. An *average* rate of progress of 63 feet per day was attained, with a maximum of 5 feet per hour.

(*d*) *Canadian System.*—Similar in all respects to the American procedure, except in the employment of light ash rods instead of rope for imparting motion to the boring tools. The depth of the holes put down rarely exceeds 500 feet, and, as the ground is very easy for drilling, as much as 100 feet can be sunk in a day. With deeper wells the advantage of speed belongs to the rope system, because the time occupied in screwing and unscrewing the rods is considerable. To exemplify this Mr. R. Nelson Boyd† gives the following record of the time taken in drawing and letting down the rods at a well then 1542 feet deep:—

Drawing up the rods,	25 minutes.
Lowering sand pump by means of rods,	14 ,,
Drawing up sand pump,	24 ,,
Changing the chisel,	3 ,,
Letting down the chisel,	14 ,,
Connecting the beam,	5 ,,
Total,	85 ,,

He had observed the same operation performed in Pennsylvania with a rope, at a depth of 1600 feet, in about 20 minutes.

(*e*) *Davis Calyx Drill.*‡—The cutter consists of a cylindrical metallic shell formed on its lower end by a process of gulleting into a series of

* "Presidential Address," *N.E.I.*, xxxv., 225.
† *Coll. Guard.*, lxvii., 897, May 11th, 1894.
‡ *Fed. Inst.*, xv., 363.

long sharp teeth (Fig. 25). The front of each tooth is perpendicular at the base to the rock to be operated upon, while the back of the tooth rises from the same line at an angle of 60°. These teeth are set in and out alternately, those having an outer set drill the hole large enough to allow the apparatus to descend freely, while the inward set dress down the core to such a diameter as allows the body of the cutter to pass freely over without it binding. The other details of the apparatus, and the method of operating it, are similar to the diamond boring process, indeed, if the serrated cutter replaces the diamond crown of Fig. 28. this illustration will then represent the complete tool of the Davis system, the upper portion *d d'* being the calyx or collecting chamber, which, however, in this system is made considerably longer than the sediment collecting cup of the diamond boring tool

Fig. 25.

In working, a continuous stream of water is forced down the drill rods, which, at the same time, are caused to be slowly rotated and forced downwards, compelling the teeth to take a powerful grip of the rock. The cutter does not act immediately the drill rods are revolved at the surface; on the contrary, the rods have to be twisted considerably before they accumulate sufficient energy to overcome the bite of the teeth into the rock, but the moment the surface strain exceeds the resistance below, small fragments of rock are hurled from before the cutter, which jerks forward and downward round the groove until momentarily arrested by the opposition of a renewed bite into the rock. The fragments of rock broken off are carried up around the outside of the boring tube and settle in the inside of the calyx.

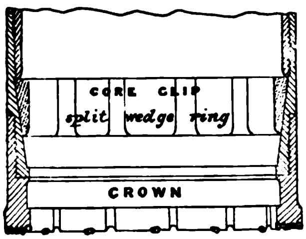


Fig. 26.

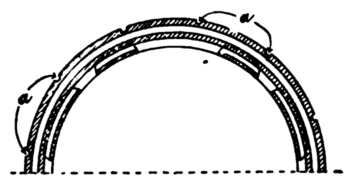


Fig. 27.

This tool can only bore through rocks softer than steel, but in special plants the Davis bit can be replaced by the diamond crown. A 1400-feet hole has been put down in Kent; at that stage the diameter was 10 inches. The best day's work was in boring from 450 to 551 feet, which was done in 10 hours.

In hard rock the toothed crowns are replaced by another form which, running on chilled shot under a specific speed and pressure, cuts faster. The shot bit is a hollow tube of soft steel varying in length according to the size of hole to be bored; a triangular notch is cut in the lower edge of the bit. The shot are of chilled steel, about $\frac{1}{16}$ inch in diameter, sufficiently hard to scratch glass. They are fed through the hollow drill rods, and on reaching the bit attempt to pass with the water through the triangular opening, but some are wedged there, and the rock is ground away by a rolling action of the shot under the pressure of the rapidly rotating bit. The proper quantity of shot to use can only be determined by experience, since if there are too many they grind on one another instead of acting on the rock.

(*f*) *Diamond Boring*.—In this system the tool receives a rapid rotary motion instead of a percussive one. The method consists in placing a series of small diamonds around the lower edge of an annular tube (Figs. 26 and 27) called the "crown." This part is composed of soft wrought iron, in which inferior diamonds are bedded, the edges of the holes being knocked down to keep the stones in position. The crown has a series of vertical grooves (*a a*, Fig. 27) round its circumference to allow water to pass from the centre outwards, and it is made slightly larger in diameter than the main boring-piece, so that the latter can revolve freely in the hole. The main boring-piece consists of a wrought-iron cylinder (Fig. 28) in two pieces, the upper one being open at the top. In the centre of this cylinder is placed a horizontal disc of metal, *a*, which divides it into two portions, and also serves as a connection to which wrought-iron pipes, *b*, are screwed. These pipes are carried to the surface, and are connected by mitre gearing to a steam engine, this giving the rotary motion to the tool. A stream of water under pressure is brought down the centre of these pipes, passes into the lower chamber, *c*, on to the bottom of the hole, and escapes by the side of the crown through the waterways. So long as the water is circulating, the débris is carried away upwards, but, as soon as the pressure is taken off, the slime would fall between the sides of the bore-hole and cylinder and jam it. This is the object of making the top piece open. The falling débris settles in the space *d d'* (Fig. 28) around the water delivery pipes.

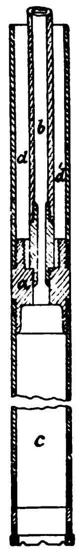


Fig. 28.

The cylindrical core produced is thus removed:—A circular *split* band of iron with vertical ribs is placed inside the lower portion of the boring tool immediately above the crown (Fig. 26), the surface on which it slides being an inverted cone. In boring, the core readily slips upwards through the split ring, but when the boring tool is raised the core gradually forces the split ring on to the smaller diameter of the cone until the pressure is sufficient to cause the core to break off and be lifted.

In the modern improved practice separate machinery is provided for pumping and rotating and raising the rods, thus dividing and minimising the risk of breakages. The drill is usually fed forward by the pressure exerted by the weight of the rods, part of which is counterbalanced, or by the hydraulic feed of the Sullivan Prospecting Co., which operates as follows:—*a* (Fig. 29) is the hydraulic cylinder with its piston *b*, and hollow piston-rod *c*. Connection to the force pump is made at the tee *d*, and to the exhaust at *e*. The inlet valves are numbered 1 and 2 and the outlet ones 3 and 4. When 1 and 3 are open and 2 and 4 closed the piston moves downwards, but when 2 and 4 are open and 1 and 3 closed the motion takes place in an upward direction. To the upper end of the piston-rod is screwed the thrust plate *f*, through which pass three stud pins (not shown in illustration) screwed into another thrust plate *g*.

Between these are two sets of ball bearings, one set on each side of the collar *h*, which is fixed to the drive rod *i*. To the opposite end of this drive-rod is secured by means of an ordinary chuck the wrought-iron pipes to which the drilling cylinder (Fig. 28) is attached, so that the collar *h* transmits the vertical motion of the hydraulic piston to the drilling crown.

The advantages of the hydraulic feed are—economy of time, saving of diamonds, and accuracy and safety in operation. The amount of water admitted to, or released from, the hydraulic cylinder can be varied to any degree by simply adjusting the inlet and outlet valves, and as the feed depends entirely on that amount it follows that it can be adjusted to the greatest nicety. The hydraulic feed allows the drill to run with slightly slower speed on suddenly entering hard rock, when the attendant can at once give the amount of feed the machine will take without injury to the diamonds. As the water escaping from below the feed piston is throttled by the outlet valves while feeding down, and led up above the level of the bottom of the piston, it follows that the water cannot escape from the bottom of the cylinder faster than it enters at the top. Hence the lower part of the cylinder is *always full of water*, and in case a cavity is struck the weight of the drill rods hanging on the piston is supported by this body of water, which is *incompressible*, and *entirely prevents the dropping of the rods*. Hence the hydraulic feed continues downwards as regularly in the cavities as in drilling through hard rock.

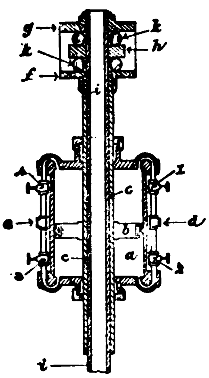


Fig. 29.

An important detail of this hydraulic drill is the friction bearing (*kk*, Fig. 29); one set of balls sustains the weight of the rods as they hang in the drill chuck, the other set sustain the upward thrust of the rods in drilling. This device reduces to a minimum the amount of work lost in friction, leaving the whole power of the engines to be devoted to drilling.

The great advantage and superiority of the diamond boring system is the perfect cores obtained from rocks of moderate hardness, which enable an accurate section of the rocks passed through to be easily constructed. In ordinary soft measures (such as coal), owing to the rotary and vibratory action of the bore tube breaking off the core, which falls to the bottom of the hole and becomes ground into mud, the indications afforded by this method in such ground are scarcely better than the slime and débris removed by sludgers in ordinary boring. The breakage of the core has lately been obviated to a considerable extent by the boring of *larger* holes, the larger amount of core inside the crown being better able to stand shocks than the smaller ones of the earlier borings.

A further improvement, by means of which the amount of core extracted has been considerably increased when boring through coal and soft rocks, is described by Mr. James Barrow,* the boring tool being so constructed that a core of the strata can be drawn up intact

* *So. Wales Inst.*, xii., 42.

This is accomplished by the use of an internal stationary core tube rivetted to the socket of an ordinary boring tube, an annular space being provided between these two parts for the passage of water. The crown on the boring tube is stepped to facilitate the cutting of the core, and as the boring tube revolves the crown penetrates through the strata and the core enters the inner or stationary tube, which, when the bore rods are raised, is lifted with them and extracted. When in operation a constant stream of water is passed down the annular space between the exterior of the core tube and the interior of the boring tube.

This modified tube was employed at Villefranche (Allier) in 1876, and Mr. Baure* states that the success has been complete, as the greater portion of the cores were extracted in an unbroken condition. Not only did they obtain a complete section of the rocks passed through, but they reduced the breakage and grinding of cores at the bottom of the hole, which so materially increases the power required for turning the tool and augments the amount of débris to be removed.

The modified crown was put to work on 12th Oct., 1876, when the boring had reached 1684·7 feet from the surface, and by the 5th of January, 1877, 745·7 feet had been bored, making the total depth from the surface 2430·3 feet. The length of core extracted was 724·18 feet, or 97·1 per cent., while with the original form of crown only 39·9 per cent. had been obtained. During the months of October and November, 1876, 462·3 feet was bored (from 1609·7 to 2072·0 feet) at an average rate of 11·887 feet per working day, operations being suspended part of this time while negotiations were being entered into for proceeding deeper with the bore-hole.

For *very* soft ground the diamond drill is quite useless, and if a hole is proceeding on that system, and such ground is encountered, the crown is removed, and percussive boring tools employed.

Accidents in Boring.—If it were not for accidents boring would be a comparatively easy, cheap, and rapid operation. It is in this

Time Occupied in Boring.	Depth Bored.	Time of Stoppages.	Cause of Stoppages.
Days.	Feet.	Days.	
12	23	28	Broken shaft of drilling machine.
104	392	5	Tools jammed in hole by fall of ground.
14	72	33	" "
16	102	7	Drawing out bottom, lining tubes, and re-boring hole to get tubes lower down.
14	212	7	" "
36	304	9	" "
4	19	16	" "
13	129	8	" "
4	19	15	" "
28	221	...	Boring rods broke.
245	1493	180	

* *Soc. Ind. Min.*, 2ᵉ Série, xiv., 25.

division that the skill, patience, and knowledge of the bore-master is put to the test. A forcible illustration is afforded by the above particulars of a bore-hole on the diamond system, carried out under the author's observation.

As the period of 245 days included 32 Sundays, the actual rate of progress per working day was 7 feet, but when stoppages are included only 3·5 feet, a reduction of 50 per cent. The top part of the hole ran very badly, and three sets of lining tubes were put in between the surface and a depth of 273 feet. Indeed most of the stoppages were due to this cause, and finally, owing to the dirt running in, the boring tools broke during withdrawal. Attempts were made to draw the lower lining tubes, and a series of breakages followed. The most serious mishap was occasioned by a piece of the broken lining tube getting cross-bound in the hole at a depth of about 1150 feet, and resisting all efforts to withdraw it for a period of 238 days. Attempts were then made to re-bore the hole by the side of this obstruction, but after going down some 40 feet the tools became jammed, and broke again and again. Finally, after a total period of 364 days had been spent in endeavouring to recover the hole, a longer time than actual boring operations were in operation, a diverting piece was successfully inserted at the point of obstruction, and the re-boring of the hole continued by the side of the original line at an inclination of about 1 in 75. In this way, at the end of a further period of 84 days, the original depth was reached, so that the total stoppage amounted to 448 days. After 266 feet had been bored in the following 56 days, the "crown" again broke off and was not recovered for 49 days. The hole was then recommenced and deepened 32 feet in 17 days, when the sides ran badly and choked up the bottom with dirt. This débris took 18 days to clear out, and then the hole was bored a further distance of 3 feet, making the total from the surface 1794 feet. Here the core tubes broke, and 60 feet or more stuck in the hole. Attempts were made to get them out for 20 days, when the hole was finally abandoned.

Thus, from the date of the serious smash at the depth of 1493 feet, the total time occupied was distributed as follows:—

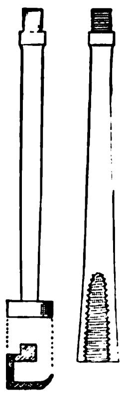
364	days	attempting to recover "crown," &c.,
84	,,	re-boring by side of diverting piece,
56	,,	effective boring for a distance of 266 feet,
49	,,	recovering tools broken in hole,
17	,,	boring 32 feet deep,
18	,,	cleaning dirt out of lower part of hole,
1	,,	boring 3 feet,
20	,,	attempting to recover broken rods, &c.,

or, in other words, 301 feet were bored in 609 days! Only 12 per cent. of this time was spent in actual boring from the bottom of the original hole, the remaining 88 per cent. being occupied with breakages. This is, of course, a most exceptional experience, and was undoubtedly due to decreasing the size of the bore-hole too rapidly. At the bottom, the "crown" was only 2¼ inches diameter, and, although operations ended so disastrously, one cannot help admiring the patience, skill, and ingenuity displayed in attempting to recover such a comparatively small article which had to be grasped at the end of a tube nearly 600 yards away.

The accidents themselves, and the tools employed during such accidents, are so numerous and complicated, that a full description would be quite out of place here, and, indeed, impossible to give within the limits of the book.

(*a*) *Accidents arising from the Boring Tools themselves.*—The constant vibrations and shocks to which the rods are subjected tends to rapid deterioration of the iron, and frequent breakages follow. Often the workmen do not screw the rods properly together, or negligently allow them to drop down into the bottom of the hole during the progress of unscrewing. To lift up the broken part of the rods a tool called the "crow's foot" (Fig. 30) is employed; it is slipped down the hole, and twisted round until the hooked part catches the rods.

If, however, the fracture had taken place some distance above a joint, when the rods were raised the top part would catch the side of the bore-hole, as the crow's foot itself only grips at a joint. In such cases an instrument called a "bell" is let down. In one form this is a bell-shaped tool (Fig. 31), with a screw cut on its inside. It is



Figs. 30 and 31.

Fig. 32.

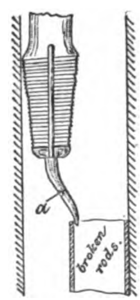


Fig. 33.

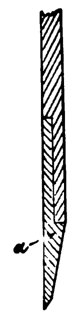


Fig 34.

dropped down on to the broken rod, and cuts a screw thread on it. All screwing tools for removing broken rods are cut with their threads running in the opposite direction to those on the boring tools, so as not to disconnect the joints of either the rods to which they are attached, or those that are broken in the hole.

If a piece breaks off the chisel, or any small tool or other hard obstruction drops in the bore-hole, an attempt is made to extract it with an implement resembling a double corkscrew, called a "wad-hook" (Fig. 32). This is generally successful, but if all attempts to dislodge the obstruction fail, then the only alternative is to chop it to pieces. Mr. Mather, in the paper already referred to, states that it had been found necessary to remove both the heavy boring head and sludger employed in his system of boring by such means. Powerful magnets have also been used with success.

In case of a fracture in the rods (tubes) of the diamond system, an ordinary screw tap is let down and a thread cut inside the broken pipe; in large bore-holes, where the diameter of the hole is large compared with that of the tube, a crooked piece of iron (*a*, Fig. 33) is placed at the lower extremity of the tap, this guiding that piece into the tube in case it should be leaning against the side of the hole.

(*b*) *Accidents arising out of the Nature of the Ground.*—Unless the strata passed through are of considerable hardness, the constant jarring of the rods, and washing action of the water, soon causes the sides to crumble and fall in over the tool. A very soft bed at any point is a source of considerable danger. In order to prevent serious accidents it becomes necessary to line or case the sides of the bore-hole.

Lining.—This is done by forcing down wrought-iron tubes in lengths of from 10 to 12 feet, the connections between each length being made "flush"; that is to say, there are not any projecting points. The lower tube is provided with a steel cutting edge (*a*, Fig. 34).

For small holes the tubes are driven down by dropping a heavy block on them, about 20 to 30 blows a minute being given. A superior method to this is to use two small jacks, which exert pressure equally and gradually, and avoid shocks and risks of bending.

For larger and deeper holes hydraulic presses are employed, having a stroke sufficient to force down one length of tube at a time. A strong framing is built over the hole, and beneath this the presses are secured. Both the hydraulic rams and tubes are carefully guided in a truly vertical direction.

Means of Widening Holes.—When a hole is cased, and boring has to proceed further, it is obvious that the diameter of the hole must be reduced, as the tool has now to pass through the tubes. In order to prevent this, before inserting the first length, the hole is slightly enlarged by a tool called a "reamer," which is very similar to the "bell," except that it is provided with a cutting edge round its circumference. In diamond boring, the reamer consists of a guide the size of the drilled hole, and a face above it, in which diamonds are set, and which cuts away the sides of the hole above the guide.

After the sides have been cased, and boring resumed, it frequently happens that additional casing is required at some point lower down; then either narrow tubes must be sunk through the first set, to reach the dangerous part, or the old casing is removed by one of the methods described below, and the hole re-bored large enough to take in the original size of tubes. As a rule, the latter method is not adopted, except when the bore-hole has become so narrow by repeated linings that the first method cannot be employed.

A tool, introduced by the Diamond Boring Company, and described by Mr. James Barrow,* consists of an undercutting or expanding crown, a simple arrangement set with diamonds, which is lowered down through the lining tubes, and expanded directly it gets beneath them. In revolving, it cuts away and enlarges the sides of the bore-hole, after each 10, 20, or 30 feet had been bored in advance with the ordinary crown. After this the lining tubes are lowered to the bottom, and boring resumed in the ordinary way. With such a tool, and the use of hydraulic presses, 800 lineal feet of wrought-iron lining tubes, weighing about 50 tons, have been forced down a bore-hole in one continuous length.

* *So. Wales Inst.*, xi., 318.

A tool of similar construction was employed at a boring in Sydney Harbour.* It consisted of a pair of mild steel levers hung scissors fashion in a steel tube. On their upper ends, rested a loose metal disc which could be depressed by about an inch by water pressure from the circulating pump, when the lower ends of the levers were swung outwards through two slots in the steel tube. Cutting diamonds were set on the extreme edges of the levers. When the reamer is being lowered down the bore the levers hang inside the tube, but when the tool has reached the desired position, the pump is started and the steel disc depressed. As long as the cutting is downward, the reamer is kept to its work by the weight of the bore-rods. On raising the bore-rods, the projecting levers are forced within the tube immediately they strike the first obstruction.

Withdrawal of Casing.—Either when the hole is finished and abandoned, or when inserting tubes of greater diameter, the lining has to be removed. Where the friction is not great, Kind's plug (Fig. 35) can be used. This consists of an oval ball of wood slightly less in diameter than the inside of the tube. It is lowered down on the rods, and a few handfuls of sand or gravel thrown on the top. This causes it to bite, when the tubes can be lifted out.

Fig. 35.

Fig. 36.

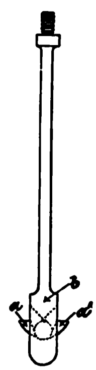


Fig 37.

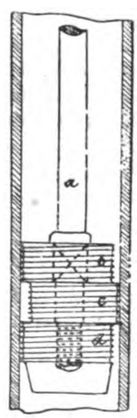


Fig. 38.

Should the friction be too great to allow the casing to be removed in one length, it is cut through by the tool shown in Fig. 36. This is provided with a sharp cutting point *a*, pressed against the sides of the tubes by a strong spring *b*. On reaching the point where the severance is to be made, the tool is revolved round and round until the lining is cut through, when the upper portion can either be removed by Kind's plug, or by a similar class of tool (Fig. 37) having two spring sides *a a'*, which are pressed inside the shank *b* so long as lowering is taking place, but which spring out and catch beneath the lining, immediately the place cut through is reached. These clips cannot be forced aside in the upward passage, and so the casing is withdrawn.

* *Fed. Inst.*, v., 386.

Tecklenburg * describes a tool which obtains the necessary grip by cutting a screw thread on the inside of the casing tubes. It consists of three eccentric discs of steel mounted on the lower end of a rod (*a*, Fig. 38). The upper disc *b* fits on a square shank below a projecting collar, the middle disc *c* is mounted on a cylindrical part, and the lowest one, *d*, is screwed on the end of the rod. The holes in the three discs are eccentric, and their outer circumferences are provided with sharp-edged screw threads. The three discs touch each other, and whilst the top and bottom ones are firmly attached to the rod, the central disc is mounted loose and can turn round the smooth portion of the rod. When the tool is introduced into the casing, the discs are so arranged that the largest radii of all three come in the same vertical plane, and since their diameter is less than that of the casing, they enter it with ease. When the tool arrives at the desired spot, a twist is imparted to it, and, as a consequence, the screw threads of the middle disc catch against the inner walls of the casing. Being eccentric this disc is forced out a short distance from the other two. A slight increase in the amount of twist causes the sharp edges of all three discs to bite into the casing sufficiently to enable the whole to be drawn out of the bore-hole by the rod. To loosen the fishing tool again, all that is necessary is to reverse the twist and free the discs by shaking.

Record of Boring.—Exact records should be kept of the work done each day, the strata bored through, and its thickness. Each sludger full of material should be carefully examined, samples taken and kept for reference (preferably in small wooden boxes) and labelled. The label should note place, date, depth, sort of material, and any remarks necessary. Never trust to memory. Neglect of these precautions has caused large money losses.

Cost of Boring.—This depends mainly on the depth to which the hole is carried. In most tenders the price per foot increases at a certain figure for every stated increase in the depth, so that one foot at the bottom of a hole may be more expensive than several feet at the top. Hence the bore-hole is usually started from the bottom of a shallow shaft, and the low rate then counted from the shaft bottom, not from the surface, so that, by sinking the pit, a length equal to its depth is cut off from the *bottom* of the bore-hole, which would be at the highest rate. It is stated † that the bore-hole at Sperenberg, 4170 feet deep, made with rigid rods and percussive action, cost 41s. per foot; while an average of a series of 37 rope-borings, with depths varying from 80 to 1300 feet, cost 41s. 3d. per foot. Mr. T. J. Berwick ‡ states that the first hole at Middlesbrough bored by Mather & Platt's system was 1200 feet deep, and cost about £8 6s. 8d. per foot. It is nearly impossible to compare the several systems, as the conditions may be quite different in each instance. In ordinary strata, the Diamond Drilling Co. will contract to put down a hole, commencing at the surface with a diameter of 9 inches at a price of 15s. per foot for the first 500 feet, and from 500 to 1000 feet, 25s. per foot, equal to 20s. per foot for 1000 feet; the company providing all labour and tackle (except lining tubes, should such be required), fuel, carriage, and fares; but the employer has to provide, gratis, on the site of the boring, about 10 to 12 gallons of water per

* *Coll. Guard.*, 1898, lxxvi., 1062. † *N.E.I.*, xxx., 88.
‡ *Ibid.*, xxx., 98.

minute for engine and other purposes. This price would not vary much even if the hole was of smaller diameter.

The following are some useful published American costs of diamond drilling operations per foot:—12 holes, 200 to 800 feet deep, total 5957 feet of boring, 9s.; 18 holes in N. Michigan, total 5046 feet of boring, 9s. 6d.; 7959 feet of boring, nearly all underground, cost 3s. 8d. Generally the cost is less in mines at work than in purely prospective operations, as all costs of superintendence, &c., are averaged down in the former case.

Mr. H. M. Chance * states that the average cost of drilling a well by the American rope system in the oil country in 1878 (including the cost of the plant), for a 1500-feet hole, was £403, or a little over 6s. per foot. As prices were at their lowest ebb then, this estimate should be increased about 20 per cent. to make it available for comparison with other methods in 1882; but as the plant would have some value when the operations were concluded he states that the net cost of a 1500-feet prospecting hole (in 1882) would be £380, or about 5s. per foot. At the same time, he points out that the cost of drilling holes by this method in the anthracite regions will be very much greater than that shown by the above figures, because the rocks are much harder, and are inclined at considerable angles from the horizontal. Mr. Redmayne † states that the 8-inch bore-hole put down 1210 feet by this system at Middlesbrough for salt cost 8s. per foot.

At a boring on the Canadian system in Austria,‡ the average sinking amounted to 3 feet 10½ inches per day, but for the 265½ days of actual work it was 7 feet 9 inches per day. These 265½ days were employed as follows:—

Drilling,	190 days	8¾ hours.
Using the sand pump,	42 "	2¾ "
Putting in casing,	9 "	1 "
Fishing up broken tools,	8 "	3¼ "
Small repairs to engine and rig,	15 "	20¼ "
	265 "	12 "

The actual drilling averaged 10 feet 6 inches for 24 hours, while the greatest distance done in one day was 22 feet 4 inches, but the ground was exceedingly unfavourable, consisting of 2000 feet of swelling and adhesive clay. The cost amounted to over £2 per foot, which includes the cost of tools, casing, and machinery, less the amount realised by their sale at the completion of the work.

The deepest bore-hole in the world is at Paruschowitz in Silesia.§ It attained a depth of 6572·6 feet, while the Schladebach hole did not exceed 5736, but as the surface level of the former was 324 feet higher than the latter it only got nearer the centre of the earth by 345 feet. The greatest difficulty was in the weight of the rods, which was reduced to the lowest limit by employing Mannesmann seamless steel tubes in place of iron; but even then at 6561 feet the total weight was 13·707 tons, and at this depth it took 10 hours to draw the rods, and as long to lower them again. Breakages were common, indeed one of them terminated the work. After the bore-hole had been put down through drift, &c., by ordinary methods to a depth of 351 feet,

* *Second Geo. Sur. Pennsylvania, Report A.C.*, 39.
† *Brit. Soc. Min. Stud.*, x., 102. ‡ *Coll. Guard.*, 1894, lxvii., 898.
§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1895, xliii., 686.

diamond drilling was commenced. When the diameter of the hole was $2\frac{3}{8}$ inches, and the diameter of the core brought up $1\frac{3}{8}$ inch, 4406 feet of rods fell to the bottom and became jammed in that portion of the hole that was unlined, and so led to its abandonment. Boring commenced on January 26, 1892, and on May 17, 1893, had reached a depth of 6572·6 feet, the final 3·28 feet having taken over 3 months to finish. The actual boring occupied 399 working days, with a daily advance of 16·4 feet. The total cost was £3760, or about 11·5s. per foot, which compares very favourably with that of Schladebach, where the cost was 37s. per foot.

Surveying Bore-holes.—The great difficulty in boring is to keep the holes truly vertical, and, in spite of all efforts to the contrary, crooked bores are common, especially where the beds are inclined. No rules can be given; the only thing to be done is to exercise the greatest care. Unfortunately, bore-holes, by all the methods, are liable to deviate from the perpendicular, the diamond drill, which was assumed to always bore a perfectly straight hole, being no better than any of the other systems. However, if an accurate survey be made, a crooked hole gives just as valuable information as a straight one.

In the method devised by Mr. E. F. Macgeorge,* clear glass phials filled with a hot solution of gelatine, and each containing in suspension a magnetic needle and a very delicate plumb-bob, are lowered into the bore-hole and allowed to remain there until the gelatine sets, when they are withdrawn, and by means of a special instrument the angles of the compass and the plumb-bob are noted. Another suggestion † is to lower into the bore-hole glass cylinders containing hydrofluoric acid, which etches a line on the glass. Both these methods are reviewed by Mr. B. H Brough,‡ who gives a full description of the instruments employed and the way of using them.

The Uses of Bore-holes in Mines are many and valuable. Every colliery ought to be provided with a set of tools, and men instructed in their use.

(*a*) *Tapping Water.*—A provision of the Coal Mines Regulation Act, 1887, is to the effect that all roads approaching old workings, where there are likely to be dangerous accumulations of water, should be preceded with bore-holes. One bore-hole is usually kept straight ahead for a distance of about 5 or 6 yards, and flank-holes, at an angle of 45° with the centre line of road, are put out for a similar distance on each side. The general practice with the leading hole is to bore in a certain distance, and then remove part of the face, a further length being then bored before any more ground is removed. In this way, the distance from the face to the back of bore-hole is never less than 5 yards. Where water is expected, plugs should be kept in readiness to drive in immediately it is released; or if the pressure is likely to be great, it is best to bore through a length of pipes fitted with a tap.

Such pipes and tap may be wedged in position in several rough-and-ready ways, but to minimise the risk of their being blown out when the old workings contain water or gas under considerable pressure an elaboration of the ordinary apparatus has been patented by Mr. J.

* *Engineering*, xxxix., 260 (1885).
† Translation by C. Z. Bunning and J. K. Guthrie, *N.E.I.*, xxix., 61.
‡ *Treatise on Mine Surveying*, 8th Edition, 1900, 318.

Cowey * (Fig. 39). A hole is first drilled for a few feet into the coal, and a tube, *a*, inserted in it. The inner end of this tube is fitted with an india-rubber sleeve, *b*, projecting slightly beyond the tube end and prevented from slipping back by a collar, while the outer end of the tube is provided with a flange which presses against a rubber ring, *c*, on the edge of the bore-hole. The pipes outside the bore-hole are screwed into this flange; *d* is a cross piece fitted with a pressure gauge, *e*, and dip pipe closed by a valve, *f*, through which the débris, water, or gas passes away. The thread of the feed screw *h* passes through a gun-metal sleeve nut, *i*, tapped to receive it. This is attached to the tubes through which the boring tools pass by a modification of the ordinary bayonet joint, a front view of which is shown. The whole apparatus is secured to a timber frame by two clamping plates, *k*, which by means of bolts forces the tube *a* and its india-rubber sleeves into close contact with the front and inner end of the hole.

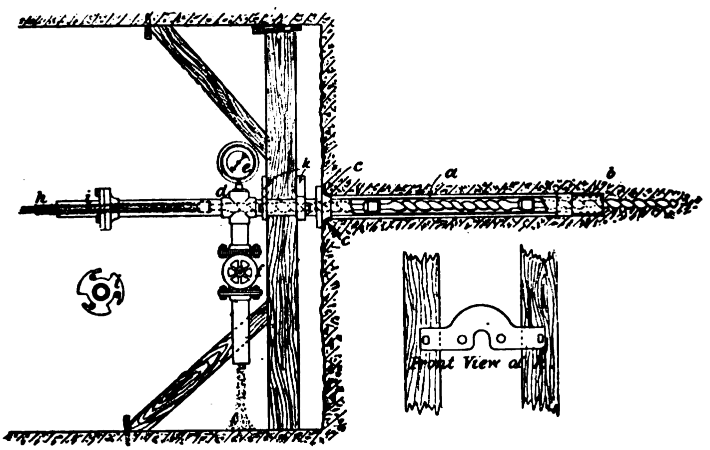


Fig. 39.

Mr. G. Burnside † has also introduced an apparatus similar in most of the details to the preceding, but differing from it in the way the stand pipe *a* is locked in the bore-hole. He employs two supporting plates round the tube and two wedges. The latter are inserted with their larger ends inwards, and when everything is in position they are drawn outwards by stretching screws, binding the supporting plates against the sides of the hole and the tube, and firmly locking the latter in position. Where abnormal pressures are likely to be encountered, either of the above methods are probably safer than the general one of simply wedging the stand pipe, but the latter acts satisfactorily in the majority of cases.

(*b*) *Releasing Gas.*—In collieries liable to sudden outbursts of fire-damp, bore-holes are systematically put out of the working places into the layers of strata in which the gas accumulates, in order to drain it out gradually. At Wharncliffe Silkstone, and other collieries where this procedure is adopted, it has met with success.

* British Patent, No. 311, 1891. † *Ibid.*, No. 2299, 1891.

(c) *Proving Faults.*—Bore-holes are of the greatest assistance in determining the amount of throw of faults, and have saved considerable sums of money, which would otherwise have been spent in unprofitable exploratory work. With their aid one can determine the gradient required to drive the roads that will intersect the dislocated seam. Especially is this the case where the hade of the fault is vertical or ill-defined, as they actually prove in such instances, whether it is an upthrow or downthrow.

Owing to the confined space in roadways, the cost of boring is rather high, as much time is wasted in screwing and unscrewing rods. From a number of cases carried out under the author's direction the cost per foot averaged 4s. for distances bored of about 30 feet, with diameter of hole 3 inches, the rate of wages paid to men being 5s. 6d. per day of eight hours. The cost of boring uphill seems less expensive than downhill, if the weight of boring tackle is counterbalanced, as the disadvantage of clearing out the hole and unscrewing of rods for such purpose is removed.

(d) *Steam and Rope-ways.*—The anthracite region of Pennsylvania supplies numerous instances of the employment of bore-holes for steam and rope-ways passing from the surface to the interior of the mine.* At Shenandoah City slope, an 8-inch hole was bored by the method employed in the oil regions, and lined with $5\frac{5}{8}$-inch casing, through which a rope travels, the space between the casing and the rock being filled in with cement. The engines and boilers are on the surface. Another hole, 6 inches diameter, was then bored, and two lines of 2-inch gas-pipe laid in it, the interstices between being filled in with cement. One pipe is used for a speaking-tube and the other for a bell-wire to the engineer at the machinery on the surface. At East Franklin Colliery there are two bore-holes, each 8 inches diameter cased, and cemented, 763 feet deep. These holes are 7 feet apart, and are used to hoist from a double-track underground slope. At Lincoln Colliery, an 8-inch hole is used to convey steam to an underground pump through a $4\frac{1}{2}$-inch steam-pipe. As this hole was remarkably dry, it was not cased. At the Clear Spring Colliery, West Pittston, a 6-inch hole was drilled 270 feet, and a line of $4\frac{1}{2}$-inch steam-pipes inserted. This hole was not cased, and, owing to the flow of about $\frac{1}{4}$ inch stream of water down it, condensation was so great that the pressure was lowered from 120 lbs. at surface to 40 lbs. at bottom of hole. Afterwards, the space between the rock and the steam-pipe was cemented, and a 4-inch steam-pipe placed inside the $4\frac{1}{2}$-inch pipe, with the result that the steam pressure at the bottom of the hole was the same as on the surface.

These holes have also been successfully used in dealing with mine fires, for providing water supplies, for stowing underground excavations, and many other purposes connected with mining.

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* *School of Mines Quarterly*, New-York, ix., 189.

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CHAPTER III.

BREAKING GROUND.

Contracts.—The greatest proportion of the miner's work consists in removing and breaking up different varieties of rock, and to do this various special tools are employed. Usually the different qualities of ground are let by contract to men, and it is here that experience is of the greatest use, as only from that is it possible to judge of the value. Hardness, in a mining sense, is different from the same term looked at from a mineralogical standpoint. Ground that is hard and brittle will often bore better than a softer variety which is tough, because, in the former instance, the blows break off small pieces, while, in the latter, the chisel has to cut its way. Another point is the question whether the ground will "shoot" well, that is to say, whether it contains a number of faces, or joints, which easily break away from the surrounding mass under the action of explosives, or, at any rate, allow the material to be so shaken that it is easily removed by wedging. At one of the collieries under the author's charge numerous intrusions of basaltic rock are met with, and he has adopted a system for judging the value of roading which is worthy of mention. A sample of every intrusion is kept and labelled, with the price per yard paid for driving through it, and, in addition, a microscopical section is cut from the specimen. When other intrusions are met with a piece is broken from each of them, and a section cut and carefully compared with other pieces and sections of which the price is known. From this comparison the price to be paid to the workmen is found.

Methods of Hastening Work.—The commonest plan of hastening work, and one that gives good results, is to pay the men a bonus for every extra yard they drive over a certain stipulated amount. So far as working is concerned, perhaps, the cheapest way is to only work one shift, for, as a rule, the night shift leave work behind for the day men to do. If different shifts of men are employed the best way is to measure up the amount each shift does, and pay them on it, as by this means each set of men know that they will receive the money for all the work they do, and consequently work harder. Where rapidity is the main object six-hour shifts are adopted, with one workman always remaining to, and starting from, the middle of a shift. This one does all odd work, fetching tools, &c.; the regular workmen are then able to keep constantly at the face.

TOOLS USED.—Shovels are principally used for removing broken débris, and always have pointed noses, to enable them to get past the larger pieces of loose stuff. The length of handle varies; commonly it is about 30 inches, this being set at an angle of from 140° to 160° with the surface of plate, which varies from 8 to 16 inches across. In some districts baskets are used for loading in preference to shovels, the coal being raked into them. They are largely employed in the South Staffordshire coal-field, and are made of wicker-work for the working places, and of iron for gate-roads, the reason of this being that the former are practically noiseless. With them a man certainly loads more stuff than with a shovel, especially where the ground is uneven, as in such cases the shovel catches on projections. Their application is limited to thick seams.

Picks.—These vary much in shape for different uses and different qualities of ground. For holing purposes, where the blow is struck in a horizontal direction, the weight is small, generally about 3 lbs., with a head 15 inches long, and a helve from 24 to 33 inches. The head will be slightly curved for holing along a straight long-wall face, as the miner naturally swings his pick in a curve, and the blow is then delivered in the direction the instrument is moved. If, however, the miner is under-cutting in a narrow road, and working in the corners against the "fast," the curved head cannot be employed, as the curved portion would catch against the side before the point entered. For cutting coal or breaking rock the shape of the shank or stem is usually square in section, tapered to a point; while for dressing rocks when sinking a chisel-shaped edge is employed. For coal work the shank

Fig. 40.

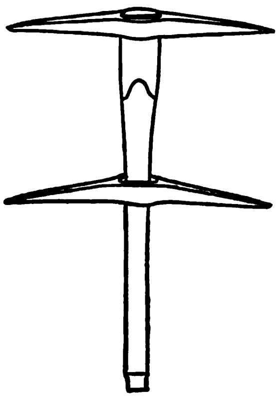


Fig. 41.

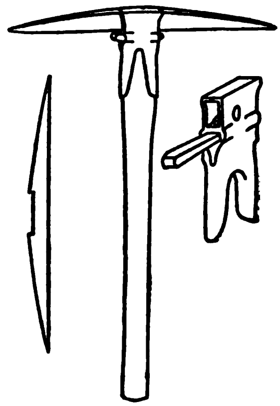


Fig. 42.

tapers uniformly from the eye to the point, but for stone work the point tapers suddenly like the sharpening of a pencil. The head part is fitted into a wooden stem called the helve, upon which the greater strain of the work is thrown; so, to prevent rupture of the wood, the eye should be made as broad and long as possible, and the two side cheeks carried down the helve a good distance. On the other hand, for under-cutting, where the tool works in a narrow slit, the eye must be made as slim as possible; if not, the pick-head cannot be turned sufficiently to enable the point to catch the sides of the cut. Helves are generally made of good straight-grained ash, nicely rounded to fit the hands of the miner.

American hickory helves are now largely employed, the only objection raised against them being that they are rather too springy, and jar the hands in delivering a blow. This objection, probably, arises more from prejudice than anything else.

A pick worthy of mention is that known as the *Rivelaine*, employed by the French and Belgian miners for holing in thin inclined seams. It is made of flat steel, about $\frac{1}{8}$ inch thick, and the helve is from 3 feet 6 inches to 4 feet long (Fig. 40), so that the miner does not have to get his arms under the face. A very narrow slit is made, and waste is reduced to a minimum.

In the day, a workman spoils the points of several picks, which he has to bring to the surface to get sharpened. The labour of doing this is considerable, and numerous devices have been brought out with a view of lightening it. The oldest consists in employing loose points, held in position by a screw, but the idea is a failure, owing to the difficulty of keeping them tight and firm, which is only possible when they are new. A better plan is that of the Hardy Pick Co., which consists in making the head loose, and either employing a tapering helve, getting slightly broader towards the top, and threading the head over the end of the handle, and allowing it to slide down into its proper position (Fig. 41), or by recessing the head of the pick, and fitting it into a rectangular iron collar at the top of the helve, and securing it in position by means of a sliding wedge (Fig. 42). Originally a double wedge was employed, with a view of making a more secure joint, and allowing for wear; but experience has shown that no necessity exists for this, and the single wedge pattern is most in favour.

The tendency at the present day is to construct picks entirely of steel, instead of wrought iron with steel points. Without repeating this remark again, it may be taken as true with regard to every other class of mining tools. The texture of steel is such, that it transmits a blow better than softer iron, and as it is stronger, the weight of the tool is less; consequently the point receives the impact better. Then again, the wearing capacity of steel tools is very much greater, and repairs are consequently less.

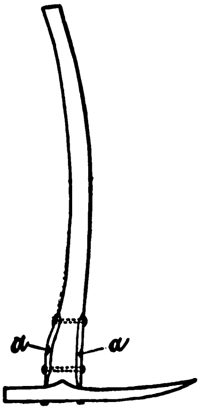


Fig. 43.

Dressers.—For breaking up all large pieces of coal and rock, a tool shown in Fig. 43 is used. The direction of the blow being downwards, it is made very much heavier than an ordinary pick. One side of the head forms a curved pick, and the other a hammer. The helve is not straight, like that of a pick, but curved, and as it is largely used for wrenching purposes, two strengthening side strips, *a a*, pass from the eye up the helve.

Wedges.—These are most useful tools for breaking up hard rocks, and getting down pieces shaken by shots. Their shapes are few, but harder rocks require smaller wedges than softer ground, as in the latter case a small tool would only push its way into the rock, and be buried in it. The general shape is shown in Fig. 44. The striking end is made small, so that the blow is delivered in the centre. For soft, cloddy varieties of ground, the penetrating end is made somewhat of a chisel shape, as this tends to split it very well; but with harder varieties of rock, small dumpy wedges are adopted, gradually tapering towards the extremity, and suddenly sharpened to a point.

Hammers.—The common form (Fig. 45) consists of an eye and two stems, tapered down to form the striking faces, which are slightly convex, and have their edges rounded or chamfered off, so that the hammer glances off the object struck when the blow is misdirected, and prevents injury to the hand of the man holding the drill. The only difference between hammers and sledges is, that the latter are heavier, and the blow is delivered with both hands. For wedge-driving, long, tapering heads are adopted, so that they may follow the wedge right into the mineral; while for drilling, shorter heads are used, as in them the material is well concentrated, and the blow takes greater effect.

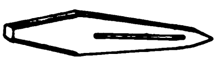


Fig. 44.

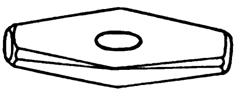


Fig. 45.

Drills.—For the present, it is proposed to treat only of those drills worked by hand. These may be divided into percussive and rotary borers. The former are either worked by the miner grasping the tool, and giving it a reciprocating action, or one end of the tool is struck with a hammer. The latter may be subdivided into two classes, one of which wears the mineral away (diamond), while the other crushes the rocks, and reduces them to small fragments, this being done either by a screw working through a nut, or by hydraulic pressure (Brandt's).

Comparing percussive borers with rotary ones, the useful effect of the force expended is decidedly in favour of the latter. In hand tools of the former class, about half the time is expended in bringing back the hammer into place to deliver a fresh blow, and, in addition, a considerable amount of power is wasted in the inertia and rigidity of the tools. Ill-directed blows are also a source of loss. Even with machine drills, the same objections hold good, but here the undoubted advantage is the obtaining of deep holes. In harder rocks, percussive action is necessary, but in softer materials, easily disintegrated, the débris tends to choke the hole, jam the drill, and cushion the blow. As the generality of coal-measure rocks can be penetrated by rotary drills, it seems preferable to use machines of that class.

Percussive Hand-tools.—For soft rock, the tool employed is called a "jumper," the hole made being a large one. It consists of a bar of iron, from 5 to 6 feet long, having a broad curved bit at one end. This bar is grasped by the miner in both hands, and a reciprocating motion given to it, and at the same time it is slightly turned between each blow, so that the cutting edge strikes in a fresh place each time.

This method is only applicable in soft varieties of rock, and is soon replaced by the system in which the tool is struck a blow with a hammer. Here two divisions of labour, called single and double hand sets, may be noticed. In the former, a man holds the drill in one hand and delivers blows with the other; in the latter, one man holds and turns the drill, while the striking is done by another man, and sometimes, in very hard ground, by two men. In single-hand tools, small drills are employed, and the power expended is more effectively applied than in double-hand sets using larger tools, as in the latter case one man is solely employed turning the drill. The bits too, in small drills, stand better than large ones, which is probably accounted for by the more uniform temper. The blows delivered with the small drills are more rapid and light, this being advantageous in a hard siliceous rock, as there is more tendency to break it off in small pieces, requiring the expenditure of less power, and there is also less liability to injure the tools. The drills of both classes are composed of a stem (generally of octagonal section), a striking face, and a bit. The end which receives the blow is made smaller in diameter than the stem, so that the blow strikes dead in the centre. The remarks previously made about constructing picks of steel apply more especially here. Steel being so much stronger than iron, the stem can be materially decreased, and the mass through which the blow has to be delivered is correspondingly reduced, with the result, that the power expended is more effectively employed.

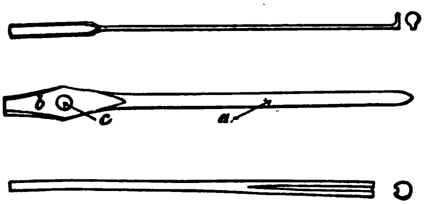
The edge of the chisel is generally curved to a certain extent, more so for softer rocks than for harder ones. The edges also are less acute for the latter class. In boring a hole of any depth, the first tool used is shorter than the following ones, and the breadth of the bit of each succeeding drill is less than the one before, so that the tool can clear itself and follow freely in the hole. The great thing in hand-drilling is to properly turn the drill, so that the hole is round; otherwise it is impossible to bore deep holes, and the cartridges employed for blasting do not fit properly, leaving spaces in which the gas expands when the shots are fired, and the useful effect is lessened. In the Cleveland iron mines, triangular holes are bored and loose powder employed, it being claimed that such form is specially advantageous in the deposits of that district; but electric machine drills, boring round holes, are making great headway there.

There is a special art in sharpening and tempering tools. The blacksmith must be experienced in the different qualities of ground. The only objection raised against steel tools is, that the points sometimes break off with the first blow or two after being put to work. The fault in such cases does not so much lie with the steel as with the smith, as the explanation of the sudden fracture is that, in hardening and tempering the point, the tool is plunged into cold water whilst a portion of it is as yet at a red heat, the consequence being that the steel is made as brittle as glass. In sharpening, in no case should the tool be heated to more than a blood colour, and no further up the stem than is absolutely necessary, and it should then be hammered lightly and quickly until quite black. After being sharpened, it is perhaps best to allow the tool to cool down before it is tempered; but such is not absolutely necessary, so long as it is not made red-hot too far from the point.

In hardening, the tool should not be heated further up than 1 inch from the point, and it is then dipped into cold water for about $\frac{3}{4}$ inch, leaving $\frac{1}{4}$ inch still at red heat. The edges of the tool will then be filed, so that the polished surface of the metal is exposed to the atmosphere, when the heat remaining in the top part gradually passes towards the thin edge, and various colours successively appear on its surface, these indicating the temperature the metal has attained.

and the degree of hardness still remaining in the steel; when the desired colour appears, the article is plunged into water, completely cooled, and retains the temper, as it is called. The colours appearing on the steel during the tempering process vary from a faint yellow, through brown and purple, to a full blue colour, the former giving the very hardest temper, while in the latter the metal is so far softened as to permit of a little bending in small articles before any fracture takes place. The experience of the smith is the only guide as to which hardness the tool should be tempered. It must be harder than the mineral to be attacked, but should also be soft and tough enough not to be brittle. There is no advantage in having a very hard, brittle tool to cut soft rock.

Scrapers.—In percussive boring, the débris produced at the bottom of the hole is cleaned out from time to time by the use of a tool called a scraper, which generally consists of a rod of copper, with a circular disc at right angles to it at one end, and a semi-circular groove, like a cheese-scoop, at the other (Fig. 46). Unless the disc



Figs. 46, 47, and 48.

end is considerably less in diameter than the hole, the powdered mineral is pushed right to the back, and prevents the bit getting at the rock when it is re-inserted. To dilute the sludge, and prevent the tool from sticking and getting hot, water is introduced in down-hill holes; a little ring of straw, or a piece of leather with a hole in it, through which the tool passes, is put over the hole to prevent the sludge spurting out.

Tamping or Ramming.—When a hole has reached its required depth, the blasting charge is inserted and rammed; that is to say, some material is placed over it to prevent the escape of the gases through the front of the hole, and so confine them at the back of it, their only escape being to blow out the rock. In preparing the hole, it is carefully scraped out for the last time, and if water has been used during boring, it is dried by connecting to the scraper a small wisp of hay, or rag, which forms a sort of plug, and sucks up moisture; or, if the hole is very wet, the claying or "bulling" iron is employed. This consists of a stem of wood (*a*, Fig. 47) and an iron head (*b*) through which a hole (*c*) passes. A lump of clay is inserted into the bottom of the bore-hole, and the stump of the claying iron driven in, forcing the clay into the interstices of the rock, and actually forming a lining round the hole. The bulling iron is lifted out by passing a cross-bar through the hole *c*. The charge and tamping are then put in, the latter in small quantities at a time, each quantity being successively rammed with the tamping-rod, which consists of a bar having at one end a flat face, while the other terminates in a cone having a groove cut in it (Fig. 48), to allow the means for lighting the shot to lie against the side of the bore-hole. This may be either a needle, or pricker where straws are used, or fuse, or wires if electricity is the agent. The farther the tamping is from the charge, the harder it is stemmed. In strong rocks blows are given to the end of the rammer by a hammer.

Hand Machine Drills.—The general type of these consists of a screwed spindle working through a nut, with a socket for the boring tool at one end, having a square on it for the ratchet-handle which communicates power.

The tool commonly employed (Fig. 49) consists of a screw-spindle, *a*, working through the nut collar *b*. The boring-bit is of the ordinary auger form, with a **V** point. The screw is revolved and pressed gradually against the rock by turning the ratchet-handle *c*, small pieces are broken off, and the hole is bored. When the advance has reached the length of the drill, it is worked back into its sheath again, and a longer one inserted. With an ordinary nut arrangement, as many revolutions have to be made with the screw to replace it in its sheath, as took place during boring. To prevent this waste of time, a split-nut, having lugs on each half tapped with right- and left-hand threads, is adopted by the Hardy Pick Co. These lugs are connected by a screw, cut with a right-hand thread at one end and a left-hand thread at the other, and can therefore either be brought in contact with, or disengaged from, the main propelling screw. Consequently the drill and screw can be withdrawn without being wound back.

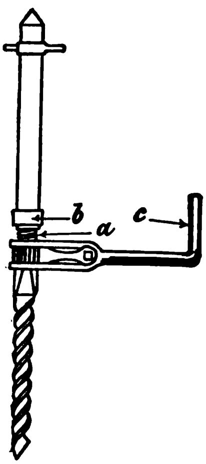


Fig. 49.

With this type of drill, a tree or prop has to be set near the face to support one end of the machine. To prevent loss of time, many machines are supplied with a stand, whose length is adjustable, as it is formed of two pieces which can slide upon each other, and be clamped together, the final adjustment being made by an ordinary lengthening screw at the bottom.

In the Elliot machine (Fig. 50) the nut is replaced by a worm-wheel, *a*, in the teeth of which, a square-threaded feed-screw, *c*, of $\frac{1}{8}$-inch pitch, takes its bearing. This wheel is carried in a ring, having a hinged joint at one side, and a screw clamp, *b*, on the other, so that more or less friction can be set up between the screw and the worm-wheel. The feed is thus automatic, and the extent is regulated by the tightness, or otherwise, with which the ring is screwed up. If the resistance is excessive, the wheel slips round to a certain extent, and reduces the full advance of the drill, which may vary from $\frac{1}{2}$ inch per revolution to nothing.

If the clamping screw *b* is slacked, the drill can at once be withdrawn without being wound back.

When boring near the sides or roof, the crank handle cannot be completely rotated, but has to be worked backwards and forwards, and a ratchet employed, thus all the time devoted to one-half the motion is lost. To remove this disadvantage the crank-handle is not connected directly to the screw, but through the intervention of bevel gearing. Bornét's* machine is so fitted, and, in addition, the nut in which the feed screw works is seated in a spring box, so that with an increase in pressure, when working in hard strata, the feed is equal to the pitch of the screw, less the amount of compression of the springs. When these are fully compressed the nut slips out of its bearings and revolves with the screw, the feed being then governed solely by the spring pressure until the resistance decreases and the nut again occupies its seat.

In thick seams ordinary stands cannot be employed. In the anthracite region of America they are replaced by a clamping device, shown in Fig. 51, attached to the Howell† drill, one of the best

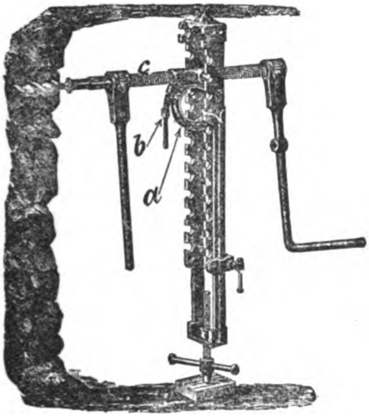


Fig. 50.

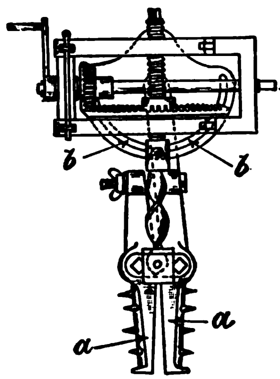


Fig. 51.

known in that coalfield. To fix the machine a hole, 3 or 4 inches diameter, is first cut into the face, and the clamping-bar *a*, which is supplied with a number of spikes, is firmly wedged in it. The illustration to a great extent explains this. The auger bit is rotated by bevel wheels, geared down from 1 : 3 to 6. A point worthy of attention is that two or three holes can be bored from one position, owing to the sector arm *b* allowing movement either to the right or left.

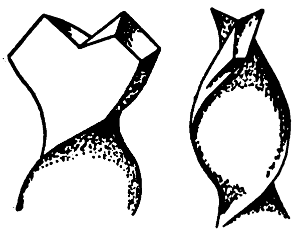
The merits of a drill depend upon its weight, the facility with which it may be set and used in different positions, and the wearing capacity of the machine itself. The rate of boring depends entirely on the form of the cutting tool and the quality of the steel, because, unless the latter is suitable metal, it is no use making it of a suitable form, as that form is soon lost by rapid wear. A great deal also depends upon the men. Unless a certain amount of skill is shown in setting the machine, and properly clamping it in position, as much time is occupied in drilling holes in ordinary varieties of rock as if they were put in by hand.

The most suitable shape of the points of the twisted augers for drilling ordinary rock-binds and coal is shown in Figs. 52 and 53.

* *N.E.I.*, xxxvii., 117. † *Report A.C. Second Geo. Survey Penn.*, 172.

This form penetrates with greater speed and less labour than any other pattern, and is easy to repair. The piece cut out of the centre should be a little more than one-third of the width of the point, and of a broad V shape, in order to keep the two outside portions as strong as possible. These should be kept as thick and stiff as the section of the steel will admit. The cutting point should be carefully kept sharp, with a good clearance left at the back. As a rule, the greater the opening in the middle the more rapid is the penetration, especially in coal, shale, and soft sandstone; but the size of the V opening is governed by the hardness and strength of the rock to be bored. When great pressure is necessary the opening at the top of the V should be narrow.

The best results are obtained in tempering, by heating 1 inch of the points to a blood-red, and then plunging them into coal-tar, as the cutting edge is made extremely hard, the points gradually becoming softer as the thickness of steel increases. Drills so treated can be re-sharpened once or twice on a grindstone, until it becomes necessary to put them in the fire again to enlarge the points.



Figs. 52 and 53.

To show the advantage of using these drills, the following may be cited:—At a colliery under the author's charge a road was driven for 61 yards, crossing the measures over a fault. The section of the road was 6 feet wide at the bottom, 5 feet at the top, 5 feet high, and it was driven at a down gradient of 2½ inches to the yard. Time occupied, 5 weeks; rate of progress, 12 yards per week. The cost was:—Labour, £47 10s.; powder and fuse, £11 18s. 9d.; total, £59 8s. 9d. The total cost per yard run was 19·488s., equal to 6·386s. per cubic yard; and the cost of explosives per yard run was 3·914s. The hardness of the measures varied considerably. A small portion could be worked with the pick, but other parts consisted of a hard, gritty sandstone, nearly too hard for the drill. Very little timbering was required, so this did not interfere much. Ventilating pipes and rails had to be laid. The road might be considered a very fair sample of a cross-cut in the Coal Measures. Similar work in another part of the pit, without the aid of a drill, cost £2 a lineal yard.

TRANSMISSION OF POWER.—In considering the question of transmitting power to the machines used in breaking ground, choice is limited to compressed air and electricity; the other means of steam, water, and wire ropes are inapplicable in the majority of cases. Steam is, to a certain extent, out of place in a mine, although, under certain exceptional conditions, it is employed, and gives good results; but its use in confined spaces, where either coal-cutting is in progress or rock-drills are being worked, is quite out of the question.

Compressed Air.—Air may be considered a perfect gas, and obeys the laws relating to such a body. These are:—

(1) That if the temperature be kept constant, the volume varies *inversely* as the pressure; if, for example, the pressure is doubled, the volume will be reduced to one-half.

(2) If the volume be kept constant, pressure varies *directly* as the

temperature reckoned from the absolute zero (-273° C. $-$ -459° F.). Thus double temperature gives double pressure.

(3) If the pressure remains constant, the volume varies *directly* as the temperature reckoned from the absolute zero. Thus if the temperature is doubled the volume is doubled.

If the above laws are clearly understood, it will be at once seen that great losses must occur in compressing air. When the volume in the cylinder is reduced by the piston, a considerable rise in temperature takes place, which can only be produced by an expenditure of power, heat being simply work in another form. If the compressed air were used immediately at the point where it was generated, no loss would take place. This, however, is never done; the heat produced by compression is lost in the transmission pipes, and all the power which produced it is lost also.

The increase of temperature during compression expands the air in the cylinder and increases its pressure, so that the piston is met both by the natural resistance of the air to compression, and by the increased resistance due to expansion by heat. Another loss through this heating is that, at the moment of discharge the air bears the pressure it should do, but as it cools the pressure falls. It has been noted that, in an ordinary compressor, the air was compressed to four atmospheres after the piston had travelled three-fifths instead of three-fourths of its stroke (see first law above), the compressed air occupying two-fifths instead of one-fourth of the space in the cylinder.

A third loss is due to the fact that the sides of the cylinder become heated, and the air on entry is expanded, so that when the piston commences its stroke, a smaller mass or weight of air is in the cylinder, but the increase of pressure due to the temperature makes the pressure normal.

From these considerations it follows that, to secure good results, there should be (1) thorough cooling during compression, (2) the air on introduction should have as low an initial temperature as possible, and (3) the air should be raised to as small a pressure as is practicable in any single cylinder.

The losses, however, do not, unfortunately, end at the compression cylinder. The loss of head in the pipes is considerable unless the pressure is high, and consequently the user is apparently between two stools. The adoption of compound compressors, where the air is first raised to a pressure of about 25 to 30 lbs. in one cylinder, and then passed through a cooling receiver to a second cylinder for final compression to from 85 to 90 lbs. per square inch, reconciles the advantages of low compression as regards the original yield, and of high compression as regards the loss of head.

The advantages of successive compressions are not fully realised unless the action is repeated in an inverse direction at the motor—that is to say, the air must first be expanded in one cylinder, then passed through a *warmed* receiver in order to bring back the expanded air to its initial temperature, and finally expanded down to atmospheric pressure in a second cylinder. The difficulties of using compound motors with intermediate warming receivers are insurmountable in many of the operations in which compressed air is used in mines, but the difficulties can be overcome if, instead of endeavouring to compound each motor separately, they are compounded mutually. This arrangement has been carried out since 1888 at Newbattle Collieries in the following manner* :—The motors are not compound, but the air is conveyed from one engine to another engine, the first being the high-pressure cylinder, the second the low-pressure cylinder, and so on. The motors are coupled up in series, and do not necessarily perform any work in connection with one another. Thus the first installation comprised three pumps, the second one being 70 yards from the first, and the third one about 100 yards from the second. The exhaust air was carried in 6-inch diameter pipes from one motor to the other, and during its passage abstracted sufficient heat from the hot air of the mine to come back to atmospheric temperature before it reached either the second or third pump. A by-pass valve was so arranged that air may be passed directly by the first or second pumps without working them. In the case of hauling engines, where their stoppage might involve the stoppage of the plant behind them, relief valves are fixed to lift at a slight increase in the pressure, and the air then expands down to the next stage.

Air Compressors.—Two systems are in use by which the heat produced during compression is absorbed. In one, water is not admitted into the cylinder, while it is in the other. The former are called "dry" and the latter "wet" compressors.

In dry compressors, air is cooled during compression by the use of a water-jacket on the compression cylinder, but at the best the action of this is very imperfect, as the area of surface exposed to the cooling action is small, compared with the volume of air compressed, so that only a small portion of the confined air can come into contact with the inner surface of the cylinder. In addition, air parts with its heat to a metal cylinder very slowly, and, with a compressor working at moderate speed, there is not time between the inlet and discharge to effect sufficient reduction in the temperature.

Wet compressors may be subdivided into two classes—(*a*) those where the air is compressed by a piston of water, (*b*) where a fine spray of water is injected into the cylinder during compression.

The former type, the design of which is due to Sommeiller, is illustrated in Fig. 54. It consists of a piston, *a*, moving horizontally in a cast-iron cylinder kept full of water. From the extremities of this cylinder spring two vertical cylinders, *b b*, closed at their upper ends by covers bolted on. The in-take air is admitted through rectangular openings, *c c*, in the sides of the vertical cylinders, the suction-valve being of leather, while discharge takes place through a conical brass valve, *d*, situated in the top. The reciprocating movement of the piston causes the water to rise on one side and fall on the other. A partial vacuum is formed above the falling water, which causes the admission valve to open and the unoccupied spaces to be filled with air; while on the return stroke the water is driven back, and the air with it, until compression in the cylinder is equal to the pressure in the receiver, and then the delivery valve opens.

These compressors have been largely employed on the Continent, the idea being that, if the air during compression was in contact with water, all heat would be absorbed. Such, however, is not the case. The air is only exposed to water on one side; a thin film of this soon

* *So. Wales Inst.*, xvii., 226.

gets hot, and, water being a bad conductor of heat, little cooling during compression takes place. As, however, a certain quantity of water is carried over into the delivery pipes at each stroke, the air is cooled before it gets to the receiver; but to be of any economical good, cooling should take place during compression. Indeed, it has been found that, to get good results, spray injection has to be introduced near to the outlet valve.

Compressors of this class resemble pumps, and must work at slow velocities. As a large body of water has to be set in motion and stopped at each stroke, considerable friction is caused, and the machine subjected to severe shocks. It must, therefore, be made very strong, and to produce the same quantity of air as a high-speed compressor must be considerably larger, and take more power to drive.

The actual position of affairs seems, therefore, to be that, by the assistance of a water piston and spray injection, a certain economy in compression is gained, while this advantage is neutralised by the extra power required to drive the machine. In addition, there is the difference between first cost and cost of maintenance in the two systems. It is impossible either to purchase large engines, or to keep them working, at the same cost as smaller ones.

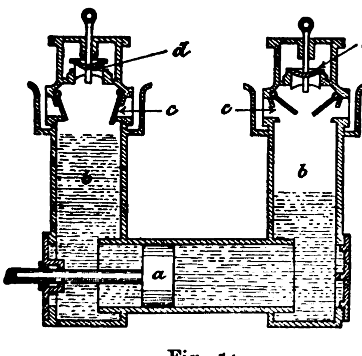


Fig. 54.

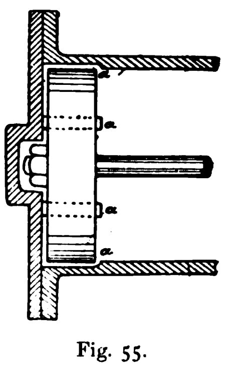


Fig. 55.

The second division of wet compressors is that in which water is injected directly into the cylinder. This answers well in keeping down the temperature, provided that the water is in the form of fine spray, that it meets the piston during compression, and that it is in thorough contact with the air. A further economy results from the fact that the power required to compress moist air is less than that required for dry air. The injected water also fills clearance spaces, and prevents loss from this cause. The absence of these in a compressor cylinder is a point of high importance. No spaces should exist between the piston and the cylinder cover at the termination of the stroke, because such spaces are filled with air at high pressure, and, on the retreat of the piston, this air expands and fills the cylinder, no free air entering until the pressure is reduced to that of the atmosphere.

To avoid clearance losses the pistons are often arranged to run dangerously close to the cylinder cover. Mr. Sturgeon has adopted a sliding end, which is lifted slightly at the end of each stroke. A preferable plan is to arrange by-pass grooves in the end of the cylinder (*a a*, Fig. 55) in such a manner that when the piston passes over them at the end of the stroke the high-pressure air escapes from the back to the front of the piston. As the pressure is thus suddenly taken off the steam piston must be properly cushioned or an injurious blow will result.

It is, however, believed that the cooling results obtained by the use of a spray of water are deceptive, as they take place principally after the air is completely compressed.

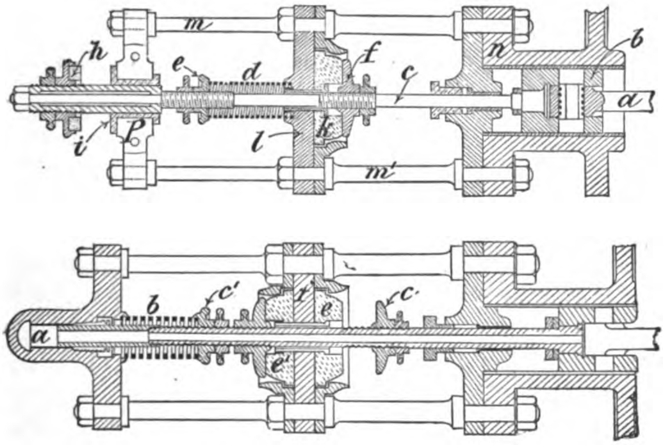
The objection to the injection system is the wear of the cylinder and piston, caused by the fact that water is not only a bad lubricant itself, but its presence in the cylinder prevents oil, or grease, getting to the working parts, as it floats on the top of the water. The situation is bad when clean fresh water is used, but much worse when, as is often the case, it is necessary to employ acid water or water containing grit or sediment. Another objection is, that the compressed air produced contains a considerable amount of moisture, and that when used the exhaust ports of the motors become clogged up by the formation of ice. By a proper arrangement of reservoirs, or draining tanks, most of the moisture in the air can be removed before it is used in the motors.

The general type of modern air compressors consists of a pair of twin compound-condensing engines having the air cylinders arranged, tandem fashion, behind the steam cylinders. Compression should be in stages, and the air passed from the low-pressure cylinder through an intermediate cooling receiver to the high-pressure cylinder. Many high-class compressors are now fitted with mechanically-operated suction and delivery valves, but, speaking generally, this is a refinement which only pays in the case of large installations. With a single engine and air cylinder arranged in a straight line it is impossible to construct an economical machine, because the greatest work in the air cylinder has to be done at the end of the stroke. At the beginning of the stroke, when the steam has full pressure, the air cylinder contains air at atmospheric pressure, and offers no resistance, but at the end of the stroke, when the pressure in the steam cylinder would be low (if expansion were used), the resistance in the air cylinder is at its maximum. All sorts of arrangements have been designed to equalise the power and resistance, but have given way to the straight line pair type, with cranks set at right angles. Expansive working can then be used, as one steam cylinder is always exerting its maximum power at the moment when the air cylinder of the other engine is finishing its stroke.

This explains the seeming paradox, how steam, say, at 50 lbs., can compress air to 70 lbs., where both cylinders have the same diameter and stroke. When it is remembered that at the commencement of the stroke the pressure in the air cylinder is nothing, that for three-fourths of the stroke it is considerably below 50 lbs., and that only at the moment of discharge does it reach 70 lbs., the explanation is self-evident.

Various Valves on Air Compressors:—

Walker's Valves.—The inlet valve is connected by a link (*a*, Fig. 56), and piston, *b*, with a controlling spindle, *c*, these reciprocating with the movement of the valve. When the piston retreats suction opens the valve, which is prevented from going too far by the spring *d*, which becomes compressed. Immediately the piston starts to return the valve is closed by the spring, and prevented from being violently dashed on to its seat by the collar *f*, which moves with the spindle coming into contact with the india-rubber buffer *k*, carried on a fixed abutment, *l*, suspended by two bars, *m m'*, attached to the cylinder cover *n*. Messrs. Walker's experience has shown that it is also desirable to buffer the valve on its in-stroke, this being done by a second india-rubber washer, *h*, striking against another fixed abutment, *i*. It will be noticed from the drawing that the tension of the spring and the position of the stops can be varied, if desired, by a nut and lock-nut arrangement, *e* and *f*.



Figs. 56 and 57.

The outlet valve (Fig. 57) is balanced by making a portion of the spindle passing through the stuffing-box hollow, the outer end passing into a small cylinder, *a*, into which air is admitted at the same pressure as in the receiver. The valve is prevented from opening too rapidly by the spring *b*, and is buffered on its in-stroke and out-stroke by stops *c c'*, arranged to engage the india-rubber blocks *e e'* (carried by a fixed cross-bar *f*), just prior to the termination of the valve's travel.

The india-rubber blocks are annular in form, but somewhat of a T-shape in cross section, the faces of the annulus being widened out to leave a projecting flange at the inner and outer periphery. With this shape it has been found that the life of the blocks is considerably increased.

Sturgeon's Valve.—The feature of Sturgeon's air compressor consists of a stuffing-box inlet valve, which is opened by the piston-rod at the commencement of its stroke, this doing away with the necessity of forming a vacuum in order to cause the valve to open. A complete cylinder, full of air at atmospheric pressure, is taken in at each stroke, and immediately the piston starts to return the valve shuts. In

Fig. 58, *i* is the inlet valve attached to the stuffing-box of the piston-rod. By means of the nuts *a a* sufficient grip can be obtained to ensure the valve opening on the forward and backward strokes of the piston. The stops *b b*, screwed to the valve, limit its travel in one direction, while its flange portion performs the same office in the other. The piston is recessed to fit over the valve at the termination of each stroke, and reduce clearance to a minimum. The outlet valves *o o* are usually eight in number, and can be taken out separately for repairs, or removed by unscrewing. A spiral spring, *c*, in each one serves to bring it back sharply on to its seat. The arrows show the direction of the air both from the inlet and delivery valves.

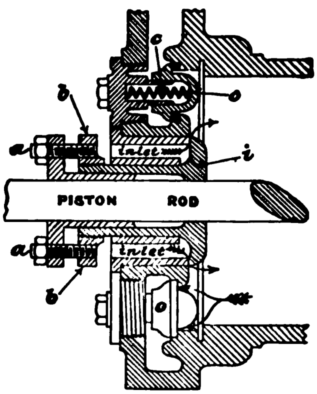


Fig. 58.

*Ingersoll-Sergeant Valve.** — This consists of two annular valves (*a*, Fig. 59) placed in a hollow piston of a double-acting air cylinder, free air being admitted through a hollow tail-rod attached to the piston. The valves do not require the aid of springs or other connections, but are opened and closed at the proper moment by their own inertia. The arrows show the direction of the intake and

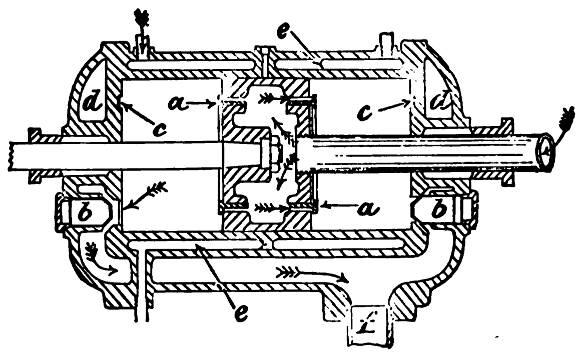


Fig. 59.

delivery; the outlet valves are shown at *b*. To reduce clearance small recesses, *c*, are turned in the cylinder covers, into which the inlet valve fits at the termination of the stroke. As there are no inlet valves in the cylinder covers water-jackets, *d d*, are provided at each end, as well as around the sides *e e*. The air passes into the receiver through *f*. A perspective view of the valve is shown in Fig. 60. Additional advantages are derived from the absence of valves in the cylinder covers, and the admission of air through the hollow piston-

* *Compressed Air Production* (Wm. L. Saunders, New York, 1891), 20.

rod. Not only can the cylinder be water-jacketed all round, but what is of far more importance, air can be drawn from outside the engine-room through the piston-rod, resulting in a considerable higher compression efficiency, as on a cold winter's morning the difference in temperature between the inside and outside of the engine-room may amount to 70° F.

Riedler Valve.—Both the inlet and outlet valves of the Riedler compressors are closed in the same manner as the pump valves of this design (for description see chapter on Pumping). The valves are perfectly free to open, but are closed at the proper moment by a cam controlled from the wrist-plate driving the steam admission valves, at a time when the wrist-plate is moving at its highest velocity, while the air piston is nearly at a state of rest. As each inlet valve is closed at the same time as the opposite outlet valve, and as the theoretical velocity of the piston movement at the time of closure is zero, there should be no wear nor shock on the valve face and seats. As no springs nor loose pieces are employed in the gear, the speed of operation is dependent only on the practical speed at which the steam engine may be worked.

*West and Jenkin's Valve.**—The inlet valve is of the mushroom type, provided with two springs on the valve stem. The lower one tends to open the valve, while the upper one, which is much stronger, tends, when free, to keep it on its seat. By an arrangement of levers and cams similar to Fig. 62 the latter spring is compressed, or let go, at the desired moment. When the piston is nearly at the end of the compression stroke, the cam compresses the stronger upper spring and relieves the valve of the downward pressure. If it were not for the pressure of air in the cylinder, the weaker opening spring below would then immediately open the inlet valve, but this cannot happen until all the compressed air in the cylinder has been exhausted through the delivery valve and the piston commences to make its suction stroke.

The outlet valves are also controlled by a cam, but are arranged with springs, and are free to open of their own accord in case the pressure in the receiver falls below the normal.

This is a point of great importance in all mechanically-actuated valves, because, unless some such device is in operation when the air is being used from the receiver faster than the compressors can supply it at standard pressure, the compressor presses air up to the maximum, and then delivers it into the mains where it expands *down* to the pressure existing there.

Means to prevent "Dancing" of Valves.—In the ordinary form of valves to which a spring is connected vibratory motion is set up, because the air tries to pull the valve open and the spring to shut it, and first one and then the other prevails.

The dancing of the valve in Walker's air compressor is reduced by causing a certain amount of friction to be set up between the spindle (*c*, Fig. 56) and one or more of its bearings. To accomplish this, where the spindle passes through the cross-bar (*p*, Fig. 56), the bearing is split longitudinally, so that the bore of the bush can be slightly contracted by means of a screwed spindle (*a*, Fig. 61), having a hand-wheel, *b*, and lock-nut, *c*, connected to the top half of the step. To provide a greater frictional surface, the spindle is made of larger dia-

* *Fed. Inst.*, vii., 239.

meter where it passes through the bearing, and is surrounded by a carbonite washer, which acts as a lubricant and prevents heating. Only a small amount of friction is applied, so as not to interfere with the free working of the valve to any appreciable extent. This device gets over the difficulty of "dancing" at ordinary speeds, but increases the power required to open the valve.

Fig. 60.

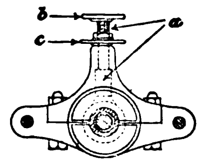


Fig. 61.

A very simple but effective device is in use at Lens Colliery (France). The inlet valves are of the ordinary poppet type, closing being effected by a spring (*a*, Fig. 62); when opened, however, the pull of this spring is taken off in the following manner :—Each end of the cylinder is provided with two inlet valves, the spindles of which, *b*, pass outside the cylinder cover. Opposite these valves is placed a small shaft, *c*, which performs one revolution to each revolution of the engine, and on this shaft, opposite each valve, is keyed a cam, *d*. At the commencement of the stroke the face of each cam engages with the spindle of the inlet valve, pushes it wide open, and keeps it there. The small revolving shaft turns this cam, and its shape is so arranged that when the piston starts to make its return stroke the cam is past the spindle, and the spring brings the valve back into its seat.

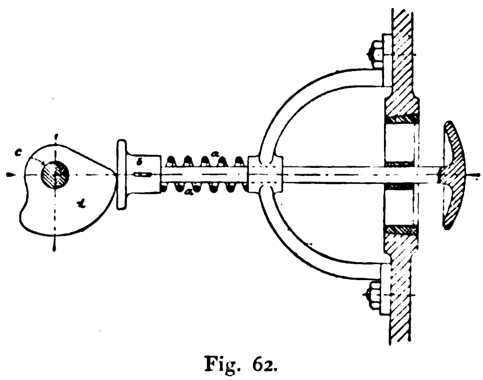


Fig. 62.

Governors.—As the ordinary speed governor attached to the steam cylinder only acts when the limit of safe working is reached, it is usual to fit air compressors with an additional appliance, which controls the speed in exact accordance with the amount of air required. In one well-known machine this is done by adding to the ordinary governor a floating lever, having one end attached to the cut-off mechanism, and the other to a plunger working in an oil cylinder. The position of the plunger is controlled by the air pressure working against a spring. Should the air pressure exceed the normal limit, the plunger moves upwards against the spring and alters the cut-off in the steam cylinder to an earlier point, while, should the air pressure fall below the normal, the spring lowers the plunger and increases the speed of the engine.

Explosions in Air Compressors.—Several instances are on record of explosions in the cylinders of air compressors with slide valves; these are due to the vaporisation of the oil introduced for lubrication. Pressures of 10 atmospheres, or 147 lbs. per square inch, are now attained, and at this pressure the temperature in the air cylinder would reach 276° C., or 529° F.; it is possible that ignition of oil may take place at a lower temperature. The formation of gases from the oils used for lubrication is sure to occur in some measure when the pressure exceeds 60 lbs. per square inch, and it is advisable, in order to prevent explosions, that the following precautionary measures should be taken:—*

Pockets or blind end in pipes leading the air must be avoided.

When compression to more than 55 to 60 lbs. per square inch is desired, compound compressors with intermediate cooling should be chosen.

If slide valve compressors are preferred, those with long curved passages should be avoided in favour of others having separate valves at both ends of the cylinder; and only sufficient oil should be introduced into the cylinder to lubricate the piston, the valves being lubricated separately.

Careful internal cleaning each week end is strongly recommended.

Surface cooling of the compressor should be as complete as possible, but it is injudicious to cool down the valve chest too much.

Conduits.—Air is conveyed from the producing machine to the motors through pipes, and a loss of work takes place from friction, governed by the following laws:—(1) Resistance varies directly as the length of the pipe, (2) inversely as the diameter of the pipe, and (3) directly as the square of the velocity. The loss from the first law cannot be done away with, as it is impossible to alter the distance between the compressor and the motor. By using pipes of large diameter, the loss from the two latter laws can be kept within narrow limits, but the expense of doing so is considerable. The experiments at Paris † show that when the velocity in the pipes exceeds 50 feet a second, the loss in pressure becomes serious even in the distance of 1 mile. The loss, however, for 2 miles is not double that of 1 mile. The size of the mains can best be reduced by adopting high initial air pressures. Friction in mains may be reduced to a considerable extent by employing glass-lined pipes, an invention lately introduced.

Receivers.—From the compressors the air is discharged into a receiver, fitted with a safety-valve and pressure gauge placed near by, which not only serves the purpose of a reservoir, but corrects the irregular delivery from the compression cylinders. Receivers also rid the air of moisture, and should be so arranged that the air passes in and out on the same side. Drain-cocks are provided at the bottom to

* *Glückauf*, 1897, xxxiii., 789. † *Inst. C.E.*, cv., 192.

get rid of the water. If the motors are any considerable distance away, small subsidiary receivers should be placed near to them in the workings.

Motors.—In these the greatest loss takes place through leakage past the piston; with an ordinary engine the condensed moisture on the sides of the cylinders act like packing, and helps to keep the piston tight; but compressed air is dry and hot, and leakage becomes serious. The most economical results are obtained by heating the air before it passes into the motor, which serves the double purpose of not only heating the air, but helps to pack the piston. It, however, introduces this disadvantage that the exhaust ports are likely to choke up with ice through the moisture freezing; but this can be prevented, to a certain extent, by having large ports, and by allowing the exhaust to take place directly into the atmosphere, and not through pipes.

In order to prevent freezing at the exhaust ports, Mr. T. Warsop* uses an arrangement consisting of a barrel with the upper end open, which is kept filled a little above half way with water. The exhaust pipe from the air motor is filled at the end with a spherical nose perforated with holes to break up the volume of air as it issues from the pipe, and is carried down into the water for a distance of about 12 inches. A cone-shaped shield of sheet iron is attached to the exhaust pipe immediately above the surface of the water to prevent the water being thrown out of the tub by the rush of air.

Efficiency.—Statements are often made of the low efficiency of the transmission of power by compressed air, and figures quoted confirming them. There are cases on record where only about 10 per cent. of the power given out by the steam engine is turned into work by the motor, but it is unfair to cite such cases as instances of the best practice and compare them with a modern electric power plant. Under the most favourable circumstances an efficiency of 73 per cent. is barely possible, while under the conditions existing in mines a total efficiency of 50 per cent. is all that can be hoped for. The efficiency of a good compressor may be put at 65 per cent., with a further loss of 5 per cent. in the conduits, while the motor itself will only give out about 50 per cent. of the work put into it. The actual condition of affairs has been summed up as follows † :—

(1) Compressed air regarded as an agent for the transmission of power is just what it is made, its value being proportionate to that of the mechanical and calorific conditions which exist at its production and utilisation.

(2) With the use of high adiabatic compressions which make the use of effective expansion impossible, miserably small yields only are obtained.

(3) With low pressures the latter defect disappears, but the dimensions of the pipes and apparatus are prohibitively large.

(4) On the other hand, by the adoption of stage compression, and especially with a mutual compounding between motors, placed far enough apart for the air, partially expanded in passing between them, to acquire the temperature of the surrounding atmosphere, yields of 50 per cent. may be easily obtained, and that with pipes and cylinders of moderate size.

* *Coll. Guard.*, lxiv., 1206.

† *Comptes Rendus Mensuels, Soc. Ind. Min.*, 1895, 153.

(5) The available energy transmitted by compressed air may be expanded by heat proportionately to the binomial of expansion itself. While other agents of power transmission, electricity for instance, correspond with a strictly defined disposability of energy, compressed air, in addition to the amount of work which it is capable of giving out adiabatically at the surrounding temperature, carries with it the ability to transform into power any artificial heat which may be imparted to it; and this transformation is effected with so high a thermal yield that the supplementary work realised practically costs nothing.

This special faculty, added to the absolute elasticity of speed, both as regards compressors and motors, and also the possibilities of regulation or storage, are features of great importance, which may often justify preference being given to compressed air over other agents for transmitting power.

ELECTRICITY.—It would be quite foreign, in such a work as this, to enter into an elaborate description of what electricity is, how it is produced, and the different systems and methods of using it; but as the mining engineer of the future will require to know a considerable amount about it, some brief description here will not be out of place. Every one is familiar with a magnet—its power of attracting bodies—and knows that each end is called a pole. This magnetic influence is exerted in certain lines, radiating from the poles, which were called "lines of force" by Faraday, who discovered that if a closed loop of wire were passed through them, a current of electricity was set up in the wire. This is the principle of the dynamo, which consists of a number of coils of wire revolving rapidly in a magnetic field. The electro-motive force depends on the rapidity of revolution, strength of magnet, and the angle at which the coils of wire pass through the magnetic field, which should be as near a right angle as possible. The current, however, set up by such action does not flow in one direction, but consists of a series of reversals in opposite directions.

At this point is reached the division line separating the two systems of electricity. In one, the current is transmitted through conductors, and used as it is generated in the machine, that is to say, in a series of starts and stops or complete reversals, such being called the alternating current; in the other, by introducing into the dynamo a device called the commutator, the current produced in the armature is, so to say, straightened out, flows in one direction, and there is then obtained what is called the continuous current.

Continuous Current.—Continuous current dynamos, or motors, as these machines will act as either, are divided into three classes, differing in the manner in which the field magnets are excited. In series-wound machines (Fig. 63 the whole of the current generated by the armature passes through the magnet winding on its way to the outer circuit. In shunt winding (Fig. 64) there are two paths for the current, one direct to the outer circuit and the other to the magnets; the latter circuit is formed of many coils of fine wire, is of high resistance, and only a small part of the current is sent round it. The compound wound machine (Fig. 65) is a combination of the two, but comparatively few turns of series winding are employed.

Series-wound dynamos require the load to be constant or have to be varied in speed with every change of load, and are seldom employed in mining work. When a series-wound motor is stationary and the current is switched on, there is no back pressure, and the field becomes strongly magnetised, with the result that the tendency of the armature to turn is at its maximum. These machines possess great starting power, and are particularly suitable for pumping or hauling work, but under a light load attain a dangerously high speed.

Shunt-wound dynamos give a fairly constant voltage at a constant speed when supplying a varying load. Such machines can easily be connected in parallel—that is, any number can be connected together to provide current for a general supply of electricity just as a number of boilers feed a common steam main.

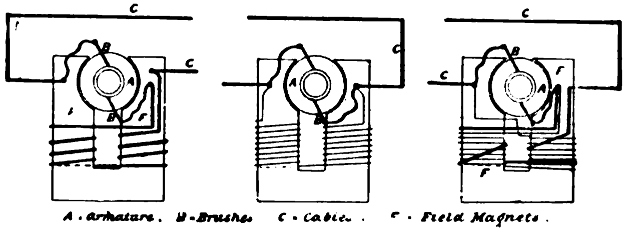


Fig. 63. Fig 64. Fig. 65.

Shunt-wound motors have not such great starting power as series-wound machines, but run more uniformly in speed under a varying load, and are well suited for fan-driving.

Compound-wound dynamos combine the advantages of both series and shunt winding, and are the most suitable for colliery purpose where more than one motor is to be used. They run at a constant speed, and give a constant voltage irrespective of variations in the load, but are not so easily run in parallel as the shunt-wound machines. The compound-wound motor is superior to the shunt-wound motor in starting power, but inferior to the series machine in this respect, and will run at almost constant speed under all loads. It is not much used, one drawback being its liability to reverse when started against a heavy load.

Mr. Alexander Siemens has directed attention to a point of considerable importance.* One of the characteristics of an electric motor is that the current passing through it depends on the work which it is called upon to do. The consequence is that, if the motor be only just powerful enough for its regular work, any accidental increase in its load will cause a current to pass which may seriously damage the motor. This, in fact, is almost the only quality in which an electric motor compares unfavourably with other mechanical motors. If these are overloaded they run more slowly or stop, but an electric motor is liable to destruction. Fortunately another quality of electric motors counteracts this disadvantage, and that is their comparative great efficiency at a diminished load. It is, therefore, advisable for economic advantages to employ comparatively

* *Fed. Inst.*, viii., 248.

large motors, although the first cost of an installation is thereby increased, but the absence of repairs will very soon repay the extra outlay. Modern motors will, however, easily carry a temporary overload of 25 per cent., and a momentary overload of 50 to 100 per cent.

Alternating Current.—The continuous current system is the one generally applied in Great Britain for the transmission of power, because up to the present, with probably one exception, an efficient alternating single current motor has not been discovered. Once started, they work very well, but the great difficulty is to get them to move against a load. There is little doubt that this will be overcome, and then a very fine field will be open for such system, especially in mines, as an alternating motor is more compact than a direct-current one, possesses no commutator, or brushes, sparking only results by severing action, and the extreme simplicity of the winding and general construction makes it very unlikely to get out of repair.

The great advantage of the alternating system is the ease with which currents of high tension can be converted into currents of lower tension, but of a larger quantity. This is a point of considerable importance, because in mines it is often necessary, in order to obtain the fullest benefits from any system of transmitting power, that small machines can be worked at isolated points where required. Now, small motors developing a few horse-power are exceedingly difficult and costly to make to work with currents of high electromotive force. As pointed out further on, for any extended application of power, the cost of conductors can only be cut down by transmitting the current at high potential in the mains. To transform this into a lower pressure is wasteful with the continuous current, and expensive machines have to be employed to do it. With the alternating system, however, the problem is a simple one. It is well known that if two wires be placed side by side, not in mechanical contact, and a current passed through one wire, a current is developed in the second wire at the moment of starting or stopping the current in the primary wire. It therefore becomes necessary, if a permanent flow is to be produced in the second wire, that the current in the primary wire must consist of a series of starts and stops, which is actually what takes place in the alternating current system. If the two coils of wire are of the same length, the current in No. 2 will be the same as in No. 1, but if the relative length of the wires in the two coils is varied, and the secondary coil consists, comparatively speaking, of a few coils of a larger diameter wire, while the primary coil is a large number of coils of a smaller diameter wire, the current generated in the former will be feebler in its voltage, but larger in its quantity, the variation being in the ratio of the number of the coils of the primary and secondary windings. There is, however, a loss of at least from 3 to 6 per cent. in transforming down moderate quantities of power, and this, with the cost of the transformers themselves, may, for short distance transmission, make the cost of an alternating current plant larger than that of a continuous current plant, although the cost of the cables is less.

Multiphase Current.—This type of machinery has already been introduced into the collieries of Great Britain, and as it is apparently suitable for mining work, a brief description may be of interest. So far as the author is aware, the first practical installation using this type of machinery was put down for experimental purposes at the Frankfort Exhibition in 1891, when 300 H.P. was transmitted a distance of 100 miles. Since that date a very large amount of machinery of this type, aggregating hundreds of thousands of horse-power, has been installed in various parts of the world, notably on the Continent of Europe and in America. Multiphase machinery is consequently no new untried type of apparatus, but has long since passed from the experimental to the practical stage.

It is, however, true that until comparatively recently no multiphase plant has been put down in Great Britain. Apparently, however, this delay was due neither to lack of knowledge nor lack of enterprise on the part of engineers, but solely to difficulties in connection with patent rights. These difficulties have now been entirely overcome, with the result that important installations of multiphase machinery are now in daily operation in Great Britain. And further, these installations are working in an entirely satisfactory manner.

In all direct current apparatus the electric current is supposed to flow in one direction. In all alternating current apparatus the current reverses its direction a given number of times per second, the number of reversals being dependent upon the construction of the machine and the speed at which it revolves.

In applying the ordinary alternating current to motive-power purposes, the great difficulty has been in constructing a motor which would be self-starting against its load, and it is apparently to overcome this difficulty that multiphase machinery has been introduced.

Multiphase currents are in the first place alternating currents, and up to the present for practical purposes only two-phase and three-phase currents have been so employed. As the tendency among electrical engineers seems to be more strongly in favour of three-phase than two-phase currents, and further as the conditions obtaining in each case are very similar, it will be better to confine the description to three-phase machinery.

In a three-phase dynamo there are what may be termed three separate and distinct alternating currents generated, but the machine is so arranged that only three conducting wires are necessary to convey the current to various motors and other current-consuming devices.

The cycle of operations in an alternating current is as follows:— Starting from zero, the pressure steadily rises to the maximum voltage of the machine in the positive direction, and then at the same rate descends to zero; it then gradually rises to the maximum voltage, but in the negative direction, and again at an equal speed returns to zero. This cycle is in practice termed a period, and an ordinary sine curve actually describes this. In three-phase machines three separate alternating currents are generated, each having its own curve, but the curve of number two phase will commence somewhat later than number one, and number three curve the same interval later than number two. From the mining engineer's point of view, however, this is not particularly important.

Three-phase generators are built by various reliable makers to suit the conditions of actual requirements. Excepting in very small machines the armature or current-carrying portion is always stationary, so that no brushes or commutators are required, the field magnets being arranged to revolve inside the armature. As no alternating current dynamo is self exciting, it is necessary, in addition, to provide a small direct current machine to furnish the necessary magnetising power, the latter is usually obtained from a small dynamo coupled direct to the main shaft of the generator, but if desired an exciting dynamo can be driven in any desired manner. For comparatively small sizes not exceeding 500 H.P. the dynamos can be arranged for driving either by ropes or belts, but in many cases, and more particularly with large plants, it is better to have the dynamo directly connected to the driving engine.

In cases where plant has been installed at a low voltage for supplying a number of motors in the immediate vicinity of the dynamo, it is a comparatively inexpensive matter to raise the pressure of the circuit to any desired amount by transformers and convey the power a considerable distance to an outlying motor, while should there be any risk of shock to an inexperienced attendant, the pressure can be again reduced by a small transformer to perfectly safe limits.

Three-phase motors can be divided into two classes—viz., short circuited motors and motors fitted with slip rings. The former type can only be built in comparatively small sizes—*i.e.*, 10 to 15 H.P. as a maximum. Slip ring motors can be built of any desired size. In both cases, however, the motors consist of cylindrically-shaped steel castings, on the inner periphery of which are arranged the main coils of the machine. These coils are stationary, and are the only parts of the motor which carry current at the pressure of the circuit.

The revolving portion of the motor is acted upon by induction, and only carries current at a low pressure. In the small or short circuited motors, the ends of the windings of the revolving portion are soldered up to brass rings, and this portion of the motor is not connected in any way with the main supply of current from the dynamo, nor with anything else. Consequently in these motors the revolving portion touches nothing but its two bearings.

In the larger or slip-ring motors, the ends of the wires from the rotor, or revolving portion, are brought out and connected to three brass slip rings on the motor spindles. Bearing on these rings are three brushes connected to a suitable resistance box, so that the motor can be started without undue shock or strain, and the speed regulated if desired. In this type of machinery, those portions of the generators and motors which carry the normal pressure of the circuit are stationary, and, as may be expected under such circumstances, the liability of the insulation of the machine to break down is reduced, as it is a simpler matter to insulate a fixed coil than one which revolves.

In the short circuited motors, as there are no collectors or contacts of any description, it is, of course, impossible for any sparking to arise.

In the larger motors, the brushes bear against slip rings at which under no conditions of working does sparking occur, but should it be desirable to completely enclose these brushes, it is a very easy matter to do so. The motors will start against their load without the slightest difficulty. The speed can be regulated within any desired limits, but assuming that the driving engine is reasonably governed, it is absolutely impossible for the motors to run above their normal speed, even of the entire load is instantly thrown off. The motors will also run in either direction with equal facility, and a three-phase motor can be reversed much more rapidly than a direct current motor.

The arrangements for wiring are very similar to what is employed in ordinary continuous current work, except that three wires must be led to each motor instead of two, but the combined area of the three wires is only equal to the area of the two wires required for doing similar work under similar conditions for a continuous current installation.

As previously mentioned, the first practical trial of the multiphase system was made at the Frankfort Exhibition in 1891, where a dynamo at Lauffen, 108 miles away, produced three currents of different phases at a pressure of 50 volts. These were transformed into three currents of 17,000 volts, and conveyed along three wires, $\frac{1}{6}$ inch diameter, to the exhibition where they were re-transformed into 60 volts, and used for lighting and the production of power. The efficiency of transmission was 70 per cent.

In 1895, Mr. T. W. Sprague * described a successful coal cutting experiment in West Virginia, where a three-phase motor at 550 volts pressure at the dynamo, undercut 200 lineal feet of face 6 feet deep in 10 hours. The motor was totally ironclad, and was without either commutator or brushes, the wearing parts being simply the bearings and pinion. A peculiarity of the three-phase type of motor was made good use of in this application—viz., its refusal, unlike a direct current machine, to do more work than it can properly be called upon to do. Heavy overloading with the former, either results in the armature burning out, or in a breakage of the weakest mechanical part of the machinery, but with the three-phase motor the overstraining will go on only to a predetermined point, when the motor will stop and refuse to make further effort until the load becomes normal again.

A three-phase system at a pressure of 500 volts was put to work in 1896 for driving hauling machinery at Gottessegen Colliery,† under stringent conditions imposed by the Prussian regulations for the management of fiery mines, and has given complete satisfaction.

A small plant has been put down by Mr. W. E. Garforth at Normanton, and a much larger one by Messrs. Stone at Garswood, near Wigan. As the latter is a fairly complete one, consisting of eight motors and lighting arrangements, a short description of its main features is given.

The *generator* is of the three-phase type, and of 120 B.H.P. wound for 500 volts at a periodicity of 40, and runs at 400 revolutions per minute. It is driven by a suitable number of cotton ropes direct from the flywheel of the engine. The armature is fixed, and the field magnets rotate inside the armature. As with all alternating current machines, a direct current exciter for energizing the field magnets is required. This is of the four pole type, and is connected direct to the spindle of the generator, and, of course, runs at the same speed—viz., 400 revolutions. The exciter is wound for a pressure of 60 to 80 volts, and, in addition to the usual commutator and

* *Eng. and Min. Journ.*, July 20, 1895, lx., 57.
† *Coll. Guard*, 1897, lxxiv., 933.

brushes of the exciter, there are two brass collecting rings attached to the spindle of the machine and insulated therefrom. Carbon brushes bearing on these rings convey the exciting current to the field magnets. As the armature is stationary, the main current of the machine is conveyed direct from terminals fixed on the top of the machine to the main switchboard, and consequently no brushes or contacts of any description are connected to any portion of the generator carrying the 500 volts current, the only portion of the machine—viz., the armature—carrying current at this pressure being stationary.

The whole of the surface arrangements at the colliery, including the screens, workshops, coal-washer, and the company's offices, and, in addition, the main roadways at each of the two pit bottoms are all supplied with incandescent lamps of sufficient number and of various sizes. In addition, there are four arc lamps for lighting the sidings and yards, and also a number of motors. The necessary wiring arrangements for lighting on the three-phase system are identical with those for continuous current work, except that the lighting should be divided into three approximately equal portions and connected across different phases of the machine, but it is by no means essential that this division should be mathematically exact, as no difficulty arises if one phase carries more load than either of the others.

About 30 H.P. is absorbed in the lighting arrangements above mentioned.

As there is a pressure of 500 volts, the lamps about the colliery proper are arranged two in series—*i.e.*, two lamps of 250 volts each in series on the 500-volt pressure.

Motors.—There are six motors driving three-throw pumps in various parts of the mine, pumping water up to the shaft bottom. All are completely enclosed, and are of the short circuited type—that is, the windings on the revolving portions are soldered up direct to internal brass rings, and consequently this portion of the machine touches nothing but its two bearings. In addition to the six pump motors, there is a 35 H.P. motor belted on to a small air compressor which is used for furnishing power to coal-cutting machines of the Ingersoll-Sergeant type. These machines are used for opening out new workings in the mine, and the motor and air compressor will be gradually moved a considerable distance in the mine as the workings extend.

Terms Used.—One of the difficulties the student has in understanding the question of the electrical transmission of power consists in ignorance of the meaning of the terms used. The whole question of electrical distribution has been illustrated by its analogy to hydraulics. Supposing a pump is circulating water through a circuit of pipes, every engineer understands the meaning of such terms as pressure, gallons per minute, friction, &c., when applied to such a current of water. If dynamo be substituted for pump, wire for pipes, and electricity for water, the conception of the phenomena of electrical transmission by a continuous current becomes clear. In dealing with water, the pressure in lbs. per square inch, the number of gallons to be delivered, and the friction of the pipes, has to be known; in electricity the pressure is spoken of as *Electro-motive Force* (usually written E.M.F.), and is measured by *volts*, the quantity is called *ampères*, and the friction is called resistance, and measured by *ohms*. To obtain the measure of electrical energy, the pressure (volts) is multiplied by the quantity (ampères), the product being volt-ampères, called *watts*. One watt = one volt × by one ampère, and 746 watts = one horse-power. The following is a useful reference table of electrical expressions:—

One Watt	A rate of doing work. 1· ampère per sec. at one volt. ·7373 foot-pounds per second. 44·238 foot-pounds per minute. 2654·28 foot-pounds per hour. ·5027 mile-pounds per hour. ·00134 Horse-power. $\frac{1}{746}$ Horse-power.	One Watt-Hour	A quantity of work. 2654·28 foot-pounds. ·503 mile-pounds. 1· ampère hour × one volt. ·00134 Horse-power-hour. $\frac{1}{746}$ Horse-power-hour.
One Kilowatt	A rate of doing work. 737·3 foot-pounds per second. 44238· foot-pounds per minute. 502·7 mile-pounds per hour. 1·34 Horse-power.	One Horse-Power-Hour	A quantity of work. 1,980,000· foot-pounds. 375· mile-pounds. 746· watt-hour. ·746 kilowatt-hour.
One Horse-Power.	A rate of doing work. 550· foot-pounds per second. 33000· foot-pounds per minute. 375· mile-pounds per hour. 746· watts. ·746 kilowatt.	One Ampère-Hour	A quantity of current. One ampère flowing for one hour, irrespective of the voltage. Watt-hour ÷ volts.
		Torque	Force moving in a circle. A force of one pound at a radius of one foot.

In hydraulics, the longer the pipes and the smaller their diameter, the greater will be the loss in transmission; so with electricity, the longer the wire, and the smaller its diameter, the greater will be the resistance and the loss. On the contrary, if the wire is short and its diameter large, no appreciable loss should (theoretically) result. The resistances of a long length of wire may be so great that all the current may be wasted in overcoming them, and none reach the points where it is required to do work. In such a case, increase the size of the wire and lessen its resistance. Copper is the metal generally used for electrical conductors, and it is a costly one. The resistances in a long length of wire may be so great that, to overcome them, a wire of so large a diameter would have to be used, that its cost would be prohibitive. One other alternative is open—to increase the E.M.F. Electricians have from the first recognised the pressing necessity of a current whose voltage is as high as possible, since the cost of copper for line wire varies in the inverse ratio of the square of the voltage employed. Thus, supposing 2000 lbs. of copper are required to transmit a given quantity of power a certain distance, with a given percentage of loss in the conductors, under an E.M.F. of 50 volts. 125 lbs. only will be necessary if the E.M.F. is increased to 200 volts. For the voltage having been increased four times, the cost of line wire will be reduced sixteen times. A current of 20,000 volts can be produced; if it could be safely used, the cost of conductors could be reduced to a minimum. This is the chief point with which the mining engineer is directly concerned. Currents of high tension are dangerous; if the circuit became broken, the current would leap the break, and produce a spark which would ignite gas in a fiery mine; while if the current were by any accidental means passed through the human body, death would result. The colliery manager is, therefore, placed in a difficult position; he wishes to use high tension currents for the sake of economy, and low tension ones for safety. From 500 to 700 volts is generally considered the maximum E.M.F. for use in mines.

Means to Prevent Sparking.—The chief danger is feared from the production of sparks, either at the brushes, or by the severance of the cable. The former is not only an element of danger, but, unless attended to, the most destructive trouble found in dynamos and motors. Its prevention depends in a great measure on the supervision of the attendant, who must keep the commutator clean, and see that the brushes are level and bear evenly, and not too heavily. The position of the brushes on the commutator is an important factor. Most machines have two marks, showing the position that the brushes should occupy at no load and full load. In dynamos the brushes should be moved forward in the direction of rotation as the load comes on, while those of the motor require to be altered backwards. Many manufacturers are, however, now supplying dynamos and motors with a constant position for brushes at all loads.

Steel clad, or enclosed motors, have latterly been largely adopted for general industrial purposes. These machines consist principally of a cylindrical steel casting, on the inner periphery of which are fixed the magnet coils, the armature bearings being carried by suitable projections cast on, or on the brackets bolted to, the main casting. The advantage claimed for such machines is freedom from mechanical in jury, as all windings, armature, and brush gear are protected by the main steel casting. To remove the probability of gas being ignited by sparking at the brushes, similar machines are commonly employed, but in such cases the motors are completely enclosed and all inspection doors hermetically sealed, thus rendering the motor completely gas proof.

Messrs. Davis and Stokes have patented an arrangement* where the brushes are placed *inside* the commutator, and also enclosed in a casing; sparks take place inside the commutator, and cannot get through to explode the atmosphere outside.

To prevent the breaking of the cable by falls of roof or sides, and consequent sparking, the general method is to allow plenty of "slack" between the points of support, so that, if a weight falls, the slack is drawn up, and the cable accommodates itself. To still further reduce the probability of severance, the cables at Plymouth Colliery † are protected by a double sheath of No. 8 steel wire on the outside of the insulation, the first stranding being of 38 wires, and the second 36 wires, laid in reverse directions. As a result the cable is capable of resisting heavy falls, its tensile strength being about 30 tons.

Mr. L. B. Atkinson introduced a safety cable, ‡ constructed on the following principles:—In Fig. 66 *a a′* are the two poles of the dynamo, and *b b′* those of the motor or lamps. These are each connected by *two* wires, a main conductor, *c c′*, and a subsidiary conductor, *d d′*, which, as they are of the same length, carry current in proportion to their area. Cut-outs (*e e′* and *f f′*), proportional to the carrying capacity, are arranged in each main and in each subsidiary conductor. If the main conductor *c* gets broken, and the subsidiary conductor *d* does not, no spark is produced, as the circuit is still closed, but the whole current now passes through the secondary wire, and at once melts its cut-out. A weight suspended by the fuse then drops on to a switch, and the whole circuit is instantly

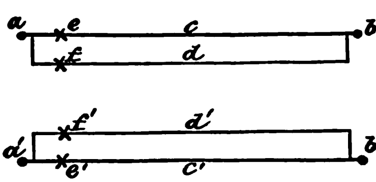


Fig. 66.

* *Fed. Inst.*, ii., 161. † *Coll. Guard.*, 1891, lxii., 395. ‡ *Ibid.*, 1891, lxii., 525.

disconnected. The cable consists of a close wound spiral of tinned copper wire, braided over, but not heavily insulated. Over this is laid a properly insulated stranded conductor of the required area. If the cable be torn down, or broken by tension, this inner conductor extends to an indefinite extent.

In Westphalia the motors are generally without contacts for receiving the current, the inductor being fixed and the revolving armature being entirely composed of circuits closed upon themselves. The starting switches are enclosed in hermetically closed cases which must rest on the earth, while, in some cases, plate switches with a bath of liquid are used instead of wire resistances. In some cases no switches are used, but the generating machinery on the surface is stopped and started by signals sent from the machinery underground. Multiphase current machines are employed, and starting is effected slowly by an independent exciting dynamo. In an underground haulage plant on the main and tail rope system, the drums are thrown in and out of gear and reversed by clutches, so that the motor always runs in the same direction.

There are certain dangers attendant on the use of non-enclosed fusible cut-outs in fiery mines. When the cut-out melts, a spark is always given off, and an electric arc may be produced which will continue for some length of time, the intensity of the spark being dependent on the tension of the current. Experiments at the Consolidation Colliery, Westphalia, proved that a lead cut-out for a normal current of 4 ampères was in each case melted, causing ignition in a fire-damp mixture by either an alternating or continuous current of 100 volts tension, while the high tension cut-out for a current of only 0·85 ampère also caused ignition. To eliminate this danger, the cut-outs should be enclosed in gas-tight iron boxes.

Efficiency.—The absolute efficiency of the ordinary means of producing the electric current by a steam-driven dynamo is small, as the electrical energy developed is only 6·4 per cent. of the energy existing in the coal burnt under the boiler, and little advance is to be hoped for so long as steam furnishes the motive power, as modern dynamos and motors have already high efficiencies in themselves. As electricity is so easily convertible into heat, it seems probable that the direct conversion of heat into electricity, which has been possible since 1823, but with a very low efficiency, may solve the question of the cheap generation of electric current. It is not too much to say that the discovery of a successful process with high efficiency will revolutionise the generation and transmission of power.

A well-constructed dynamo of moderate power will transform into electricity 90 per cent. of the energy put into it by the steam engine. In many of the recently-erected plants the engine is coupled direct to the dynamo, but although this practice has much to recommend it, yet in power installations comprising several motors which are stopped and started indiscriminately, it follows that the engine has to stand the severe strains thereby induced. In such cases it appears preferable to connect the dynamo and engine by rope belting, which takes up the shock, but which occasions a loss of about 15 per cent. between the engine and dynamo. The efficiency from the dynamo will therefore be about 76·5 per cent., while a further loss of 10 per cent. is usually allowed for in the conductors. Care must always be exercised that the conductors in all cases are sufficiently large to carry the current, and the rule as to this which has been commonly accepted by almost all Insurance Companies is, that the current density (or, in other words, the number of ampères flowing in any conductor) must not be greater than the rate of 1000 ampères per square inch sectional area of copper. A simple calculation will show that to transmit power from a dynamo to a point a thousand yards away with an electromotive force of 500 volts—that the cables calculated at the above rate—viz., 1000 ampères per square inch sectional area—will give exactly 10 per cent. loss at this distance. Consequently, if the distance is under 1000 yards at the same tension, the loss will be proportionately less than 10 per cent., and for greater distances, using the same rated cables, the loss will be proportionately greater. It is, however, usual for distances over 1000 yards to use cables of a larger size. This loss can be reduced by increasing the size of the cables, but the better economical arrangement is obtained by having a definite relation between the cost of the cable and the power lost in it. The interest on the difference between the cost of a cable sufficiently large to give only 5 per cent. drop, and one allowing 10 per cent. may more than equal the cost of the energy lost by adopting the latter size.

Motors have an efficiency of 90 per cent., but, as they run at high speeds, gearing between them and the machinery is necessary, and a further loss of 20 per cent. may be allowed for. Commencing, therefore, with 100 at the steam engine, only 85 is put into the dynamo, which gives out 90 per cent. = 76·5. A loss of 10 per cent. in the cables gives 68·8 as reaching the motor, having an efficiency of 90 per cent. = 61·96, which is further reduced by 20 per cent. in gearing down to 49·57 per cent.

The smaller electrical mining installations, therefore, utilise about the same percentage of useful effect as the *best* types of compressed air plant, but the latter are rare. Large electrical machines give higher efficiency results. Electric plants cost less in the first instance, and are worked at a lower rate. Their chief advantage consists in the ease and rapidity with which they can be put down or altered. As an instance of this fact, the author may state that at one of the collieries under his charge an electric pump was put to work a mile in-bye in six days from the time that the engine, dynamo, and stores were delivered on to the ground.

POWER MACHINE DRILLS.—These machines impart to the tool a reciprocating motion. They consist of a cylinder and piston, to the rod of which is attached a drill. The requirements of a good machine are that it should be of simple and strong construction, occupy little space, be easily handled, and, above all, the wearing parts should not only be easy of access, but easily replaced when broken. As all the work of the drill is done during the forward stroke, while in the return only the weight of the tool and friction of the machine have to be overcome, the piston is reduced in area on one side. In order to bore a round hole the tool is partly rotated after each stroke, and as the hole deepens means are provided for moving the machine forward, so that each blow is delivered with full force. Numerous attempts have been made to perform the feed automatically, but, although success has attended these efforts, the machines become much more complicated. With an automatic feed the advance is regular, while often, owing to the varying nature of the ground, it is required to be anything but regular—sometimes faster, sometimes slower. Then, again, men have to be kept to look after drills while they are working, and may just as well employ themselves in feeding forward the tool to the best advantage as to stand by and do nothing. In the old type of machine drills the piston was made to admit and cut off the admission of air into the cylinder by striking tappets attached to a valve, and although these parts were made as light as possible, yet for every stroke of the drill two blows were struck, with the result that the parts were rapidly worn away, numerous breakages occurred, and the expense of maintenance became very great. In many modern power drills the use of tappets has been abandoned, and what are known as steam (air) moved valves are adopted; their construction is therefore more simple, as the machine only consists of two moving parts. In some types a further simplification has been carried out; by means of suitable ports and openings in the cylinder the piston is made to admit and cut off steam by its own movement. They then consist of only one moving part, and that the piston itself.

It would be quite impossible to give a description here of even the majority of good machines that exist, so well-known representatives of the two main types have been selected for illustrating the way in which they work.

The Ingersoll Rock-drill.—The cylinder A (Fig. 67) has admission ports, P P′, and exhaust port, E, and also two open passages, F F′, connected direct with the exhaust port through the small passages, D D′, so that if there were nothing in the cylinder to close D D′, each end of the valve would be open to the exhaust. The

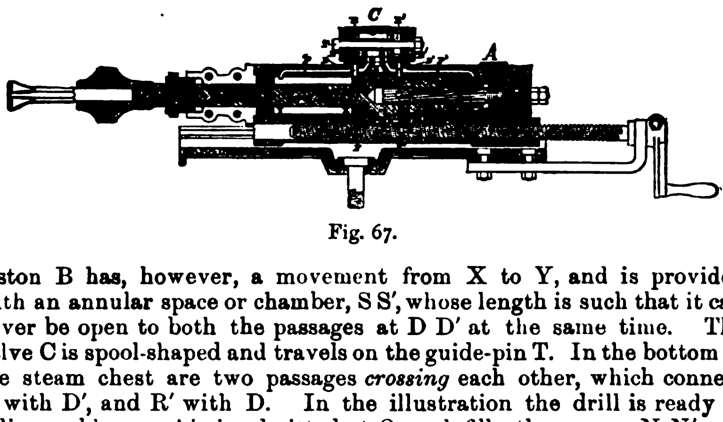


Fig. 67.

piston B has, however, a movement from X to Y, and is provided with an annular space or chamber, S S′, whose length is such that it can never be open to both the passages at D D′ at the same time. The valve C is spool-shaped and travels on the guide-pin T. In the bottom of the steam chest are two passages *crossing* each other, which connect R with D′, and R′ with D. In the illustration the drill is ready to deliver a blow. Air is admitted at O, and fills the spaces N N′ and R′. As R′ is connected with D, which is closed by the piston, no outlet is possible. R is connected to D′, and is open to the atmosphere through the annular space S and passage F′. No motion of the valve therefore takes place until the piston moves. Air passes from N through P′ to the back of the piston at M, and drives it forward; the exhaust passage S S′ approaches D, and when the distance D D′ is traversed is open to it. At the same instant D′ is shut off by the back end of the piston, D is suddenly opened to the atmosphere, and the chamber R′ being connected with it is exhausted. The air around the valve rushes towards this opening, carrying the valve with it. Thus the valve is reversed, the machine exhausts, and the motion of the piston also reversed.

The Optimus Rock-drill.—In order to economise the consumption of air, and to provide better cushioning for the piston at each backward stroke, the air used in the forward stroke to deliver the blow has been utilised in the Optimus compound drill for making the backward stroke also. When the subsidiary piston *e* and valve *f* are in the position shown in Fig. 68, the cylinder *a* is in communication

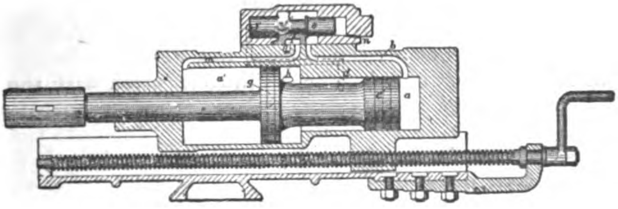


Fig. 68.

with air at full pressure through the passage *b*, while cylinder *a′* is in communication with the atmosphere through the ports *m* and *h*. The piston *c* consequently moves forwards and uncovers the small port *d*, allowing compressed air to pass to the back of the valve piston *r* and to move it to the right, because the area of *r* is greater than that of *e*, while in addition the back of *e* is in communication with the atmosphere through the passage *n*. When the valve *f* moves over, it cuts off the supply of air from the compressor, and places cylinders *a* and *a′* in communication through the ports *b* and *n*. As the area of piston *g* is greater than *c*, the air used in the forward stroke now drives the piston backward, but immediately *c* passes the port *d* the cylinder *r* is placed in communication with the atmosphere through the ports *d* and *h*, and the constant pressure acting on the piston valve *e* at *l* moves the valve *f* over to its original position; air again enters the cylinder *a* and the action is repeated.

The Adelaide Rock-drill.—This contains only one moving part, the piston, in this respect resembling the Darlington drill invented in 1873, but possessing an advantage over that type, as the air is used

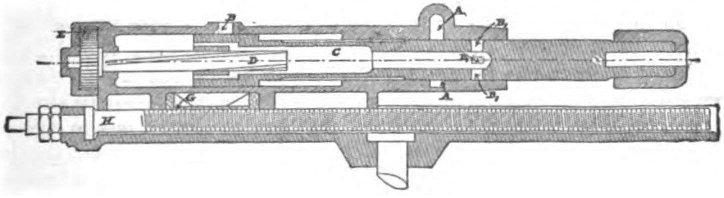


Fig. 69.

expansively and the consumption reduced. It will be seen from Fig. 69 that the one moving part (the piston C) works in a cylinder having ports and passages so arranged that the air or steam is automatically cut off and admitted by the piston itself. Air is admitted through an *annular* port, A, by which means the pressure is equalised on all sides of the piston-rod, and unequal wear avoided. The exhaust takes place through port B. The piston-rod is hollow, and small ports through the piston head allow free communication between the back end of the cylinder and the interior of the piston-rod; the front end of the piston is of smaller area than the back end. As illustrated, the piston is just completing its forward stroke.

The piston acts as a valve, for as soon as it reaches B free communication is opened with the atmosphere, and exhaust takes place, not only here, but also through B′, which has by this time passed outside the cylinder cover. The inlet aperture A, being always in free connection with the air receiver, the pressure now acts on the small area at the front of the piston, and drives it backward, until such time as this part also is brought in connection with the exhaust; at the same moment as this takes place, B′ comes opposite A, compressed air enters through the hollow rod C, passes into the back end of the piston, and drives the drill rapidly forward against the rock. Admission takes place during half the stroke, the air working expansively for the second part.

The object of discharging a portion of the exhaust at the gland, or working end, is of great practical importance, as by this simple device all the fine dust which falls on the machine when drilling uphill holes is blown away from the piston-rod, and the wear and tear of the rod and gland from this cause is entirely avoided.

The means employed to rotate the tool are the same as those adopted in all modern drills. A spiral or rifled bar, D, having three grooves, is fitted at its head with a ratchet wheel, E, which is recessed into the cover of the cylinder. Two detents, also fixed in the cylinder cover, are forced by small springs to engage with the teeth E. The grooves in the spiral bar accurately fit into corresponding projections on the recess in the piston-rod, and hence, through the action of the detents, the piston turns the bar during the out-stroke, but in the instroke the bar turns the piston, and the tool assumes a new position for the delivery of the next blow.

Brandt's Drill.—This machine is of an entirely different character to any others. It consists of a hollow steel drill, fastened to a head-piece, which is again fastened to a cylinder, and rotated by means of worm-gearing from two water-power engines, driven by hydraulic pressure. The stone is neither powdered, as with percussive borers, nor worn away, as with diamond drills, but is broken in the path of tool into small pieces, and a core formed in the centre. The water under pressure not only rotates the drill and presses it against the face of the rock, but keeps the hole clean and free from débris. By opening a valve, water is conveyed to the front of the revolving piston, so that the drill can be drawn out of the hole when required. The drill itself is of conical shape, with the base turned towards the rock. It is furnished with four cutting edges, two arranged in the outer circumference of the annulus, one set directly to the front, and the other outwards, while the other two edges are arranged on the inner circumference, directly ahead of the other towards the inside, thereby reducing the core.

At Shamrock Colliery, Westphalia,* this drill was employed

* *For. Abs. N.E.I.*, xxxvii., 34.

several years driving a drift 5000 feet long, the water being obtained from behind tubbing, and conveyed in pipes 2½ inches diameter. Two drills were worked, and a ventilator driven by a turbine. Three sets of holes, 2¾ inches diameter and from 4 feet to 4½ feet long, were drilled and fired in each 24 hours, each set occupying about 2 hours. Each drilling machine used about 1 cubic foot of water per minute. With hand-drilling in sandy shale and sandstone, the average speed was 17 inches per day, at a cost of 18s. 6d. per foot. With the machine in similar strata, the average speed was 6½ feet per day, at a cost of 29s. 6d. per foot. An elaborate series of experiments have been carried out at Beihilfe Mine, near Freiberg,* on the power, effect, cost, and wages earned, by driving with Brandt's, compressed air, and hand-drills; the three systems being simultaneously employed in three levels, with six men in three eight-hour shifts per day. Taking the diameter of the hand-drilled holes as unity, the ratio of the sizes of the holes with the compressed air, and Brandt's drills, were respectively as 1 : 2·44 : 8·05, and the power necessary to drive them as 1 : 3·26 : 8·04. The useful effect of the compressed-air drills was 25 per cent., while the hydraulic ones had a duty of only 8·5 per cent. The speed of driving by hand was 0·774 feet per man per shift; by compressed air drills, ·423 foot per man per shift; while Brandt's drill advanced ·472 foot per man per shift. This machine, which was successfully employed on the Mont Cenis, St. Gothard, and Simplon tunnels, can only be used in situations where water is easily got rid of. As a rule, mining engineers have quite enough difficulty in dealing with water already in mines without introducing any more.

Rotary Power Drills.—Several rotary drills for coal work are now on the market. They consist of a small electric or compressed air motor, connected by suitable gearing to an auger-shaped drill Including supports, the weight is about 150 lbs., which is well within the compass of one man to move about, although it is found that a man and a helper will do better work than one man alone. Indeed, the rapidity of drilling is so great that it takes the greater part of one man's time to attend to the feed mechanism and the augers, while the other man is arranging and picking the places for the holes. The machines vary from 3 to 4 horse-power for soft to hard coal, and a hole 6 feet deep has been drilled in one minute.

Grant's Drill.—This machine is of stronger construction, and has been designed for drilling in coal measures. It consists of (1) the drilling machine proper, (2) the column, (3) the telescopic shaft for transmitting power from the motor to the drill, and (4) the electric motor. It is a rotary machine, and has a specially strong thrust bearing of the conical roller type built for a working pressure of 6 tons. All parts are entirely enclosed and work in oil. The drills are of the twist pattern. The column consists of a weldless steel tube with a malleable iron foot and two jack screws of the usual type. It carries a short horizontal arm, free to move up and down or to be rotated, and to this is fixed a slide block, to which in turn the drilling machine is secured. The telescopic shaft which connects the motor to the drill consists of a steel tube with two solid shafts sliding in it, each shaft being fitted with a special universal joint and automatic coupling for attaching to the motor and machine generally. The

* *Ibid.*, xxxi., 45.

motor may be of any type of 4 H.P. Its base is a revolving turn-table, and it is also mounted on trunnions cast in one with the turn-table, so that it can be tilted at any angle.

Supports.—The supports upon which a drill was carried were originally either a rigid framework of clumsy construction, introduced with difficulty into narrow and uneven rock excavations, or a heavy carriage moving on rails, the latter, although carrying several machines, requiring that the road should be clear of débris before the drills could be set to work. The modern form consists of a vertical column (*a*, Fig. 70) resting on a base, in which lengthening screws are provided. By this means the necessary breadth of base is obtained to give stability to the column, and to permit the mounting on it of a swinging arm, *b*, upon which the drill is attached. This arrangement allows the drill to be used upon all sides of the column for drilling holes inclined in any direction. Bars are passed through the holes *c c* in the top of the lengthening screws, and prevent them from becoming loosened by vibration. With a stretcher bar, drilling can be recommenced immediately after blasting, as the drill and column can be separately carried over the débris. With such a support, the machine is adjustable in all directions. It may be shifted sideways on the arm, raised and lowered on the column, and, by first tightening the clamp *d*, the arm and machine may be bodily swung round the column.

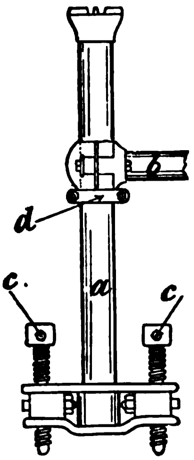


Fig. 70.

Instead of attaching the drill to the clamp through a centre bolt, the Rand Drill Co. have designed an arrangement (Fig. 71) in which the foot of the shell carrying the drill is made of a cone shape, and grasped by a hooked bolt, *b*, which is distinct from the bolts binding the clamp to the arm. If a similar clamp is attached to a tripod, the drill can be changed from one support to the other with little labour, and without disconnecting the feed-screw and removing the machine from its guides, which has to be done with the old arrangement.

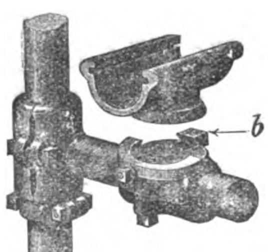


Fig. 71.

Where the length of the stretcher bar exceeds 8 feet, an objectionable vibration is set up, and, in high places, drills have to be mounted upon tripods. These consist of a light, steel frame, generally consisting of three cylindrical telescopic legs, fastened into sockets in the top, and kept in position by having weights hung upon them when the tripod is in place. By means of the telescopic arrangement and special socket-joints, the tripod may be adjusted into any position and adapted to the most uneven surface.

Electric Percussive Drills.—The difficulty in constructing a percussive electrical drill has been partly overcome by employing the principle of the solenoid. A solenoid consists of insulated copper wire coiled in the form of a spiral, but the iron core is movable instead of fixed, as in the case of an ordinary electro magnet. When a current passes, it has the same power of attraction as a magnet, and the iron core is drawn up to about the central point.

In the *Marvin* drill,* two solenoids are placed against each other, end to end, and a plunger plays freely from the centre of these solenoids. The whole is placed in a boiler tube casing, having a spiral spring in the back part. The plunger is composed of a central portion made of wrought iron, and a forward and backward portion made of aluminium bronze, all rigidly connected together. The generator furnishing the current is of the simplest kind, so that the polarity of the wires is reversed at each half revolution of the armature, with the result that through the action of this current on the solenoids a reciprocating action of the plunger is obtained, as first one and then the other solenoid attracts it, and pulls it in opposite directions. About 600 blows per minute is found to be the best speed. The object of the spiral spring is to store up the energy of the back stroke, and return it in the forward stroke, helping the magnetic impulse, and greatly assisting the strength of the blow.

In a trial made in the hard granite of Quincy Quarries,† a hole, $1\frac{1}{2}$ inch diameter was drilled at an average rate of $2\frac{3}{4}$ inches per minute, with an expenditure of less than 4 H.P. delivered to the generator. The chief features, however, were the extreme ease with which the power could be transmitted from the generating station, and the great simplicity of the drill itself. For the purpose of exhibiting the ease with which the drill could be taken to pieces, and defective parts replaced by others, it was several times opened and entirely taken apart, the time required for this being less than three-quarters of an hour.

The Engineering and Mining Journal ‡ states that the results obtained from the machines in practice are unsatisfactory, as not only are they of faulty construction, but they present a more serious trouble—viz., the heating of the solenoids and piston. The heating of the solenoids seems to be due to the rapid reversing of the electric current through their coils, and this not only means loss of efficiency, but is often so intense as to make the drill objectionable in a small heading. An installation of these machines was made at Lake City, Colorado, in 1891, but after experiments they were withdrawn owing to the objectionable heating, unsoldering of connections, and breaking of drill chucks, due to the crystallisation of the bronze of which they were made. These defects may be remedied by better electrical and mechanical design of solenoids and connections, and the adoption of an all steel plunger and chuck. Two plants were installed in mines in the Rocky Mountains in 1896, but particulars of the result of the experiments are not given.§

In the *Bladray* electric drill || a cylindrical cam, formed with a spiral surface, is attached to the drill shaft in combination with an electric motor to which a similar cylindrical cam is affixed. The cam attached to the drill shaft is connected with a spiral spring which imparts the requisite percussive action to the drilling bar immediately the cam reaches the limit of its throw. The feed of the drill and the

* *Eng. and Min. Journ.*, 1891, li., 600. † *Ibid.*, 1891, li., 400.
‡ *Ibid.*, 1891, lii., 720. § *Amer. Inst. M.E.*, xxvi., 416.
|| *Coll. Guard.*, 1897, lxxiv., 964.

rotation of the cutter tool are almost identical with those of ordinary rock drills. The motor is of the polyphase type. The machine has a stroke of 3 inches, and in a trial at Johannesburg is said to have delivered 700 blows a minute, each of 400 lbs., with an expenditure of 2·04 horse-power at the engine driving the dynamo. It has not been adopted in practice.

In the *Meisoner* drill,* introduced by Siemens and Halske, the electric motor is separate from the drill itself and can be transported separately, the connection between motor and drill being made by a flexible shaft. This flexible shaft is connected through bevel wheel gearing to the shaft operating the drill which imparts a reciprocating action to the plunger. On the same shaft is keyed a small flywheel. The combination of the flexible shaft, the wheel gearing which reduces the speed, and the flywheel prevents recoil on the gear, and allows the use of an electric motor of the highest speed and efficiency.

Forms of Bit.—The first form of bit for machine drills was that of a chisel, shaped from the end of a round, or more generally octagonal, section steel bar. The edge of the chisel is usually rounded or convex, while the angle of the cutting edge varies from 60° to 100° according to the hardness of the rock, the most common angle being 90°. The bit is usually made half as wide again as the diameter of the shank to enable the tool to clear itself, but the projecting ends are made smaller when the rock increases in hardness. In order, however, to obtain more striking surface, two chisel edges crossing each other at right angles were tried. This did the work better, but as the hole got deep, ready escape of the débris was prevented, as the tool nearly filled the hole. To remove this difficulty, the two chisels were made to cross each other on a slope, forming a tool like the letter **X**, which is the shape now generally adopted. Bits like the letter **Z** have been tried with most satisfactory results, so far as the efficiency of the boring is concerned, but the difficulty of sharpening them prevents their general application. For making and dressing the drill bits, a set of tools called "swages" are employed. These are like moulds shaped to the form of the bits required.

It is of the utmost importance that drills should be quickly and properly sharpened. An expert smith and striker may in favourable cases sharpen and temper as many as 30 chisel bits in an hour, but at large mines when hard rocks are met with, a field is open for the introduction of sharpening machines. Several are on the market, and the history of the nine British patents relating to the invention of these machines and the manner in which they perform their work have been fully described and illustrated in the *Colliery Guardian*, of Dec. 9th, 1898, vol. lxxvi., p. 1060.

Use of Water in Boring Holes.—Experience has proved that by using water in the holes the speed of drilling is considerably increased, and such is always done in drilling down-hill holes. With up-hill holes, water cannot be employed with ordinary means. Messrs. Dubois and François exhibited at the Paris Exhibition in 1889 a device which overcame the difficulty. A small copper pipe is fixed in a groove extending throughout the length of the drilling bit, and is connected by a small flexible tube to a tank fitted to the back of the piston-rod, but prevented by suitable means from rotating with it.

* *Eng. and Min. Journ.*, 1898, lxvi., 759.

With each stroke of the piston, water is thrown on to the place where the cutting edge strikes, the bottom of the hole is always kept clear, and the full effect of the blow from the drill is obtained ; the deeper the hole, the greater the effect.

A good automatic injection reduces the time occupied in drilling a hole, and effects a saving in motive power, maintenance, and lubrication, because for a given advance the number of blows struck is less. The latter part of the hole is drilled as quickly as the first portion, and the saving in time amounts to two-thirds.*

The Rand Drill Co.† obtain similar results by using a hollow drill bar formed of a steel tube to which are fastened movable steel points. These are shaped like the regular X bit, and are supplied at such a low rate as not to be worth sharpening when dulled. They are pressed on to the drill bar by a special machine, and do not come off while in operation if proper care has been exercised. The current of air which is allowed to pass through the piston and drill bit, when the machine is making its forward stroke, allows the drill point to strike on the solid rock each time.

The Leyner drill employed at the Newhouse Tunnel, Colorado, also used water injection through a hollow bit, which not only removes the débris, but keeps the bit cool and in temper. It is stated‡ that the amount driven increased 20 feet in the first month this improvement was applied.

Cost of Machine and Hand Drilling.—For two years at Ramsbeck lead mines § careful comparisons have been made between the cost of driving levels by hand and by machines. The strata consist of hard schists and greywacke. With hand boring, the average speed of driving double tramway roads was found to be 9 feet 10 inches per month, while with machines it was 35 feet. The saving, taking economy and *speed* into account, was 304 per cent.

Saving in money by using machine drills, . .	£116	14	5
,, ,, per yard driven, ...	1	11	3
,, ,, per cent., ...		20·6	

Interest on capital and amortisement was taken at 13 per cent. Repairs to drills amounted to 10·49 per cent. of the working cost.

Experiments have been conducted at the Rammelsberg Mine in the Hartz,‖ where six types of machine drills have been tried for several years. The saving was 2s. 3·89d. per ton of ore won in favour of machine as compared with hand drilling, including all costs, during the year 1880-81. The saving in favour of machine drilling for the years 1877, 1878, and 1879 was 10·39d., 1s. ·07d., and 1s. 5·2d. per ton respectively, which shows a progressive increase, probably due to improvements in the machines and training of the men.

The following figures relating to the Vosberg Tunnel, U.S.A.,¶ show the difference in the speed of machine drilling compared with hand :—

* *Soc. Ind. Min.*, vii., 3e Série, 393.
† *Eng. and Min. Journ.*, 1893, lvi., 238.
‡ *Ibid.*, 1902, lxxiii., 553.
§ *For. Abs. N.E.I.*, xxxi., 24. ‖ *Ibid.*, xxxii., 43.
¶ *The Vosberg Tunnel*, Leo von Rosenberg (New York, 1887), 26.

	East End.		West End.	
	Length. (ft.)	Excavation. (cub. yds.)	Length. (ft.)	Excavation. (cub. yds.)
Hand drilling, . .	60·81	537·50	65·73	419·62
Machine drilling, . .	181·11	1069·27	138·63	1095·77

Average for hand drilling, both ends, 63·27 feet, for machine drilling, 159·87 feet; a gain in speed equal to 152·7 per cent.

COAL CUTTING BY MACHINERY.—Under suitable conditions, coal can be holed much cheaper by machinery than by hand, except, probably, when wages are low. The great advantage, however, is that less small coal is produced, as with the pick a man, to under-cut a certain distance, has to remove enough height at the face to get his arms in. To a certain extent, machines cannot well be used in old mines, the work requiring to be specially laid out for them. Their success depends in a great measure on personal organisation and superintendence of the officials in charge of the operation. Many of the failures can be accounted for in this way. Only by attention to the details of filling and hauling the coal away from the face can the machines be worked with that regularity which will make them pay. In mining with the pick, the men themselves look after their tools, but when machines are employed considerable extra attention devolves upon the management, as the machines have to be kept in order, duplicate parts provided in the stores, hose pipes maintained in good condition, and every detail carefully attended to.

The chief advantage of machine mining, apart from the reduction in the cost of under-cutting, results from the increased production from a given length of working face with the employment of a smaller number of men. A smaller length of roadways and face have thus to be constructed and kept in repair for any given output. New collieries can be developed more rapidly, and become remunerative long before they would do if developed by hand labour. The disadvantage is the additional capital required at a time when the mine is being opened and not paying. With a good roof requiring little timber, machines are used with a considerable amount of success, but in a tender coal the roof is crushed down upon them, or supports have to be set near the face. These get in the way of a machine, which cannot move round them like a collier. Indeed, a fairly strong roof is a *sine qua non*, because machines not only require more room between the wall face and the packing than a miner, but make so much noise when at work as to prevent the attendants hearing the preliminary warning sounds that the roof generally gives before it breaks down. In order to minimise this risk, it is usual to momentarily stop the machine at short intervals to listen for any sound of the weightening of the roof.

The many different types employed, which often only vary from each other in detail, may be divided into (*a*) the circular-saw class, (*b*) the band-saw class, (*c*) the percussive, and (*d*) the bar type.

Machines worked by Compressed Air.—*Gillott and Copley's* is a representative of the circular-saw type. The cutter wheel is a malleable-iron disc, 4 feet diameter, furnished on its outer periphery with a series of chisels, these being of two kinds, single and double, placed alternately. Power is supplied by an engine having cylinders 9 inches diameter by 10 inches stroke, geared down about 5 to 1. The machine is drawn forward by a wire rope, which is attached to the hook (*a*, Fig. 72), then passed round a pulley at the end of the face, and finally brought to, and coiled on, the drum *b* by the action of a ratchet-wheel and pawl, which can be so regulated that either one or more teeth are taken at a time, thereby allowing the machine to be fed slower if the under-cutting is hard. This machine cuts from back to front, and brings its débris out, if the cut is above the floor.

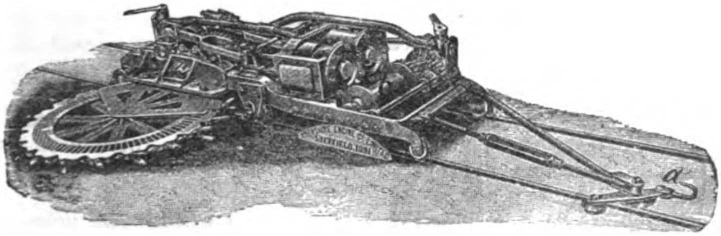


Fig. 72.

Rigg and Meiklejohn's machine also cuts like a circular saw, but with this advantage—it holes into the face on the underside of the sleepers; or, in other words, flush with the bottom of the coal. It can be employed in the thinnest seams, as its height is only 16 inches. It is provided with four adjustable screws, one on each corner, by means of which the cutters can be made to work at any angle, and the axle-boxes are also adjustable to allow the machines to progress at any angle, irrespective of the level of the rails. It revolves, however, from front to back, and carries the débris into the cut, requiring the services of an assistant to clean it out. The cut can be made alternately in opposite directions.

Diamond Coal Cutter.—An experience of over fifteen years with many types of machines induced Mr. W. E. Garforth to design the special

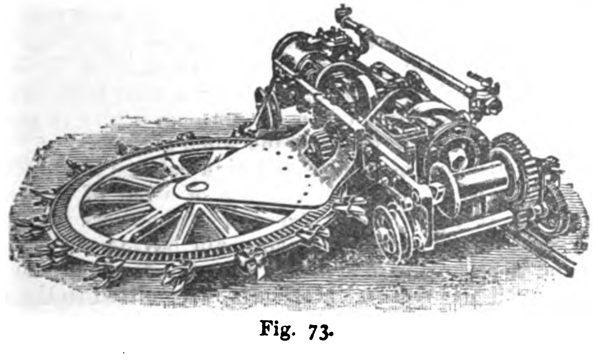


Fig. 73.

form illustrated in Fig. 73, which possesses several novel features. It makes the deepest cut of any rotary wheel machine (from 5½ to 6 feet), and also the highest, the cut in exceptional cases being as much as 9 inches, although 5½ inches is the usual one. This leaves such a space below the coal that, when the timber is withdrawn, the leverage due to the depth breaks off the coal at the back of the holing. The cutter wheel is made in halves to facilitate transport, and is provided with detachable cutter boxes, somewhat similar to a tool holder, which give a certain amount of rigidity to the cutters, prevent them getting broken off, and enable a complete set to be changed in five minutes. Two cylinders, each 9½ inches diameter by 9 inches stroke, are employed for driving the cutting disc, the necessary rotary motion being transmitted to the rack on the cutter wheel through gearing in the proportion of 22 to 1. In order to balance the entire machine, the cylinders are placed at either end of the framework. By fitting on an extra pair of axles and wheels and turning over the machine, it can be made to cut at any desired height. From February 12th, 1897, to March 11th, 1897, a machine cut 3014 lineal yards in 42 shifts of eight hours each, including everything. There can be little doubt from the results given below that the introduction of this machine marks a distinct advance in the problem of successful machine mining.

The *Jeffrey Long-wall* machine of the disc wheel type possesses some novel features. In common with all long-wall machines it is self-propelling, but the rate of feed is adjustable whilst at work, and can be started or stopped without stopping the machine. The cutting wheel may be tilted up or down by turning a handle, so that obstacles may be ridden over or an uneven floor followed. One rail only is employed on which the machine runs, there being two wheels—one in the front and one in the rear of the machine—the rail being held in place by jacks. An idler wheel is provided at the front end, which takes the side thrust of the machine due to the pull from the cutting wheel. The feed is so arranged that the machine will cut at three speeds, the highest being 25 inches per minute, medium 16 inches, and the slowest 8 inches per minute.

Baird's machine represents the band-saw type. The cutters are of various shapes, and are mounted on an endless chain, carried by a jib which projects beneath the coal from 3 feet up to 5 feet as required. Motion is given by an 8-inch cylinder by 12-inch stroke engine, through gearing to a cylindrical shaft in the centre of the machine. On the bottom of this shaft is a cam, or sprocket wheel, which drives the chain carrying the cutter teeth. As this chain has to be carried over the top of the rails, the machine cannot undercut in the bottom of the seam unless the floor is taken up. The difficulty is got over to a certain extent by canting the machine when at work.

The *Mitchell* machine of American design belongs to the chain type of cutter for longwall work, and consists of a bar of hardened tool steel projecting at right angles from the framework carrying the driving engines. This bar carries the chain having cutters fixed in the links, and the whole is so arranged that the depth of the cut can be regulated from 3 to 6 feet. Motion is transmitted to the chain by means of spur and bevel wheels, the gearing running in oil.

Harrison's machine, which is largely employed in the United States, consists of a percussion drill which chips away the coal. A broad pick bit is secured to the end of the piston-rod of a small cylinder mounted on wheels. The cutting tool is chisel-shaped, with a triangular slit in its face. To perform the undercut, two boards, 6 feet by 3 feet, are laid on the floor close to the face and slightly inclined towards it. The machine, mounted on 14-inch wheels, is run on these boards, air turned on, and the face attacked at the angle shown in Fig. 74. The machine is balanced on the wheels, and the operator, lying behind it, sprags the wheels with his feet, keeps the machine up to its work, and by means of the handles swings it about and regulates the direction of the blow.

Machines of a similar type have often been designed, but the violent shock against the rear head of the cylinder, when the piston made its backward movement, not only made it impossible to keep them to their work, but broke them to pieces. India-rubber cushions are not sufficient remedy for this evil. Here the difficulty is surmounted by interposing between the piston and cylinder head an air cushion of adjustable pressure, and, it addition, the valves are so arranged that the rebound of the pick actually aids in moving them. Prof. Wheeler* states that it takes about six minutes to shift the boards, one and a-half minutes to change the bit, and sixteen minutes to cut 4 feet wide by 4 feet deep. To disconnect load up the outfit on a truck and remove to the next place, unload and start to work again, takes about twenty minutes. The cutting capacity is found to be between 60 and 70 lineal feet per ten hours shift, with an air pressure of 80 lbs., the average for six machines for a month being 63·8 feet. A Harrison machine weighs only 700 lbs. and costs about £120. The cost per day for power, repairs, interest, and depreciation, is put at 3d. per ton.

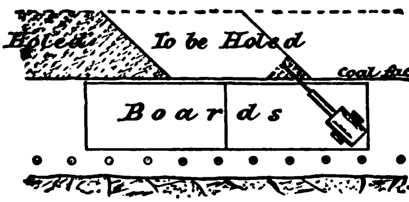


Fig. 74.

The *Ingersoll-Sergeant* machine is similar in general appearance to the Harrison, but is furnished with an air-moved valve like their drills. It is claimed to be simpler in construction, to be more under control, to deliver a harder blow, and to be more economical in air than the Harrison.

The *Yoch* machine is of the same type as the Harrison or Ingersoll, and, although 400 lbs. heavier than either, is considered by Mr. W. Blakemore † to be as easy to steer, having larger cylinders, being stronger and somewhat more compact, to strike a harder blow, less liable to get out of order, and to work with less vibration. He adds ‡ that two years' further experience with the three machines confirms this view, and that for seams where nodules of pyrites or hard stones are to be met with in the holing, percussive machines were to be preferred to any other type, as the intelligence of the workman could

* *School of Mines Quarterly*, New York, ix., 308.
† *Fed. Inst.*, xi., 193. ‡ *Ibid.*, xiii., 490.

direct every blow, the slightest twist of the handles at the rear causing a corresponding deflection of the pick. In this way, the operator could cut all round the obstruction, and finally remove it without serious damage.

German Machines.—Several types of percussive machines are used in the inclined seams of the Westphalian coalfield, differing little in construction from rock drills except in the method of attaching them to the stand and in the shape of the cutting tool. In addition to an adjustable sleeve or collar gripping the upright of the stand, the connecting device is arranged so that the cutting machine may be rotated and the tool describe an arc. In this way the cut can be made in any desired direction. The width of the cut averages 3 to 5 inches, and a depth of 10 feet can be made, although from 6 to 8 feet seems more preferable. The breadth of the cut seldom exceeds 10 feet, so that in wide stalls the machines require re-setting several times.

The *Jeffrey* pillar and stall coal-cutter consists of a bed frame, occupying a space about 2 feet wide by 7 feet 6 inches long, composed of two steel channel bars, the top plates on each forming racks with the teeth downwards, into which the feed wheels of the sliding frame engage. On the rear end of the latter is mounted a pair of 5-inch by $5\frac{1}{2}$-inch engines, or an electric motor, from which power is transmitted through straight gear and worm wheels to the rack, which feeds the sliding frame forward. In the later machines, an endless chain carries

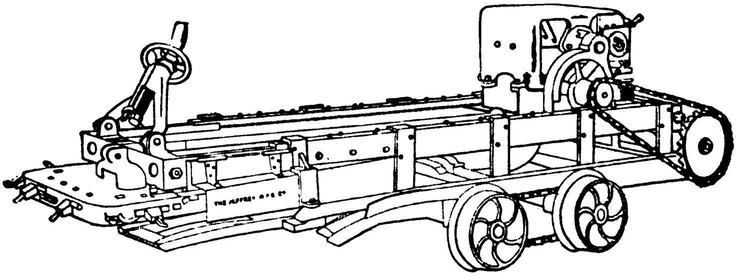


Fig. 75.

cutting knives, which work around a triangular-shaped cutter head. Two advantages are thus secured:—Only three wheels are required to guide the chain—viz., two in the cutter head and the sprocket wheel for conveying power, while the sliding frame is contained wholly, with the exception of the cutter head, within the stationary bed frame, insuring perfect protection to persons working around the machine. All the cutting tools are interchangeable, but are set at varying angles in sockets forming part of the chain, as shown in Fig. 75. While the machine is making its cut it is firmly held in position by two screw-jacks, one at the back and the other at the front.

In this machine the cut is parallel to the face, or in the same direction as the miner works, while in the others it is at right angles. When the cut has reached the required depth, usually about 5 feet, the cutter chain is thrown out of gear and withdrawn, the machine moved sideways along the face over the width of the groove, and another cut made. This gets over two disadvantages—(*a*) the inability of most coal-cutters to work in stalls where the props are set at short intervals, since so long as the distance between them is not less than 3½ feet, this machine can easily be placed in position; (*b*) the irregular holing generally produced when the floor of the seam is undulating. Rotary wheel machines must cut a straight groove; this one can follow any variation in the floor which takes place within its width.

By arranging the cutter frame at right angles to the floor, a modification of this machine has been introduced for shearing a vertical groove from the top to the bottom of any bed of coal. The method of using such a machine is to place it in position on the floor at the working face, adjust jacks under it, and raise it to the roof. After the first cut has been made at the top, the machine is lowered a distance equal to the height of the groove, and is then in position to cut again.

The chain form of this machine takes less power to drive than the bar type, but both labour under the disadvantage of being large and heavy, and expensive to move about from one place to another. After the first cut under has been made, it takes about twenty minutes to move the machine sideways and fix it in position for the second cut.

Machines Driven by Electricity.—Although machines generally under-cut coal cheaper than manual labour, the difficulty of driving them by compressed air nullifies the advantages to a certain extent, even where favourable conditions exist. The cost of installing compressed air is considerable, and its transmission to the face presents difficulties; not only are the pipes expensive, but the cost of labour in laying them is large. If the pipes are carried along the sides of the road on supports, any fall of roof or sides will break them; while if they are buried beneath the floor leaks cannot be detected. These latter considerations are not so important in the main roads as they are in those approaching the face, which are constantly being altered in dimension, and in which repairs are frequent.

Electricity appears to be particularly applicable to the operation of coal cutting. In the facility with which power can be carried about, this medium stands unrivalled, and the cost of upkeep is less than with other systems. The only objection is the danger that may result from sparking at the motors in situations where explosive atmospheres may exist. This danger appears to have been exaggerated. In the first place, the majority of mines do not contain explosive atmospheres, and in the event of a sudden outburst of gas, the motor may be stopped. Sparking at known points, or by short circuiting, appears to be preventable, as it depends on the design of the machine, on the intelligence of the workmen operating it, and last, but not least, on the common sense of the purchaser. In the desire to secure economy in outlay, less money is often spent on safeguards than should be the case.

Mr. T. B. A. Clarke * considers that a fair average performance for each electrically-driven machine cutting 4½ feet under may be taken at 80 lineal yards per shift of eight hours, and that the machines should cut on two shifts, leaving the third clear for repairs and peri-

* *Fed. Inst.*, xi., 492.

odical overhauling—a practice always advisable. Compound wound dynamos, over compounded to the extent of about 10 per cent. to allow for loss of pressure in the line at full load, and series wound motors, capable of going up to 16 horse-power without undue heating, should be employed. He prefers a cable of the type insulated with pure vulcanised rubber, covered with a strong protective sheath of tarred hemp and braid, having a standard insulation of 2000 megohms per mile, as the cost of this is very little more than that of the lower standards. Twin and concentric cables are objectionable on account of their want of flexibility, liability to kink, and risk of short circuit. Armouring the cable renders it less liable to abrasion, but a fall of roof is almost certain to drive the armouring into contact with the copper core, and thus put the circuit to earth. Ordinary cables, when abraded, can be patched and used in the roads for extension of the branch circuit. He considers the disc wheel is the most suitable implement for long-wall coal-cutting, and that it is of great importance that rigidity and absence of vibration should be secured as much as possible. Unless the rails on which the machine travels are firmly propped and secured, the machine will not keep up to its work, and the current used will vary considerably instead of remaining steady. Finally, the satisfactory working of the motor itself depends largely on the proper fixing and design of the brush gear. In one especially designed for this purpose, and giving very satisfactory results, the brushes used are carbon and the commutator segments are cast copper. As the cable erection at the face is of a temporary character, while liability to leakage is great, it has been considered advisable to use a pressure sufficient to give good efficiency, and yet too low to cause any injury through an accidental shock. A pressure on the surface of 400 to 440, giving 380 volts at the motor, meets these conditions.

The *Goolden** cutter consists of a long bar, taper or parallel, having a series of steel tools arranged on it. This bar is rotated at the rate of about 500 revolutions per minute, the electric motor running at about 700 revolutions. The cutter-bar is drilled with a series of holes, each of which is placed in a direction nearly, but not quite, at 90° to the next adjacent one, with the result that the cutters form a left-handed spiral, which serves to equalise the cutting action, and also a right-handed spiral, which acts as a sort of corkscrew, and draws the débris out of the cut. After trying various forms for the cutters, a V-shape has been adopted, with the edge nearest the machine sloping across the cut; so that when the tool has entered about $\frac{1}{8}$ or $\frac{1}{4}$ inch a wedging action commences, and the ridge of coal left between succeeding cutters is split off. As a maximum performance at Nostell Colliery, this machine cut 55 yards of face an average depth of 3 feet 8 inches in 55 minutes.

The *Heppel and Patterson* machine is of the rotary bar type, with the cutting bar having three dovetail grooves running along its length, in which are placed the teeth, these being kept in position and the required distance from one another by suitable strips of metal. The whole of the cutting mechanism can be swung about for examination of the cutting bar and during the removal of the machine from one part of the mine to another. The small coal produced by the machine

* *Inst. C.E.*, civ., 104.

	In a Seam 3 feet thick.			In a Seam 1 foot 6 inches thick.		
	Nature of Holing.			Nature of Holing.		
	Favourable.	Hard.	Very Hard.	Favourable.	Hard.	Very Hard.
Price for getting coal by hand per ton,	1/6	1/8	1/10	3/2	3/6	3/10
Percentage of slack by hand,	35	40	45	45	50	55
,, ,, machine,	20	20	20	30	30	30
Average selling price per ton, round (including nuts), at 6/- per ton, hand,	4/9·3	4/7·2	4/5	4/5	4/3	4/1
,, ,, slack, at 2/6 per ton, machine,	5/4	5/4	5/4	4/11·5	4/11·5	4/11·5
Price for filling out coal with machine holing, including getting bottom up,	1/-	1/1	1/2	2/-	2/1	2/2
Yards holed by each machine per day of 16 hours,	200	160	120	200	160	120
Holed by 8 machines, per week, . . . tons	8,000	6,500	4,900	4,000	3,250	2,450
,, ,, in 48 weeks, say . . . ,,	384,000	312,000	235,200	192,000	156,000	117,600
Cost per ton for holing by machine—Labour (one man at 6/- per day, one at 5/- per day),	1·6	1·9	2·6	3·1	3·9	5·1
Allowance for first cost of plant (£900 per annum),	·6	·7	·9	1·2	1·5	1·9
,, ,, power (£1210 per annum),	·8	·9	1·2	1·5	1·8	2·5
Total cost of coal-getting by machine,	1/3·0	1/4·5	1/6·7	2/5·8	2/8·2	2/11·5
Saving as compared with hand labour,	3·0	3·5	3·3	8·2	9·8	10·5
Saving in yield of coal,	6·7	8·8	11·0	6·5	8·5	10·5
Total saving,	9·7	1/0·3	1/2·3	1/2·7	1/6·3	1/9·0

during holing is removed by an endless scraper chain, which, it is claimed, entirely overcomes the difficulties experienced in other machines of the bar type from the jamming of the cutting tool.

The *Jeffrey* machine, as described above, but with the engines replaced by an electric motor, is largely in favour in America. The current required is from 30 to 50 ampères at a pressure of 220 volts; the armature is calculated to run at 1000 revolutions per minute, while the cutter-bar makes 200 revolutions. The momentum of the armature is such that obstructions met with by the cutter-bar are not perceptible, so that the machine is caused to run steadily. A great number of these machines have been applied, and the amount of work done by each averages from 600 to 900 square feet of under-cut in ten hours.

*Van-Depoele.**—A machine of the percussive type has been placed on the market in America. With a stroke of from 5 to 6½ inches, obtained by the action of a solenoid, it delivers from 300 to 350 blows per minute, and weighs a little over 700 lbs.

Cost of Coal-Cutting.—Mr. R. W. Clark † gives the actual figures for a day's work, taken at haphazard, as 6¾ lineal yards of under-cutting per hour, as the average performance of four machines during three shifts. He states that the holing was exceedingly hard, and that this may be taken as a fair performance, as, almost always, little delays will occur. The working place should not be too long, as if there is any delay in filling the coals out, the machine will be stopped on its own journey. The chief point on which success depends, is the removal of the machine from one place to another. This must be made as expeditious and as simple as possible. A great deal depends on the readiness of the men. Three men have moved the machine about 2000 yards up some very low roads, taking about sixteen hours in unfixing, removing, and fixing up again. The deputies should be men of quick observation and ready resource, and able to estimate how much work there is to be done in every shift in every face, and to arrange for the regular working of the machines. In 1883, 3⅝d. was paid per lineal yard cut, this including removal of machine and laying pipes in the roads leading to the face.

Mr. Geo. Blake Walker gives a comparison, reproduced on p. 83 of the relative cost of coal-getting by hand and by machine.‡

It will be noticed that the greatest saving results from the reduction in the amount of small made by machines.

Mr. T. B. A. Clarke has prepared the accompanying table giving the results obtained at a number of collieries with machines driven by electricity during two or three years.

The high cost at Lidgett is due to the hard nature of the holing and the low height of the workings, which causes hindrances in the handling of the machines.

From an average of eleven Jeffrey pillar and stall machines, worked at Scott Haven, in Pennsylvania, Mr. W. S. Gresley§ gives the production of each machine at 25,000 tons of coal per annum, while the savings, including renewals, supplies, and interest and depreciation, amount to fourpence per ton. There was an increased yield

* *Eng. and Min. Journ.*, 1891, lii., 245.
† *Brit. Soc. Min. Stud.*, x., 124. ‡ *Fed. Inst.* i., 132.
§ *Inst. C.E.*, cxxxi., 117.

of large coal of 3 per cent. due to the machines, while the total number of men employed for the same output was less by 33 per cent. than if manual labour were employed.

Colliery.	Depth of Undercut.	Nature of the Holing Material.	Average length of Holing Cut per day.	Sets of Cutters used per shift.	Thickness of Coal.	Labour cost of Holing per ton.	Average Electrical Horse-Power at Dynamo per Machine.
	Feet.		Lin. yards.		Feet.	Pence.	H.P.
Lidgett, . .	3½	Strong bind with lumps of pyrites,	55	4	2	3·30	21
Nostell, . .	4½	Hard bind with pyrites in thin layers,	80	2	3	1·40	18
Astley and Tyldesley,	3½	Strong spavin without pyrites,	75	2	3½	1·40	17
Stanton—							
(a) Stanhope Seam,	4½	Soft spavin, .	85	1	5	0·84	16
(b) Eureka Seam,	4½	Hard spavin, .	80	2	4	1·00	18
Sutton—							
(a) Top hard Seam,	4½	Ordinary spavin,	75	1	5½	0·90	17
(b) Dunsil Seam,	4½	Hard spavin, .	75	2	3	1·30	18
Cannock and Rugeley—							
Bass Seam, .	4½	Bind, . . .	80	1	5½	0·81	17

Mr. W. E. Garforth * states that the introduction of machines in a seam 4 feet thick has reduced the getting price from 2s. 1½d. per ton by hand to 1s. 3½d., a difference of 10d. per ton, from which must be deducted the cost of working the machine, interest on capital, redemption, repairs, and renewals, while the production per man per day has increased from 3¼ tons by hand mining to 6 tons by machines. The introduction of a deep holing machine making a cut of 5½ feet, and by keeping the face straight has resulted in a more regular fracture of the coal, which has reduced the number of shots to 6 or 7 per day, as compared with 35 to 40 on a similar length of face when the undercutting was done by hand. At another colliery where the seam lies at an angle of 20° to 27°, the cost has been reduced from 2s. 3d. per ton by hand to 1s. 4½d. per ton by machine.

After keeping strict accounts of all costs and charging to the coal-cutting machines all upkeep expenses, and interest on and redemption of capital invested, Mr. W. D. Hardie† states that at a Canadian colliery machine mining reduced the getting cost by 6·62 pence per ton as compared with pick mining.

Mr. E. W. Parker ‡ gives the following figures to show the greatly increased use of these machines in the United States :—

* *Fed. Inst.*, xv., 384. † *Ibid.*, xvii., 176.
‡ *Amer. Inst. M.E.*, Feb., 1899.

	1898.	1897.	Increase.
Coal won by machinery, . .	32,413,144	22,649,220	9,763,924
Number of machines used, . .	2,622	1,956	666
Number of firms using machines, .	287	211	76
Average tons mined by each machine,	12,362	11,572	790

Stanley's Heading Machine.—Few of the machines yet described can be applied for driving narrow roads. The Stanley Header (Fig. 76) has been designed for such a purpose, and consists of a cutter-bar driven, through gearing, by a pair of vertical engines. The cutter-bar is composed of a massive iron casting, placed parallel to the face of coal, and carrying on each extremity a bar of iron, 2 feet long, to the ends of which the cutter-knives are attached. This tool is revolved, and cuts out an annular excavation, leaving in the centre a core of coal, which is removed by hand-wedging.

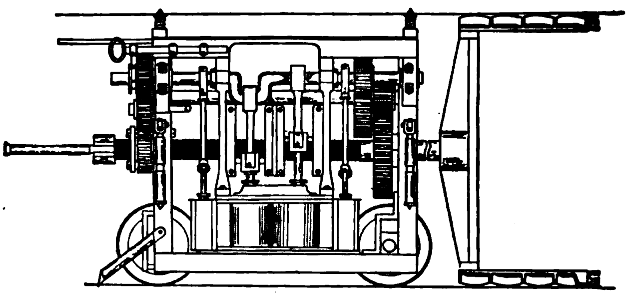


Fig. 76.

The machine may be considered a practical success. It has now been working several years, and has given satisfaction in every case. The actual speed of cutting is from 2 to 3 inches per minute. The wedging down of the core and placing machine in position for a fresh cut takes on an average about an hour. The chief saving results from the increased proportion of large coal and the rapidity of the work.

At Hamilton Palace Colliery * two machines were employed, one working immediately in front of the other, each taking out a circle 5 feet diameter, leaving a block of coal 1 foot in between. In order to judge of the merits of such machines by the actual work done over a period of time, the record on the following page was kept when a comparatively clean and continuous area of coal was being operated upon.

The lessened cost during the last two fortnights was due to a reduction in the miners' wages. The conclusion arrived at, after all the experience gained, was that the heading machine drives a place 11 feet wide about four times faster than hand labour at about double the cost, all outlays for cutting, removing the coal, laying the pipes, and shifting the machines being included.

* *Fed. Inst.*, vi., 7.

Fortnights.	Shifts Worked.	Distance Cut 5 feet in Diameter.	Distance Cut per Shift.	Amount Paid for Cutting and Filling.	Cost per Lineal Foot Cut.
		Feet.	Feet.	£ s. d.	s. d.
1	23	283	12·30	35 9 9	2 6·09
2	23	270	11·74	33 3 9	2 5·50
3	24	276	11·50	31 4 6	2 3·15
4	18	212	11·77	23 8 2	2 2·50
5	19	230	12·10	20 18 0	1 9·80
6	23	284	12·34	24 19 6	1 9·10

Boring Cross Cuts.—Machine drills, for boring air-holes* to serve as connections between winning head-ways, are largely employed in the Saarbrücken coal-field. They are of the rotary type, having jagged teeth cutting-edges in the circumference of the drill. Four men can drill from 34 to 46 feet, 12 inches diameter hole, in an eight-hours shift. With the Munscheid and the Hussmann machines two men are required, who will bore a hole 20 inches diameter at the rate of 1·09 yards per hour; with holes 11¾ inches diameter, the cost of boring is given at 1s. 4½d. per yard. The ordinary sizes are for holes 14, 16, 18, and 20 inches diameter, the first cost of a machine being about £35.

EXPLOSIVES—**Gunpowder.**—Although numerous attempts have been made to replace this explosive with other substances, it still remains unrivalled for the special operation of getting down coal under conditions where inflammable gas is not present in dangerous quantities and the mine is not dry and dusty. Gunpowder should consist of a mechanical mixture of 75 per cent. saltpetre, properly refined, 15 per cent. charcoal, preferably made from alder or willow wood, and 10 per cent. of sulphur. With a view, however, of producing something cheap, not only have the proportions of charcoal and sulphur been increased and saltpetre decreased, but impure chemicals have been employed instead of pure ones, with the result that, in common gunpowders, the purchaser pays for quantities of useless material that do no work.

In the manufacture the ingredients are first pulverised separately, and then mixed together and ground under heavy rollers for from two and a half to ten hours. Even if suitable proportions and materials are employed, grinding must be carried on for some time, or the mechanical mixture of the ingredients is incomplete and combustion imperfect. High-grade sporting powders are milled for ten hours, not so much with a view to increase their strength as to prevent or decrease "fouling," and as it is just as essential that no smoke, or as little as possible, should be given off when the charge is fired underground, blasting powders should be milled for a similar length of time. The best results have been obtained in Germany by the use of rye straw for charcoal, carbonised to brownness, with sulphur reduced from 10 per cent. to 3 per cent. The problem is to get rid of the sulphur altogether.

The so-called smokeless powders may be defined as chemical compounds, and generally consist of gun-cotton and picric acid, sometimes

* *For. Abs. N.E.I.*, xxxiii., 58.

alone, sometimes in combination, mixed with retarding agents to prevent detonation. The absence of smoke is a great advantage, but safety in storing and reliability in keeping quality is greater. The slow-burning character of gunpowder makes it an admirable rending compound. It gives out its energy in a constant heaving force, and brings down coal in large lumps. No other explosives do so; their energy is locally developed, smashing up such a soft substance as coal, and entailing a loss to colliers and colliery owners. So far as cost is concerned, gunpowder compares favourably in all ordinary operations with any other explosive. So long as powder will blow the bottom of the holes out, nothing is gained by using more powerful explosives; but in strong rocks the employment of powder means shallow holes and slow progress. Where everything is sacrificed to speed the holes are bored deep, and sufficient explosive used to break up the rock into small fragments, and so hasten its subsequent removal. Gunpowder possesses an advantage which is not shared by any other explosive; it can be used either with or without detonators, and be made to do more work at will.

Nitro-Glycerine.—This substance is formed by the action of a mixture of nitric and sulphuric acids on glycerine. It is a bright, oily, colourless and odourless fluid, has a faint sweet taste, and is poisonous, causing headache and colic. It is such an unstable compound that its use has been forbidden by law in this country and in most Continental ones; but, mixed with other substances, it forms the base of a large number of modern high explosives.

Dynamite is a plastic substance of reddish-brown colour, consisting of nitro-glycerine absorbed in porous kieselguhr, which is earth consisting of the shells of diatoms (nearly pure silica), found in Hanover and other localities. Many other absorbent materials have been tried, but kieselguhr has given the best results. This choice has been further justified by the absence, after explosion, of the noxious fumes of carbonic oxide, which render charcoal, although equally absorbent, so hurtful to the health of the miner. Ordinary dynamite contains 75 parts of nitro-glycerine and 25 parts of kieselguhr. In the open air, *in small quantities*, it burns freely, quietly, and without explosion. One advantage of the dynamite class of explosives is that they are plastic, and therefore, when tamped, fit accurately into the hole. Metal rods or rammers should never be employed to tamp the charge. A wooden rod should be used, and the cartridges gently, though firmly, squeezed into place.

Blasting Gelatine is said to be the most powerful of known explosives, and is a tough, slightly elastic, semi-transparent substance, resembling ordinary gelatine. It contains 93 per cent. of nitro-glycerine, together with 7 per cent. of nitro-cotton, and on explosion resolves itself into carbonic acid, water, and nitrogen, there being just enough oxygen to combine with the carbon and hydrogen. It is stated to be 50 per cent. stronger than dynamite, and more insensible to shocks than that substance.

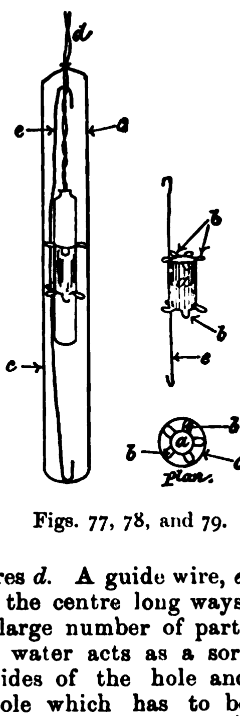
Gelatine-Dynamite.—This is a compound better known to miners and contractors, being more used for blasting rock which is required to be removed in as large pieces as possible, as its action is a heaving and rending, rather than a disruptive one. In appearance it is more opaque than blasting gelatine, and consists of 80 per cent. of that explosive, with nitrate of potash and wood-pulp added in proportion.

Gelignite is similar in composition. It consists of 65 per cent. of blasting gelatine and 35 per cent. of the absorbing powder.

In cold weather all nitro-glycerine compounds freeze, even at a temperature of 46° F., and are very dangerous to use when in such a state. The cartridges may, however, be softened, without danger, in warm-water warming-pans. They must not be put in the warm water to do so, but first in a water-tight vessel, and then that vessel placed in warm water.

Rackarock.—This explosive is largely employed in America. It is composed of 80 per cent. of potassium chlorate and 20 per cent. of nitro-benzol. The former of these ingredients is solid, and the latter liquid, and both are non-explosive during their manufacture, storage, and transport. Little danger attends the use of this explosive as explosion can only take place after mixture, this being generally done immediately before charging.

BLASTING IN DRY AND DUSTY MINES.—The passing of the British Mines Regulation Act, 1887, materially modified the use of explosives underground, as General Rule 12 states that "in places likely to contain either accumulations of gas or coal-dust, a shot shall not be fired unless the explosive is so used with water or other contrivance as to prevent it inflaming gas, or is of such a nature that it cannot inflame gas." The one fault of gunpowder is that it gives off a certain amount of flame on explosion, and its use is, therefore, not allowable under the circumstances just stated. To meet the altered conditions, and yet to continue the use of explosives, numerous methods have been proposed.



Figs. 77, 78, and 79.

Water Cartridge.—A cartridge of gelignite (usually of such a size that only one is necessary) is held in a skeleton case (*a*, Figs. 77 and 79) having a number of thin metal diaphrams, *b*, which keep the cartridge in the centre of the case (*c*, Figs. 77 and 79) containing the water. A detonator is inserted into the last cartridge, and a fuse, or electric wires, passed from it to the outside of the bore-hole. The space between the charge and the case is filled with water, and the outer end firmly tied round the projecting fuse or wires *d*. A guide wire, *e*, is also placed in the bag to keep the charge in the centre long ways. The objections to this apparatus are (1) the large number of parts and delicate handling they require; (2) the water acts as a sort of cushion between the explosive and the sides of the hole and so lessens the effect; (3) the large-sized hole which has to be bored; (4) and a liability of rupturing the case and letting out the water.

Permitted Explosives.—Under section 6 of the British Coal Mines Act, 1896, the Secretary of State has power to prohibit the use of any explosive underground, which he is satisfied is unsafe, and under this section has made the following order:—

1. (*a*) In all coal mines in which inflammable gas has been found within the previous three months in such quantity as to be indicative of danger, the use of any explosive, other than a *permitted* explosive, as hereinafter defined, is absolutely prohibited in the seam or seams in which the gas has been found.

(*b*) In all coal mines which are not naturally wet throughout, the use of any explosive, other than a permitted explosive, as hereinafter defined, is absolutely prohibited in all roads, and in every dry and dusty part of the mine.

2. In all such coal mines or parts thereof as aforesaid, the use of permitted explosives is prohibited, unless the following conditions are observed:—

(*a*) Every charge of the explosive shall be placed in a properly drilled shot hole, and shall have sufficient stemming:

(*b*) Every charge shall be fired by an efficient electrical apparatus, or by some other means equally secure against the ignition of inflammable gas or coal dust:

(*c*) Every charge shall be fired by a competent person appointed in writing for this duty by the owner, agent, or manager of the mine, and not being a person whose wages depend on the amount of mineral to be gotten:

(*d*) Each explosive shall be used in the manner and subject to the conditions prescribed in the schedule hereto:

Provided that nothing in this order shall prohibit the use of a safety fuse in any mine in which inflammable gas has not been found within the previous three months in such quantity as to be indicative of danger.

There are a large number of permitted explosives under the above order, which are described in an appendix to this chapter. The majority are of the hydrocarbon class, and consist of ammonium nitrate, mixed and ground together with some member of the naphthalene group, an inert substance often being introduced to lower the temperature of explosion. Most are acted on by moisture, and must be protected by waterproofed cases, and all require detonators of suitable strengths before explosion can be produced. Statements have been made from time to time that the fumes produced on the explosion of some of these substances, more especially roburite, have an injurious effect on the health of the workmen, but in every instance where these have been investigated (in Lancashire and the North of England) no ground has been found for such complaints.* Some cases of illness have been traced to roburite, but these have been found to be due to the neglect of the proper precautions in its use which are published by the manufacturers. Workmen having cuts, or skin knocked off their hands, should be careful when handling the cartridges, and should wash their hands before eating food, or there is a danger of some of the substance getting into their mouths.

All are stated to be flameless, but none are absolutely so. Everything seems to depend on the tamping. It should be clearly understood that they are only relatively, and not absolutely, safe, no explosive having yet been found which will in no circumstances ignite fire-damp. Experiments appear to show that damp or moist stemming gives additional security against the ignition of fire-damp or coal dust. Mr. M. Walton Brown† states that the experiments of the French Commission showed that the retardation of ignition characteristic of fire-damp mixtures, the almost instantaneous mixture of the gases

* *Fed. Inst.*, ii., 368 † *Ibid.*, ii., 488.

resulting from the explosive with the surrounding atmosphere, and the quick cooling consequent thereon, combine to make explosives, whose temperature of detonation is less than 4000° F., incapable of igniting explosive fire-damp mixtures under normal conditions of use; that is to say, if properly stemmed. The degree of safety becomes greater as the temperature of detonation falls below the above value. With any of the dual mixture explosives, the greatest care in manufacture is necessary, as it is essential that perfection be ensured in the mixture. The safety of ignition in explosive atmospheres also depends upon the almost instantaneous mixtures of the gases resulting from detonation with a sufficient volume of surrounding air, it being highly probable that it may be dangerous to fire a shot in a too limited space, and with a weight of explosive too great for the volume of the surrounding air, as compared with the volume of the gases produced by the detonation.

Firing the Charge.—Explosions may be divided into two classes —(*a*) where combustion proceeds slowly through the mass of the compound, and (*b*) where instant ignition takes place, called detonation. The power in (*a*) is applied slowly, with rending effect; while in (*b*) the gases are instantly generated, their force is localised, and a shattering effect results. To produce the latter action detonators have to be used, these consisting of a small quantity of a powerful explosive, fulminate of mercury, enclosed in a copper capsule.

Three modes of firing charges are in use—(1) squibs or germans, (2) fuses, (3) electricity. The first can only be employed with gunpowder, but the second and third with any explosive.

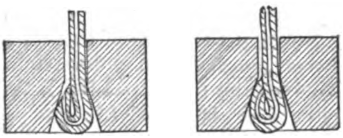
(1) **Squibs, or Germans.**—These consist either of a straw or paper spill filled with fine powder. When "germans" are employed, a copper rod, about $\frac{5}{16}$ inch diameter, called a "needle," has to be inserted in the hole during tamping. This needle reaches from the outside to the cartridges, and is turned from time to time to prevent it getting jammed, and finally withdrawn, leaving an open passage through the tamping to the powder. The squib is then inserted in this hole, and a slow match applied to the outside end.

(2) **Fuses.**—Frequent miss-fires with straw squibs, and premature explosions, together with the production of a shower of sparks, led to the introduction by Bickford, in 1831, of safety fuses, the principle of which is to enclose a thin string of gunpowder in a sheath of some material or combination of materials, with a view of protecting the core from rough usage and moisture. Many different qualities are made to meet the varying conditions of employment—viz., the time stored before use, influence of climate, temperature of mine, and presence or absence of moisture.

For ordinary work the thread of powder is protected with rope yarn, coated with different varnishes, or, if moisture is present, a further lining of tape and varnish is given. For blasting under water, gutta-percha coverings are employed, but such fuses cannot be stored long, owing to the rapid oxidation of the gutta-percha. To prevent this, an exterior coating of tape and composition varnish is applied, which not only delays oxidation, but retains the efficiency for a long time. Metallic fuses, in which the core is covered with lead pipe, have been introduced, but are not much employed, owing to their weight, brittleness, and liability to damage by torsion.

Ordinary fuses are sold in coils, 24 feet long, and burn at the rate of 2 feet per minute. Miss-fires occur generally through deterioration and the use of inferior qualities. The store-room should be dry, or the powder will be affected, and the fuse should not be in contact with any oily or greasy article. All gritty and sharp substances should be avoided in ramming, as the fuse is often cut through, and a miss-fire follows.

Under the Mines Regulation Act, powder can only be taken into a mine in cartridges. These generally consist of a reel, or bobbin, of compressed powder, having a hole, conical at one end, passing through the centre. In firing with a fuse, it is first cut to obtain a fresh surface, and threaded through the bobbin. One end of the fuse is doubled back into the conical hole at the bottom of the cartridge, and pulled tight, the subsequent bobbins being threaded over the front. In doubling the fuse back to bind it in the cartridge, care should be taken that the string of powder rests directly against the cartridge (Fig. 80), and not against the return portion of the fuse (Fig. 81). Numerous miss-fires may be traced to the neglect of this simple precaution.



Figs. 80 and 81.

With detonating explosives, a piece of safety fuse is cut clean, and inserted into a detonator until it reaches the fulminate. The upper part of the cap is then squeezed with a pair of nippers, with a view not only of securing the fuse in position, but also of developing the power of the fulminate.

For use under water, care should be taken to make the upper end of the detonator water-tight where it joins the fuse. With nitro-glycerine explosives, a cartridge is opened at one end, the detonator pushed in (leaving about one-third of the copper tube outside the cartridge) and securely tied in position. The detonator should not be pushed too far into the cartridge, or the fuse may set fire to it before the spark can explode the detonator. Holes are charged by putting in one or more cartridges, and squeezing each with a wooden rammer, a cartridge with a detonator and fuse is then inserted, *but must not be squeezed.* Loose sand, or water, is all that is required for tamping, but the power of the explosive is increased by tamping. A good plan is to insert on the top of the priming cartridge and detonator a ball of soft clay and press it home, then put further tamping on this.

In firing shots in mines, where naked lights are not allowed, a small copper wire is commonly employed, one end of which is made red-hot by putting it into the flame of a safety lamp, while the other is inserted into the fuse. The wire is generally passed through a small hole in the glass of the lamp. To get rid of the difficulty of passing wires into lamps, and prevent the emission of sparks when the fuse is fired, Messrs. Bickford have designed an ignitor, which consists of a small tin tube, containing a small glass phial, holding sulphuric acid, resting against a small quantity of chlorate of potash and sugar; one end of the fuse is inserted into the open end of the tube, and the glass phial broken by gripping the tube with a pair of pincers (Fig. 82). The sulphuric acid acts on the mixture, lights the end of the fuse, and all sparks produced are kept within the tube.

At the Aubin Colliery in the department of Aveyron, France, a modification of a device for lighting pipes, cigarettes, &c., by the heat generated by the compression of air, has been in use for some time. It consists of a metal cylinder, in which a well-fitting piston moves, the piston-rod carrying a cross-piece so that a firm hold is given for the hand. One end of the fuse is passed through a small hole in an india-rubber ring into the cylinder. A quick and strong thrust is given to the piston, the air in the cylinder is compressed and heated, and the core of the fuse ignited. It is said that, with a little practice, ignition always takes place at the first thrust, and as the sparks from the burning of the first inch of fuse are thrown out inside the cylinder, they are thereby cut off from the surrounding atmosphere.

In Richter's apparatus a pair of special pliers in conjunction with a percussion cap and asbestos-covered fuse is employed. The fuse is first cut off perfectly square by nippers (Fig. 83) at the end of the pliers, and the special lighting cap fixed closely on. The pliers are then opened to their full extent, which automatically contracts a spiral spring inside the barrel, and the lighter with fuse attached is placed exactly in the chamber contained in the barrel of the pliers (Fig. 83). By pressing the trigger with the thumb of the right hand, as shown in Fig. 84, the spiral spring inside the barrel is released, and shoots a bolt on to the percussion cap. The issue of smoke from vent holes on both sides of the oblong part of the pliers indicates beyond doubt that no miss-fire has taken place.

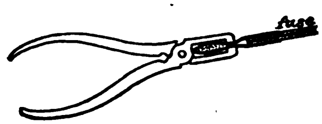


Fig. 82.

Fig. 83.

Fig. 84.

Several accidents have been traced to the use of these types of ignitors, premature explosion having taken place only a few seconds after the ignitors were fired.* It is considered that owing to the confinement of the gases inside the fuse, when the burning of the fuse does not destroy the outer covering, the pressure increases until either the resistance of the envelope is overcome and the fuse bursts, or if the resistance of the walls be too great, the explosion extends to the unconsumed portion of the core, which at once explodes and flashes out violently. In one experiment, flame suddenly traversed the entire length of 40 inches of fuse. In fuses where the covering is partly burnt and destroyed such explosions cannot be caused, as the gases

* *Fed. Inst.*, xii., 171.

evolved from the powder can escape freely through the damaged covering.

Blasting by Electricity.—The practice of igniting shots by the aid of the electric current has been gaining ground for a considerable number of years; with it no question can arise as to whether shots have missed fire or not. Ignition with ordinary fuse sometimes hangs for a considerable time, even up to twenty-four hours; sparks from the fuse are got rid of by numerous devices, but as no sparks are produced by electricity it must be better. Then again, there is no chance of premature explosion. Every one can be in a place of safety before the shots are fired; indeed, in some collieries where blasting might produce an explosion, all the shots are fired from the surface when the pit is free from men.

Two systems are in use; in one, electricity of high tension and small quantity is employed, while in the other the electricity is of low tension and of large quantity. The former are called "tension," or "machine," fuses, and the latter, "quantity," or "battery," fuses.

Tension Fuses.—These consist of two copper wires, with the ends separated from each other by a small interval, in which is placed a priming composition, and the whole inserted into a detonator. The current, in leaping across the interruption, meets with great resistance from the low conductivity of the material passed through, heat is generated, and the priming and detonator fired. The priming composition generally employed is known as Abel's, and consists of a mixture of 10 parts of sub-phosphide of copper, 45 parts of sub-sulphide of copper, and 15 parts of chlorate of potash, well rubbed together in a mortar, with sufficient alcohol to moisten the mass, and afterwards carefully dried.

Quantity Fuses.—Here the two copper wires are joined together by a very thin, short length of platinum wire, and surrounded by a substance inflammable at a low temperature. The current passing down the copper wires meets with great resistance in passing across the small section platinum wire, and generates sufficient heat to fire the priming. As the circuit is uninterrupted, and *quantity* only is required to heat the wire to redness, an ordinary battery may be used.

Comparison.—The advantages of high tension lie chiefly in the convenient form and ready action of the machines employed to excite electricity. These are of small dimensions, light weight, simple in construction, and do not readily get out of order. In addition the means of discharging the machine may be removed until the required moment. For this reason such system is useful in mines where the operations are carried out by men of no scientific knowledge. A great advantage, however, is the fact that a large number of shots can be fired simultaneously with more certainty than with a battery, and that line resistance has small effect on the current, so that cables of small diameter can be used.

The disadvantages are, that the fuses are more or less affected by moisture and heat, and that the wires carrying the current have to be well insulated. Low tension fuses are more trustworthy than high. The insulation of the line wires need not be very perfect. Certainty of action is almost always possible, as each fuse can be tested before use by coupling it up to a galvanometer and passing a weak current through it. It does not, however, necessarily follow that miss-fires cannot take place after low tension fuses have been tested in the galvanometer, because two conditions may happen. Either the two copper wires may be in contact, and allow the current to pass, or even the small testing current may break the delicate bridge of connecting wire, and the fuses thus appear all right at the test, but all wrong afterwards. When low tension fuses had to be fired by batteries they were not so convenient as high tension, as only a limited number of shots could be fired simultaneously, unless a large battery power was available. Batteries soon get cumbersome, and always require a considerable amount of attention. Low tension fuses can, however, be fired from an electric light circuit, while high tension ones cannot, and as dynamos are common at collieries, low tension fuses are becoming more and more applied. Specially constructed magneto machines generating a current of low intensity are now made for firing low tension fuses, and are recommended for use in preference to batteries. Low tension fuses cost a fraction of a penny more than high tension ones, but year by year are becoming more used in Europe, while in Canada and the United States high tension exploders and fuses are practically unknown.

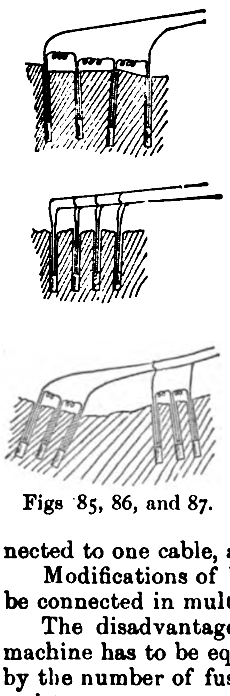
For firing tension fuses, two types of machines are employed—(*a*) the frictional, (*b*) the magneto type.

Frictional Machines.—The machine most in favour is that of Bornhardt, which, from its simplicity, compactness, and portability, possesses many advantages. Electricity is generated by the friction of two revolving discs of ebonite against two small cushions covered with cat-skin, and is received by two cones, and transmitted by a metallic conductor into the interior of a Leyden jar, from which it is discharged by pressing a button. The apparatus is, however, very delicate; both glass and ebonite being so hygroscopic, that a machine can rarely be depended upon to work many hours consecutively. Unless the places in which it is used, and the rubbers, are dry and warm, the machine will not furnish any current, as the electricity is conducted away by the condensed moisture as fast as it is generated.

Magneto-Machines.—These consist of an electro-magnet, between whose poles an armature, wound to a very high resistance, is caused to rapidly revolve by means of crank motion and gearing. An electric current of high potential is generated, and at the moment of maximum intensity is sent out to the outside circuit, in which are the fuses, the explosion of these being instantly accomplished. To prevent the risk of miss-fires the machine should have a considerable reserve of power, and care should be taken to see that the connecting ends of all wires are clean and are firmly twisted together.

Simultaneous Blasting.—The advantages of firing a number of shots simultaneously, especially in shafts or headings, are self-evident, particularly where machine drills are employed. In the first place, as soon as the machines have been removed and the holes charged, the rock should be shot down as quickly as possible. Then all the shots going off at once assist each other, their force is applied collectively, and the whole of the rock is brought clean away, while, if fired separately, each individual blast has to tear out the mass of rock allotted to it, the result being that in the former case less explosive is required and, in addition, a minimum amount of time is taken up in the operation. Another advantage of simultaneous firing is that all the smoke produced by the explosion is generated at one time and the men only have to wait for this to clear away, while if shots are fired independently they have to wait after each blast.

For firing a large number of shots at once electricity is particularly useful, the reduced quantity of explosive used balancing the cost of the electric fuse, the saving in time already referred to remaining as an advantage. Another point of importance is the question of missed shots. When firing with fuse one can never be sure whether the shot has really missed or only hung fire, and, unless explosion takes place, the working has to be fenced off for a considerable time, thus entailing a loss; but with electricity nothing of the sort occurs. After the current has been passed through the wires the place can be approached at once without danger. In order to avoid miss-shots it has been proposed to use a hollow tube during stemming, one end of which is inserted into the charge and the other projects out of the hole. After ramming is complete, the tube is withdrawn, and the detonator and connecting wires pushed down the passage into the charge. Should a miss-fire occur the detonator can be withdrawn and another inserted. The objections are the danger in pushing the detonator into, or withdrawing it from, the hole, and the reduced effect of the blast due to the fact that a vent hole of at least $\frac{1}{2}$ inch diameter is left extending from the explosive to the atmosphere.



Figs 85, 86, and 87.

For firing by electricity two main systems of connecting the wires to the machines are in use. In the first, the fuses are connected in series—that is to say, one wire of the first hole is connected to one wire of the second hole, and the remaining wire of the second hole to one wire of the third hole, and so on until all are joined, when there will be one wire of the last hole and one wire of the first hole left unconnected. These are now joined by means of conducting wires to the machine a considerable distance away in a place of safety (Fig. 85).

The second system is known as the parallel one. In this, one wire of each shot is connected to one cable, and the other wire to the second (Fig. 86).

Modifications of both these systems are possible, as the holes may be connected in multiple series (Fig. 87).

The disadvantage of the series system is that the power of the machine has to be equal to that required to fire each fuse, multiplied by the number of fuses, and that unless the fuses have all the same resistance, or vary only within narrow limits, only the most resistant will be fired.

Bickford's Volley Fuse.—To render the operation more simple than with electricity, Messrs. Bickford have designed a method in which ordinary and special fuses are employed for simultaneous blasting. A length of safety fuse is connected to one side of an explosive disc in a tin tube. The required number of special fuses are snugly tied together, their ends cut clean and level, and inserted into the tin tube, touching the other side of the explosive disc. The mouth of the tube is protected by a waterproof substance, such as pitch. To fire, the length of the safety fuse is lighted, this ignites the explosive disc, which starts all the special fuse burning at the same time. The particular point, however, consists of the special fuse, which is manufactured to burn at the rate of 9000 feet per minute, the speed of ordinary fuse being only 2 feet per minute. To enable operators to adapt the instantaneous fuse to any available length to suit their particular requirements, the inventors supply on demand the ignitors with fuse looped as in Fig. 88, so that if the whole length of fuse so looped is, say, 10 feet, the miner can cut it into single lengths of 3 feet and 7 feet, or any proportion of 10 feet (taking care not to detach it from the ignitor). This does not affect the simultaneousness of the explosion, as, owing to the rapidity of burning, small differences in the lengths of the special fuse are not of any moment.

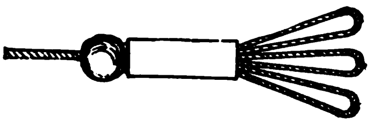
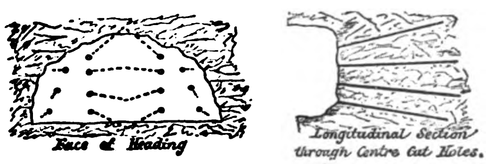
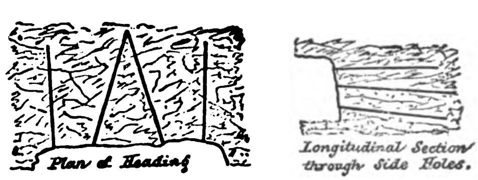


Fig. 88.

Position of Holes.—The situation and inclination of holes in rock drifts depend on the nature of the rock, and on the system of drilling employed. With hand drilling and single blasts, everything depends on the skill of the miner, who carefully examines the faces and decides on the position, direction, and depth of the hole; the conditions that have to be fulfilled being that the rock should be as free as possible on one side, and that neither too much nor too little rock should be attempted to be dislodged. In the former case, if there is too much resistance the hole will act like a cannon, and the tamping will be forced out, producing what is known as a "blown-out shot," while, in the latter case, the explosives will be wasted.



Figs. 89 and 90.



Figs. 91 and 92.

With machine drills and simultaneous blasting, there is not so much necessity to consider the lines of least resistance, although such is generally done. Many different arrangements can be employed. The following may be considered a typical example.* A wedge, or core, is first blasted out of the centre of the heading, this being known as a centre-cut, the sides being blasted out afterwards. A centre-cut needs about eight holes, divided into two sets, four each, arranged in nearly vertical lines, at equal distances from the centre line of the heading. Each hole of one set of the centre-cut is drilled

* *The Vosberg Tunnel*, Leo v. Rosenberg, p. 24.

in a direction intended to meet the corresponding one of the other set at the centre line of the heading, so as to form a wedge. These are drilled 10 feet deep. Where the character of the material only requires one set of holes in the sides, these are three in number, and from 7 to 9 feet deep. The inclination of the holes in the different sets are shown in Figs. 89 to 92. The holes inclining upwards are drilled dry, those horizontal, or inclined downwards, wet. Sometimes second side rounds are required; these consist of two holes each. At the Newhouse Tunnel, Colorado, U.S.A., the work was said to be much hastened by the addition of a so-called plunger hole at the upper centre of the cut, which inclined slightly downwards.*

Blown-out Shots.—The combustion of powder produces large quantities of gaseous products, which, in the case of blown-out shots, are driven violently into the roadways, and at the point of discharge act like a piston, driving back the air flowing past the hole in both directions, and producing a partial vacuum, into which the gas contained in the coal is exhausted, and diluted with the air current until the firing point is reached. Clouds of dust may be raised at the same time, and if this mixture comes into contact with flame, a serious explosion is readily produced. It is also suggested that the sound wave produced by a blown-out shot may cause sufficient pulsation in the atmosphere to force flame through the gauze of a safety lamp. It is, therefore, desirable that blown-out shots should be prevented, care being taken that all the holes are placed in such position that they do the work allotted to them, and bring down the coal. It is most important that the stemming should be unfissured, and

Fig. 93.

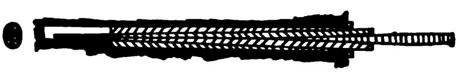


Fig. 94.

adhere closely to the sides of the hole, so that the gaseous products cannot escape before the complete ignition of the powder. To remove, however, any chance of such an occurrence, various tamping plugs have been designed, the majority of which consist of an arrangement of metal wedges tightly secured in the hole, generally by the aid of a screw. They are expensive in first cost, and easily lost. A later device is the employment of a cylinder, or rough octagon of pine-wood, with a wedge-shaped piece cut out of it and a saw cut made as a continuation of the wedge-shaped cut. The wedge *a* (Fig. 93) is placed against the charge, the block *b* above it, and the explosion drives the wedge up into the body of the block, and binds it firmly against the sides of the hole. The use of tamping plugs does not seem to afford any greater security than ordinary tamping, if the latter is properly applied.

VARIOUS METHODS TO SUPERSEDE BLASTING.—Numerous methods have been proposed to do away with blasting, such as the application of compound wedges.

* *Eng. and Min. Journ.*, 1902, lxxiii., 552.

Elliott Multiple Wedge.—The construction and method of using these can be readily seen from Fig. 94, the advantage claimed being that only a small-sized hole is required, and that the weight of the whole apparatus, including boring machine and wedge, is very small, while the expansive force developed is large, owing to the fact that the impact of a blow is more effective than other means of applying wedging power.

Haswell Mechanical Coal-getter.*—In this machine the rending action is accomplished by a wedge between two feathers, the wedge being drawn out by a combination of a screw and lever. The bursting action takes place towards the back of the hole, and not at the face, where least required.

Burnett's Roller Wedge.—The amount of friction between the sides of the wedge and feathers, in ordinary systems, is very great. To overcome this difficulty, Mr. Burnett† designed a roller wedge, in which rolling is substituted for sliding friction. It consists of two external plugs, or feathers, with an internal wedge running on roller bearings. This wedge is drawn out by the action of a screw and nut, driven by a ratchet and pawl arrangement.

Hydraulic Wedges.—To increase the power of these machines hydraulic pressure has been called into requisition. A man's strength, acting on a lever working the piston of a small hydraulic pump, is capable of producing an enormous pressure, which can be applied to driving in wedges. Instead of applying the hydraulic apparatus directly to the wedge, which compels the operator to stand close to the face, in some designs the pressure pump is fixed a considerable distance away, and the water is conveyed to the wedge through a pipe.

Lime Cartridges.—Messrs. Smith and Moore designed a process for bringing down coal by utilising the expansion of quicklime, when water is applied to it. Ordinary mountain limestone is calcined and ground to a fine powder, and compressed by hydraulic power into a cartridge, having a groove running along its full length. The cartridge is about 5 inches long and 2½ inches diameter, and when taken from the press is wrapped in a sheet of paper, and placed in an air-tight box to keep away damp. Coal is holed and shot-holes drilled in the ordinary way, and cartridges placed in them. An iron tube ½ inch diameter, having a small external channel on the upper side, and provided with perforations, is inserted along the full length of the hole. Several cartridges are placed in each hole, the grooves formed in them during the process of manufacture lying against the tube just referred to, and the mouth of the hole is tamped in the usual way. A small force-pump is connected by suitable means to the end of the tube projecting from the hole, and water forced in. The hand pump is then detached and carried away to another hole. The water acting on the lime greatly expands its bulk, and the coal is forced down.

This system has been employed and gave good results at Shipley Colliery for a considerable time, but has not met with much favour elsewhere. It can only be used for certain classes of coal, and great care has to be exercised to keep the cartridges dry. They readily absorb moisture from the atmosphere, and completely lose their efficiency.

* *N. E. I.*, xxxiii., 37. † *Min. Inst. Scot.*, viii., 2.

Bosseyeuse.—For a considerable length of time an apparatus has been in use at the Marihaye Colliery, Belgium, which consists of a rock drill of the Dubois-François type, boring a series of holes grouped in a certain pattern in the face of the work. The drilling tool is removed and replaced by a hammer head, a number of plug and feather wedges are then put in the holes, and driven in by the battering ram till the rock is broken down and split up. No explosives are used, and trials over a period of many years show that the employment of the machine has not increased the cost of working.

Oxy-hydrogen Gas.—The decomposition of water into its elements by electricity is a comparatively easy matter, and the resulting mixture of oxyhydrogen gas forms a powerful explosive. The idea of substituting this gas for the explosives ordinarily used is fascinating, as it may be obtained from water by a slight expenditure of electrical power.

At Mont Cennis Colliery, Westphalia,* experiments were made with about $\frac{3}{4}$ ounce of distilled water, containing a small quantity of soda lye (added to increase conductibility) enclosed in a steel cylinder 7 inches long, $1\frac{1}{4}$ inches diameter, and $\frac{3}{32}$ inch thick, capable of standing a pressure of 1200 atmospheres. Two conductors were passed through the steel lid, and the electrodes were made of ordinary iron nails. The electric current of about 1 ampère and 10 volts was passed through for some forty hours, when about $\frac{2}{3}$ ounce of water was decomposed and the pressure within the cylinder had risen to 450 atmospheres.

When blasting, the cartridge is connected to two electric conducting wires, introduced into the shot hole, tamped in the usual manner, and exploded by a spark, produced by a Bornhardt or other igniting apparatus, leaping from one electrode to the other. Experiments demonstrated that such cartridges produced the same blasting effect as $5\frac{1}{4}$ ounces of the ordinary nitrate of ammonia explosive, such as westphalite, &c., and it was also hoped that the idea would provide a safe method of blasting for fiery and dusty collieries, but the ignition of a gaseous mixture of fire-damp was caused several times.

The cost of generating the oxyhydrogen gas is small, but the cylinders themselves have to be so carefully made that they are costly. It also remains to be proved that the internal pressure of over 6500 lbs. in the cartridges is unattended with danger.

Prohibition of Blasting.—From time to time suggestions are made that blasting should be prohibited in mines. Undoubtedly, there are seams of coal which can be economically worked by wedges, but such are few and far between. With a seam that is thin, hard, and blocky, and adheres tenaciously to the roof, wedging is of no use; the coal breaks short, and wedge after wedge is inserted with little effect. On the other hand, where the coal is soft, the wedge, on expanding, simply widens the sides of the bore-hole. As in too many cases the direct causes of explosions can only be conjectured, every cause to which explosions have been traced shares a prejudice which evidently does not rightly belong to them all. Although the occurrence of some explosions can be directly traced to blasting, it must not be assumed that all are due to this cause, or that if it was stopped entirely they would cease. When a large explosion takes place the

* *Coll. Guard.*, 1897, lxxiv., 1065.

loss of life is so serious that public attention is directed to it, and the other accidents which happen in mines are apt to be lost sight of. Statistics, however, show that the death-rate is higher from several other causes than from explosions; for instance, falls of roofs and sides. Now, with blasting, the men are away from the working face, but with wedging they must be there, and are liable to be injured by falls which take place, especially in thick seams. Wedges are claimed to produce more round coal than when shots are used, but such is not necessarily the case. If the charge employed is properly proportioned it can be made to do what is required; all that has to be done to produce the coal in a large round state is to vary the amount of explosive.

To show the increase in cost due to prohibition of blasting, Mr. W. Y. Craig * arranged for the best miners at Podmore Hall Colliery to be employed to work at day wages on two places for one month with, and one month without, powder. In a 12 yards drift, working one month without powder, the wages paid were £16 0s. 10d., quantity produced 233 tons 11 cwts. 3 qrs., cost per ton 1s. 4d; same worked with powder, wages £17 9s. 3d., including 8s. for powder and fuse, coal produced 327 tons 16 cwts., cost per ton 1s. To this has to be added the increased cost per ton of the fixed charges, such as superintendence, timber, and road maintenance due to the diminution in quantity. In each shift 10·64 tons were got without powder, 14·26 tons with powder, the difference being 3·2 tons per shift, so that the quantity was 24¾ per cent. less than when worked with blasting. The total increase of cost, minutely and carefully calculated, was 1s. 2½d. per ton by working without powder.

Experiments in narrow heading with the Hardy Pick Company's wedge instead of explosives, at the König and Wellesweiler Collieries † in the Saar district, proved that the cost was increased 49 per cent., and in long-wall work 56 per cent. The financial results of a diminution in blasting at Maybach Colliery, and partly substituting wedging, was that the cost increased by nearly twopence per ton as a minimum.

At Blackwell ‡ experiments were made on a length of 114 feet of the Alfreton deep, soft coal face, with roburite, carbonite, and gunpowder. In each case the face was holed 5 feet deep, with the result that the cost of getting round coal was increased a halfpenny per ton by using high explosives over gunpowder, while 1½ to 2 per cent. more slack was obtained by carbonite, and 3 per cent. by roburite, than by gunpowder. It was also stated that the increased quantity of slack produced by high explosives reduced the average selling price by one penny per ton.

The accidents due to firing can be best prevented by careful supervision of the work, by placing the operations under the control of a well-regulated staff with a steady and attentive person at the head, by careful examination of the working face before firing, and, above all, by good ventilation. The number of shots required can be decreased by deep undercutting. Finally, the loss of life may be entirely removed by firing all the shots simultaneously from the surface when all the workmen are out of the pit, this being the procedure at some of the South Wales collieries.

* *N. Staff. Inst.*, iv., 53. † *Coll. Guard.*, 1896, lxxii., 723.
‡ *Fed. Inst.*, xiv., 435.

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APPENDIX.

*List of Permitted Explosives under the order of the British Secretary of State.**

Albionite, consisting of the following mixture:—

	Parts by weight.			
	Not more than	Not less than	Not more than	Not less than
A mixture of — Nitro-glycerine,	83	80½		
Nitro-cotton,	7	5		
Nitrate of potassium,	10½	8½	86	84
Wood-meal,	3	2		
Chalk,	½	...		
Oxalate of ammonium,	...	...	16	14

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

* This list is subject to revision in accordance with the results of experiments made from time to time in the Government Testing Station at Woolwich.

Ammonite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium, ...	89	87
Di-nitro-naphthalene, ...	13	11
Moisture, ...	½	...

Amvis, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium, ...	91	88
Wood-meal, ...	6	4
Moisture, ...	½	...
Di-nitro-benzol, ... } Chlorinated naphthalene, ... }	6	4

the chlorine not to exceed 1 per cent. by weight of the finished explosive.

Aphosite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium, ...	62	58
Nitrate of potassium, ...	31	28
Charcoal, ...	4½	3½
Wood-meal, ...	4½	3½
Sulphur, ...	3	2
Moisture, ...	1½	...

Arkite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine, ...	54	51
Nitro-cotton, ...	4	3
Nitrate of potassium, ...	23	21
Wood-meal, ...	8	6
Chalk, ...	½	...
Oxalate of ammonium, ...	16	14

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Bellite, No. 1, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium, ...	85	82
Di-nitro-benzol, ...	18	15
Moisture, ...	¾	...

Bellite, No. 3, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium, ...	95	92
Di-nitro-benzol, ...	8	5
Moisture, ...	¾	...

Bobbinite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Potassium nitrate, ...	65	63
Charcoal, ...	19½	17½
Sulphur, ...	2½	1½
Ammonium sulphate, ...	11	9
Cupric sulphate, ...	6	4
Moisture, ...	2½	...

Britonite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine, ...	27	25
Nitrate of potassium, ...	34	31
Wood-meal, ...	43	39
Carbonate of sodium, ...	½	...

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Cambrite, consisting of the following mixture :—

		Parts by weight.			
		Not more than	Not less than	Not more than	Not less than
A mixture of	Nitro-glycerine,	27	25		
	Nitrate of barium,	4½	3½		
	Nitrate of potassium,	32	28		
	Wood-meal,	42	39	100	92
	Sulphuretted benzol,	½	...		
	Carbonate of sodium, } Carbonate of calcium, }	½	...		
	Oxalate of ammonium,	...	...	8	...

the wood-meal to contain not more than 20 per cent. and not less than 10 per cent. by weight of moisture.

Carbonite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	27	25
Nitrate of barium, } Nitrate of potassium, }	36	30
Wood-meal,	42	39
Sulphuretted benzol,	½	...
Carbonate of sodium, } Carbonate of calcium, }	½	...

the wood-meal to contain not more than 20 per cent. and not less than 10 per cent. by weight of moisture.

Clydite, consisting of the following mixture :—

		Parts by weight.			
		Not more than	Not less than	Not more than	Not less than
A mixture of	Nitro-glycerine,	27	25		
	Nitrate of barium,	36	32		
	Wood-meal,	41½	38½	100	92
	Sulphuretted benzol,	½	...		
	Carbonate of sodium, } Carbonate of calcium, }	½	...		
	Oxalate of ammonium,	...	...	8	...

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Dahmenite, A, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	93½	91½
Naphthalene,	6½	4
Bichromate of potassium,	2½	1½
Moisture,	1	...

Dragonite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	37	34
Nitro-cotton,	3	2
Nitrate of potassium,	46	43
Vaseline,	6	5
Wood-meal, Charcoal,	13½	11

the wood-meal and charcoal together to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Electronite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	75	71
Nitrate of barium,	20	18
Wood-meal, Starch,	10	7
Moisture,	½	...

the wood-meal to be slightly charred

Faversham Powder, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	86	84
Tri-nitro-toluol,	12	10
Chloride of ammonium,	2	1
Chloride of sodium,	3	2
Moisture,	½	...

Fracturite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine, ...	53½	51½
Nitro-cotton, ...	4	3
Potassium nitrate, ...	25	21
Wood-meal, ...	7	5
Ammonium oxalate, ...	16	14

the wood-meal to contain not more than 17 per cent. and not less than 5 per cent. by weight of moisture.

Geloxite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine, ...	57	54
Nitro-cotton, ...	5	4
Potassium nitrate, ...	22	18
Wood-meal, ...	7	5
Ammonium oxalate, ...	15	13

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Haylite, No. 1, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine, ...	27	25
Nitro-cotton, ...	1½	½
Wood-meal, ...	14	12
Nitrate of potassium, ...	21	19
Nitrate of barium, ...	21	19
Mineral jelly (free from acid), ...	8	6
Oxalate of ammonium, ...	12	10

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Kynite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine, ...	27	25
Nitrate of barium, ...	36	30
Wood-meal, ...	42	39
Chalk, ...	½	..

the wood-meal to contain not more than 20 per cent. and not less than 10 per cent. by weight of moisture.

Nobel Ardeer Powder, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	34	31
Kieselguhr,	14	11
Sulphate of magnesium,	51	47
Nitrate of potassium,	6	4
Carbonate of ammonium,	½	...
Carbonate of calcium,	½	...

Nobel Carbonite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	27	25
Nitrate of barium,	4½	3½
Nitrate of potassium,	32	28
Wood-meal,	42	39
Sulphuretted benzol,	½	...
Carbonate of sodium, } Carbonate of calcium, }	½	...

the wood-meal to contain not more than 20 per cent. and not less than 10 per cent. by weight of moisture.

Normanite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	34½	32½
Nitro-cotton,	2	1
Potassium nitrate,	46½	42½
Wood-meal,	9	7
Charcoal,	2	1
Ammonium oxalate,	12	10

the wood-meal and charcoal together to contain not more than 20 per cent. and not less than 10 per cent. by weight of moisture.

Pit-ite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	27	25
Nitrate of barium,	35	31
Wood-meal,	43	40
Carbonate of sodium, } Carbonate of calcium, }	½	...

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Roburite, No. 3, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	89	86
Di-nitro-benzol,	13	9
Chloro-naphthalene,	2	...
Moisture,	½	...

the chloro-naphthalene to contain not more than 1 part of chlorine.

Saxonite, consisting of the following mixture :—

		Parts by weight.			
		Not more than	Not less than	Not more than	Not less than
A mixture of	Nitro-glycerine,	68	58	91	73
	Nitro-cotton,	5½	3½		
	Nitrate of potassium,	30½	21½		
	Wood-meal,	8½	5		
	Chalk,	½	...		
	Oxalate of ammonium,	...	...	27	9

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Special Bulldog, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of potassium,	86	84
Carbonate of magnesium,	3½	2½
Charcoal,	13	12
Moisture,	2	...

Stow-ite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	61	58
Nitro-cotton,	5	4½
Nitrate of potassium,	20	18
Wood-meal,	7	6
Oxalate of ammonium,	13	11

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Thunderite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	93	91
Tri-nitro-toluol,	5	3
Flour,	5	3
Moisture,	1	...

Victorite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitro-glycerine,	27	25
Nitrate of barium,	36	32
Wood-meal,	41½	38½
Sulphuretted benzol,	½	...
Carbonate of sodium, } Carbonate of calcium, }	½	...

the wood-meal to contain not more than 15 per cent. and not less than 5 per cent. by weight of moisture.

Virite, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Oxalate of ammonium,	12	9
Nitrate of ammonium,	40	35
Nitrate of potassium,	38	33
Sulphur,	5	4
Charcoal,	12½	10½
Moisture,	2	1

Westfalite, No. 1, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	96	94
Resin,	6	4
Moisture,	½	...

Westfalite, No. 2, consisting of the following mixture :—

	Parts by weight.	
	Not more than	Not less than
Nitrate of ammonium,	92	90
Nitrate of potassium,	5	3
Resin,	6	4
Moisture,	½	...

CHAPTER IV.

SINKING.

Position of Shaft.—The commercial success of collieries depends in a great measure on the position of the shafts, and before deciding on their situation, every point should be given careful consideration. In proved districts where the inclination of the seams is known, the shaft is generally placed in the deepest point, especially where quantities of water are expected, as both water and coal gravitate to the shaft and render haulage easy. Dealing with water in dip-workings is most expensive. It is often advisable to place the main shaft somewhere about the centre of the royalty, so that equal areas can be worked on all sides of it. Surface considerations may, however, overweigh the majority of the underground points. The disposal of the produce must be carried on easily and cheaply; proximity to towns or places where a household trade can be carried on is important. Communication with railways or waterways should be studied. A supply of water for boilers, &c., is requisite, many collieries labouring under great cost and disadvantages through being unable to obtain this. In unexplored districts, it is well not to make the first shaft a principal one, but to sink it down to the seams, and after proving their inclination, &c., to decide on the position of the main winding-shaft from data so obtained.

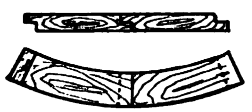
Form of Shaft.—At the present time, so far as European practice is concerned (except in Scotland), the general custom of colliery districts is to make shafts circular. Various other shapes have been tried—square, elliptical, and polygonal—but have been abandoned in the majority of cases. In order to economise space many of the earlier shafts were made rectangular, and are still often so sunk in Scotland, and in the United States, but it has been found that round shafts are easier and cheaper to sink, more capable of resisting the pressure of "heavy" strata, absolutely necessary in running ground (the pressure being equalised), and more suitable for the application of metal tubbing. The waste of space and other disadvantages due to circular form are less considerable than had been supposed; indeed, by careful arrangements the space wasted may become almost nothing. The ventilation of large coal-mines could not be well carried out with rectangular shafts, as the running of the cages would interfere too much with the passage of the air; indeed the space unoccupied by the cages is a positive advantage in numberless instances.

It is a curious fact that rectangular shafts are only to be found in countries where timber, which is solely employed for securing the sides, is cheap and abundant and other materials absent. In all other places where stone, bricks, or iron are available for lining purposes the circular shape is alone adopted.

Size of Shaft.—This depends entirely on the size of tub employed and on the output required. After deciding on what daily quantity is to be extracted, and the weight that each tub shall contain, the number of tubs to be drawn each day and each hour can be obtained. Knowing the depth of the shaft, the speed at which winding is to take place, and the time occupied in changing the tubs on the cage, and allowing a margin for interruptions, the number of tubs to be raised at each lift is easily found. Then, after deciding how many decks or platforms there are to be in the cage, the number of tubs on each deck is established. As the tubs have to be of a certain size to hold the quantity they have to contain, the number on each deck determines the size of the cage. If the shaft is only to have one cage working in it, its diameter must be such as will allow a rectangle of the size of the cage to pass through freely, allowing a margin for clearance of from 6 to 10 inches at the corners. If two cages are to be employed two rectangles should be plotted on paper, with a clearance space between of from 12 to 18 inches, and a circle inscribed round them, allowing a similar space as before for clearance at corners. The diameter of this circle gives the size of the shaft.

Where pumps are required, and have to be placed in the winding shaft, the room they take up must also be allowed for. The better plan is, however, to keep everything except winding appliances out of the main shaft.

OPERATION OF GETTING DOWN TO THE "STONE-HEAD."—The first operation in sinking is to get down to solid regular strata, technically called the "stone-head." In the majority of instances some drift or loose deposits have to be passed through before firm ground is reached, and a foundation obtained for the masonry or other means which are to be employed for permanently securing the sides of the excavation. Often this preliminary operation is very troublesome and expensive, depending entirely on the nature of the strata.



Figs. 95 and 96.

(*a*) **Where the ground is moderately hard** it is usual to first dig down a few feet, and then place at the bottom of the excavation a circular frame of timber called a "crib" or "curb." This consists of an annulus divided into a number of segments having joints (Figs. 95 and 96); with narrow curbs the segments are usually connected together by one bolt, but in broader ones two will be employed. At the surface a square frame is formed by four pieces of timber intersecting each other, held by notches where they cross, and with the ends projecting to some distance beyond. This is often held down by pegs which give it a grip on the ground. Timber laggings will now be driven *behind* the curbs at necessary points where the nature of the ground requires them for support, and the two frames are then connected by nailing on strips of stronger planks (called "stringing deals") at intervals round the shaft on the inside; in addition, short vertical struts called punch props are placed between the curbs to keep them in position (*c*, Fig. 97). Then the ground is removed for a further distance down, a third frame put in, lagged behind, and hung by a further set of planks from the second curb (Fig. 97, *1*, *2*, *3* are the curbs, *a a* the laggings, *b b* the stringing deals).

Instead of timber laggings the space between the curbs is often filled in with a dry walling of bricks called "back casing," the curbs being hung from each other by stringing deals as before.

If the ground is soft, and does not afford sufficient support for the curb at the bottom of the excavation, the whole structure is hung by chains or iron bolts from strong baulks of timber placed transversely across the shaft at the surface. These tie-bolts are added to and lengthened as additional curbs are fixed below until the firm ground is reached.

Instead of employing wooden curbs for timbering through loose ground, the practice is becoming general of using iron "binding" rings. Four of these go round the circumference of the shaft outside brickwork, and are made of flat bar iron about 3 inches by ¾ inch. They are connected together by bolts, each segment overlapping at the joints. The same rings are used for the temporary support of the sides of the shaft during sinking through ordinary ground, and, apart from the additional safety gained, it is advisable to insist on their being put in immediately sinking commences below the last brickwork whether the ground apparently needs it or not, because, although the rocks appear strong to commence with, layers of soft material may set in needing timbering, and in this event it is difficult to put in the binding rings without erecting temporary scaffolds, as they must be fixed from above downwards. If they are put in as sinking proceeds everything is easy, because the men have the solid bottom to stand on to fix the rings in position. The distance apart of these rings depends on the nature of the ground, but 4 feet is usual in ordinary measures. As soon as this distance is sunk a ring is placed in position, and is suspended from the upper curb by a series of iron hangers, each about 1 inch square, having each end bent back to form a hook. The upper end is hooked over the angle edge of the last curb, while the lower end supports the first binding ring. Laggings are then driven down around the circumference of the shaft, and are made tight by wedging, if necessary. Afterwards sinking proceeds until a further distance of 4 feet is reached, when the second binding ring is hung from the first, and laggings put round as before.

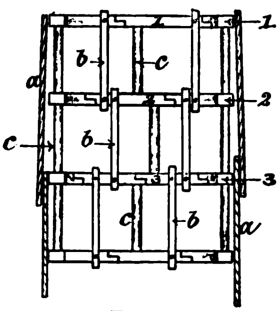


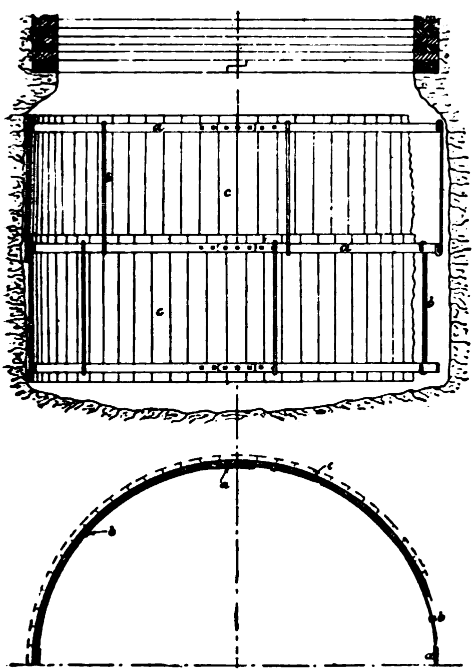
Fig. 97.

By arranging a number of bolt holes in each segment and making all these holes of the same size, and an equal distance apart, the segments can be made to overlap each other more or less, as desired, and thus fit a smaller or larger excavation, if necessary. In Figs. 98 and 99, *a a* are the iron binding rings, *b b* the hangers, and *c c* the timber laggings.

The permanent lining is then put in by one of the methods described further on, care being taken that all the temporary timbering is removed.

(*b*) **Where the ground is loose** different methods to the foregoing have to be employed. Sinking through quicksands and heavily watered beds is one of the most costly operations connected with mining, and calls forth all the skill and experience of engineers. The means used for reaching the "stone-head" where quicksands are present depend in a great measure on the thickness that has to be passed through.

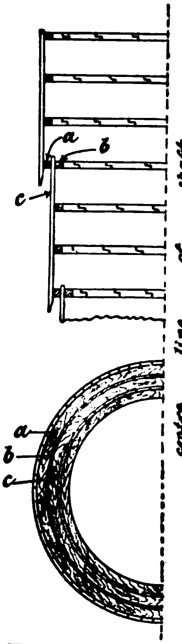
(1) *Pile-Driving.*—At one time the general method adopted was by what is known as "piling," which consists of driving vertically downwards, all around the circumference of the shaft, wooden planks with their edges touching each other, and supporting them internally with curbs. The planks or piles used are generally from 10 to 15 feet long, 6 inches broad, and 3 inches thick, having their lower end tapered off to a cutting edge, and their upper one strengthened with a wrought-iron hoop, so that they are not split by the blows of the wooden driving maul. In forming the cutting edge, all the taper is given on the inside, the outer side not being touched, as if it was cut to a V form the piles could not well be driven down vertically, as the tendency would be for them to incline towards the centre of the shaft. In hard ground the cutting ends of the planks are shod with iron to enable them to penetrate more easily.


Figs. 98 and 99.

The width of the supporting curbs depends on the size of the excavation. They are, however, generally made about 6 inches broad, and placed at closer vertical distances in large shafts than in smaller ones.

When the bottom of the first length of piles has been reached, and a curb placed round as a support, a second set are driven down *inside* the lower supporting curb, so that the diameter of the shaft is reduced in that length by twice the thickness of the laggings and twice the breadth of the curb, or, if 6-inch curbs and 3-inch piles are used, by 18 inches. As this reduction takes place with each course of piles, the shaft has to be commenced at the surface with a diameter sufficiently large to allow it. It therefore becomes necessary that the thickness of the quicksand to be passed through should be approximately known, such being usually found by boring. If piles 15 feet long are used a fresh course will have to be put in about every 12 feet, therefore if the quicksand is 60 feet thick, five reductions will take place, altogether amounting to $5 \times 1\frac{1}{2} = 7\frac{1}{2}$ feet. If a 15 feet shaft is being sunk with brickwork lining 18 inches thick, the diameter at the bottom of quicksand must be at least 18 feet, and at the surface the excavation will require to be $18 + 7\frac{1}{2} = 25\frac{1}{2}$ feet diameter.

Commencing at the surface, the ground is excavated as far as it will stand, and the first curb carefully laid down, with its centre coinciding with the centre of the shaft; the lining of piles is then driven down as far as possible, and the ground taken out on the inside till a sufficient distance has been sunk to require the support of another curb, which is accordingly placed in position. The piles will then be driven down a further distance, more ground excavated, and so on until the bottom of the first set of piles is nearly reached. A supporting curb (*a*, Figs. 100 and 101) will then be fixed against the piles and a second one *b*, 18 inches less in diameter, will be placed inside it, leaving an annular space of 3 inches between the two. A second set of laggings, *c*, will now be driven down in the space left between the two curbs, and the same cycle of operations gone through as before. This process is repeated until the solid ground is reached.



Figs. 100 and 101.

The method just described is the one generally adopted in the North of England, and where the ground is very loose and of a watery description. Sometimes, however, instead of driving down the piles vertically they are inclined outwards (*a*, Fig. 102), and then as the ground is excavated towards their lower end, the pressure gradually drives them forward. When the ground has been got out for a short distance in the bottom, supporting curbs *b* are fixed in the same manner as before. As the piles in this instance do not touch each other at their lower ends, straw, or similar material, is pushed between the joints, to prevent the sand from flowing into the shaft.

When the ground is very loose or watery, the difficulty of using the latter class of piling is surmounted by the so-called method of "quartering," in which only a portion of the circumference is attacked at a time. Commencing from the upper curb ground is taken out for a depth of 3 feet in the centre of shaft, piles 4 feet long are driven down for a length of about 8 feet round the circumference of the shaft, and when each has gone in its full length the top end is knocked back under the curb. The ground is got out for a length of 3 feet in front of the piles, a segment of a curb laid on the bottom perpendicularly under the upper one, and the space between filled in with dry brick-work; when this is completed the two curbs are connected by nailing on stringing deals, and a further series of piles driven down at the end of those already in position. Sufficient ground is then excavated

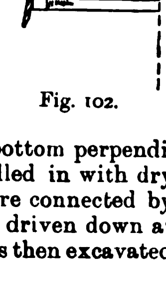


Fig. 102.

in front of the piles until room is obtained for another segment of the curb, this joining up to the first one laid. The space between this and the upper curb is then filled in with dry brickwork as before, more piles driven down, the ground excavated, a third segment laid, and the process repeated, segment after segment being "quartered" in, until the whole circumference is firmly secured for the length under consideration. A lower length is then attacked in a similar manner, and then another, and so on until solid ground is reached.

(2) *Drums.*—The method of pile-driving is an exceedingly expensive one, and is often superseded by one of the so-called "drum" methods. In this system a drum either of wood or iron of a diameter sufficiently large to allow the permanent walling being inserted inside it is sunk through the sand.

(*a*) *Wood.*—A curb (Fig. 103), 14 or 18 inches broad by 6 inches thick, is first laid truly level on the top of the bed to be sunk through, and a tier of masonry built on it to a height of about 3 feet when a second curb will be laid, and connected to the first by iron tie-bolts passing through the brickwork. In order to prevent the dislocation of the masonry, and to reduce friction during descent, a close lining of planks is nailed around the outer circumference, these being planed at the edges where they meet, to ensure a water-tight joint. A further length of masonry is then built on the second curb, a third one laid and connected with bolts, and laggings placed round the outer circumference, as before. In Fig. 103, *a* and *b* are curbs, *c* a wrought-iron connecting bolt, and *d* the lagging planks. Where the ground is of loose description, the weight causes this drum to sink, but if the beds are more coherent, the bottom curb is provided with a cutting edge, either by bevelling off the inside or by attaching an iron shoe. Opinions differ as to the advisability of employing cutters at all, it being contended that they are merely a source of weakness, as when any exceptionally hard substances are met, the tendency is to turn the cutter outwards, and often rupture the drum. The ground in the centre of the shaft is then slowly removed, and the cylinder sinks. A man stands on the drum with a straight edge and level and gives directions as to where material is to be excavated if one side "hangs" behind, but care is taken not to remove any ground near the curb for fear the drum should suddenly sink, and "cant" over.

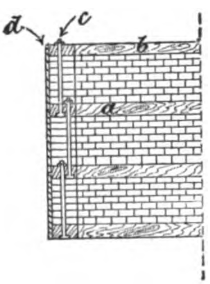


Fig. 103.

When the drum has sunk, say a distance of 3 feet, more brickwork and another curb will be added at the top, and connected to the others by bolts as before. This is repeated every time the drum sinks the certain specified distance, until, in the course of time, the solid ground is reached.

The great difficulty encountered in sinking by this operation is in keeping the drum truly vertical. Constant supervision and care must be exercised to prevent canting. As a matter of fact, the drum never goes down regularly, but does so by fits and starts, sometimes falling through 5 or 6 inches at a time. With each such movement cross-staffs are placed on the curbs, and a spirit level applied, to see if the apparatus is horizontal. If it is not, either a small quantity of ground is taken away from beneath the highest part, or additional weights are added to the drum on that side.

(*b*) *Iron.*—The objection to wood drums is, that they require nearly as large an excavation as if piling was employed, for often, after getting down some distance, the whole structure sticks, and cannot be moved. A second one has then to be sunk telescope fashion inside the first. To get over this, wrought or cast-iron drums are used, as, although they sometimes have to be telescoped one within the other, comparatively little space is lost. With cast-iron ones, the circle is composed of a certain number of segments, varying from 4 to 5 feet long by 2 feet deep, strengthened by vertical and horizontal ribs, similar to Fig. 126. As these strengthening ribs are on the *inside*, the outside surface is smooth, and meets with little resistance in passing through the ground. The joints between the different segments are made with sheet lead and bolts, and a cutting edge is attached to the bottom segment. The procedure is very similar to that with brick drums. They are usually weighted, and to make this more easy to carry out, the ribs are made broader. If sufficient weight cannot be applied by placing material on these ribs, two sets of timber buntons are placed across at right angles to each other, and a platform laid on them, upon which any amount of débris can be placed, a passage being left through the centre for the workmen to reach the bottom of the cylinder.

On the other hand, it often happens in very watery ground that the drum has a tendency to sink too fast, and, unfortunately, not to do this equally, but to get lower on one side than the other, and as this is a point which it is particularly desirable to prevent, the tubbing is hung at four points by a chain and lowering-screw arrangement from strong transverse beams at the surface. Where such means are employed, the tubbing is easily kept perpendicular, as, even if the sand is watery on one side, or boulder-stones cause an obstruction, it is only necessary not to let out a screw on the side which requires checking. Instead of cast-iron drums, which are liable to break, owing to the unequal strain to which they are subjected, wrought-iron ones are sometimes employed.

In Germany, these iron drums have been forced down through ground of moderate hardness, both by hydraulic hand presses and mechanical presses working in combination with, and actuated by, hydraulic accumulators. By this improvement it was found possible to keep the sinking cylinder in advance of its work, but the means for loosening and removing the material inside the cylinder did not keep pace with such improvements. The walls of the cylinder have consequently been fitted with a number of pipes, through which the loose material is pumped up, while a revolving cutter, which works in the centre of the shaft and throws the material out towards the circumference, is used for the disintegration of the quicksand or clay which is being sunk through.

Comparing the two systems, there is little doubt that, where the thickness of ground to be passed through is large, the iron drum possesses certain advantages, as by its use a smaller excavation is necessary; its sides do not offer such a resistance in passing through the strata, and the time of sinking is less, owing to the ready way in which the various parts are put together and added to; but unfortunately, it often breaks, which occasions months of delay, and increases the cost of sinking. This is the only advantage possessed by wooden drums; instances are to be found where such have been pushed into an oval form, and yet have not collapsed.

When the sinking has reached the stone-head, no matter what system has been used, the procedure afterwards is always of a similar character. The ground is carefully prepared for the seating of a curb upon which the permanent lining is brought up to the surface by one of the methods to be described further on, all temporary timbering being removed as the work comes upwards. As a matter of fact, the lining is usually carried a short distance above the surface of the surrounding ground to secure some "tip" for the débris which is excavated from the sinking.

METHOD OF PROCEEDING AFTERWARDS.—On reaching the solid ground, excavation proceeds with the tools described in the previous chapter, those employed depending entirely on the nature of the strata which have to be passed through. Several difficulties are encountered where machine drills are employed. Owing to the uneven nature of the bottom, the ordinary tripod stand is used with difficulty, taking from five to ten minutes to fix, and then the legs move during drilling if the ground is soft. As no roof exists, the vertical stretcher bar has to be replaced by a horizontal one. This is not easy to fix, and takes so much time to adjust, that often, instead of moving the bar and drilling holes in the most favourable position for blowing, they are put down in such places as suit the drill, and consequently are not so effective. Considerable time is also lost in raising drills and bars out of the way when blasting takes place.

To obviate these disadvantages a boring frame is employed consisting of four main stretcher bars, *a a* (Fig. 104), hinged to a central support, *b*, and suspended by a chain, *c*, and capstan rope. Each of these bars is provided with a lengthening screw and claw, so that the whole structure can be readily clamped in position, and as it shuts up when not fixed against the side of the shaft, it is equally easily withdrawn. To keep the structure from lifting by the impact of the drills when boring, four secondary arms, *d d*, are arranged near the top of the frame, these being strutted against the sides at a slight inclination upwards, and, in addition, heavy cast-iron blocks, similar to those used on the tripod stand of an ordinary percussion drill, can be fixed on the central support *b* to counteract the upward thrust. As each of the arms *a* may be moved radially around the centre, if the drills are mounted on swinging arms (see Fig. 71), they can be placed at any angle and clamped in any position, and the holes put in anywhere.

Where drills are adopted, the general procedure is to first bore all the holes required, hoist up the frame and drills by an engine, fire the holes simultaneously, and then load up the débris until the bottom is clear, when the drills are again lowered and fixed, and drilling recommenced. In hard ground, probably only one set of holes will be bored and blasted and the rock removed in twenty-four hours.

Another practice gaining ground, is to lower the walling stage to about 8 or 10 feet from the bottom, wedge it there and form an artificial roof, and then use ordinary vertical stretcher bars.

Another method proposed, and, indeed, tried in two instances, is to start at the surface and bore a series of holes 200 or 300 feet deep with the aid of the diamond drill, and fill them up with sand. Blasting then commences by removing 4 or 5 feet of sand from the holes, and firing them in groups, this process being repeated until the bottom of the holes is reached, when the drills are again introduced, and a further distance bored. The Pottsville shaft, U.S.A., was sunk in this manner,* 25 holes being bored $1\frac{3}{4}$ inch in diameter about 3 feet 3 inches apart in one direction, and 4 feet in the other. The central group of holes was always fired first, and the outside rows afterwards. The process was expeditious, but the financial result does not appear to be satisfactory. At Harris Navigation Colliery, the same method was tried for about 70 yards but abandoned.

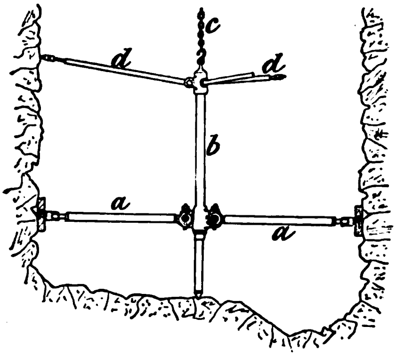


Fig. 104.

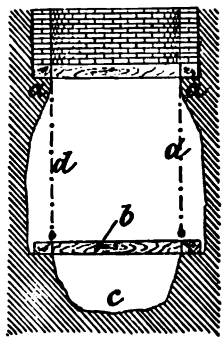


Fig. 105.

With the object of providing support for the curb carrying the upper length of lining, when sinking recommences, the excavation is carried down for about 3 to 5 feet, lineable with the *inside* of the curb (*a*, Fig. 105), then shorn back until the diameter is large enough to take in the permanent lining, and afterwards carried downwards this size, until the strata require more support than temporary timbering affords. A seating will then be made for a curb, *b*, leaving a space, *c*, in the bottom of the shaft for the collection of water, &c., and the walling built on it up to the curb above, the ground *a* being removed for this purpose, not all at once, but in sections.

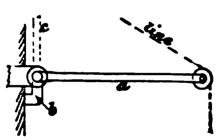


Fig. 106.

Keeping the Shaft Vertical.—This is done by the aid of a centre line which is either a cord of special manufacture about $\frac{3}{8}$ inch in diameter, or preferably a copper wire, long enough to reach from the surface to the bottom of the shaft when completed. One end of this line is coiled on a small drum situated near the top of the pit, and the other end is led by pulleys to the exact centre of the shaft. As a rule, the central point is a hole bored through a baulk of timber placed across the shaft, but a better plan is to provide a hinged arm (*a*, Fig.

* "A New Method of Sinking Shafts." E. B. Coxe, *Amer. Inst. M. E.*, i., 261.

106) built firmly into the masonry. When in use this is kept in its proper position by the stop *b*, but if not, it is folded upwards into the position shown by dotted lines at *c*. After the line has been passed through the centre hole, a link is attached, from which a weight can be hung, this dipping into a bucket of water at the bottom, so that the line is steadied. As soon as the proof has been made the weight is removed, and the cord wound up again on the drum.

In order to minimise the time lost in steadying the plumb-bob, Mr. W. Foulstone * has designed an arrangement consisting of a wrought-iron girder fitted with a pulley at the end hanging over the shaft, and with a rack on its upper surface. This rack is geared into wheels supported on two fixed girders projecting a short distance over the shaft, which also carry a small winch on which the testing line is wound. By means of the gearing and rack, the wrought-iron arm carrying the centre line can be run out, so that the latter hangs exactly in the centre of the shaft. The centre line and weight, when not in use, are left hanging in the shaft, near to the side, some 30 yards above the bottom out of the way of shots, and can be run out by the rack to the exact centre, and the weight lowered by the drum, in a few moments.

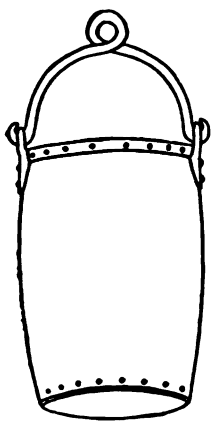


Fig. 107.

Fig. 108.

For determining whether sufficient ground is removed, the master-sinker is provided with a "centre" staff, which is a wooden rod about 1¼ inch square, and equal in length to the outside *radius* of brickwork. This is moved round the central point as excavation continues.

For setting out the curbs exactly beneath each other a series of cords (*d*, Fig. 105) are hung all around the circumference of the shaft at intervals of about 3 feet. These are attached to the inside of the upper curb, and serve, not only to set the curb below, but also as a guide for the amount of excavation. Every third curb will be checked by the main centre line, the intermediate ones being set out by the side lines.

Winding Débris.—The material excavated is brought to the surface in wrought-iron barrels called kibbles, hoppits, or bowks, the general shape being shown in Fig. 107. At the top is a bow of wrought-iron swung to the body by two eye-pieces riveted to the sides of the kibble. Attachment is made to the winding rope through a spring hook (Fig. 108). With such construction time is lost at the surface, as the full bowk has to be taken from the rope and replaced by an empty one. For this reason the tipping kibble is preferred. Its body is similar to the one already figured, but the wrought-iron bow is not attached at the top but at a point below the centre of gravity, so that when full, the tendency is for the kibble to turn over and empty itself. To prevent this happening during hoisting, two short vertical pins (Fig. 109) are riveted to the inside of the bucket,

* *Fed. Inst.*, v., 364.

and an ordinary chain link, sliding on the arms of the bow, passed over them. On reaching the surface the safety links are lifted off the pins, when the hoppit immediately turns over and empties itself. With such a system the kibble is only removed from the rope at the bottom of the shaft, one disconnection being saved. The seams of these kibbles must be caulked, as when there is any water in the bottom of the shaft, a certain quantity is loaded up each time with the débris.

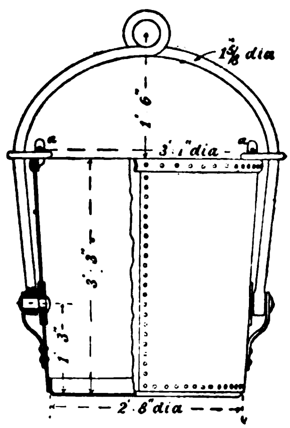


Fig. 109.

Covering over Pit Top.—This was originally done by means of a travelling platform, which could be wheeled over the shaft when the kibble reached the surface, and removed again when descent had to be made. The labour here is considerable, and time is lost. To get over these drawbacks, two hinged doors with their weight counter-balanced are adopted. These, when open, form a fence protecting the pit top on two sides; the other two are guarded with a permanent fence. When these are down they entirely close the opening, and two rails on the upper side of each door form a continuation of the tramway going to the dirt heap.

Even, however, with these a little time is lost, as each door has to be lifted separately; so, to remove this complaint, Mr. Wm. Galloway has designed an arrangement of levers and counterbalances (Fig. 110)

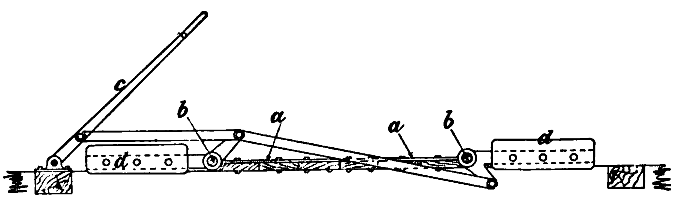


Fig. 110.

by means of which both are opened at the same time. Two hinges, *a a*, are bolted to each door, and keyed on cross shafts, *b b*, to which, by means of a handle, *c*, and connecting links, a movement of rotation can be given, and as the hinges are fixed to the cross shafts the doors lift when the latter turn. The weight of the doors is counterbalanced by four blocks of metal, *d*, so that they will stand at any position in which they are placed.

Guides.—The introduction of guides in sinking pits is desirable to prevent the oscillation of the kibble, which gets especially large in deep undertakings, considerable time being lost in steadying it before winding commences. Two methods are adopted; in the first, a single guide rope is passed down the centre of the shaft, while, in the other, two ropes are used. In each system these guides, which are of flexible wire, are coiled on a drum worked by a capstan engine at the surface, and can be lengthened as the sinking proceeds; they also form the means by which the walling stage is raised during bricking operations. In the former, however (see description, p. 139), the walling stage is removed during sinking, and the kibble is guided to the bottom of the shaft; while, in the latter, one end of each guide is always attached to the walling stage which remains in the shaft during sinking, and the kibble is only guided to the point where the walling stage is suspended. Each system has its advantages, as with one central rope the kibble is guided all the way, and if a heavy weight be hung at its lower end, the centre line of shaft is obtained without any further trouble, while, in the two-rope system, walling can proceed while sinking is going on below, thus saving considerable time, an advantage not possessed by the other method.

The system of employing two guides was patented by Mr. Wm. Galloway in 1875. In it, two wire ropes (*a a*, Fig. 111) are connected at their lower end to the walling stage, and pass over two pulleys on the headgear to drums worked by a steam crab, each drum being able to be moved independently, to provide for any casual irregularity in the length of guides. An iron frame, consisting of two legs joined together by a cross-bar, called the "rider," clasps the two guides loosely at four points, *b b*, thus preventing any chance of cross-binding. The winding rope passes through a hole in the centre of the rider. The capping connecting the winding rope and chain going to the kibble is provided with a buffer, *c*, consisting of alternate layers of india-rubber and sheet iron, which are of larger diameter than the hole in the rider cross-bar, and therefore cannot pass through it. When the kibble arrives at the surface the balanced doors are closed, a tipping waggon (one form of which is shown in Fig. 112, the sketch explaining itself) run beneath, and the kibble emptied into it. The waggon is then removed, the doors opened, and the bucket and rider lowered away until the walling stage is reached, when the arms of the rider are caught by two buffers on the bridle chains. The kibble and winding rope continue their descent, passing through the square opening in the stage, until the bottom of the shaft is reached. In ascending, the winding rope slides through the central opening in the rider cross-bar, until the buffer on the capping comes in contact with it. The rider is then lifted to the surface.

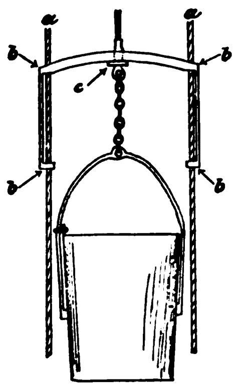


Fig. 111.

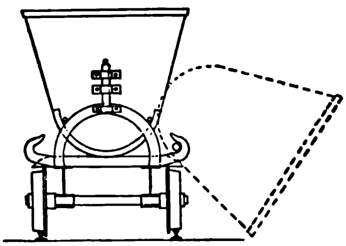


Fig. 112.

In sinking the Harris Navigation shafts, the time occupied in winding, changing, &c., before adopting guides, was 4 minutes 49 seconds from a depth of 475 yards, whereas, after the guides were put in, the time fell to 3 minutes 26 seconds from a depth of 530 yards.*

LINING SHAFTS.—In describing the operation of getting down to the stone-head, both timber and iron were alluded to as being employed for securing the sides of the excavation only as a temporary means. As soon as this point is reached some other method of a more permanent character is adopted. Several substances are employed for permanent lining under ordinary circumstances, such as wood, stone, or brickwork, but, except in cases where the two former are plentiful and cheap, they are rarely used. Bricks are plentiful in most colliery districts, and in the great majority of instances are adopted. Sometimes they are moulded to the shape of the shaft, and when such is done the labour of laying them is reduced and the joints are well made, but in large shafts, where the curvature is small, ordinary 9-inch bricks are generally employed as they are much cheaper.

Bricks.—For all mining purposes, the bricks used should be good hard burnt ones, and free from cracks and stones. The clay of which they are composed should be rich in alumina and thoroughly ground in a pug-mill; they should also emit a ringing sound when struck. The surface should not be too smooth, a probable result of over-burning, or the mortar does not readily adhere to them. When made by machines in which wires are used for cutting the blocks of clay into the required shape, the edges are left rough, and this, instead of being a disadvantage, really assists the brick in laying hold of the mortar.

Number of Bricks required.—The easiest way to find out how many bricks are required for walling is to calculate the cubic contents of masonry for each yard in depth, and then multiply by the total depth.

If D = the outside diameter of brickwork in feet and d the inside diameter $(D^2 - d^2) \times \cdot 7854$ will give the area in square feet of the annular ring; this multiplied by 3 (number of feet in yard) and divided by 27 (cubic feet in cubic yard) gives the number of cubic yards of masonry for each yard of depth, or simpler still, divide at once by $\frac{27}{3} = 9$. Ordinary bricks are $9 \times 4\frac{1}{2} \times 3$ inches, so that a cubic yard of masonry would contain $4 \times 8 \times 12 = 384$, if mortar was absent. As this occupies a certain space it is usual to consider in practice that 1000 bricks will build 3 cubic yards.

Mortar.—The mortar used is generally composed of lime and sand, and should be of a slightly hydraulic character. The ingredients, whatever they may be, are usually mixed in a mortar mill, which not only considerably reduces the labour of production, but also the cost, as with it all rough parts are ground up, and no refuse is left, as there would otherwise be if ordinary hand-made mortar was employed. As a substitute for sand, clinker-ashes from underneath boilers are largely employed with most satisfactory results, as they give ordinary lime somewhat of an hydraulic character, and the mortar sets very much quicker and harder than when sand is used. It is, however, very necessary that these ashes should be free from the finer or smaller parts. As they are a waste product at collieries, considerable economy results from their use. Where the strata are

* *Inst. C.E.*, lxiv., 26.

wet, and the brickwork has to resist the passage of moisture, cement is often used, either by itself or mixed and ground up with lime. Where cement is adopted, it should be used as quickly as it is made, if not, it partially sets, and has to be broken up and made over again. Thus, not only is time lost, but the cement sets neither so well nor so quickly on the second operation, and the strength is materially reduced.

Whatever quality of mortar is employed, too much must not be used, as it is not so good for resisting pressure or the passage of water as a brick. The proper thing to do is to lay a bed of mortar, and not place the brick in its proper position, but drop it down a few inches away, and then rub it towards the place at which it is to be fixed. When the bricks are of a close-grained character they absorb moisture so quickly from the mortar that the mixture dries before it is properly set, so, to prevent this, it is usual before laying such bricks to soak them in water.

Thickness of Brickwork.—The thickness of walling depends entirely on the diameter of the shaft and the nature of the strata. If it is coherent rock a single brick is used, more as a preventive of weathering action than as an actual support. In looser ground, brickwork from 14 to 22 inches thick is put in. Opinions differ as to whether brickwork in shafts should be made solid—that is to say, whether it should be carried up to the limits of the excavation, or whether it should be finished off at a certain distance and some looser substance interposed between it and the strata. The author's experience is decidedly in favour of the latter. Where the brickwork is made to abut against the rocks, and heaving takes place, it is either bulged or broken, but if, on the other hand, some soft packing substance is interposed between the sides of the rock and the brickwork in the shaft, the first result of pressure is to compress and tighten this loose material. If any heaving takes place at one point, all the pressure is not thrown on the brickwork opposite to it, but, owing to the soft compressible stuff being interposed between, is distributed over a larger extent of surface. At the same time, it should be pointed out that no spaces or cavities should be left between the brickwork and the sides of the shaft, but every opening carefully filled in with loose, fine material. Coke dust or well-burnt small ashes are excellent for such use, and often the small dust from stone-breaking machines, where such can be obtained, is employed. Sand is too heavy for shaft work.

Ordinary Curbs.—The brickwork is put in in sections, each length being supported on curbs. Wooden curbs are generally employed, similar to those already described, but as they decay somewhat readily, cast-iron ones are often substituted. A curb of this material employed in a shaft 19 feet diameter is shown in Fig. 113. It is cast angle shape, and is 10 inches broad by 4 inches high by ¾ inch thick. Ten segments form the circle, and each one is strengthened by two ribs. Two holes are left in the transverse ribs at each end, through which bolts are passed to connect the segments together.

Water Rings.—If the strata are at all wet, more or less moisture always percolates through the masonry, and is collected in what are called "water rings" or "garland curbs," from whence it is conducted down the shaft in tubes. The ordinary construction of water ring consists of an iron curb cast with a hollow groove. These are bedded as usual, but the brickwork for a short distance above is shorn back (Fig. 114), so that the water readily passes into the groove, but in

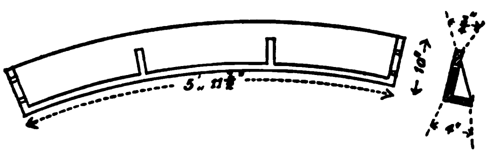
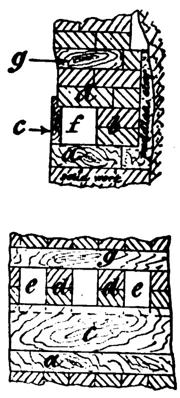


Fig. 113.

Fig. 114.

winding shafts the small pieces of débris which drop off the cage, unfortunately pass in with equal readiness, and soon choke up the water room, necessitating frequent cleaning out.

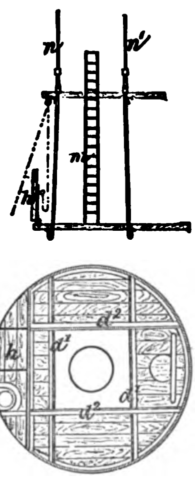
A superior construction for larger quantities of water is illustrated in Figs. 115 and 116. For a few courses the brickwork is made solid, and an ordinary curb, *a*, fixed in position. All the joints in the curb and between it and the brickwork are made with tarred flannel, and the space behind the curb is well rammed with puddled clay. Two courses of brickwork, *b*, are laid, but are set back from the rest of the work as figured. A shrouding, *c*, provided with a ledge on the *inside*, is nailed all round the front of the curb, the horizontal and vertical joints being made with tarred flannel as before. A series of bricks, *d*, are then placed, bridging over the space between *b* and *c*, but these are not continuous all round the shaft, blank spaces being left alternately; the result is, that a series of pigeon-holes are formed (*e*, Fig. 116), the object of which is both to allow water to readily pass into the space (*f*, Fig. 115), and to afford means for removing the sediment which collects in the course of time. After two rows of these bridge bricks have been put on, a light curb, *g*, is fixed, and on it the ordinary brickwork of the shaft is built.



Figs. 115 and 116.

Walling Stages.—When commenced the operation of walling is carried on as rapidly as possible. It was formerly performed on ordinary scaffolds supported by cross-baulks of timber, which rested on the brickwork already put in, holes being left at intervals for the insertion of byatts. This necessitated the labour of raising the scaffold each time the work got too high for the masons to reach. Such procedure is entirely superseded by employing a circular stage, a little less in diameter than the finished size of shaft, which is bodily lifted up by a crab-engine on the surface. In its ordinary form it consists of three parts, a central one and two side-pieces working on hinges, connection being made to the ropes by two sets of three bridle chains. The great advantage derived by this latter method is speed, as instead of having to lift the scaffold, it is only necessary to signal to the engine on the surface to have it drawn up. As soon as it arrives at the proper point it is steadied, either by pushing a series of small radial bolts into holes left out in the brickwork, or by driving down two wedges into the annular space between the stage and the masonry.

In large shafts the walling stage is a very elaborate and substantial structure, and is so constructed that sinking can be carried on underneath while bricking proceeds at a higher level. Mr. Wm. Galloway, in the No. 1 pit at Llanbradach, has adopted a form, shown in Figs. 117 and 118, which consists of a wooden floor on an angle-iron frame, part fixed and part movable, and an upright tube connected to this iron frame. The lower frame consists of four pieces of angle-iron, d^1 d^2, crossing each other at right angles, a circular band of angle-iron in three segments, and a straight piece of angle-iron joined to the short ends of d^2 and to the ends of the circular frame, as illustrated. The object of the latter piece is to enable the hinged door *h* to be placed in the part forming the smaller segment of the circle. When



Figs. 117 and 118.

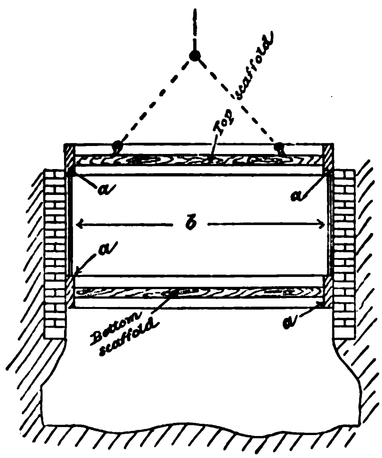


Fig. 119.

the stage is taken past the pipe buntons the door is raised up. Four upright pieces of angle-iron connect the upper frame and the lower one, and four plates of sheet-iron, attached to the four uprights, form the fence around the central opening in the stage. The roof is 10 feet 6 inches above the stage proper. It is formed similar to the floor, but is of rather smaller diameter, and is covered with sheet-iron. An iron ladder, *m*, provides a means of access from one stage to the other. The whole structure weighs about 5 tons, and is suspended from the guide ropes *n n*, which are 5 feet 6 inches apart from centre to centre. In the No. 2 shaft the details have been altered somewhat, two openings being provided, as two kibbles are employed for winding purposes. In this instance suspension is made by two ropes, which serve the purpose of four guides, by the following attachment:—The end of *each* suspension rope is attached to a strong screw in the pit-head pulley, and passes downwards to the walling stage, then round a small pulley fixed on it, proceeds a short distance across the stage, round another pulley similar to the first, then vertically up the shaft, and over another pulley on the pit-head frame, finally going to the drum of the capstan engine.

A model of a similar appliance was exhibited by the Roche la Molière Company at the Paris Exhibition, 1889. It consisted of an iron ring from 25 to 39 inches deep (*a*, Fig. 119) of the exact diameter of the finished shaft, suspended from bridle chains. A similar ring was hung about 10 feet below, and the two connected together by a series of iron rods. These two rings support two scaffolds, on the upper one of which the men stand to do the bricking. The bricks, &c., are placed round in contact with the upper ring, the platform slowly raised, and another tier of masonry placed in position. In this way the time usually spent in measuring the diameter and ascertaining the verticality of the shaft is saved, the top ring being kept a few courses above the brickwork to give a guide to the masons, the object of the two rings evidently being to keep the scaffold in a vertical line. Where the spaces between the masonry and the sides of the shaft are to be filled in with cement, &c., deeper rings are employed, so that more of their height might be left below as a support until the cement sets.

Supporting Curbs.—It often happens that when the sinking is passing through rotten ground lengths of walling are required to be put in to secure the sides, but suitable places cannot be found on which to seat the curbs. In such cases the difficulty is got over by one of two methods, either by putting in what are called "square frames," or by supporting the curb on a series of iron plugs driven in all round the circumference of the shaft.

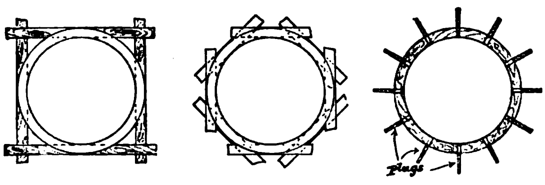


Fig. 120. Fig. 121. Fig. 122.

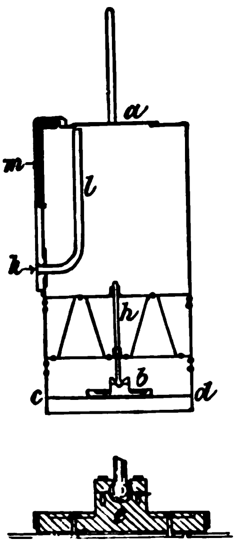
A square frame, with its sides equal to the diameter of the shaft, is placed at the point where the walling is to commence, and as the corners of this frame project a considerable distance beyond the circumference of the pit (Fig. 120), sufficient support is afforded to the curb. In large shafts the amount of ground to be excavated for a square, having its sides equal to the diameter of the pit, would be so great that the cost would be a serious matter; so, to remove the difficulty, and yet obtain some support, the square is replaced by an octagon (Fig. 121).

The better method is to bore a series of holes, 2 inches diameter and 3 to 4 feet apart, around the circumference of the pit, to a depth of 3 to 4 feet, depending on the strength of the ground. These must be on a truly horizontal plane, and wrought-iron or steel plugs are firmly driven into them, leaving a projecting portion upon which the curb is bedded (Fig. 122).

Ventilation.—This is usually done by laying a line of sheet-iron pipes from 15 to 20 inches diameter down the side of the shaft, and connecting them with a small blowing fan at the surface. These pipes are held in position by dog-hooks driven firmly into the masonry, and are usually connected to one another by a bolt passing through a light bracket riveted to each pipe.

Lighting.—In districts liable to sudden outbursts of gas the same precautions have to be adopted in sinking as in ordinary working, and safety lamps are employed, but these give a very imperfect light in a downwards direction, where the sinker wants it most particularly. Of late years the electric light has been employed, with most satisfactory results, as, owing to the clear light given, the men do a great deal more work. A cluster of incandescent lamps, protected by a glass globe, is generally employed, this being suspended from a cable, which is wound on a drum at the surface, and which gives a ready means of raising or lowering the lamps, either to give more light, or to remove them out of danger when shots are being fired.

A concentric cable, or two cables insulated from each other but joined together to form one rope, can be employed. This cable, which should be long enough to reach to the bottom of the shaft when sinking is complete, is coiled on a drum, and the two terminals of one end soldered to two copper rings fixed concentric with the drum axle, but insulated from it and from each other. Two copper strips, fastened to, and insulated from, the wooden framework of the machine, rest on these rings, and are connected by binding screws with the cables from the dynamo. These strips and rings form a rough commutator and brushes, allowing the drum to be revolved without breaking electrical contact. The current passes from the dynamo to the strips, thence through the rings to one end of the shaft cable, and to the lamps suspended from the other end.



Figs. 123 and 124.

Dealing with Water.—The presence of a small amount of water largely increases the cost of sinking. A small quantity is got rid of by baling with a bucket into a tipping barrel, similar to the tipping kibble, and then winding it to the surface. This is a very slow and costly procedure, and where the quantity is at all large, one of the different classes of pumps will have to be employed. These are described in the chapter on pumping.

To save the time and cost of baling Mr. Galloway has designed a pneumatic water tank, which consists of a cylindrical barrel, 4 feet 2 inches diameter and 8 feet high, closed at the top in which there is a door (*a*, Fig. 123) bolted to the cover, this giving access to the interior when necessary; the bottom, *c d*, is 5 inches above the base of the cylinder, and has a central opening 18 inches diameter for the valve seat which is turned in a lathe. The valve *b* consists of a block of cast-iron (*e*, Fig. 124), having its lower face turned true, and over which a sheet of leather is tightly capped. A circular plate of iron, 16 inches diameter, is bolted to this valve, by bolts having countersunk heads, as shown in Fig. 124. A spindle, *h*, working through two guides, having a turned ball in its lower end, is held loosely in a socket in the valve, as shown, by which means the vertical movement of the valve is secured, while the ball-and-socket joint enables it to readily accommodate itself to the seat in any position in which it may be turned.

At *k* is one-half of an instantaneous coupling, supplied by the Vacuum Brake Co, constituting the outer end of the pipe *l*, which passes through the side of the cylinder, and rises to within 1 inch of the top of the barrel. A glass gauge, *m*, shows the height of water in the tank, this being protected from chance blows by strong ribs of angle iron.

Vacuum is created by air pumps at the surface, and is equivalent to 20 to 22 inches of mercury; 3-inch pipes are carried down the pit and connected to 30 feet of flexible hose, having a stop-cock and a corresponding half of an instantaneous coupling. The barrel is filled in thirty seconds. It was possible with this arrangement to sink in Pennant sandstone, with 5000 gallons per hour, at the rate of 5 to 5½ yards per week, or with 7000 gallons rather under 4 yards, the rock being very hard and compact. The highest rate of progress in the same ground with only 500 gallons per hour had previously been 6½ yards.*

A self-filling and discharging barrel for use in sinking has been described by Mr. George E. J. McMurtrie.† It consists of an ordinary open topped cylindrical barrel suspended on two shackles, with a piston working up and down it, this being connected to the large shackle link. The piston is provided with a number of small valves to allow the air to pass through as it descends, and a joint is kept between the sides of the piston and the barrel by a leather and junk ring. Twelve small holes are drilled through the shell just below the piston when it is at its highest position, in order to allow of the ready admission of air when the barrel is discharging.

There is a circular valve in the bottom provided with a projecting spindle, and guides above and below it. This acts both as an inlet and outlet valve, as is usual, the water being discharged into a chute or launder, which is run over the top of the pit. When the barrel is lowered the projecting spindle is the first point to touch the bottom of the chute, and the valve is consequently lifted upwards. Valves of this class are usually made solid, but this is grated, and is provided with a cover of sheet india-rubber. It does not fall directly on to its metallic seat, as an india-rubber ring of circular section is stretched tightly round the valve in a small groove turned in the edge. A shield of perforated plate is provided beneath the lower guide to prevent large stones passing into the valve when the barrel fills, while a hinged lid in the shield gives ready access to the valve for the removal of any small débris which may have passed through.

When these types of improved barrels are employed in conjunction with a storage tank suspended in the shaft, fairly considerable quantities of water can be easily dealt with, and at a possibly cheaper rate than if pumps were employed. These storage tanks are shaped

* *So. Wales Inst.*, xvi., 119. † *Brit. Soc. Min. Stud.*, xxi., 160.

on one side to fit the shaft, and are suspended from two wire ropes which pass from them to two steam winches on the surface. They can thus be easily raised or lowered at any point where a spring is met with. The ropes by which they are suspended act as guides for the water barrel which is wound up and down by another small engine. Even when the pit bottom makes water the storage tank, with a small pump worked by compressed air slung a few yards below it, can be let down near to the sinkers, and both can be lowered as the sinking proceeds. The pump only delivers water into the storage tank, as the water barrel afterwards conveys it to the surface.

KEEPING OUT WATER BY TUBBING.—Ordinary masonry is of little use for stopping back water if the measures contain large quantities, and it is desired that this should not have to be continually dealt with. As a rule, it happens that water-bearing beds are usually succeeded by others of an impervious nature, so that if there can be introduced at such point some water-tight material the water is prevented from coming into the pit. Such lining is called tubbing. The material employed may be either wood, cast-iron, or masonry; the former, however, is seldom employed at the present time. Its upkeep is great, it is scarcely ever water-tight, and its only recommendation is cheapness in first cost, where wood is plentiful.

Coffering.—Where the pressure is not excessive, a special setting of masonry, technically called "coffering," is largely employed. It is cheaper than cast-iron, and where properly put in is very successful. The following is a description of what is probably the largest application of this method, the shaft being 20 feet diameter in the clear, the coffering extending about 55 yards (from a depth of 105 yards to 50 yards below the surface).

After passing through the water-bearing beds the shaft was sunk 20 yards below the point where the last feeder was met, and a cast-iron curb put in and supported on iron plugs. Upon this about 26 yards of 14-inch brickwork was built, and then the walling was carried up solid for 12 feet, until the water-bearing strata were met with. The object of doing this was to provide some substantial support for the coffering, and to prevent any risk of the masonry settling and cracking. It was decided to put in the coffering 2 feet 3 inches thick. Some means have to be adopted to carry off the water running from the rocks, and to prevent it passing over the brickwork and washing the mortar joints away. To do this what are called "plug boxes" were bedded on the solid work. Six of these were placed at equal intervals around the circumference, and were formed of wood, 12 inches square by 2 feet 9 inches long, having a hole 3 inches diameter bored along their longer axis to within 2 inches of the back (*a*, Fig. 125), and then a vertical hole, *b*, bored from the top to meet the horizontal one. In this latter vertical wooden pipes having horizontal openings were carried up behind the brickwork, and allowed the water to pass away through the openings in the plug-boxes. The holes in the water troughs were bored at vertical intervals of 3 inches. As the brickwork and puddle reached each hole it was plugged up and the water conveyed away through the next higher one. The solid walling was then brought up level with the top of the plug-boxes and the coffering commenced.

This consisted of five rings of brickwork, the special feature of this system being that the joints are broken both vertically and horizontally. Header courses are not employed, stretchers only being used. To commence with, the first ring, *c*, is of ordinary brick 3 inches thick, the second ring, *d*, for the *first* course is laid with bricks 1½ inches thick, the third and fifth rings, *e* and *g*, are similar to the first one, while the fourth ring, *f*, for the *first* course, is also made with 1½-inch bricks; afterwards, ordinary bricks, 3 inches thick, are used in all the rings, so that the horizontal joints of the second and fourth courses throughout the work are the thickness of half a brick below the others. The method of laying the bricks is the usual one for the first, third, and fifth courses, and when these are in position, the spaces between are filled with thin liquid cement, and the second and fourth rows are laid by dropping the bricks into the mixture reposing in the gullet, these being what are called "floating courses."

After getting up about 12 or 18 inches the space between the back of the brickwork and the strata is filled in with good loamy soil, which should be free from pebbles and should be well and carefully rammed, no spaces being left. Instead of soil, well puddled clay is sometimes used, but experience is more in favour of the former. With clay, no matter how carefully the work is done, there is a tendency for "faces" to be formed between successive layers and lumps, through which water finds its way. The mortar used for laying the first, third, and fifth rings was a mixture of lime, cement, and ashes well ground in a mortar mill; for the intermediate rings, pure Portland cement was employed.

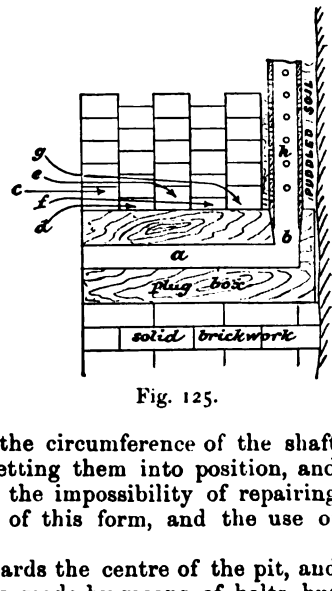


Fig. 125.

Iron Tubbing.—Where the pressure of the water is great, and long lengths have to be put in, masonry tubbing is not applicable; indeed every form has given way to that in which cast iron is employed. At one time rings going completely round the circumference of the shaft were employed, but the difficulty of getting them into position, and their liability to break, together with the impossibility of repairing them, caused an early abandonment of this form, and the use of segments has now become general.

At first the flanges were placed towards the centre of the pit, and the attachment of one to the other was made by means of bolts, but in consequence of the lowering of the ground, and the effect of side pressure, it was found that bolts were not to be trusted, and that frequent ruptures took place. In England this method has given way to the system in which the flanges are placed away from the removal of the pit, it being found that the pressure of the sides and When t[illegible]ing which is adopted, is sufficient to retain the segments in with a stor[illegible]d to keep the joints water-tight. The author was surprised quantities of [illegible] visit (in 1891) to the Continent, that the old system of rate than if pu[illegible]flanges towards the inside of the shaft was still in use * So. Wales [illegible]gineers at the different collieries visited contended that no reliance could be placed on wooden wedging, as it is always decaying, and that although some little difficulty is encountered through movements of the ground, these are counterbalanced by the more perfect water-tightness of the tubbing. In this method the flanges, both horizontal and vertical, are planed in a lathe, and two V grooves cut in them. A layer of sheet-lead is then interposed, and the two segments screwed tightly together by means of turned bolts, the pressure forcing the lead into the V grooves already alluded to.

The method of putting in the work is the same whatever system is adopted. After getting through the water-bearing strata, and reaching some impervious beds, a bed is first formed on which the wedging curb can be placed. This is dressed truly level with the aid of hammer and chisels, blasting being strictly forbidden, so as to obviate any possibility of fracturing the rock. This is the keystone of the whole operation, and requires the greatest care. Formerly wedging curbs were constructed of oak, but this has been abandoned in favour of cast iron. They are built up of segments which, in the case of upcast shafts and furnace ventilation, are sometimes of smaller diameter than the tubbing plates, the projecting portion being afterwards used as a foundation on which a lining of brickwork can be built. For an important undertaking they would be about 18 inches wide by 6 inches deep, and are cast hollow to lessen the weight. The segments of the curb are set in position on the bed prepared, and ½-inch sheeting of soft deal placed in the joints in such a manner, in this and other cases, that the end of the grain of the wood is presented to the inner part of the shaft where wedging takes place. The important operation of wedging the curb is then commenced. All around the circumference, in the space between it and the sides of the shaft, is placed well-dried timber, free from knots, with the grain upwards. As many well-dried, finely-tapered, pitch-pine wedges as possible are then driven in, care being taken that this operation proceeds all round the shaft at the same time in order to distribute the pressure, and prevent any chance of the segments being displaced; props are also set from the sides over each joint to keep the curb from lifting. When no more timber wedges can be got in, steel chisels are employed, and, in the spaces they make, further wood is inserted. A second wedging curb is usually placed above the first, and sometimes a third one. The top one of these always has a rebate or ledge placed on it, against which the segments of the curb abut.

Tubbing plates (Fig. 126) are cast in segments of such a length that the circumference is divided into equal parts, their height varying from 18 to 36 inches, according to the pressure to be resisted. Flanges, cross-ribs, and brackets are cast on the back to give strength, and a hole is provided in the middle of each to allow water to pass through while the operation of laying the plates is proceeding. The top and one of the side flanges are provided on the outside with a projecting ledge, which keeps the joint sheeting and adjoining segments in position.

When the wedging is finished, the first layer of tubbing plates will be laid on the curb, sheeting being placed between both horizontal and vertical joints, and a wedge tightly driven down between the back of the plates and the sides of the strata as a preventive against any of the segments moving. A second layer of segments is then laid on the first in a similar manner, and the process repeated until the top of the water-bearing strata is reached, the vertical joints being broken in each course, as in building masonry (Figs. 127 and 128). The spaces between the plates and the sides of the excavation are filled in

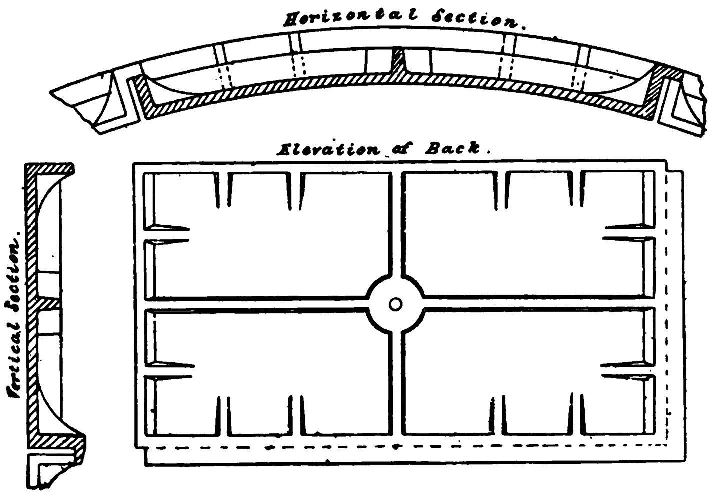
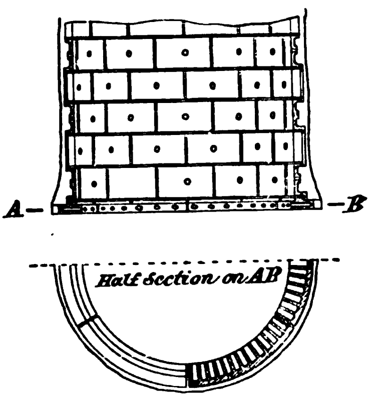


Fig. 126.

with soil or concrete packing. A wedging curb will be placed on the top if it is found that the water rises above the level of the last line of plates. All the horizontal and vertical joints are then carefully wedged, as long as the grain of the wood between the joints can be opened with a chisel, commencing at the bottom and proceeding upwards, attacking each ring in order, and plugging up the hole through the centre of each segment at the same time. If this operation is carefully performed it will be found that the length tubbed will be quite dry.



Figs. 127 and 128.

In many instances much time and money is saved by not waiting until the bottom of the water-bearing beds is reached, but putting in wedging curbs at intermediate places and building tubbing up from one to the other, successive feeders of water met with being thus kept out of the shaft. Of course, for the success of this operation, it is necessary that the nature of the beds met with is such as affords foundation for the curbs, but although each wedging curb may not be water-tight during the time of sinking, yet when the pressure of the lower length of tubbing is brought up against it such leakage may be altogether or nearly stopped, and, although each foundation may be bad by itself, yet when they are brought to bear in support of each other, the water may be stopped back. In the Seaham winning* ten successive lengths of tubbing were thus put in, and, although the total quantity of water which the engineers had to contend with at different periods of the operation was 6240 gallons, yet never more than 540 gallons per minute was actually in the pit bottom, this being the maximum amount, the average quantity being 136 gallons. The total amount of water tubbed back was 4880 gallons per minute, which would have been the quantity required to have been raised or pumped to the surface if intermediate wedging curbs had not been inserted. After reaching an excellent foundation in the coal measures, three main wedging curbs were put in as the base of the iron tubbing, and the sinking through the coal measures commenced without a drop of water in the bottom.

Messrs. J. J. Atkinson and W. Coulson† were the first to point out the curious accidents which happen to tubbing fixed between an upper and lower wedging curb through the confinement of water and *air*. It has never been satisfactorily explained how air and gas confined behind tubbing can have a greater pressure than that due to the hydrostatic head, but it is a fact that such is so, and unless some escape is provided, no matter how thick the tubbing is, the inevitable result will be that it becomes cracked or displaced from its seating. To prevent such occurrences, either the water behind each lift is connected with the water behind the other lifts by means of small pipes, and thus, in effect, rendering the whole of the tubbing open-topped through the medium of the uppermost lift, or a pipe is carried up from behind the tubbing to the height necessary to balance the pressure of water. As this takes up a large quantity of pipes a short length is sometimes inserted through the tubbing near the top of the lift, and only extended a small distance up the shaft, but a loaded valve is provided at the top, where all the pressure of the water is. This valve discharges the air and prevents the pressure getting higher than is due to the water alone.

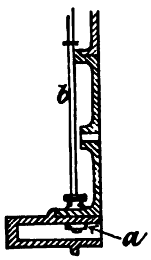


Fig. 129.

The more general practice is to place a valve (*a*, Fig. 129) in the wedging curb, and to carry a length of pipes, *b*, behind the tubbing to the next wedging curb. After the tubbing has been wedged and plugged the water rises and drives out all the air. When water has been running through the pipe for some hours the valve *a* is closed.

Strength of Tubbing.—The thickness of cast-iron tubbing varies directly with the pressure it has to support and the diameter of the shaft. As the pressure also varies as the depth, if the diameter and the depth are both doubled, the thickness of the tubbing will have to be increased four times. Mr. J. J. Atkinson ‡ gives a complete reasoning for the following formula, from which the thickness at any depth can be found :—

$$t = \frac{6d}{\frac{m}{p} - 1}$$

* *N.E.I.*, v., 117. † *Ibid.*, xi., 9. ‡ *Ibid.*, ix., 175.

where t equals thickness in inches, d equals the diameter in feet, p equals the pressure in tons per square inch due to depth, m equals the working load or resistance to crushing of the material employed. Remembering that a cubic foot of water weighs 62·5 lbs., 12 cubic inches will weigh 0·434 lb., so that for every foot of depth a pressure of 0·434 lb. per square inch is exerted. To obtain, therefore, the pressure per square inch due to any head of water, the depth from the surface in feet is multiplied by 0·434. The resistance of cast iron to crushing (average of various qualities) is about 90,000 lbs. per square inch, but to be on the safe side, one-sixth of this amount (15,000 lbs.) is taken as the working load, and should be substituted as the value of m in the formula given above. To the thickness so found, $\frac{1}{8}$ inch should be added to allow for corrosion of metal, and wear and tear.

In shafts of large diameters the thickness of the upper segments should never be less than $\frac{5}{8}$ inch, or they are liable to be fractured by blows. In the above formula notice is not taken of the strength imparted by flanges and ribs, which will give additional security. Theoretically, each segment should be different in thickness to the others, but as this would involve considerable expense in casting, the thickness is varied about every 8 or 10 yards.

Corrosion.—Certain substances contained in solution in water have a very injurious effect on iron, saline matters and chlorides being especially destructive. No satisfactory means have yet been devised for stopping such action, the best preventive, probably, being a coating of a hard varnish applied before the tubbing is seated. The front of the segments in upcast pits, where furnace ventilation is employed, is also attacked by the gases generated by the combustion of the coal. Sulphurous acid is produced, and mixing with water forms sulphuric acid, which rapidly eats away the iron to such an extent that in a few years its nature is completely destroyed, and it gets so soft that it can be cut with a knife. The best and generally used preservative is a lining of fire-brick, a seating for it being made by fixing one of the wedging curbs so that it projects from 3 to 6 inches into the shaft. The great objection to this procedure is that by covering up the face of the tubbing the detection of leaks is made difficult, but of the two evils the lesser is chosen.

Cost of Tubbing.—Mr. G. C. Greenwell* gives the following statement of the actual cost of putting in metal tubbing in a shaft 14 feet 9 inches diameter :—

Cost of wedging curb :—

	£	s.	d.
Dressing and preparing bed for curb, and laying same ready for wedging, ...	£34	9	0
Wedging (stone very hard), ...	10	4	11
Wedges (5435 used) and sheeting (material and manufacture),	5	3	2
Wedging curb (10 segments, each 7 cwts. 1 qr. 17 lbs. = 74 cwts. 2 lbs., at 6s. 9d. per cwt.), ...	24	19	7
	£74	16	8

* *Mine Engineering*, pp. 166-169.

Cost per yard of tubbing:—

10 segments to circle, each 18 inches high by $\frac{1}{8}$ inch thick, weighing 4 cwts. 1 qr. 12 lbs. = 85 cwts. 2 qrs. 24 lbs., at 6s. 9d. per cwt., ...	£28	16	6
Painting, tubbing, sheeting wedges * (4428 used), and backing with soil, marl, &c., ...	4	1	6
Putting in and wedging tubbing—			
Putting in, ...	0	10	9
Wedging (twice in going up and once in going down), .	1	1	9
	£34	10	6

Shireoaks shafts have more tubbing in them than any others in England—viz., 170 yards put in in eleven lengths, and weighing about 600 tons in each shaft. The internal diameter is 12 feet, and the pressure at the bottom is about 196 lbs. per square inch. Mr. John Jones, the present underviewer, who put in the tubbing, states that the cost per yard of the lower and stronger part, which has a thickness of 1$\frac{3}{8}$ inch in the body, was as follows:—

126 cwts. cast iron, at 7s., ...	£44	2	0
Fixing and wedging, ...	4	0	0
Wedging curbs and laying (each about 10 yards apart),	10	0	0
	£58	2	0

SINKING BY BORING.—Kind-Chaudron Method.—Looking at the ease with which bore-holes are put down through water-bearing rocks, the idea occurred to engineers that supposing the tools and implements employed were made large enough, it might be possible to bore shafts. Little difficulty was encountered with the actual boring operations, but for a long time it was found impossible to successfully dam back the feeders of water, as no means were at hand to put in a water-tight lining. Cylinders of tubbing were lowered into the pit, but it was found impossible to make a joint at the bottom impervious to water. After many failures the difficulty was surmounted by Mr. Chaudron, by the introduction at the base of the tubbing of what is known as the moss-box, and he, in conjunction with the celebrated bore-master Kind, devised a scheme by means of which numerous pits have been successfully sunk through beds containing a very large amount of water.

The boring tools are similar to those ordinarily employed, modified to suit the changed conditions. First of all, a smaller shaft, 4 to 5 feet diameter, is bored, which is kept 50 or 60 feet ahead, and then the main shaft is taken out to the size required. The cutter for the smaller shaft consists of an iron framework (Fig. 130) in the base of which are fixed, in sockets, a number of steel cutting teeth, *a*, which can be easily replaced if anything goes wrong. This tool is fitted with two guides, *b* and *c*, which are also furnished with cutting teeth. When the shaft has been bored sufficiently deep with this tool, a larger one (Fig. 131) is inserted, this differing from the first, not only in its size, but in the fact that the teeth in it are set on an inclined plane, and that the central part is furnished with a loop or guide, *a*, which fits into the smaller hole already bored. Owing to the shape of the teeth the strata is cut in the form of an inverted cone, and all the

* These wedges were 4½ inches long by 1½ inch on face by ½ inch thick.

débris produced falls down the inclined slope into the smaller shaft, in which, at the bottom, is placed an ordinary kibble, which collects the material and renders the use of a sludger unnecessary.

These tools are moved up and down by an oscillating lever at the surface, just the same as in an ordinary boring apparatus. A winding engine, drums, and ropes are provided for the rapid removal (during changing) and lowering of the tools. Sinking thus proceeds until the solid foundation is reached, where the seating for the base of tubbing is found.

While the shaft is still full of water a water-tight joint is made by the moss-box. This consists of two rings of tubbing (*a* and *b*, Fig. 132) which can slide over each other, and each of which has a bottom flange turned outwards and an upper flange turned inwards. These two are strung together by iron tie-rods, *c*, and the space between them completely filled with moss, so that when the upper

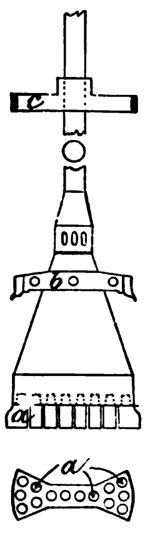


Fig. 130.

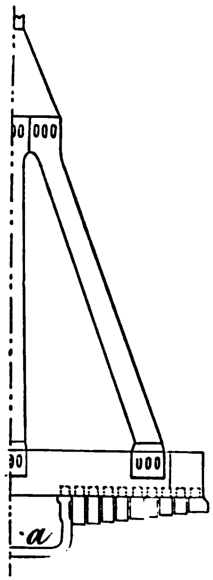


Fig. 131.

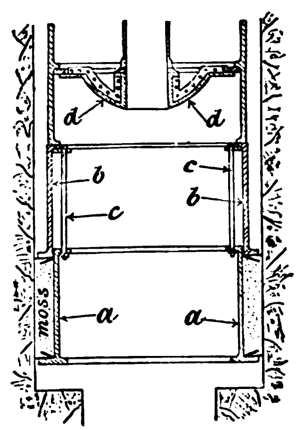


Fig. 132.

one slides down this moss is compressed. Other segments are connected above these two rings, all of which have the flanges pointing inwards. The tubbing consists of cylindrical rings, about 4 feet 6 inches high, cast in an entire piece. There are no vertical joints. A strengthening rib is cast inside each ring, and the top and bottom flanges are turned in a lathe, and bolt-holes bored in them. Before being used each ring is tested by hydraulic pressure in a specially constructed box with from two to five times the pressure it has to support. These rings are put together at the surface with $\frac{1}{8}$ of an inch of sheet lead between the joints, and the whole structure lowered bit by bit by screws and strong iron rods.

The chief point upon which successful lowering depends is the means adopted to balance the enormous weight of the long length of tubbing. Near the bottom a diaphragm (*d*, Fig. 132) is fastened to the flange of one of the segments, and in the centre of this is a tube. When lowering is being carried on the weight of the tubbing forces the water up the central aperture; the amount displaced by the diaphragm, and the resistance it meets with during its passage through the water, are so great that a large portion of the weight of the tubbing is supported; indeed, in some instances it is more than counterbalanced, and where such happens water is introduced at the top of the diaphragm, to be pumped out again, if necessary. This regulation is operated so successfully that in one case, where the entire weight of the tubbing was 800 tons, it was so counterbalanced that not more than 40 tons were ever on the lowering rods at one time.

Several modifications of the process have been designed. At No. 27 pit, Produits Colliery, Belgium, the moss-box was dispensed with, and an india-rubber ring about 2 inches thick, having forty-eight oblique teeth 2 inches deep, was attached to the bottom flange of the lowest ring of tubbing. Before the tubbing was lowered on to the bed cut to receive it, the whole was rotated about its axis in order to sweep every particle of débris from the ledge. The counterbalancing column of water inside the tubbing was also done away with. The hole in the false bottom was covered over with a blank flange, and water added little by little on the upper side, until, finally, the whole of the inside was filled in order to press the tubbing firmly down on to the rock ledge, the compression of the rubber ring forming the water-tight joint. Concrete was then run into the space between the outside of the tubbing and the sides of the excavation, and when this had set the water was drawn out from the inside of the tubbing. The base was wedged up afterwards in the ordinary way.

Lippmann's Method.—To the foregoing method several objections may be taken. It has been found that nearly as much time is taken to enlarge the small shaft as to bore it, and attempts were therefore made to carry out the whole operation at the same time. With a straight chisel turned round a centre blows are struck more closely near the centre of the shaft than at the circumference, and considerable labour is wasted. Messrs. Lippmann have got over this difficulty by making a drilling tool in the shape of a double Y (Fig. 133), in which two teeth are placed in that portion cutting round the circumference of the shaft, and only one towards the middle; more blows are thus given at the periphery than at the centre. Another improvement is that the engine is not connected directly to the boring lever, but motion is communicated by means of an endless chain and eccentric, which prevents all shock. The débris is extracted by an iron box divided into three compartments, each of which has nine holes, closed by valves opening outwards. This box is lowered to the pit bottom, and alternately raised and dropped for about fifteen minutes, being at the time gradually turned round. The sludger has usually to be filled twice before recommencing to bore. For securing the sides similar tubbing to that of the Kind-Chaudron method is adopted.

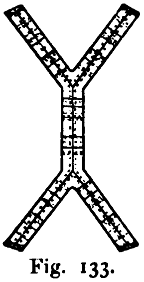


Fig. 133.

Pattberg Method.—An important advance in such methods of sinking consists in providing the tubbing with a cutting edge and forcing it down by means of accumulator hydraulic presses erected at the surface. Such procedure is now common to several methods which differ in the way in which the shaft is bored and in the means employed for removing the débris. Unfortunately, further complications have resulted from the irregular strains thrown on the tubbing by the hydraulic presses and from the falls of loose ground. In the Pattberg process the lining drum is strengthened by the insertion of broad rigid annular ribs between the ordinary tubbing rings at intervals varying from 10 feet in the lower part of the shaft to 18 feet in the upper portion. These rings are laid against the ordinary tubbing flanges, and are tied together by tension rods, the intermediate spaces being filled with good masonry or concrete.

The actual boring is done by a V-shaped percussion drill, taking out the shaft full size, the detritus being continuously removed by a high-pressure water-flush and a compressed air-pump. The tool is light, and works with a short, rapid stroke. It is suspended from a hollow boring-rod, which is used for the introduction of water under pressure to flush out the sludge, the mixture being pumped up from the lowest point of the conical bottom of the shaft by two compressed air pumps fixed at the side of the rods.

Sack Borer.—In the improved process of Sassenberg and Clermont percussive boring of the full shaft section at one operation is employed, and the comminuted rock is cleared out by sacks which are attached to the boring frame and sweep round the bottom of the excavation. These travel to the surface on guide frames attached to the main rod, and when filled can be hoisted to the surface by a winch without interrupting the regular work. A shaft 23 feet internal diameter has been sunk with this apparatus, and the sacks, each containing 1 to 1½ cubic yards of débris were drawn up about every half-hour, which corresponds to a removal of about 50 cubic yards, and a progress of 1 yard per diem.

SINKING THROUGH QUICKSANDS.—Triger's Method.—In this system, sheet-iron cylinders, divided into three air-tight compartments, are sunk into the ground, and compressed air forced into the lower one. The workmen are thus placed in a sort of diving-bell, and if the pressure of air is greater than that of the water in the sand, the latter is forced back, and prevented from entering the lower compartment. The rubbish excavated is removed in a small kibble. Trap-doors allow communication from one chamber to the other, the joints of these being made carefully air-tight. The doors of the second and third chambers are never allowed to be opened at the same time, so that little loss of compressed air takes place. Sinking proceeds until solid ground is reached. The depth which can be attained by this method is limited, for as the pressure of water outside the cylinder increases with the depth, a higher pressure of air has to be used in the lower compartment to stop the influx of water, and a point is soon reached above which the men cannot work. At Aix-la-Chapelle, 121 feet of quicksand was passed through by this method, the greatest pressure of the air employed being 2·8 atmospheres.

With the Aid of Divers.—In the sinking of a shaft at the

Bjuf Coal Mines, Sweden,* by means of an annular casing having a cutting shoe of steel at its lower end, and the annular space filled in with concrete to increase the weight of the cylinder, considerable difficulty was found in keeping the shoe and its following sections vertical, owing to the presence in the sand of many large boulders, often weighing from 1 to 2 tons. After trying many methods, the use of divers was proposed, and four expert men were obtained from Stockholm. A platform large enough to carry the air pumps and the men was suspended in the shaft immediately above water level, but was hung from the surface in such a way that it did not follow the descent of the caisson. Operations were commenced when the shaft was 95 feet deep with 16 feet of water in it. The smaller boulders were carried through to the surface by grappling irons fixed on them by the divers, but the larger ones had to have a hole drilled in them, in which could be inserted an iron pin and key, called by masons a "lewis."

The divers were employed nearly six months, and carried on their difficult work with considerable accuracy. In the earlier stages of the work they remained under water about two hours at a time, and then came up to the platform for an interval of from fifteen to twenty minutes rest. Later, when the work became more difficult, and the shaft contained a maximum depth of 69 feet of water, the divers could not work longer than an hour, sometimes only half an hour, at a time, with intervals of repose varying from ten to thirty minutes.

Poetsch's Method.—An improvement for sinking through water-bearing strata was introduced by Mr. Poetsch in 1883. It consists in freezing the running ground, and transforming it into a solid mass of ice, through which sinking proceeds by ordinary methods, just as if the ground was of a tenacious and solid character. A well-known principle is that, when any liquid is rapidly converted into vapour, it absorbs a considerable quantity of heat, and that the absorption is more rapid the more volatile the liquid. In the machine employed for producing the freezing mixture, liquid ammonia is placed in connection with the receiver of an air-pump, and rapid exhaustion set up. The ammonia at once commences to boil, and the vapour produced is absorbed by suitable means, with the result that a still more rapid evaporation is produced, which communicates intense cold to the mixture employed for the freezing operation. The liquid used for this purpose is a solution of chloride of calcium, adopted because it does not freeze until the temperature reaches $-34°$ C.

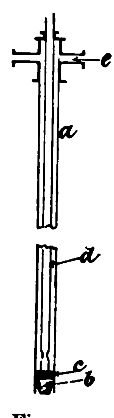


Fig. 134.

The actual procedure is as follows:—A series of bore-holes are sunk through the water-bearing strata until the solid measures are reached, and are lined with tubes (*a*, Fig. 134) as they go down. After penetrating through the quicksand, the lower ends of these tubes are made water-tight by means of lead stoppers, *b*, and several layers of cement, *c*, are poured into the interior. The greatest care is exercised in getting the joints of the outside pipe water-tight, as if they are not, the solution of chloride of calcium escapes into the ground, and

* *Rev. Univ.* (3ᵉ Série), xxv., 1.

renders freezing very difficult. Into the centre of each of these larger pipes a smaller one, *d*, of about one-third the diameter is introduced, having its lower end open. These latter pipes are provided with stop-cocks, and joined to a central distributing pipe, suspended above the top of the shaft. The freezing mixture, prepared as above, is then forced by a pump down the small tube, and on reaching the bottom circulates in the annular space between the two pipes, rises to the surface of the ground, and is collected in another series of pipes, *e*, from whence it is again returned to the freezing machine, and used over again. By this means the ground between each pipe within the shaft itself, and also the ground outside the limit of the shaft, is frozen hard enough to give solidity. The most intense cold is at the bottom of the pipes, and as a result small cones of frozen ground, with their bases downwards, are first formed, the dimensions of which increase progressively.

The method of sinking after the ground is frozen, is to excavate a space with the aid of picks and wedges, blasting being expressly forbidden, and then to secure the sides by means of ordinary curbs, and laggings. Second and further lengths will be sunk, and timbered, in a similar manner, until the quicksand is passed through and solid ground reached, when a wedging curb will be put in, and cast-iron tubbing brought upwards.

At Emilia Pit, Germany,* the apparatus was charged with 950 quarts of solution of ammonia, the daily consumption of which was about 53 quarts. Freezing occupied 3 days, when sinking was commenced and done without any difficulty, at the rate of about 2 feet per day. Sinkers were paid 55s. per running yard. The circulating tubes were removed very easily, the solution of chloride of calcium being passed through them *heated*, instead of cooled. Total cost of plant was £3000; expense of erection, £960. Total cost for shaft, completed and walled, allowing 25 per cent. of first cost of plant, for depreciation and expenses of erection and removal, was about £26 per running foot.

When the water-bearing ground or quicksand lies at a considerable depth below the surface, the strata both above and below offer considerable resistance to the expansion of the ground while freezing is going on, and there is great risk of the circulating pipes being flattened. Mr. Saclier † therefore suggests that the refrigerating pipes should be spread over a circle 3 feet larger in radius than that within which sinking is to be effected, and that the ground at the centre should *not* be frozen. He advises the putting down of a bore-hole in the centre of the projected shaft to allow of the escape of the water forced out of the strata by the abnormal pressure developed by the freezing of the mass. Means must also be adopted to prevent the freezing of the ground near the central bore-hole, by carrying down within it, a pipe through which hot air or water may be circulated. This circulation need not be commenced, until the issue of water from the bore-hole proves, from the extra pressure generated, that the freezing of the quicksand has become a certainty.

Gobert's Method.—As the freezing solution of the Poetsch process has to be forced down into the pipes from the compression

* *For. Abs. N.E.I.*, xxxiv., 72.
† *Soc. Ind. Min.* (3e Série), xi., 647.

apparatus situated at a higher level, the pressure inside these tubes must be greater than outside, and this pressure becomes higher the greater the depth. If under such conditions, either a pipe should crack or a joint leak, a by no means improbable accident owing to the contraction caused in the tubes by the intense cold, the freezing solution will pass into the surrounding strata, and communicate to it its uncongealable properties.

In order to avoid the serious consequences of a mishap of this kind, Mr. A. Gobert, who had charge of the first and many subsequent sinkings by the Poetsch process in France, dispenses with the freezing solution entirely, and obtains the necessary cold by allowing anhydrous liquid ammonia to vaporise in the tubes. A number of pipes are sunk through the water-bearing strata, outside the circumference of the ground to be excavated, and are closed at their lower end; inside each one is introduced a serpentine or helicoidal tube reaching nearly to the bottom, into which liquid ammonia is allowed to trickle, and to escape into the larger outer tube through a number of small orifices placed at intervals along its length.

The design of this serpentine injector is important, because it is necessary for rapid cooling that vaporisation should take place quickly, and that liquid ammonia should not be allowed to drop to, and accumulate at, the bottom of the tube. The ammonia gas escapes through a branch near the top of the outer pipe, is drawn back to the freezing machine, compressed into a liquid, and again forced into the small central pipe. As the necessary heat for vaporising the liquid ammonia is abstracted from the surrounding strata, the ground soon freezes, and as the pressure inside the pipe is lower than outside if there should be a leaky joint or fracture in the tube, the water from the surrounding strata will find its way into the pipe, become frozen and effectually prevent further leakage.

In dispensing with the freezing solution of the Poetsch process, Mr. Gobert claims greater economy in the cost of sinking, the avoidance of a possible cause of failure due to leakage of solution, of being able to freeze any desired portion of the strata without freezing the whole, and of being able to commence sinking at the surface before all the ground is frozen. The freezing action commences at the surface, and as each successive part of the injector tube becomes coated with ice, the liquid ammonia will pass further down and escape by lower orifices into the outer tube, until finally it reaches the bottom, when freezing will be complete.

Deepening Pits already Sunk.—The common way of doing this, without stopping the pits drawing coal, is with the aid of a tail-rope fastened below the cages. If any depth is to be carried out, the rope employed will be made in two lengths with a view of saving time. The preparation is rather a simple one. First of all, means are provided at the inset level, for receiving the débris out of the sinking kibbles. Then an ordinary rope is provided with a capping at each end, and the upper one passed through the bottom of the cage, and made fast by driving an iron pin through the eye of the capping, and usually further secured by glands to the bottom of the cage. The kibble is attached to the other end of the tail-rope, and when the cage is raised by the winding engine at the surface, the kibble is lifted also. The method of procedure is to fill a kibble at the bottom where sinking is going on, lift it to the inset, empty the contents into tubs standing there, and then lower down again. Sufficient tubs are provided to contain all the dirt produced in the night-time, and the tail-rope is then taken off the cage (an operation done in five minutes), the cage lowered to the inset level, and the débris wound to the surface.

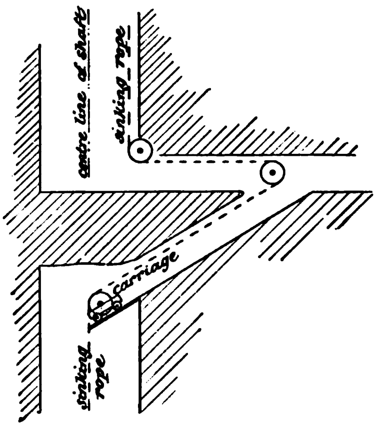


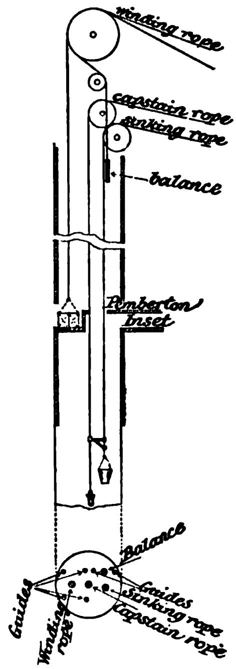
Fig. 135.

The above system can only be applied when the pit is not winding coal. In many cases this difficulty is surmounted by commencing at the inset level, a short distance away from the shaft, and sinking an inclined pit until its axis meets that of the drawing shaft, when it is continued vertically downwards. At Haine St. Pierre Colliery, Belgium,* with such procedure, the shaft was deepened from 984 to 1246 feet without stopping winding. The débris was drawn by an engine at the surface, a rope from this passing down the side of the winding pit, and then deflected by pulleys along the line of the incline, finally passing into the vertical position required for sinking, by being conducted over a pulley supported on a carriage, the rope passing through a hole in this (Fig. 135). When the kibble is at the bottom of the sinking, the carriage is at its lowest point, and the rope hangs vertically in the pit, but as the kibble is lifted the carriage is pushed up the incline, the kibble hanging in a vertical direction until the inset level is reached, when it is removed, and an empty one put on. On the return journey the carriage follows the kibble as it is lowered, until it comes to the end of the guide. The rope then descends vertically downwards. A spring is placed just above the capping on the rope to prevent any shock when the kibble strikes the carriage.

In another case the winding shaft was not interfered with. A certain thickness of ground was left provisionally between the bottom of the winding shaft and its continuation, and a drift driven at this level from the upcast pit. A small cage carrying a single tub was worked in the upcast pit, and after a certain number of tubs had been lowered to the communication drift and placed on a siding there the rope was disconnected from the cage, carried along the top of the level on rollers, and attached to a similar small cage working in guides fitted on one side of the shaft being sunk. The spare tubs were then successively lowered to the bottom of the sinking, loaded with débris, and raised again to the drift. After all had been filled, the rope was disconnected from the cage in the sinking pit, re-attached to the one in the upcast shaft, and the tubs raised to the surface. By using cages and tubs, and dispensing with kibbles, the work was hastened,

* *For. Abs. N.E.I.*, xxxvii., 58.

as the débris was wound to the surface direct without the delay of tippling and re-loading.



Figs. 136 and 137.

At Alexandra Pit, Wigan, a shaft of 19 feet diameter was deepened from 260 to 772 yards in two years by the following method, coal being wound all the time. One cage was taken out, and a balance weight, equal to a cage and four empty tubs, put in its place, this working down the side of the pit on two guides, the winding rope being diverted from its ordinary position by means of a pulley on the head-gear (Figs. 136 and 137). Three scaffolds were put in at the Pemberton 4 feet inset, to prevent anything falling on the sinkers, and a hole left through for the passage of the kibble. A platform on wheels was provided on a level 6 feet higher than that employed for caging the coal, which could be run over the hole left in the scaffolding. A small winding engine at the surface drew the sinking débris from the bottom of the shaft up to the level of this platform, which was pushed over the shaft, the kibble removed, and the dirt tipped into ordinary tubs standing at the level of the inset. These were then placed on the cage and drawn to the surface. A capstan rope, worked by a special engine at the surface, passed down the *centre* of the shaft and formed a guide for the sinking kibble, during such times as bricking was not being proceeded with. When this rope was not in use it was kept in position at the bottom of the pit by a heavy circular elongated block of iron. Fig. 138 gives an enlarged view of the guide employed; *a* is the capping of the winding rope, to which is attached the detaching hook *b*. Below this comes the guide *c* and weight *d*, the latter being of cast iron with a hole bored out to receive the vertical bar *e*, which fits into *d* loosely, so as to be readily withdrawn for examination. Above the weight a horizontal bar, *c*, projects, clasping the bar *e* above the weight, and projecting to the capstan rope on which it runs freely with plenty of "play." Below the weight comes the kibble and bridle chains. The capstan rope *g* is placed absolutely central in the pit. When about to fire shots the men were signalled away first, and directly they had gone the capstan rope and weight attached was raised a few yards so as to be out of the way of the débris.

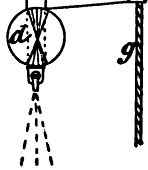


Fig. 138.

The bricking scaffold was made of timber, and suspended from bridle chains, and consisted of 3 parts, a centre one and two side pieces working on hinges. During bricking operations the winding rope was drawn up clear, the weight on the capstan rope taken off, and the latter connected to the bridle chains of the scaffold, which, when not in use, was suspended in the shaft from cross baulks placed there on purpose.

For short distances shafts are sometimes sunk upwards. A dividing brattice is usually placed across the shaft, and the débris allowed to accumulate over one-half of its area, this forming a sort of natural platform on which the men stand to work. For the purpose of ventilation wooden boxes or troughs are built in the débris.

Widening Shafts.—This is a very awkward and costly operation if winding is to be carried on at the same time. In such cases it is usual to place a series of byatts or buntons below each other in such a position that the cage misses them. At night-time these buntons are covered over with planks, and scaffolds formed, on which the men work, and take out the ground.

For widening air shafts an openwork platform like a gridiron is employed, which may be raised and lowered by ropes attached to a winch at the surface, and on it the men stand to perform the work. The holes through the platform are too small to allow the larger pieces of débris to fall through, and these are loaded into a kibble and raised directly to the surface. The small particles which fall through the platform, on reaching the bottom of the shaft, may be guided by deflecting boards into a storage hopper, and can be loaded at any convenient time into ordinary tubs and lifted to the surface. The brickwork is best put in from a Galloway or similar scaffold.

If the shaft is not required for winding purposes the best procedure is to fill it up to the surface with some loose non-coherent material, which is removed again as the old lining and sides are taken out to the required size. This saves all the labour and time of changing scaffolds. In a deep shaft portions only of its length would be filled up at a time.

Cost of Sinking.—The cost depends on the hardness and inclination of the strata, and especially on the quantity of water. If the beds are highly inclined the cost is greater, as the rocks do not blow well. The general rule is to obtain tenders for sinking and walling the whole depth, and to deal with a certain quantity of water. If this quantity is exceeded, either allowances are given or the contract broken. Such contracts act very well, if the nature of the ground is well known, and no difficulties are encountered, but master-sinkers, as a rule, are persons of small capital. So long, therefore, as they are making money everything proceeds smoothly, the manager is relieved of anxiety, his only care being to see that the work is carried out properly and with safety. But if the work is proceeding at a loss the contractor's means are soon exhausted; although sureties are generally bound by agreement, yet concessions have to be made. In view of this, the system of carrying on by men at day wages is gaining favour, superintendence being given by competent chargemen, who, in addition to a stipulated wage, receive a bonus for every yard done during the week in excess of a stated distance.

At Ramrod Hall Pit, Staffordshire, through the different varieties of the rocks of the coal measures, the cost of sinking in 1889 was 11·12 shillings per cubic yard, which sum included the labour of putting in the walling 9 inches thick and backing the same with soil, all wages above and below ground (except winding engineman and stoker), blacksmithing, powder, &c.; value of materials used for lining not included. Colliers' wages at this date were 10 per cent. above minimum of sliding scale. The amount of water was small, and could be dealt with by baling. An allowance of 25s. was made for each water ring put in.

At Sandwell Park Colliery, the contract price for sinking and walling the No. 3 shaft, 15 feet diameter in the clear, was £8 12s. 6d. per running yard, equal to 6·82 shillings per cubic yard of excavation. The above price rose at the same percentage as collier's wages, which at that time were 3s. 4d. per day, the minimum of the sliding scale. The contractors found all labour in pit, banksmen, tools, blasting agents, lights, &c., fixed all scaffolds, ventilating pipes, &c., and deposited the spoil at such places as required, up to 40 yards from pit top. The company found engine power, enginemen, sinking kibbles, lining material, and sharpened all tools. No allowance was to be made for water until the quantity exceeded such as could be raised by tipping barrels. The total sum paid under this head for the entire sinking amounted to £6 16s. 9d. For each water ring put in £2 was paid, and for each square curb £3 15s. The average rate of sinking and walling (working continually from Monday morning to Saturday night) was 8·04 yards per week.

Messrs. Forster-Brown & Adams give detailed statements of the cost of sinking and walling two shafts, each 17 feet diameter, at Harris Navigation Colliery,* including all labour, coal at boilers, smith work, explosives, stores, &c. From their paper the following figures are extracted :—

Average cost per yard for sinking 50 yards in *shale* near bottom of shaft.

	Without Pumps.	With Pumps.
Labour, ...	£9 8 2	£10 2 4
Materials (stores, explosives, &c.), .	2 11 4·8	3 0 4·9
	£11 19 6·8	£13 2 8·9

Average cost per yard of sinking 50 yards in hard Pennant grit rock, with pumps.

	By Hand.	Using Three Machine Drills.
Labour, ...	£32 17 1	£22 19 8
Materials (stores, explosives, &c.), .	11 16 1·9	11 3 4
	£44 13 2·9	£34 3 0

Average cost per yard, in depth of 50 yards, of 18-inch walling with two iron curbs in such distance.

Labour (sinkers, masons, smiths, enginemen, &c.), .	£4 7 11·4
Stores (candles, oil and grease, sinkers' suits, &c.), .	0 17 10·7
Material (bricks, lime, and coal), ...	6 2 0
	£11 7 10·1

Equal to £1 3s. 10d. per cubic yard of masonry.

* *Inst. C.E.*, lxiv., 23.

Where 82½ per cent. of the strata passed through was hard rock, and 17½ per cent. shale, the average depth sunk and walled per week, exclusive of stoppages, was, in a length of 69 yards, 2·19 yards; while where 38¾ per cent. was hard rock, and 61¼ shale the speed averaged 4·08 yards per week over a length of 421 yards. Towards the bottom the ground only contained 6 per cent. of hard rock, and the speed of sinking and walling reached 6·77 yards per week.

The following table shows the comparative cost of various modes of sinking through water-bearing strata:—*

System.	Colliery.	Cost per foot of Sinking.		Total Depth of Sinking.	Strata passed through.	Time in Months.
		£	s.	Ft.		
Triger, . .	La Louvièrie, .	98	3	42	Quicksand, ...	2
" . .	Havré, . .	888	19	124	Running sand and water-bearing chalk, .	48
Chaudron,	L'Escarpelle, .	20	17	331	Sand and chalk, . .	11
" .	Saint-Waast, .	37	8	321	Chalk, marl, and sand, .	29
" .	Saint-Barbe, .	33	3	180	Clays, marls, and sand, .	18
" .	Saint-Marie, .	12	9	344	" " " .	13
" .	Rothhausen, .	38	11	338	White marls, . . .	25
Poetsch, .	Archibald, .	17	16	131	Quicksand, ...	...
" . .	Emilia, . .	25	16	140	Sands, &c., . . .	8
" .	Koenigs Wasterhausen	30	0	98	Sands with large boulders,	6

Detailed statements of the cost of sinking several shafts by the Kind-Chaudron process will be found in the *Colliery Guardian* of January 23, 1880, p. 129.

In sinking two shafts at Vicq † for the Anzin Company by the Poetsch process, each 385·88 feet deep, and respectively 12 feet and 16·4 feet diameter, costs were carefully taken from the beginning to the time when ordinary sinking commenced. The total cost of the sinking was as follows:—

	Per cent.	Total.	Per foot.
Patentee's royalty, ...	4·6	£1,310·40	£1·697
Temporary plant and buildings, .	2·7	783·30	1·015
Borings for freezing tubes, . .	10·4	2,946·95	3·818
Freezing plant, ...	35·0	9,930·65	12·893
Measuring apparatus, ...	0·3	76·00	0·098
Cost of freezing, ...	4·7	1,321·25	1·712
Sinking and tubbing, ...	40·5	11,498·20	14·898
Carriage on material, ...	0·6	182·50	0·237
Tools, ...	0·7	210·30	0·273
Sundries, ...	0·4	114·60	0·148
	99·9	£28,394·15	£36·789

* *For. Abs. N.E.I.*, xxxv., 33. † *Soc. Ind. Min.*, 3ᵉ Série, ix., 140.

The Thiers pit, sunk in the ordinary way through similar ground, cost £75 per foot. As the entire cost of the plant was charged to this single sinking, its employment in subsequent work will relieve the cost to the extent of nearly £13 per foot. The items directly chargeable to the freezing plant were as follows:—

Patent rights,	£1310·40
Boring,	2946·95
Erecting,	563·39
Measuring instruments,	76·00
Freezing cost,	1321·25
	£6217·99

This sum, equal to £8·06 per foot, represents the money available for pumping, temporary lining, and the other numerous expenses incidental to sinking through heavily watered strata. The total expenses of sinking may be summarised as follows:—

		Cost per foot.
Material,	£9,387·27	£12·162
Freezing,	6,217·99	8·057
Sinking,	12,788·88	16·570

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CHAPTER V.

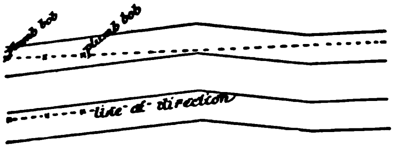
PRELIMINARY OPERATIONS.

Underground Roads.—Having reached the seam from which mineral is to be extracted, the first operation consists in driving a series of passages called levels or roads. Their direction is governed by the relative position of the shafts and the area to be won, by the system of working adopted, and by the inclination of the seam. Their size is governed by the dimensions of the tubs employed and by the proposed system of haulage, as, if a double line of rails has to be used the dimensions of the roads will necessarily be larger than where only a single line is in operation. The direction is also influenced by the question of haulage, for if mechanical means are not employed, the gradients of the roads will have to be such that a horse can readily draw material along them, and as the dip of the mine and the position of the shafts are fixed points, the roads in this case will have to be driven in such direction that the necessary gradient is given.

Another point is the question of dealing with water. Wherever possible, the gradients should be such that all water gravitates towards the shaft. Perhaps, in all seams of moderate and regular inclinations, the best plan is to drive the main road practically along the strike of the seam, only deviating from that line to such an extent as will give a slight fall towards the shaft. Where seams have undulating gradients, roads carried along the strike necessarily vary in direction with each change in the dip. For any system of mechanical haulage, the best results are obtained where the roads are driven straight, so that when the dip varies we usually find that the straightness of roads is more looked to than any actual question as to whether they are following the strike of the seam or not, as it only requires a little more engine power to haul along the material.

Means of Keeping Direction.—Having decided upon the position of the roads, they are kept in the proper direction by very simple means. At the commencement two or three points are determined, and marked on the roof, with the aid of a compass or theodolite, and plumb-bobs are suspended from them in such a position that the straight line made by these three shall be in the direction in which the level is to be driven. Three points are much to be preferred to two, as in case any movement takes place in any of them, it is usually found out, such not being the case where only two are adopted; as an additional precaution, it is better that these lines should not be attached to timber frames or settings, or the pressure of the ground is liable to move them out of position. To determine whether the road is proceeding in the proper direction, an observer stations himself behind the plumb-bob farthest from the face, and lights are held against the other two lines. Another workman is stationed at the face with a light, which is moved about until its position coincides with the line given by the three fixed suspended plumb-bobs.

In some instances the points are fixed in the axis or centre line of the excavation, while in others they are placed nearer to one side of the road, of course preserving the same line of direction. In the latter case, the point obtained on the working face will not be the middle of the road, but somewhere about a foot from the side. This latter arrangement is preferable, because if the road does get slightly out of line when the determining points are fixed in the middle, the straight line given by these points will pass down the road (Fig. 139), but if such points are only 1 foot from the side it would be impossible to get the line through (Fig. 140).



Figs. 139 and 140.

Means of Keeping Gradient.—For haulage planes uniform gradients are preferable, as the cost of cutting through small irregularities of the floor or roof, and indeed, dislocations caused by faults, is soon repaid by the ease and smoothness with which the plane is afterwards worked. In the case of large faults, modifications of the gradients have to be introduced, but even in such cases it is usual to make the inclination approach as near to the regular one as possible. The instruments employed for keeping the gradient uniform are also of a simple character. Often an ordinary T-bob (a wooden frame shaped like an inverted T) and plumb-line are used, the vertical piece being placed on such an inclination that it corresponds with that to be given to the floor. This is rather a clumsy instrument. A more convenient form is that of a straight edge (*a*, Fig. 141) about 6 feet long, in the upper side of which a level, *b*, is bedded in a small secondary triangular block of wood, *c*, the angle that this latter piece makes with the former being such that, when the bottom side of the straight edge is parallel with the line of inclination of the road, the level is truly horizontal.

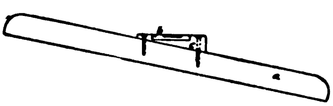


Fig. 141.

Operation of Driving.—Having determined the direction and gradient, the work is, as a rule, carried out in the following manner:—The first operation consists in holing or undercutting the seam; that is to say, either the lower part of the coal is cut away with a pick, or, if a soft layer exists beneath the seam, undercutting is performed in it with the object of reducing waste, because holing the coal makes nothing but "small," which is comparatively worthless. The width of the undercutting is equal to the width of the road, but its depth depends entirely on the nature of the seam. Strong coals require deeper holing than tender ones. In performing undercutting, the miner lies on his side, and naturally removes more height at the face than at the back, because at the former place his arms and the helve of the pick have to be inserted, while at the immediate back only a space equal to the width of the tool is necessary. If the undercutting is deep, part of the man's body is also introduced, and consequently more of the coal has to be cut away. For this reason, except where the nature of the coal absolutely requires it, holing should not proceed any further under than a man can conveniently reach without inserting his body. The coal undergone is got down by cutting a vertical groove along one side, and then breaking down the remainder either by blasting or by wedging.

In some collieries gas exists in the coal under such pressures that it assists the workman in hewing the coal, and roads can best be driven by attacking the whole height of the seam at one time. If holing were resorted to, it would drain the gas, and render the operation of getting down the coal above, a more difficult and expensive one.

Ventilation.—Except under exceptional circumstances, one road is never driven alone, two parallel ones (*a* and *b*, Fig. 142) being carried forward at the same time, these being connected at intervals by other roads, called "thurlings," or cross-cuts (c c'), the object of which is to provide a way for air to pass to the face and ventilate it. When the second thurling is driven, the first one is blocked up by building a wall in it. Such obstruction is called a "stopping," its object being to force the air further inbye, and prevent it going back to the shaft until it has ventilated the workings. It is obvious, however, that the current of air will naturally pass through the last thurling, and when the road goes on further, the face will remain unventilated, unless some means are adopted for carrying air to it. This is done by one of two methods; either by carrying bratticing or by iron, canvas or wooden pipes called air troughs or "trows."

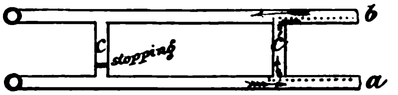


Fig. 142.

Bratticing is generally fixed by putting props along the line of roading, but instead of using ordinary short lids to such props, a long strip of wood about 3 inches broad is employed, and firmly secured against the roof by driving the prop beneath it. The brattice cloth is attached to these laths by nails, and temporarily divides the roadway into two, as shown by dotted lines in Fig. 142. The pure air passes up one side and down the other, as indicated by the arrows.

This system is largely employed, and is unsurpassed where the roof is regular, as the laths rest evenly against it, and form an air-tight joint. With irregular roofs bratticing is impracticable, and air troughs have to be used. These consist of sheet-iron pipes, from 10 to 15 inches diameter and 6 feet long, with a socket and spigot end. A temporary stopping is built across the road, immediately before the last thurling, and one of these pipes put through it. As the heading proceeds, other pipes are added. The air passes through them, and back again along the road. In seams with a tender roof, or in deep mines subject to heavy weights, it is advisable that as few cross-cuts as possible should be made between the winning headways. As the ordinary ventilating pressure is insufficient to force an adequate amount of air through long lengths of pipes, small subsidiary fans driven by electric motors are often employed The air current must then be conveyed to the working places through pipes, because brattice cloth is not rigid enough to resist the increased pressure.

Supporting Roof.—In every mine the roof has to be supported, this usually being done by timber, owing to the facility with which it can be introduced into the workings, and replaced from time to time when necessary. The roof is tested by knocking on it with a pick, or other instrument, when, if insecure, a hollow sound is given out. It is not always possible to be sure by this test, as the occurrence of a number of small faults, or slips, makes the roof disjointed, and less tenacious than if none were present. Slips are unaccompanied by dislocation, and are very difficult to detect, even by careful observation. Where a seam is known to contain them, minute examination must be resorted to, as a place might look safe on inspection, and immediately afterwards come in.

It does not appear that the depth of the mine has any effect on the strength of the roof. The order of working successive seams has an influence on the roof of the contiguous beds, owing to the release of gas; but from observations made by Mr. A. R. Sawyer* in North Staffordshire, no definite results can be fore-shadowed.

Two systems are in use for the operation of setting timber; in one it is performed by the workmen themselves, while in the other a special set of men are employed for the purpose. Both systems have advantages. In the former, the miner immediately detects any change in the ground, and can at once set the required support, without running any risk while waiting for a deputy to come; in the latter, deputies are continually going round (oftener than in the other system), and as they have been brought up to this kind of work are very skilful. In Yorkshire certain special men go round to set timber, and prepare the working places for the men, leaving a sufficient quantity of timber cut into proper lengths, the workmen having instructions, in case the roof becomes dangerous, to set any extra timber necessary, or to leave the place and send for the deputy. In Lancashire most of the colliers set their own timber in the face (not in the roads), and the props are drawn by officials. The colliers are subjected to the orders of the officials, who, if sufficient timber is not set, order more to be put up.

The general experience seems to be that if a workman has to look after his own safety, and set his timber, he generally does it better than if it was entrusted to a deputy; while, on the other hand, an opinion is held that the miner, not being paid for setting timber, is apt to be negligent, to consider it time lost, and only put up props where absolutely necessary.

Timbering.—Of all the varieties of wood, fir and pine furnish the greatest proportion of that used in mining; larch may be considered the miner's timber *par excellence*. It can be obtained in good straight lengths, makes little waste in cutting, resists great pressure, and bends to a considerable amount before breaking, and its life is a long one, whether the place be wet or dry. For props, Norway fir is largely employed, and for such purposes is perhaps as good as larch, as it resists great pressure if such is applied along its length in the direction of the fibres, and is very straight, easily cut and fashioned; but t breaks rather easily when the pressure is applied transversely; and is therefore not trustworthy for bars. Oak for positions of reliability

* *Accidents in Mines* (*Falls of Roof and Sides*), p. 34.

SETTING TIMBER PROPS

H.W.Hughes. Photo.

BUILDING A COG

is universally employed, but is not used so much in roadways and workings on account of its cost, and the fact that, excepting in large pieces, it grows very crooked, and is not easily shaped.

The simplest form of support employed is that known as the prop, or tree, which consists of a piece of timber fixed in a vertical position between the roof and the floor (*b*, Fig. 143). These are employed

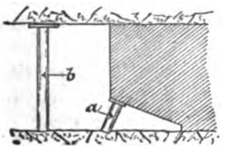


Fig. 143.

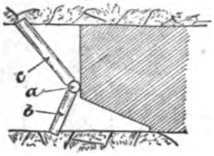


Fig. 144.

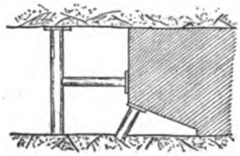


Fig. 145.

mainly in the working places, and almost invariably at the top of them is placed a small headpiece for spreading the surface over which resistance takes place. This is called a "lid," and is generally a piece of wood 12 to 18 inches long and 3 to 4 inches thick, often made by splitting a piece of round timber through the middle. In the working place two or three rows of these props are employed, those of two consecutive rows alternating with each other.

In inclined seams props must not be set vertically, but at an angle a few degrees less than at right angles to the dip of the mine, because the tendency of the roof is to slip downhill. Consequently, if the props were set at right angles any movement of the roof would cause them to reel over and take positions where they would be least effective in supporting the weight. On the other hand, when they are fixed with what is called a small amount of "sprag," the slipping of the roof tends to drive them into a line at right angles to the dip, and as this distance is shorter than the one they previously occupied, the props are tightened and offer more support to the roof. The method of setting props is illustrated in Plate II. They are cut a little longer than the distance between the floor and the roof, and are driven into position with a sledge hammer, while the lid is pushed lightly in the opposite direction, to prevent it travelling with the prop. In seams with a heavy roof and a hard floor, breakages are reduced by setting the props on a small heap of loose material, while to facilitate subsequent withdrawal the bases of the props are often slightly champfered off, which localises the spreading or fuzzing out of the timber.

Mr. W. H. Hepplewhite suggests tapering or thinning one or both ends of the props, so that the ends will yield instead of the props breaking.* The amount of taper is to be determined by the length of prop used, but should not be less than 9 inches nor more than 18 inches. The thinnest point of the tapering should not be less than half the thickness of prop used. He states that when props are so treated, instead of breaking, the tapered portions simply become fuzzy and turn up at the ends by reason of the superincumbent weight of the strata, as the ends being reduced in area become relatively weaker than the other portions of the prop.

* 1899. British Patent, No. 9925, and *Fed. Inst.*, xix. 8.

Small single props, called "sprags," are used for securingthe coal during the process of holing (*a*, Fig. 143). An elaboration of this, employed where the coal is liable to break away from the face, is the special timbering to which the name of "cocker sprags" is applied which consists of a longitudinal piece (*a*, Fig. 144) strutted against the face, and kept in position by the small sprag, *b*, going to the floor, and a second one, *c*, binding it from the roof. In other instances, a similar result is obtained by driving in a horizontal strut between the nearest row of props and the face (Fig. 145).

Where the roof is filled with faces which cross and re-cross each other, dividing it into a series of blocks, vertical props are not sufficient support, as they only keep up that part over or near the lid. In such cases transverse pieces of timber, called "bars" or "struts," are employed. If the sides are firm, these bars may be supported on them by cutting a recess (*a*, Fig. 146) on one side of

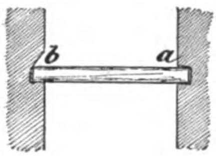


Fig. 146.

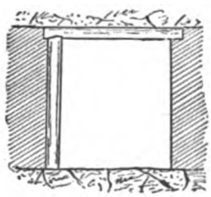


Fig. 147.

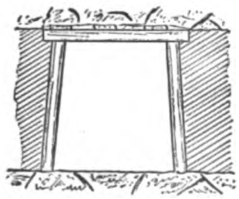


Fig. 148.

the road, and a groove, *b*, on the other, then inserting one end of the bar into *a*, and driving it tightly into the position shown. If one side of the road and the roof require support, often one bar and one prop are employed (Fig. 147). For the purpose of distributing the pressure, and increasing the surface of resistance, the timber is lined with boards, or laggings, placed longitudinally. If the roof only requires support laggings will be laid across from one transverse bar to the other; but if the sides are also bad, laggings will be placed all round the setting.

For main roads and other positions, where the nature of the ground requires it, entire sets of timber are employed, these consisting of two upright props, and one bar on the top of them (Fig. 148), with laggings around. The chief point to be observed here

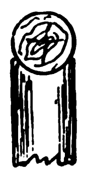


Fig. 149.

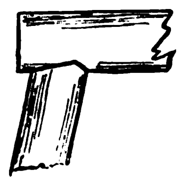


Fig. 150.

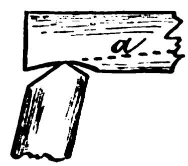


Fig. 151.

is that no hollow spaces should be left between the laggings and the roof. If any exist they must be filled up; if not, should the roof break away, it descends on the timber with a blow like that of a hammer, and often displaces it from position.

Joints.—The several pieces constituting a set are held together by different forms of "notching," each of which resists pressure coming from a certain direction. Where it is entirely from the roof, the common practice is to simply flatten the bar slightly at the point where it rests on the tree, and the weight soon tightens the pieces together. With a view of obtaining a larger bearing on the props, they are sometimes hollowed out at the top end (Fig. 149), the bar resting in the space so formed. It is, however, very difficult to shape this groove so that an equable bearing is obtained, and if this is not done the prop soon splits. To resist side pressure as well as pressure from above, the joint shown in Fig. 150 is largely employed. It is of the greatest importance that this should be nicely made, and that the end of the prop should fit evenly against the shaped portion of the bar. The great mistake is to shape the piece as shown in Fig. 151. If this be done the bar soon splits along the dotted line *a*.

Where the side pressure is great, the power of resistance is much

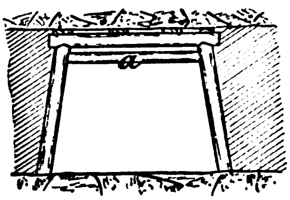


Fig. 152.

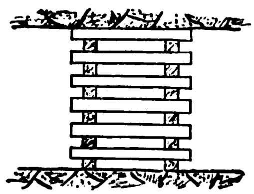


Fig. 153.

increased by placing a second horizontal piece (*a*, Fig. 152) between the two vertical props.

"Chocks," or "Cogs."—For resisting heavy pressure, either in the working places or along the main roads, chocks, or cogs, are largely employed. These consist of pieces of timber laid horizontally, the alternate layers of which cross each other at right angles (Fig. 153). They may be composed either of broken timber from the workings, or refuse material, such as old railway sleepers, waggons, or wreckages. If applied in the face, these chocks are built on a small heap of loose material, which allows them to be easily removed. If required to stand for any length of time, the space in the interior is filled in with loose dirt. Their size is an exceedingly variable one; perhaps the largest are employed in South Staffordshire, where they run from 9 to 12 feet square and 10 feet high. The construction of one of these cogs is shown in Plate II. They are capable of resisting enormous weights, as the more pressure applied the more they resist.

Double Timbering.—In some parts of Great Britain and on the Continent a system of double timbering is used to resist heavy pressure. The weakest part of a bar being its centre, it is strengthened there by a longitudinal piece (*a*, Fig. 154) kept in position by two struts, *b b*, which rest on two other horizontal pieces of timber, *c c*, these latter being finally fixed by two short sprags, *d d*, resting on the floor. In such manner not only is the top bar strengthened, but the two side props as well.

So much of the useful space is taken out by the two angle struts (*b b*, Fig. 154) that this style of timbering could not be employed if the road were a wide one containing a double way. The various parts are therefore arranged in a somewhat different manner. Two longitudinal timbers are placed beneath the bar in such position that the distance between the props is divided into equal spaces. A transverse strut (*b*, Fig. 155) is put between the two pieces *a a*, and the latter are kept in position by a series of cross-struts, &c., *c*, *d*, as before, as will be readily seen from the sketch.

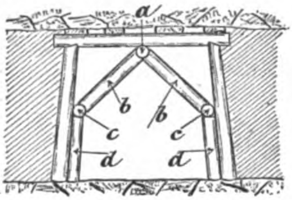


Fig. 154.

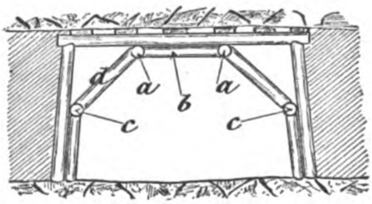


Fig. 155.

In fixing this interior frame all the longitudinal pieces are first placed in position, and held there by a wire lashing until the uprights and cross-struts are firmly wedged in their proper positions.

A modification of this method has been employed where the ground was exceedingly heavy and the timber subjected to severe

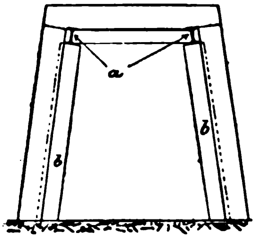


Fig. 155*a*.

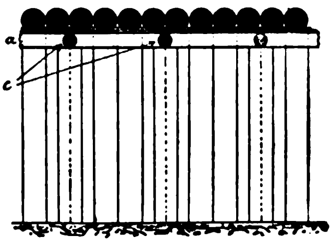


Fig. 155*b*.

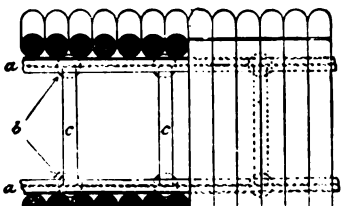


Fig. 155*c*.

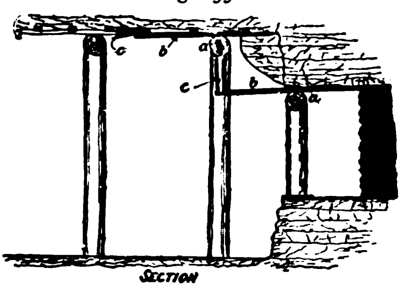
strains, both from the top and sides, to such an extent that an ordinary frame of two props and a crown piece entirely failed to withstand it. After several renewals had been made, double timbering was decided upon, part of the inner frame being of steel.

Fig. 155*a* is a cross section, Fig. 155*b* a longitudinal section along the axis of the roadway, and Fig. 155c a plan, in part of which the crown bars of the outer setting have been removed to show the girders and stretchers of the inner framing.

The outside sets of timber were put in side by side, touching each other, and after 12 feet or so had been done in this manner, two steel H-girders, *a a*, 6 inches × $4\frac{1}{2}$ inches × $\frac{1}{2}$ inch were placed parallel with the axis of the roadway beneath the bars in the right and left-hand corners, and supported at each end by props, *b b*. Other props were placed beneath the girders at distances of 4 feet. Finally stretchers, *c c*, were driven from girder to girder—one at each end and two in between at intervals of 4 feet. The girders thus support the crown-pieces of the outside setting, as well as the "push" from the side. Under ordinary circumstances the crown-pieces of the outside setting would be nipped or shaped at the ends and the props cut to fit into them in order to take up some side pressure, but as the steel girders keep the outside settings in their place, the bars were not cut, but simply flattened to a small extent in order to obtain more bearing surface. After a further length of 12 feet had been timbered with the outer settings, a second lot of girders and supports was put in as before, the result being that where the two girders touch each other there are two vertical props, and two stretchers of the inner framing touching each other—at all other points the inner props and stretchers are 4 feet apart. The size of the timber throughout was 9 inches diameter.

Courrières Method.—The measures adopted at Courrières

Fig. 155*d*.



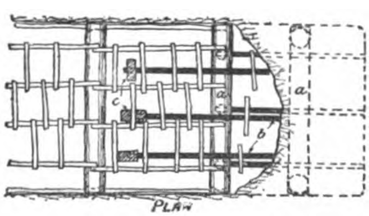


Fig. 155*e*.

Colliery, France,* for preventing falls of roof consist in systematic

* C. Le Neve Foster, *British Government Report on Mines and Quarries for 1899.*

timbering, and in supplying each worker at the face with three iron bars about 1½ inches square and 4½ feet long, and compelling him to make use of these bars to form a sort of temporary shield in advance of the last row of timber props. The iron bars are placed about 20 inches apart, and are driven in over the last crown-piece and firmly secured by wedges. As the work proceeds the temporary protecting shield is pushed on when another row of props has been put in, the iron bars are withdrawn and then driven on in advance beyond the new set of supports. The men are so practised that it takes them very few minutes to knock out the wedges, drive the bars forward, and wedge them up again.

Figs. 155*d* and 155*e* explain the method, which is simple and effective; *a a* is the last timber crown-piece, *b b* the iron bars, and *c c* the wedges keeping them in position.

Driving through Loose Ground.—In driving through watery and loose ground, special timbering has to be adopted, and put in with a view of removing as little material as possible. The general name of "spilling" is applied to such operations. First of all the frames (*a* and *b*, Fig. 156) will be fixed in position, and probably a sole piece, *e*,

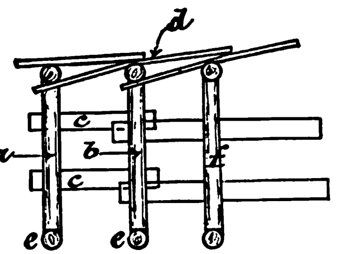


Fig. 156.

will be added, as well as the two uprights and the cap; then laggings or planks, *c c*, are driven forward behind *b*, these being inclined slightly outwards at an angle of about 15°, the pressure of the sides gradually bringing them close up against the sets. Other laggings are driven forward, inclined as shown at *d*, and a small quantity of ground excavated in front of *b*, until room is obtained for another set, shown *in position* at *f*. When this has been inserted laggings will be driven, inclined outwards as before, for a similar length, and the process repeated until the ground is passed through.

If the material is very loose, these laggings will have to be driven near together and the joints between them made as close as possible, and occasionally, in some cases, the ground at the back of the road will have to be supported by planks strutted against the first set.

The objection to this system is that, in spite of every care, a quantity of material oozes through the joints in very loose ground, leaving large empty spaces behind. To prevent this, the system on the Continent is to fill the face and the floor with a series of conical wedges, driving these forward and so making progress. The sides and the roof are supported by laggings and sets, the former driven in in the same manner as in spilling.

Preservation of Timber.—The pickling of timber with preservative compounds in order to lengthen its life underground under conditions where dry rot is prevalent, has scarcely received the attention its importance demands. In the damp, hot airways of some mines, a fungoid growth forms very rapidly and timber sets soon become rotten. The loss of the timber itself is by no means the only damage, as the labour charges for renewing the worthless sets forms a large item of expense.

Compounds applied to the skin of the timber are all more or less failures. Creosoting has met with considerable success for surface work. The timber is first put in a boiler, a vacuum produced and creosote forced in by a pump until the pressure equals about 100 lbs. on the square inch, the timber absorbing from 6 to 12 lbs. of creosote per cubic foot. Creosote is a liquid obtained from the distillation of tar and contains much naphthalene, hence timber so treated is far more inflammable than ordinary wood. For such reason its use underground cannot be regarded with favour.

At Saint Eloy in Auvergne * experiments were carried on for ten years on seven varieties of wood, each sample being sawn into fifty-two discs, the first and last of which were preserved in their natural condition above ground, while the remainder were placed underground in a damp level having a temperature of about 70° F. Two discs in each ten were unprotected, while the remainder were subjected to treatment by (1) sulphate of iron, (2) sulphate of copper, (3) chloride of zinc, (4) creosote, (5) three coats of oil paint, and (6) tar. The unprotected specimens were almost all destroyed in a comparatively short time, from 2½ years to 3½ years. The preservative effects of the different substances are given in a table, but, although all the processes increased the life of the timber, yet no rule can apparently be drawn, as the action of each substance seems to vary with the character of the timber upon which it is tried. In the extreme case, the durability of the treated timber was 150 times greater than that of the untreated material. Creosote seemed to be the least effective of all the substances experimented with.

At several Scotch collieries timber is treated by the Aitken process, which consists in soaking it in a strong boiling solution of common salt and chloride of magnesium, the proportion of salt to chloride of magnesium being about 7 to 1, while there should always be unmelted salt in the boiler bottom. The timber should be dry, free from bark, and well seasoned. Timber 6 inches diameter requires boiling for about two days, while one day's boiling is quite sufficient for 4-inch prop wood. Pitch pine and larch require longer treatment than softer woods. When the timber is removed from the tank in which it has been boiled, it is soft and unfit for use, and must be dried by a few days' exposure to the open air, the props being preferably placed on end. The total cost of the treatment, exclusive of royalty, is about 1¼ pence per cubic foot. At Niddrie Colliery,† in a temperature of from 68° F. to 80° F., and where the air varied from dry to moist, ordinary timber decayed in ten months, while timber treated by the Aitken process remained sound after 2½ years. At one of the Fife Coal Company's pits two pieces of timber, each weighing 10 lbs., were selected for experiment; only one piece was

* *Inst. C. E.*, civ., 394. † *Fed. Inst.*, x. 533.

treated, and after soaking and drying weighed 12 lbs. Both were placed underground in a return aircourse, and after eleven months were examined and reweighed. The untreated timber only weighed 5 lbs., while the treated piece weighed 12 lbs., exactly the same as when put in. They were again replaced in the mine, and after a total exposure of three years the treated piece was found to be sound, while the untreated one was decayed and worthless. The strength of the timber is apparently unaffected by the process.

Mr. F. Haselmann, in introducing his process into some German mines, directs attention to the fact that in the ordinary methods for preserving timber a physical impregnation only is produced by simply *soaking* the timber in a chemical solution, and that the preservative compounds so easily introduced into the cells may equally easily be dissolved out again by the action of water. In his opinion complete impregnation can only be effected when the solution containing the preservative compound, together with the timbers floated in it, is raised to a temperature of 123° C. under a pressure of about 2½ atmospheres. Boiling is continued for several hours, preferably in a solution of sulphate of iron or copper, in order to induce a chemical combination of the impregnating materials with the cellulose, and microscopical examination afterwards seems to prove that the walls of the wood fibres are impregnated through and through, while the hollow spaces of the cells are absolutely free. The results obtained by the process confirm those of the Aitken patent.

Strength of Pit Mining Timber.—As numerous experiments have been conducted and recorded on the strength of timber, it is a comparatively easy matter to find out the breaking strain of beams loaded in various ways. Such experiments and rules, mostly relate to sawn timber selected so as to be of uniform quality, and consequently cannot be applied for determining the strength of bars and props used for mining purposes. Indeed, most of the hitherto published strengths relate entirely to strains applied transversely, and give no guide to the amount of longitudinal stress which the miner's prop will bear with safety.

Prof. H. Louis* has conducted 190 experiments extending over eighteen months upon the behaviour of ordinary pit props supplied to collieries when subjected to end pressure, care being taken to see that the pieces selected for experiment were neither better nor worse than the usual pit props of commerce. He points out that, as the material is essentially non-homogeneous and very variable in character, the subject is one of great complexity, and the results obtained can only be looked upon as approximations to the real facts. The main conclusions deduced from the experiments are summarised as follows:—

Of the ordinary soft woods, sound Baltic whitewood and redwood and larch make the strongest pit props; their strength may be taken as equal to 1½ tons per square inch of area of the small end.

The strength of a pit prop is practically independent of its length, within ordinary limits; but as the strength of a prop is that of its weakest part, a long prop evidently presents a greater possibility of including some spot of especial weakness than does a short one, this probability of failure being dependent upon absolute length, and not upon ratio of length to diameter.

* *Fed. Inst.*, xv., 343, and xvii., 14.

Slow grown timber is somewhat, but not greatly, superior to fast grown.

No timber should be used for pit props while it still contains any sap, and attention should be given to thorough seasoning.

Only seasoned and sound props should be submitted to antiseptic treatment, and the props should be given time to season after treatment before being used.

Crooked props, props with large knots, and, above all, gouge-marked props should be avoided; wind shakes are of less importance.

A prop that has been drawn after having been set is decidedly weaker than when originally set.

Withdrawing Timber.—The economical gain resulting from the careful and systematic drawing of props after the coal has been got in the working faces is not the only advantage effected. The roofs of most seams of coal generally settle down much more steadily and regularly on the "gob" or packing when all props are removed than if any are left behind, and, consequently, careful withdrawing of timber may prevent the occurrence, and undoubtedly minimises the frequency of those sudden pressures or "weights" which often have such a disastrous effect on the working places, and which are productive of so many accidents to workmen.

The apparatus commonly used for withdrawing timber is variously known as "ringer," "gablock," or "dog," and chain, and consists of a length of chain and an ordinary lever of the second class where the weight to be moved is between the fulcrum and the point where power is applied. The lever consists of a bar of iron, generally about 4 to 6 feet long, having a curved point, and provided with a hook some 7 to 9 inches from the fulcrum end. When a prop has to be pulled out of a waste or the gob, the first thing done is to select the nearest *firm* prop to it, because some comparatively immovable point must necessarily be obtained for the fulcrum of the lever to rest upon. One end of the chain is then hitched round the prop in the gob, the other end pulled taut, and the nearest link attached to the hook of the lever whose fulcrum end rests against the firm prop. In Fig. 157, *a* is the prop to be withdrawn, *b* the firm prop, *c* the lever, and *d* the chain. If the end of the lever be moved in the direction shown by the arrow, the prop *a* must necessarily travel towards *b*. As soon as the limit of travel is reached the lever is moved back to its original position, the chain again drawn tight and dropped over the hook, and another pull made, this operation being repeated until the prop *a* is comparatively loose. Owing to the small amount of space in the working places

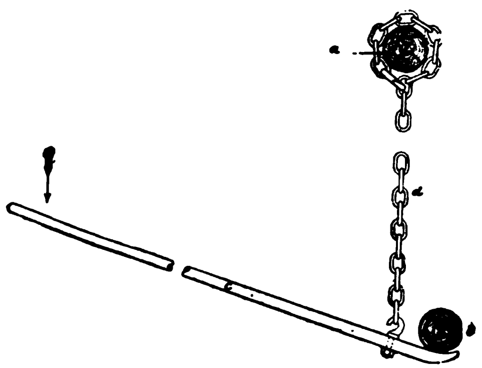


Fig. 157.

relatively short levers have to be employed, the maximum leverage obtainable being about 10 to 1. If a prop is firmly embedded in the débris this leverage is insufficient to move it, and the workmen often endeavour to assist the action of the dog and chain by striking blows on the prop with a sledge hammer. As they have to go beneath the broken roof to do this, the practice is attended with considerable danger. In addition, the necessity of taking hold of a fresh portion of the chain at each stroke of the lever results in a considerable loss of labour, as the prop springs back some distance as soon as the pressure is taken off the chain.

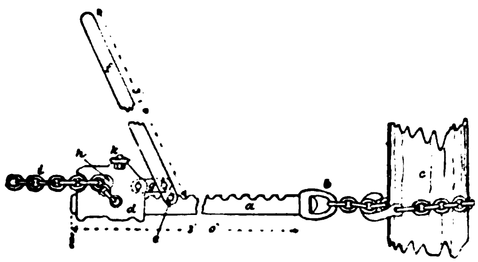
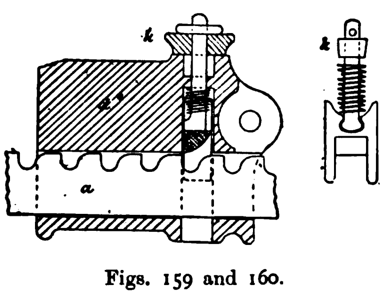


Fig. 158.

To avoid these disadvantages, Mr. W. Sylvester has designed the pulling jack, illustrated in Fig. 158, which consists of a notched bar, *a*, 3 feet long, with machine-cut teeth about 1 inch apart and $\frac{7}{16}$ inch deep along one edge. One end of the bar is provided with a swivel joint, *b*, to which is connected some 3 feet of chain and a hook for attaching it to a firm prop, *c*. A sliding block, *d*, is passed over the other end of the bar *a*, and connected to it by a bolt, *e*, lever, *f*, and link, *g*. This sliding block has a jaw-shaped recess, *h*, in one side, enabling it to be easily and securely fastened to any link of the chain *i* attached to the prop being withdrawn. When the lever *f* is slightly raised, and the bolt *e* reached forward into the next tooth, the block *d* can be pulled towards *c*. A spring catch bolt, *k*, falls at right angles into the notches of the bar and holds the block in position, while the lever reaches forward into the next tooth. Figs. 159 and 160 show an enlarged sectional view of the block *d* and catch bolt *k* in the position when the latter is raised and turned sideways on shoulders, provided for the purpose of allowing the block *d* to be easily slid into any desired position on the notched bar *a*.



Figs. 159 and 160.

The method of using the pulling jack is as follows:—It is first attached to the prop *c*, the sliding block *d* run back to its furthest limit, and the catch bolt *k* turned round and allowed to drop into the first notch. A long chain is lashed round the prop to be withdrawn, the other end pulled tight, and the nearest link placed sideways in the jaw *h*. Whilst the machine is being worked the click of the catch bolt as it falls into the notches indicates how far the lever has to be moved each stroke. When the sliding block has been drawn to the limit of its travel along the notched bar, it can be released by pressing the lever forward as if about to make another stroke. This relieves the catch bolt of the weight, and enables it to be raised and lifted on to the shoulders, as shown in the illustration, when the block can be moved along the notched bar and placed in position for a further movement of from 2 to 2½ feet, if necessary.

The leverage obtained is 30 to 1, and a man of average strength can lift a dead weight of 2½ tons. By employing chains of varying lengths several props can be removed at each fixing of the machine, while, owing to the comparatively long travel of the sliding block and the large leverage, the work is carried on more quickly and easily than with the dog and chain. The machine is very useful underground, as it can be employed for many different purposes, such as tightening ropes or chains, releasing tubs that have become jammed together, and, indeed, for moving heavy weights generally. The application of the machine is shown in Fig. 161, where a prop surrounded by a quantity of loose material is being removed. In this case the chain is hooked round the prop as low down as possible, and passed over the top of a short sprag or sleeper reared against the prop.

Fig. 161.

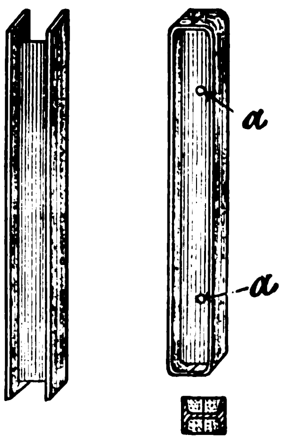
As the sprag reels backwards the prop is lifted upwards. The illustration shows the sliding block at the end of its travel; the catch bolt must now be withdrawn, the block pushed along the notched bar and relocked, and the chain pulled taut and its nearest link placed edgeways in the jaw of the sliding block, when the apparatus is ready for further use.

At Konigsborn II. Colliery, in the South Dortmund district, small screw jacks are used for changing broken props beneath steel girders, with very satisfactory results. The bars can be pushed close up against the roof, and the operation performed much quicker and safer than if the caps were temporarily supported by a spare prop, as is generally done when changing broken timber. The work done by the timberers is increased at least one-third.

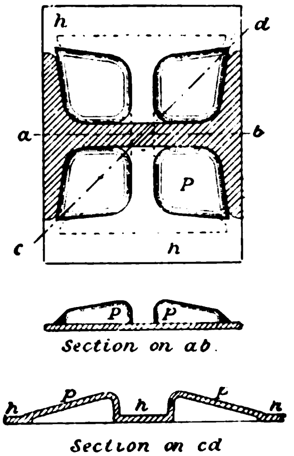
Iron and Steel Supports.—So far as props are concerned, no great success has as yet been obtained, although in some instances they are largely used. The first cost of either iron or steel is always so much larger than that of wood, that if metal props are employed it is absolutely essential that none should be lost. If they are, the economy resulting from the decreased breakage is more than counterbalanced.

Cast-iron props have been tried, but have not met with much favour. They are somewhat easily broken, very heavy, and consequently dear.

Ordinary steel girders of the H form, if used as props, present a sharp and uneven surface to the roof, or floor, or to timber lids. Firth's arrangement removes this difficulty. A piece is cut out of the web at each end (Fig. 162), and a flat top and bottom formed by turn-



Figs. 162 and 163.



Figs. 164, 165, and 166.

ing over the top and bottom flanges until they meet (Fig. 163). In addition, holes, *a a*, are punched in the web about a foot from each end, into which a hook may be inserted for the withdrawal of the prop.

With a 6-inch section girder, half this length has to be cut out of the web at each end to allow the flanges to be bent back. To prevent this waste, Mr. W. E. Kenway has patented * a separate, or detachable, foot having an area greater than that of the end of the girder, which constitutes so broad a bearing that the lower or upper ends of the prop are prevented in a great measure from either sinking into the floor or pressing into the roof. These feet may be made of cast iron in the form of a rectangular plate having projections on its upper surface of such size and shape as to be suitable for engaging with the middle web and flanges of the prop, or preferably they can be constructed out of sheet-iron or steel. Tongues or semi-detached pieces are then cut out on each side of the middle line, and are bent out of the plane of the plate. The middle web of the prop is engaged be-

* 1894, British Patent, No. 23,356.

tween these tongues, which by their elasticity secure the foot to the end of the prop.

These tongues can be slit out in many varied shapes and positions, but instead of doing this the plates are commonly made with the parts for holding the prop stamped out as represented in plan in Fig. 164, and in cross-section in Figs. 165 and 166. Four symmetrically arranged projections, *p p*, are made by the stamping process from the foot-plate *h*, and these projections are highest at those parts which engage the middle web of the prop, the other parts inclining downwards towards the edge of the plate (see cross-sections). Each plate is constructed to take two sizes of girder as shown in Fig. 164, where a small prop is represented in section, and a large one in dotted lines. These detachable feet are comparatively cheap, if the fact is borne in mind that they avoid any waste in cutting the girders, and they can be varied in size to suit the nature of the floor or roof. They can be immediately attached to, or detached from, props of various lengths, and do not interfere with the drawing of the props. The girder comes away easily leaving the shoe behind, the latter being picked out afterwards.

The greatest application of steel girders in English mines is to replace the timber bars used on ordinary sets, retaining, however, the two vertical wooden props. It is obvious that, as the lower flange of the girder is smooth, and cannot be notched like a timber bar, if there

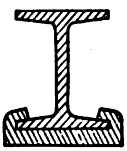


Fig. 167.

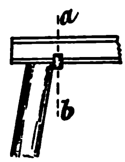


Fig. 168.

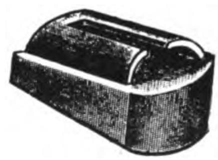
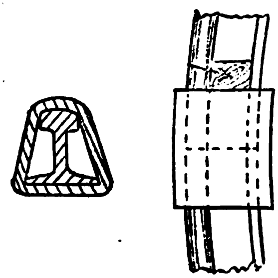


Fig. 169.

is any side pressure, means have to be adopted to keep the props in their correct position, and prevent them from being pushed inwards. This is done in a very simple manner. About 4 to 6 inches from each end an ordinary chair is fixed on by the blacksmith, this consisting of a short piece of bar iron about 1 inch by $\frac{3}{4}$ inch, crossing the bottom flange, and, turned round at each end, gripping the upper side. The enlarged sketch (Fig. 167) is a transverse section on line *a b* (Fig. 168). Any common scrap iron can be used for this purpose. The chairs are placed in position before the bar goes down the pit, and the labour cost for each girder for such addition is 3d.

Mr. E. Thompson has designed the shoe shown in Fig. 169, into which the steel girder slides, for use with wooden props. The girder cannot cant over, nor the props be pushed down by side pressure. This saves the wood props, which are liable to split when the girder is forced over on to the edge of the flange.

The author has had considerable experience of the utility of these steel supports. For bars up to 7 feet long a section measuring 5 inches by 4 inches by $\frac{1}{2}$ inch, weighing 66 lbs. per yard, is employed, these costing 9·28s. They replaced oak bars, measuring $6\frac{1}{2}$ inches quarter-girth, costing 2·66s. The price of steel was, therefore, 3·49 times that of wood. As an experiment, lengths of roading were timbered alternately with wood and steel (bars only, timber being used as props), but before any definite results could be observed the district fired, was dammed off and abandoned. After a lapse of nine months the roads were re-opened, and it was then found that the steel bars had scarcely suffered at all, only a few being displaced through their timber supports breaking. Owing to the fallen roof at places where timber bars had been set, over £100 in wages was spent in repairs, which would have been unnecessary had steel bars been employed throughout, and, in addition, the first cost of the timber was entirely lost. On a main haulage road, 12-feet girders, of a section 6 inches by $4\frac{1}{2}$ inches by $\frac{1}{2}$ inch, weighing 78 lbs. to the yard, and costing 20·95s. each, have been employed, replacing timber bars 9 inches quarter-girth, costing 9s. each. The first cost of steel was here 2·33 times that of wood. The date of fixing each girder was noted, and numerous instances could be given of their lasting out from three to four sets of timber before removal. Two especially may be instanced; they were fixed at a junction, where the pressure was very heavy, and actually stood for 13 weeks before removal, while the longest time an oak bar lasted in the same place was a fortnight; many failed in a week, and it was quite useless putting in Norway timber, as it broke in two days.



Figs. 170 and 171.

If the steel bars were worthless on removal, the actual cost in the above instance would be less than timber, but all that has to be done is to take them out and straighten them, and then they are practically new. Their advantages are not so apparent where timber lasts a long while, but with heavy pressures, and in return air-ways, they are far superior. They must be set very carefully, with an equal level bearing, both on props and to roof; if not, they turn over and present their weakest side to the pressure. When they take a permanent bending set, the best thing to do is to either turn them over, or, if the bending is large, remove and straighten. With these precautions, the author has rarely found them break.

On the Continent complete frames of steel are largely used. In some cases they are composed of two pieces, the top portion bent into the shape of an arch ⌒, and connected at the summit by fish-plates and bolts, the lower end resting on an iron shoe fitted to a wooden baulk, timber lags being driven behind the frames against the sides of the excavation. Elliptical shaped sets are also employed, but the common form is composed of two pieces of circular shape ○. Instead, however, of making the joints with fish-plates, the frames are connected together by a sliding iron collar, which is secured in its place by driving between it and the frame two pieces of wood like rail keys. Figs. 170 and 171 show the application of such a joint at Firminy, where old pit rails are used.

At Lens timber lags have been done away with, and small strips of channel steel, about 2 inches by $\frac{3}{8}$ inch, used in their place. A great advantage of steel is that it does not occupy so much space either as timber or masonry, and thus a greater effective area of roadway for the same amount of excavation is secured, or the cost of driving the road is reduced, because less excavation is required to get the same effective area.

For use where complete girder frames are adopted, Mr. E. Thompson suggests the use of a steel clip (Fig. 172), which is made in two halves and grooved so as to fit the flanges on both sides of the bar and prop at the joint (Fig. 173). The prop can be driven up under the bar, and the latter forced close up to the roof, while the clip can be fixed after the setting is erected. Both bar and prop are practically interlocked and prevented from canting over or shifting in any direction. Only one bolt is required for securing the two halves of the clip. The rigidness of such a setting is to some extent a disadvantage.

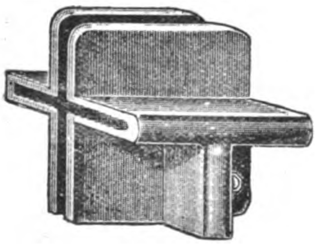


Fig. 172.

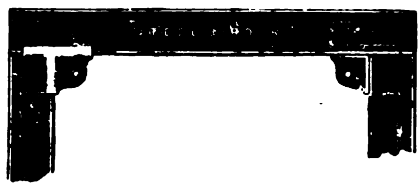


Fig. 173.

There is nothing to give way, and such a state of tension may be induced that either the girders break or the whole may suddenly spring apart and collapse, without giving any preliminary warning as ordinary timber does.

Corrugated sheeting has been adopted by Mr. E. F. Melly on a somewhat novel plan in the so-called 7-feet seam of the Warwickshire coalfield.* When driving a road with the Stanley heading machine, it was decided to leave 18 inches of coal underfoot, owing to the floor consisting of soft fireclay, and to take down a portion of the roof. The roof was then supported by curved, black, corrugated iron sheets, 5½ feet wide by 2¾ feet long, with a spring in the arch of 15 inches, of No. 15 gauge, this being the thickest that the manufacturers would undertake to corrugate. There were seven corrugations, the weight was 58 lbs., and the cost was 4·33s. per lineal yard (£8 3s. 6d. per ton). The cost of erection, including fixing a few bricks to make the sides solid where necessary, and packing securely overhead, was 1½s. per yard in wages. The roads stood well and gave less trouble than where the same road was supported with timber bars, as the soft wet roof rotted both bars

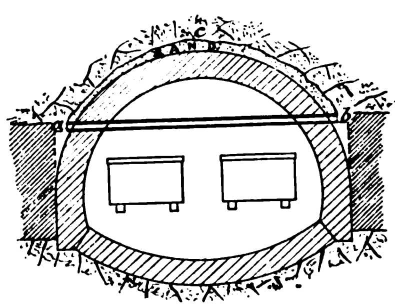


Fig. 174.

* *Fed. Inst.*, xiii., 279.

and lagging. The only drawback appears to be that, after once being used, the sheets are of little use except as old iron, unless other similar places have to be supported.

For permanent situations, where girders are placed on masonry side walls, considerable economy results. The worst feature about an arch is the large amount of space which is lost through the semicircular form at the top. Taking an ordinary roadway (Fig. 174) occupied by two tubs, an arch has to be so made that the curve of its upper portion allows the tubs to pass through without catching, and as a result a high space exists in the centre, which not only costs a lot of money to excavate but serves no useful purpose. If a girder, *a b*, be placed on the top of the walls, the excavation of the area *a b c*, which contains 4·28 cubic yards, becomes unnecessary, and, in addition, the cost of the brickwork will be saved. In the illustration under notice this will amount to 2·08 cubic yards per lineal yard, which will cost for labour, material, and mortar quite 29·32s. Against this has to be put the price of the girder, amounting to 20·95s. One of these will be required for each lineal yard. The girder and side walls, therefore, effect a saving in first cost of 8·37s. per yard run in material, to which has to be added the reduced cost of the excavation, in this case at least, 14·98s.

Side walls and girders are not so capable of resisting side pressure as an arch, but this difficulty can be overcome by turning small brickwork arches in between each girder (Fig. 175) in the same way as is done with fireproof floors of buildings. There is a certain amount of spring in steel girders, and when weight comes on to these small arches there is a risk that the girders will bulge in the middle and allow the arch to flatten. To prevent this happening, tie-rods, *a*, are placed across from girder to girder.

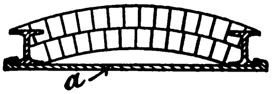


Fig. 175.

Masonry.—For all permanent situations, securing the sides with masonry still finds greatest favour. It is, perhaps, more expensive to put in for reasons already stated—viz., the greater excavation required both for the masonry itself and to obtain the same effective area, but when required to stand for many years it cannot be surpassed. It is, however, necessary to make the lining continuous all round the road. The practice of building arches without an invert is not to be recommended; if an arch is worth putting in at all it should be put in well, and, in addition, some soft packing material, such as sand, must be introduced between the lining and the strata. No vacant places should be left behind the brickwork, and all timber used for the temporary support of the excavation while the work is being put in should be removed. The introduction of a soft material between the brickwork and the strata not only distributes the pressure over a considerable area of brickwork and prevents local weight, but, as it gradually gets compressed, acts as a resisting medium itself. This packing should neither be too much nor too little; from 12 to 18 inches gives the best results. To show how important it is, the result of an experiment made by the author in 1888 may be cited. Two successive lengths of 7 feet diameter arch were built, one with masonry 18 inches thick, packed behind with a foot of sand, and the other not less than 18 inches thick, but built solid. The latter was crushed to pieces and had to be taken out in a year; the former is still in and does not show a crack.

The shapes of arches are many. The circular form is the strongest, but requires so much excavation that it is seldom employed. An ellipse is perhaps the next strongest, but this again requires a large space. The form generally adopted is a combination of the two. The side walls and top usually form part of one curve, struck with a radius equal to half the width of the road, while the invert, or bottom, is a portion of another circle having a larger radius. This ties the whole structure together, and prevents either the bottom lifting up or the sides heaving in. Two forms adopted by the author for a single and double way are shown in Figs. 176 and 177. They do not contain any

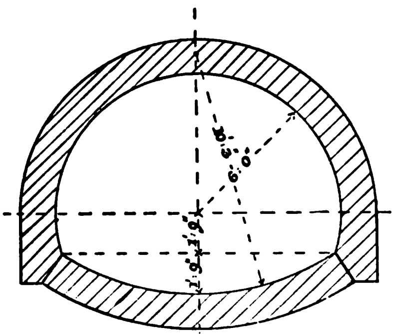


Fig. 176.

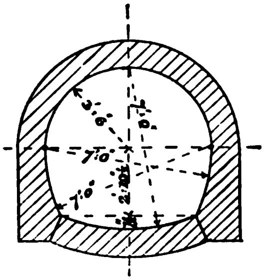


Fig. 177.

straight lines. In the 12-feet arch all the portion above the invert is part of a circle to radius 6 feet, while the 7-feet arch contains portions of four circles—*i.e.*, the two side walls and invert to radius 7 feet, and the semi-circular upper part to radius 3 feet 6 inches.

These arches are put in in lengths, which vary with the nature of ground; 6 to 9 feet, with a bad roof, and up to 5 to 7 yards, with a strong one.

The first procedure in putting in arches is to remove the ground; to do so two methods are in vogue. In one—the general English custom—a small road is driven right at the top of the arch. and the ground excavated on each side and downwards, while in the other, the first road is driven at the base of the arch and the ground removed upwards.

In timbering the ground, the peculiar point is that all the main pieces are set *parallel* with the axis of the road, and not *transversely*, the reason for such departure from the usual practice being, that as the masonry is brought upwards all the timber has to be removed, and this could not be done, especially in the upper portion, where the two walls are approaching each other, unless it lay in the same line as the brickwork. Another point is, that if trees have to be set, as they frequently have, in the middle of the excavation, the *smaller* end should be placed downwards, the reason of this being that when the masonry in the invert is built round them, other props are set on the brickwork to the point they are holding up, and then those going through the masonry are drawn out, and if the larger end were downwards it would be impossible to do so. The method of timbering will be understood by examining Figs. 178 to 181, which illustrate the position of affairs at two stages of the operations. Supposing in Figs. 178 and 179 the top head has been driven, and an amount of ground, shown by the dotted lines, has to be excavated, the first procedure is to set two long bars, *a a*, one end of which rests on the arch already put in, *g*, and the other on a timber set, *f*, placed in the head. These two will probably be connected by a strut, *b*. The ground will then be excavated, first on the sides, and other longitudinal bars, *c c*, put in, connected to the other two by struts, *d d*, and behind these lags will be placed if the

Fig. 178.

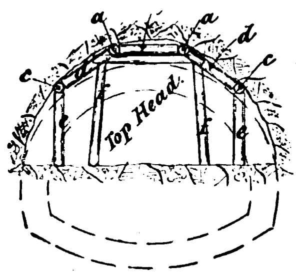
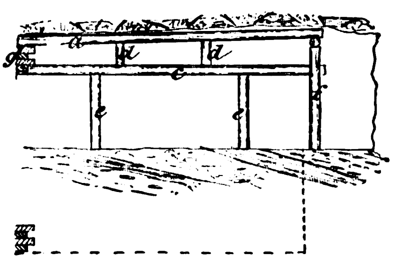


Fig. 179.



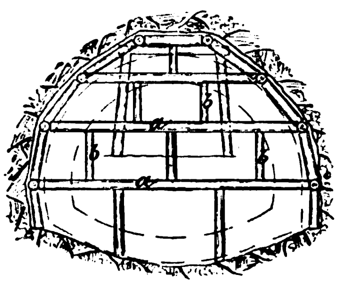


Fig. 180.

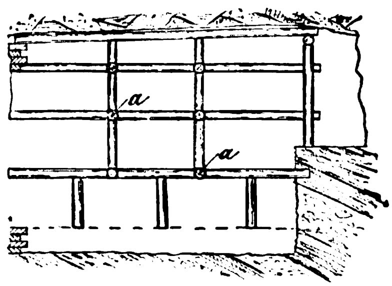


Fig. 181.

ground requires it. At this stage Figs. 178 and 179 represent the position of affairs, the two longitudinal pieces, *c c*, being supported by small temporary props, *e e*, set on the floor.

As the excavation proceeds downwards the props *e e* are removed, as soon as space is obtained for other longitudinal pieces. This process will be repeated until a complete lining, consisting of longitudinal bars and cross-struts between them, exists all round the excavation. In heavy ground the longitudinal pieces are often connected by transverse bars (*a a*, Fig. 180) and in addition vertical props, *b b*, are set between, until at the completion the work presents the appearance shown in Figs. 180 and 181.

The masonry is now commenced. First of all a lining of sand is spread in the bottom, and shaped to the curve of brickwork, of course at the proper gradient. A wooden frame or "template," made of the exact shape of the finished inside dimensions of the invert and side walls, is fixed at such a height above this sand as will allow the thickness of the brickwork which is going to be used to be placed between it and the sand. The first ring of masonry is generally laid dry. Operations commence at the centre line, placing the longer length of the brick parallel with it, and adding successive rows on each side until a point (*b*, Fig. 182) is reached. This distance is such that the ends of each ring when joined form a straight line, pointing towards the centre of the circle, of which the invert is part (*b a*, Fig. 182). The succeeding rings are put on by spreading a good bed of mortar over the one first laid, dropping the bricks down a few inches away from the position they will eventually occupy, and then slipping them along until they get into their proper places. By doing this, not only is the excess of mortar in the bottom pushed away, but a quantity is gathered up into the end and side joints, and, in addition, close contact between the mortar and brick is made. This procedure is repeated with each layer until all the invert is put in.

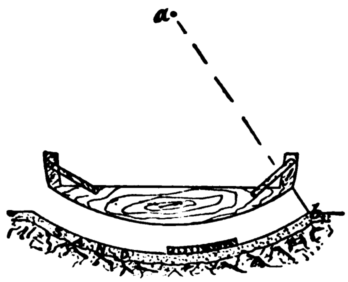


Fig. 182.

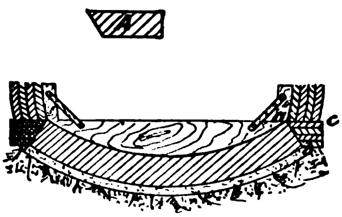
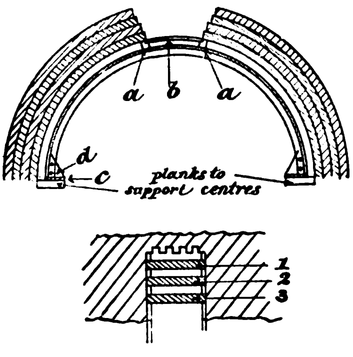


Fig. 183.

The building of the side wall now commences. The point *a b* (Fig. 183) is the weakest in the arch, so, as a compensation, the brickwork is increased in strength there (see also Figs. 176 and 177). With the exception of the small portion of masonry cross-shaded on the left-hand side of Fig. 183, all the brickwork in arches is laid in stretcher courses, but for this small piece English bond is used, and the bricks in each course are alternately at right angles to those of the invert, and, as they are laid horizontally, have to be cut into the shape shown enlarged at A. When the point *a c* (Fig. 183) is reached, the bricks are laid longitudinally again, but to obtain the proper curve, *culvert* or *arch* bricks are employed for the first course. Each ring is kept perfectly separate from the others—that is to say, they are not bonded together.

When the side walls have reached their proper height the centres will be set, laggings put on, one by one, and the brickwork gradually brought round until the two sides nearly meet. To close up the top properly, the mason should be outside the arch, but as this is impossible in mines, the difficulty is got over as illustrated in Figs. 184 and 185. When the space between the two sides diminishes to about 2 feet, or such width as a man can conveniently work in, two grooved laggings, *a a*, are put on. Up to this time the masons have laid the courses parallel with the direction of the arch, they now put the remainder in transversely, but still keep the longer axis of the bricks in the same direction. Commencing near the length already in, the man lays a strip of iron (*b*, Fig. 184, and No. 1, Fig. 185), which is curved to the same radius as the arch, in the groove of the laggings. He then makes up the small portion, supporting it on No. 1 iron, retires backwards, puts on another iron, No. 2, and keys in the part between No. 1 and No. 2, goes back again, puts on No. 3, and repeats the process, until the length under consideration is secured.

Instead of using timber centres, which block up the upper portion of the road, the author has invariably employed iron ones, which possess the great advantage not only of being light and easily fixed, but also of leaving the centre of the road free. In some instances, they have been made from old railway rails, dropped into a wrought-iron shoe, or in others of angle or T iron, at the base of which a return plate about 6 inches square is placed (*c*, Fig. 184) and secured to the angle iron by a small gusset stay, *d*. The laggings employed are usually about 3 inches thick, and it must be remembered that twice the thickness of these has to be deducted from the



Figs. 184 and 185.

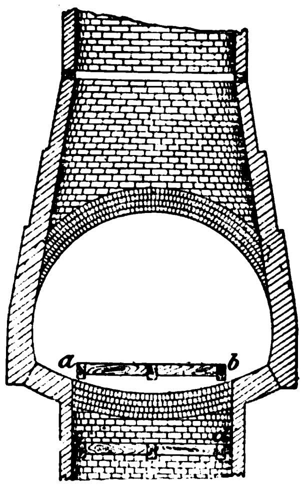


Fig. 186.

diameter of the arch to find the size of centres required, therefore, with a 12-feet arch, the centre should measure 11 feet 6 inches. With iron centres the author has put in over 100 yards of 12 feet arching in the main road of a colliery, and never stopped drawing through it a single day.

Arrangement of Inset.—In the great majority of cases the empty tubs, after being removed from the cage, have to be brought back by the side of the pit shaft, and for such reason the hanging-on place is made wider than the diameter of the shaft, indeed, it is usual to provide a passage on both sides. The shaft brickwork and the arching are best connected by "belling" out the former, as shown in Fig. 186, this being by far the strongest construction, and, in addition, room is provided for bearers, to which either guide pulleys for haulage ropes or main supports for water or steam pipes can be attached. A sump frame, *a b*, will be provided to receive and keep the cage steady while changing is going on, and if two or more decks are used, another frame of cross-bearers, *c d*, will be put in. On the latter the cage rests during changing, and as it drops there with considerable force, Mr. Emerson Bainbridge has employed spiral springs at Nunnery Colliery, Sheffield, which are simply let into the bearers and receive the cage (Fig. 187). There are six springs to each cage, each 9 inches long by $5\frac{3}{4}$ inches diameter, made with $9\frac{1}{4}$ coils of $\frac{3}{4}$-inch steel. All jar and shock is avoided.

The arrangement of the tramways at the pit bottom should always be such that from the point where the full tubs are removed from the haulage ropes, to that where the empty ones are again attached, the motion should be due to gravity alone. To a certain extent, where engine power is available, it is, comparatively speaking, an easy task to haul the tubs to such a height above the hanging-on place that a regular fall is obtained towards the shaft for the full tubs, and a fall in an opposite direction for the empty ones. The landings are technically called "kips," and it is advisable that they should be as long as possible, so as to get standing room for a large quantity of tubs; winding may then go on, up to a certain limit, even while the haulage machinery is standing. To still further facilitate rapid changing, it is best to arrange matters in such a manner that the tubs always pass into the cage on the same side at the pit bottom as they do at the surface.

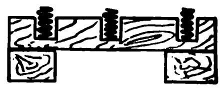
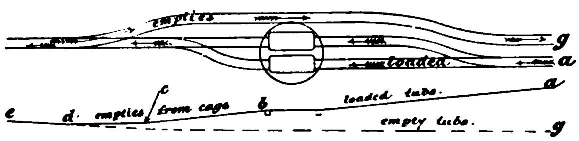


Fig. 187.

The subject of caging the several decks simultaneously is dealt with in chapter viii., and all that will be done here is to describe the operation of getting the tubs (waggons) to the apparatus used for this purpose. A favourable plan is to arrange the shaft at one extremity of the main haulage road, and haul the tubs by mechanical means to the point *a* (Figs. 188 and 189); the full road is then laid at a slight inclination (about $\frac{1}{2}$ inch to the yard) towards the shaft, the tubs gravitate there, and are placed on the cage by an onsetter. The empty ones gravitate away from the shaft down the slope *b c*, having a grade of $3\frac{1}{4}$ inch to the yard to give the required speed, along a slight flat,



Figs. 188 and 189.

e d, and then *up* the incline *d e*. The tubs will not proceed far up *d e*, but do so for some distance, owing to the momentum they have gained coming down *b c*, and travel just far enough to clear the points at *d*. As the slope is against the tubs, their direction of motion is changed, and on their return down *e d* they are switched off automatically by spring points into a road to the left having a down-hill grade, pass by the side of the shaft to the point *g*, where they are again attached to the haulage rope, and proceed into the workings. From the time the tubs leave the rope at *a* to the time they are again attached at *g*, no labour is necessary, the movement being quite automatic.

Mr. M. H. Douglas * has described, in an excellent paper, several systems of laying out shaft landings, all of which are worthy of study. One, however, needs special mention, where, owing to the inclination of the seam, caging takes place at two decks simultaneously, without the use of any balance arrangement (Fig. 190). There are two shafts, about 40 feet apart, each sunk to the same seam, and two engine planes, each fitted up with a double line of rails. The coals hauled out of the No. 1 engine plane are drawn above the switches *s*, and lowered down into the road *x x'*, as required, and are hung on exclusively at the high level, the road *x* being used for No. 1, and *x'* for No. 2 pit. In arranging the roads for the removal of the empties, advantage was taken of the natural dip of the seam, the road *y* being

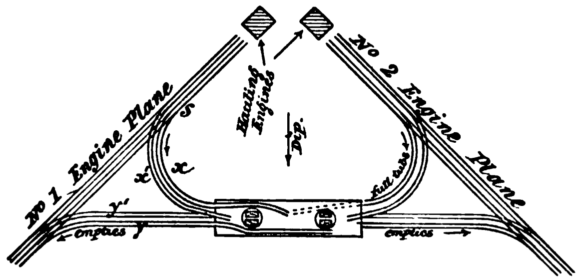


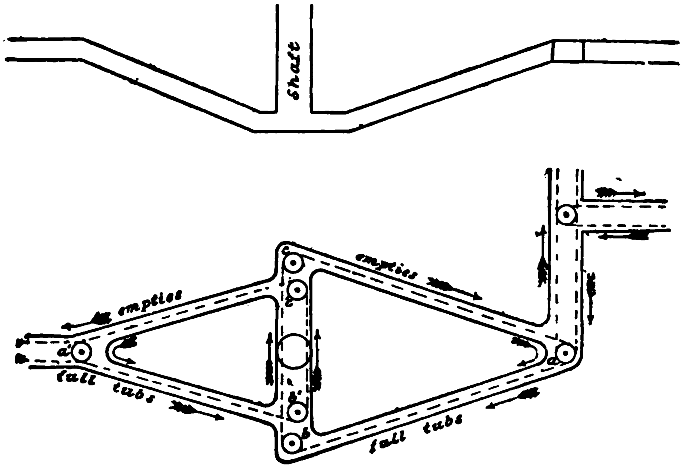
Fig. 190.

used exclusively for No. 1, and *y'* for No. 2 pit. The same method is pursued with the coals hauled out of the No. 2 engine plane, with the exception that these tubs are used entirely at the low levels, the gradient being formed by driving stone drifts for the full and empty roads. The high and low levels differ in height exactlv 8 feet. The sketch explains itself, if it is remembered that the tubs from No. 1 engine plane feed the top decks of both pits, while those from No. 2 engine plane feed the bottom decks. The only objection to such a system is that equal quantities of material must be drawn by each engine plane.

The inset at No. 5 pit, Bascoup, Belgium, affords a fine example of the automatic and continuous movements of the tubs in one direction. The landing is laid with a double line of rails, and passes through the centre of the shaft, parallel with the longer axis of the cage (Figs. 191 and 192). From each end of it branch off two side roads, each laid with a single line of rails; one set proceeds towards the north, and the other towards the south. The two roads to the north, and the two roads to the south, rise from the shaft, and each pair unite at a point about 100 yards above the level of the pit bottom, where the motive pulleys of the haulage are fixed. Roads branch off level to the east, and further junctions are arranged, as shown in plan (Fig. 192), each having separate wheels on vertical shafts. Two endless chains exist in the roads driven to the rise, one on each, and these pass round the motive pulleys. The full tubs descend towards the shaft in one road, and the empty tubs return from it in the other. The same chain passes upon pulleys on the upright shafts *a a'*, and also round the return pulleys *b b'*, *c c'*, situated at the two extremities of the inset,

* *Brit. Soc. Min. Stud.*, i., 443.

and passes through the shafts without interfering with the cages, or even with the movement of the tubs in the hanging-on place, as the tubs gravitate from *b* to *c*. The application is remarkably simple and efficient, a noteworthy point being that the direction of motion of the tubs is never changed, except at the working face. The plan and section explain this; the pit bottom is at the lowest point, the dotted lines represent chains, and the arrows the direction of motion.



Figs. 191 and 192.

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N. E. I.: *The Use of Iron Supports in the Main Roads of Mines instead of Masonry or Timbering*, G. Meyer, and W. J. Bird, xxxvii., 135; *On the Introduction of Steel Supports for the Maintenance of Main Roads in the Mines of Cleveland*, A. L. Steavenson, xxxvii., 221.

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INST. C.E.: *Timbering in the Ampthill Second Tunnel*, E. E. Matheson, cxx., 335.

CHAPTER VI

METHODS OF WORKING

The Two Main Systems.—Broadly speaking, there are two systems of mining coal, called "bord and pillar," and "longwall." Outside the North of England and Scotland the former is but little practised in Great Britain, while the latter, which originally took its rise in the Midlands, is very extensively applied. Endless modifications of each system are employed, and the two gradually merge into each other, until it becomes impossible to say to which system some methods belong. The tendency of the present day is to employ longwall more and more, and this method is slowly but surely superseding every other one. There are, however, some seams which it would be impossible to work longwall—that is to say, at any reasonable cost.

Shaft Pillar and Subsidence.—It is necessary that a certain area of coal around the shafts should not be worked, but should remain to afford support, and to prevent any risk of what is known as "creep." It is impossible to give any general rule by which the size of shaft pillars for given depths may be determined. Everything depends on the nature of the beds overlying the seam, the inclination of the strata, the nature of the floor and roof, and the stowing of the excavation.

It is hard to prevent creep in seams having a soft floor, especially if water is present. The pressure on the pillars of coal forces up the soft underclay in the roads between the pillars. When once this action commences it is most difficult to stop, or to keep the roads open; everything seems to be on the move. Perhaps the only method of prevention in longwall work, is efficient and close packing; leaving large pillars is not sufficient, as Mr. J. A. Longden* mentions an instance of a Derbyshire colliery, 520 yards deep, where the shaft pillar was 260 yards broad by 800 yards long, the mine being flat, and yet creep came on so seriously that great fears were entertained that the shaft would be lost. The pit bottom arching had to be put in three times, finally with layers of oak and brickwork alternately.

The working of beds of coal always lowers the overlying strata, giving rise to what is known as "subsidence." A certain height is taken out, and, although the excavation may be filled with material, such packing, even at the best, is loose compared with the solid coal originally existing. The gob is compressed, and the overlying strata and the surface sink down. If the area of subsidence was limited to the strata immediately above the area worked, the problem of determining its direction, if not its amount, would be easy; but even in level measures the disturbance extends beyond the limit of the excavation.

* *Brit. Soc. Min. Stud.*, xii., 127.

With inclined seams the fracture of the beds *never* takes place in a vertical direction, but always in a plane approaching the perpendicular to the inclination of the strata. Mr. Callon * advocated the theory, known as that of the "normal," that subsidence takes place at right angles to the planes of stratification, and extends, without sensible diminution in amount, right up to the surface, whatever may be the depth of the beds. He points out that in seams worked by longwall with complete stowing, the maximum subsidence commences at the centre of the excavation, and gradually extends to the boundaries, when the fracture of the bed immediately above the seam takes place at the points where it is supported on the solid strata. The loosened mass then leaves the bed above it and sinks down on to the stowing below, and a similar process takes place with each successive bed right up to the surface. When unconformable strata overlie the lower measures the direction of the lines of fracture will be considerably altered, as each bed will break at right angles to its bedding plane (Fig. 193). In pillar workings without gobbing the roof falls and fills up the excavation, and the amount of subsidence depends on the compressibility of the débris. With very hard rocks, and a moderate depth, pillar working might cause less subsidence than longwall with complete packing. In the case of hard rocks a bell-shaped cavity, narrowing upwards, will be formed by the breaking down of the roof, while, with soft and non-coherent strata, the cavity will be funnel-shaped.

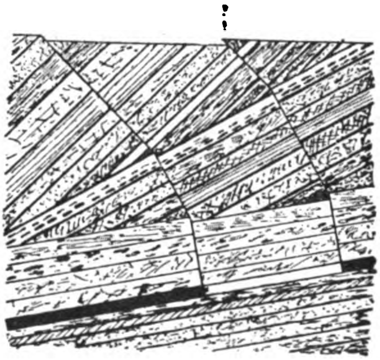


Fig. 193.

Owing to serious subsidences taking place in the neighbourhood of Liége, Mr. G. Dumont was commissioned to inquire into the matter, and, after an exhaustive examination of the district, drew up a report covering over 300 pages of a quarto volume † giving unqualified support to the theory of the "normal," except for seams lying at a greater angle than 68°, because, in the latter, the intensity of the pressure is diminished by the friction due to the obliquity of direction which the broken fragments must take. Thus, if *a b* (Fig. 194) represents the weight of the broken block A B, this force may be resolved into *a c* and *a d*. The greater the inclination the less becomes the force *a d* acting at right angles to the bedding planes, and totally disappears when they are vertical. Experience seemed to demonstrate that when the angle of inclination was 68°, *a c* was equal to *a d*.

Unfortunately, the correctness of Mr. Dumont's deductions is questionable, because the difficulties of observation were increased by the presence of old workings and of the workings of several collieries within a very small area. The Colliery Owners' Association drew up

* *Lectures on Mining* (English translation), ii., 306.

† *Des affaisements du sol produits par l'exploitation houillère*, Liége, 1871.

a reply * admitting that the "law of the normal" may hold good where the seams are of small inclination, but arguing that the propagation of a fracture following the normal of the stratification of highly-inclined beds is a mechanical impossibility. They considered that the fracture at the lower extremity of the working will take place in inverted steps, and the fracture at the upper extremity will resemble a flight of steps viewed from below, while the average inclination of these steps will fall between the normal and the vertical (Fig. 195), approaching the one or the other according to local circumstances. They also remark that in steep seams † account must be taken of the fracture by crushing, which, according to Coulomb, occurs at an angle of 45°. The combination of this force with that tending to break the bed by bending, induces fracture along a line intermediate between the

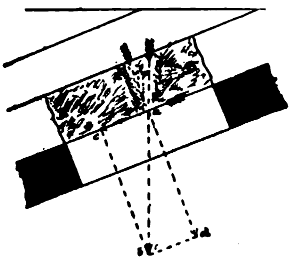


Fig. 194.

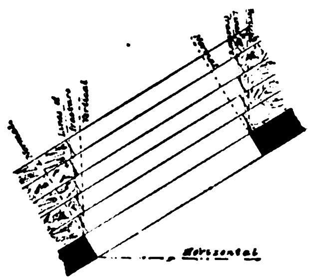


Fig. 195.

two directions, and such line goes further from the normal as the inclination of the strata increases.

The diversity of opinion among engineers led Mr. H. Fayol to review the whole subject, ‡ and to conduct a series of observations both on ingenious models and on actual subsidences due to working seams of coal in cases where such observations could be made free from all complications. He commenced by summarising the contradictory opinions that have been expressed, for example :—

(1) Upon the extension of the movements upwards—

(a) The movement is transmitted to the surface whatever may be the depth of the workings.

(b) The surface is not affected when the workings exceed a certain depth.

(2) Upon the amplitude of the movements—

(a) Subsidence extends to the surface without sensible diminution.

(b) Movements become more and more feeble as they extend upwards.

(3) Upon the relative positions of the surface subsidence and the mining excavation—

(a) Subsidence always takes place vertically above the workings.

(b) Subsidence is limited to an area bounded by lines drawn from the perimeter of the workings, and perpendicular to the beds.

(c) Subsidence cannot be referred to the excavation either by vertical lines, or to the normal of the beds, but only to lines drawn at an angle of 45° to the horizon, the angle of repose of the ground, or some other similar angle.

* *Des affaisements du sol attribués à l'exploitation houillère*, Liége, 1875.

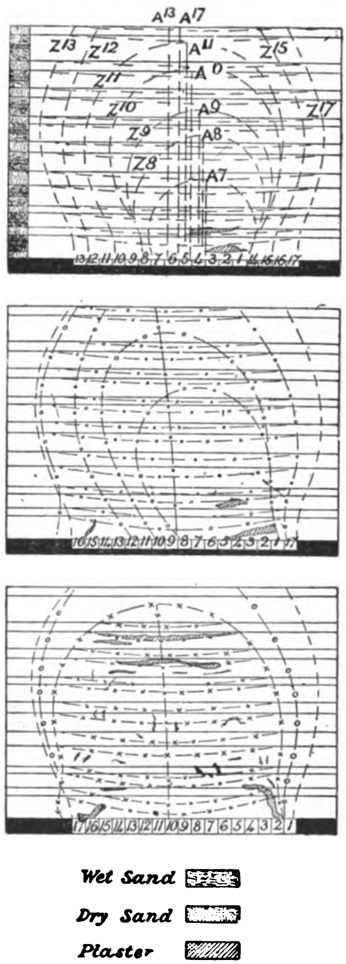
† *Op. cit.*, 108.

‡ "Note sur les mouvements de terrain provoqués par l'exploitation des mines," *Soc. Ind. Min.* (2e Série), xiv., 805.

(4) Upon the influence of gobbing—

(a) The use of packing protects the surface effectually.
(b) Packing simply diminishes the effect of subsidence.
(c) Subsidence is greater with stowing than without it.

Mr. Fayol points out that the theory of the normal is based on the erroneous supposition that beds *break* at right angles to the planes of stratification and at the perimeter of the excavation, but from actual experiment he found that in 80 per cent. of the observed cases the plane of fracture was an inclined one, and adds that although opinions are greatly divided these differences are more apparent than real. They are the result of generalising from single facts which are only particular cases of the following rule :*—*In stratified deposits the zone of subsidence is limited by a sort of dome which has for its base the area of excavation; the extent of the movement diminishes the further one goes away from the centre of that area.*



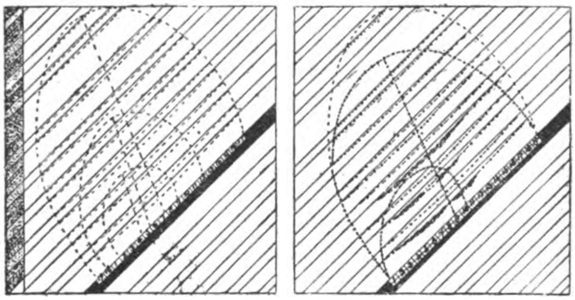
Figs. 196, 197, and 198.

Not only were careful observations made of the extent and amount of subsidence produced in working the mines at Commentry, but, in addition, the following experiments were made on models to reproduce on a small scale movements in the overlying strata caused by working seams of coal, in such a manner as to be able to observe the progress of events. On the bottom of a wooden box having a glass front were placed, side by side, small pieces of wood of equal thickness, about an inch wide, and as long as the width of the box; several rows of these small pieces of wood were sometimes placed one above the other. Upon them were laid successive beds of artificial strata, varying from $\frac{1}{24}$ inch to an inch or more in thickness, consisting of earth, sand, clay, plaster, or other materials. To enable the least movement to be

* This paper is the most important one which has been published on the effect of coal-working on the surface, and throws considerable light on what is perhaps the most intricate problem in mining, and about which few facts are known. A careful summary of it, and also of Mr. Dumont's memoir, by Mr. H. F. Bulman, is given in *Journ. Brit. Soc. Min. Stud.*, vol. xii., 1890, and by Mr. W. Galloway in *So. Wales Inst.*, vol. xx., 1897.

followed, small pieces of paper (about $\frac{3}{8}$ inch long) were laid in the planes of stratification, and ink lines were drawn on the glass front of the box exactly covering the lines formed by the paper strips. When the small pieces of wood were withdrawn one by one, excavations were formed and movements produced in the artificial strata.

Fig. 196 represents the effect produced in the overlying beds by taking away in the order indicated by the numbers the upper row



Figs. 199 and 200.

of wooden pieces, which were each about 0·4 inch thick. The original level of the beds is shown in full lines, and the amount of subsidence in dotted ones. After the seventeenth pillar is removed the beds have become bent, as illustrated, the limit of the movement being indicated by the curves Z^{13} and Z^{15}; the zone of sinking is an expanding dome, which increases as the area of excavation extends.

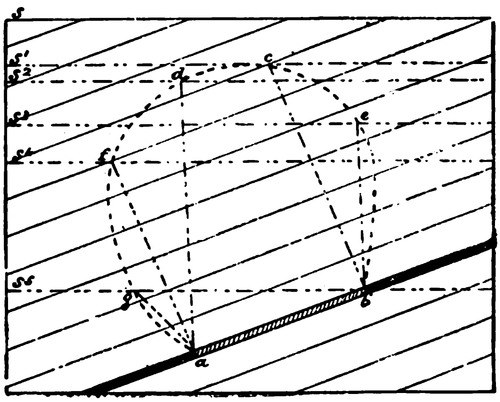


Fig. 201.

(The index figure on each curve is the number of the last pillar taken away.) The sinking of each bed takes the form of a basin, but diminishes regularly in proportion as it is higher above the excavation. The greatest deflection of the sunken beds are indicated by the lines A^7, A^{10}, &c., which nearly coincide with the axis of the domes. The shaded portions denote cracks and fissures.

The depth of the excavation was doubled by the removal of the second row of pillars in the order indicated by the numbers on Fig. 197, the subsidence produced being shown by lines so – o – o – o. The line of maximum deflection did not remain vertical, and some of the domes were inclined. The amount of subsidence was greater in the lower beds, but not at the surface, while the limit of the movement did not extend so far as when the first row of pillars were withdrawn, the boundary of the latter being indicated by a plain dotted line.

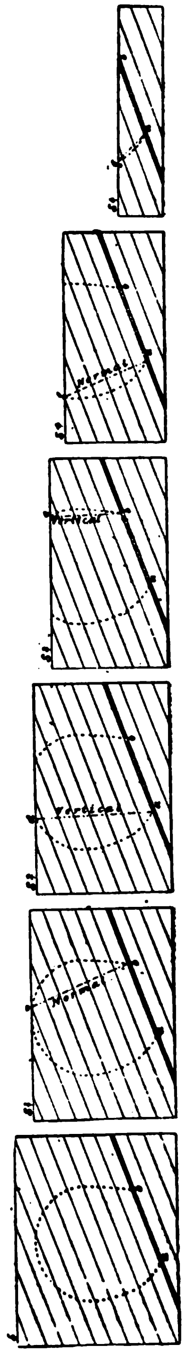
The removal of the third row of pillars (Fig. 198) did not produce either so much movement vertically or laterally as was occasioned by the first or second set, but the number and extent of the cracks and fissures were considerably increased. In this figure, the subsidence caused by the removal of the pillars is shown thus:— the third row, - x - x - x; the second row, o – o – o – o; the first row, – – – – – –. In similar experiments, however, the settlements produced by removing the second and third rows of pillars were greater than those occasioned by the removal of the first.

Similar experiments conducted on inclined beds are illustrated in Figs. 199 and 200, showing the amount and extent of the subsidence caused by removing two rows of pillars in the order indicated by the numerals. The line of greatest deflection was always between the vertical and the normal to the strata, and it departed further from the normal in proportion as the beds became more inclined. This conclusion agrees with the one expressed by the Liége Colliery Owners previously referred to.

As the domes extend outwards over the area excavated, a pillar of coal left for surface support must be made large enough to prevent any chance of the two overlapping domes touching each other or subsidence will take place at the surface *above* the pillar.

If the beds are horizontal, the dome is arranged symmetrically round its axis, which is vertical. Each of the beds included in the dome sinks in the form of a basin, and the extent of the movement diminishes in proportion as it is further from the centre of the excavation. If the beds are inclined the dome is no longer symmetrical, and its axis is inclined.

The theory of the dome reconciles many of the contradictory opinions which have been expressed on subsidence, and explains how observations which seem to be diverse from each other



Figs. 202 to 207.

are not really so. The position of the subsidence varies according to the depth of the excavation below the surface. For instance, in Fig. 201, the working of the area *a b* will produce a movement in the overlying strata limited by the dome *a b e d g*. When the surface level is at *s* there is no appearance of subsidence, but if s^1 represented the level of the surface, there would be a small subsidence, limited on the right-hand side by the normal *b c* drawn from the highest part of the excavation. On the other hand, if the surface level be at s^2, not only will subsidence take place along a certain area over the workings, but the limit of the movement on the left-hand side will be at *d*, a point *vertically* above the edge of the excavation at *a*. At surface level, s^3, the boundary of the subsidence will be at *e* vertically above *b* on the one side, and somewhere between the vertical and the normal on the other side. If the surface level existed at s^4, subsidence will be found on the left-hand side above the line *a f*, which is normal to the inclination of the seam, and at an angle larger than 90° on the right-hand side of the workings. Finally, if the depth from the surface to the workings be represented by the line s^5, subsidence takes place on the left-hand side along the line *a g*, which makes an angle of 45° outside the normal. Figs. 202 to 207 have been prepared, in order to enable the student to clearly understand this reasoning. They are reductions from Fig. 201, with each successive layer of strata removed. The position and effect of the movements at the surface are thus clearly dependent on the depth of the workings, provided the strata are conformable, and not interfered with by faults.

The amount of subsidence is dependent on the nature of the overlying rocks, the depth of the excavation below the surface, the thickness of the seam, and the nature of the material used for packing or stowing. The compressibility of different materials varies, and subsidence will naturally be less in extent and more gradual over portions carefully packed with hard compact sandstone than where the stowing consists of soft shales. In order to determine the amount of compression, which rocks previously broken will undergo under various pressures, Mr. Fayol made a number of experiments which are summarised in the following table *:—

	Volume before being broken.	Rocks previously crushed or broken, volume remaining under pressures of			
		1422 lbs. per sq. inch.	2844 lbs. per sq. inch.	7100 lbs. per sq. inch.	14,220 lbs. per sq. inch.
Clay, . . .	100	100	90	75	70
Shale, . . .	100	128	116	110	97
Sandstone, . .	100	136	125	120	105
Coal, . . .	100	130	125	118	109

These pressures correspond approximately to depths of 546, 1092, 2730, and 5460 yards. It is difficult, however, to give any rule as to the amount of shrinkage which will take place in the ordinary stowing of a mine, because of the irregularity of the excavations, and of the

* *Loc. cit.*, 816.

fact that a large proportion of empty spaces remain unfilled in spite of the greatest care. At Commentry, above goaves without stowing at depths less than 328 feet, and in seams from $3\frac{1}{4}$ feet to $8\frac{1}{4}$ feet in thickness, subsidences varying from 0 to 80 per cent. of the height of the excavation have been observed; above goaves with stowing at depths included between 165 and 820 feet, subsidences have varied from 0 to 50 per cent. of the height of the excavation; at some points above the main seam, where from 65 to 82 feet of coal was removed, the ground sank 33 feet. Mr. S. R. Kay * mentions a subsidence of 70 per cent. over a 5-feet seam at a depth of 360 feet, and of 64 per cent. over a $3\frac{1}{2}$-feet seam at a depth of 990 feet, which are larger than expected, although experiments at Bent Colliery † on a 5-feet seam worked on the bord and pillar system without stowing, proved a *maximum* subsidence of 73 per cent.

At Montrambert and La Béraudière a shrinkage of only 30 per cent. took place, but this low result is possibly due to the peculiar method of working. At Bully Grenay, after six seams of a total average thickness of 29·36 feet had been worked with stowing, the total subsidence was 13·61 feet, equal to 46 per cent. In South Staffordshire, thick seams at comparatively shallow depths are worked beneath canals and railways, without any especial precaution, except in so far that the embankments of the canals are raised and repuddled, and the bottom filled in as subsidence takes place. In such a manner 30 feet of coal has been taken out at a depth of only 432 feet, the subsidence produced being $13\frac{1}{3}$ feet, equal to 44·4 per cent. All the time workings were taking place water remained in the canal, and traffic was not interfered with except on two occasions, when subsidence took place so rapidly that the staff of workmen employed could not raise the puddle quickly enough to keep pace with the movement, and the water had to be temporarily run off to enable them to do so.

The varying results above-mentioned may possibly be due to the fact that observations have been made at different points over the excavation. In every observed result, subsidence has always been greater at the centre than at the sides of the workings. When the seams are inclined, shaft pillars require to be larger on the rise side than on the dip. Mr. Longden‡ recommends for level seams, the leaving of 1 yard in breadth for each yard in depth—that is, a shaft 200 yards deep should have a pillar 100 yards radius or 200 yards diameter. This is an excessive amount, but the error is on the safe side.

Mr. Joseph Dickinson § considers that the direction of subsidence may be judged of from the slopes taken by faults and mineral veins and by analogy. The slope of a fault in horizontal strata averages about 1 in 3·07 from the perpendicular, varying according to the hardness and cohesion of the strata from about 1 in 5 in hard rock to 1 in 3·75 in medium, and 1 in 2·5 in soft. He considers that for horizontal seams not exceeding 6 feet in thickness, and with strata of the average hardness of those in Lancashire, ordinary subsidence may be taken as extending on all sides to one-tenth of the depth, and that to obtain security a margin should be added. This margin is limited by

* *Inst. C.E.*, cxxxv., 117.
† *Min. Inst. Scot.*, vii., 230.
‡ *Brit. Soc. Min. Stud.*, xii., 128.
§ *Man. Geo. Soc.*, xxv., 600.

some engineers to an additional one-tenth of the depth, while others add an arbitrary amount. Where the strata are softer the extent of the subsidence is sometimes taken at one-sixth, or even one-fourth of the depth to the working, while on the other hand, for hard siliceous, rock such as is met with in South Wales, reductions are needed. He also agrees with other writers, that in seams of moderate inclination larger areas are required for support on the rise side than on the dip. A series of diagrams accompany the paper showing some of the suggested methods for defining areas for support with strata of average hardness lying at varying inclinations.

Observations on the rate of settlement at eighty-two different points have been carried out systematically at Zwickau, by Mr. C. Menzel,* who states that the relation between the surface depression and the thickness of the seam varies between 1 : 1 and 1 : 7, but in the larger number of instances it ranges about 1 : 2. He states that for depths between 350 and 400 yards the relation between settlement s, thickness m, and depth t in yards, may be expressed as follows:—

$$s = \frac{t + 350}{350m},$$

but for greater depths he considers that 400 will be preferable to 350, as probably more correct.

The occurrence of faults must be carefully noted, as where they cross the area affected, the lines of subsidence are deflected and pass along them. Being lines of fracture themselves, they introduce planes of easy sliding, along which movements may be transmitted to considerable distances, and in contrary directions to what may otherwise be reasonably expected. Sometimes they extend, and at others diminish, the area of surface affected. Fig. 208, which is an example from actual practice, illustrates the former case, where a valuable building standing on the line of fault was damaged by the workings of a seam of coal 3 feet thick.

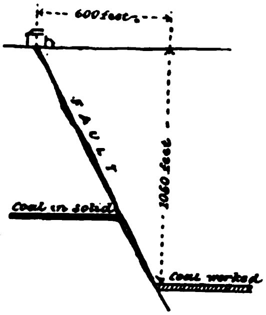


Fig. 208.

Where the regular beds are covered with a layer of drift of a soft, loose, sandy material, the area of subsidence may be unlimited, especially if the deposit contains water, as the movement has a tendency to expand outwards, the beds sinking along the angle of repose. Fig. 209 from Dumont's memoir† illustrates the probable effect on a row of houses, resting on a soft stratum, of the excavation of an area, *a b*. The houses at both ends will be moved towards the centre, and those in the middle crushed. The fractures in the buildings follow in preference the weakest paths, and their direction is different on opposite sides of the excavation. Indeed, the inclination of the cracks is characteristic of the direction in which movement takes place, and affords a ready determination of the point from which subsidence is being produced. In one actual case with workings at a

* *Inst. C.E.*, cxl., 331.

† *Op. cit.*, 70.

depth of 860 feet, buildings were considerably damaged at a distance of 660 feet from the limit of the excavation, in spite of the fact that the seam dipped at a gradient of 1 in 10 from the houses.

The drainage of old workings, or the flooding of a mine, may set up fresh movements a long time after the original ones have ceased.

Reduction of Subsidence.—Careful and efficient stowing is the only remedy. One of the most interesting experiments of modern mining has been tried with success near Shenandoah City, Pennsylvania, at the Kohinoor Colliery. It consists in the filling in of the breasts or stalls with a mixture of small waste coal from the culm heaps, and water. At first, the method was introduced for the purpose of preventing the subsidence of a large house in Shenandoah City, beneath which a chamber 700 feet long, 300 feet wide, and 60 feet high, was found to exist. An 8-inch bore hole was drilled from the surface into the cavity, and down it was poured a thick mixture of small coal and water. The former was obtained from a neighbouring waste heap, and was carried to the top of the bore-hole by an ordinary push plate conveyor, working in a semi-circular trough. At the top of the bore-hole a stream of

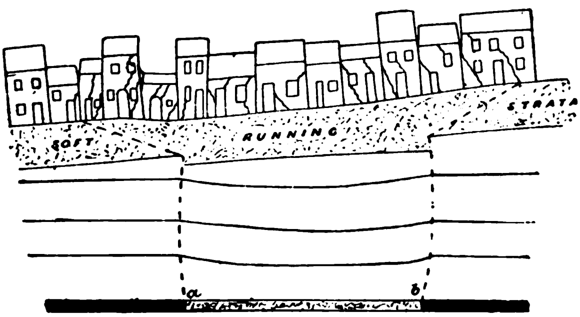


Fig. 209.

water met the small coal and carried it into the excavation. Only a small quantity of water is required, and this readily drains away, leaving the small coal packed into heaps underground. Not only has this reduced the area of ground required on the surface for waste heaps, but experience has proved that the packing thus introduced sets so solidly, that after a short interval roads may be driven through it, and the coal previously left in ribs can be mined, thus increasing the amount won.

This practice introduced to prevent subsidence, is now carried on as a method of packing to increase the yield from a given area. Up to the time of the author's visit, thirteen bore-holes, 8 inches diameter, varying from 308 to 398 feet in depth, had been put down at various points during the six years the system has been in operation. The annual cost is about £2,000, half the expense being borne by the colliery company and half by the lessor. The bore-holes are located on the apex of anticlinal ridges, and each one will fill an area of about 4 acres. The sludge takes a natural angle of about 5°. The present length of conveyors is about 1600 feet, in five sections. The engine supplying power is direct-acting, and has a cylinder 18 inches diameter by 36 inches stroke, while the pump delivering water is 9 inches diameter by 38 inches stroke. Two locomotive boilers, carrying 90 lbs. pressure, supply steam for the entire plant.

Arrangement of Labour.—Before describing the methods of mining, some reference should be made to the two systems under which the labour is carried out. In one, the miner not only gets the coal, but carries out odd work, such as packing, repairs to roadways, &c., while, in the other, a skilled class of colliers are employed simply as hewers at the face, all dead work being performed by separate staffs of men. In the latter system the labour is subdivided, each class of men carrying out special duties.

If the hewers are employed solely at the face, a larger tonnage is produced per man, and hence less extent of workings is required, with a corresponding reduction in the cost of maintaining a smaller area under timber. The face moves faster, the weight has less time to break up the coal, the roof is always "green" (or fresh), and there is consequently less liability to accident.* Except under special circumstances, coal is invariably mined cheapest where the face travels fastest; the exception is a seam having a very strong roof and floor, as here it is possible to move too fast.

The division of labour does not actually produce more coal with fewer men, for other colliers have to be employed to perform the work the hewers originally did. The old out-put is, however, produced from a smaller extent of workings; and, on an average, about one-half of colliery cost accounts are capable of reduction in proportion as the output is increased, and the area from which it is produced is reduced. So far as maintaining roads is concerned, the chief point is to see that the gob is carefully packed, and that all props are removed, so that the roof can settle and not break down.

The above observations do not apply so strongly except in such places where, from the nature of the roof and the seam itself, the amount of repairs is large, and keeps the miner away from the actual coal-getting for a considerable part of his time. Timber drawing is certainly best performed by a separate staff of men, who should, preferably, be set the work by contract.

Bord and Pillar Working.†—After driving out the main roads, the first operation is to divide the coal into a series of rectangular blocks (Fig. 210) by means of drivages, called "bords" and "walls," the line of the latter being generally spoken of as "headways course." The bords are driven from 4 to 5 yards wide, and always in a direction at right angles to the cleat of the coal, or, as it is generally termed, "on the face"—that is to say, the working faces of the bords are parallel with the lines of cleavage of the coal. Headways course is at right angles to these, or, in other words, parallel with the cleat, so that the working face in the walls is at right angles to the cleavage planes, and as the cleat runs approximately north and south in the North of England coalfield, headways course is generally taken to mean north and south, and bordways east and west. As a rule, walls are driven about 2 yards wide, but sometimes both bords and walls are driven 5 yards wide, and the roof allowed to fall.

The first procedure is to drive out the main roads. At large

* *So. Wales Inst.*, xv., 114.

† Also known as "post and stall," "pillar and stall," and in Scotland as "stoop and room."

collieries there are usually four proceeding at once, two intakes and two returns. Before these roads have gone far, bords and walls can be commenced on either side of them, leaving, however, sufficient coal on both sides to prevent any risk of creep. At one time, the pillars which were cut off by the bords and walls were made only just large enough to keep the roof up, and were left. The walls were as little as 12 to 15 yards apart, and the bords turned out of them commenced at 3 yards wide and were gradually widened out, until at the centre of the pillar only a thin piece of coal remained. As the bords approached the other wall they were narrowed down again. As much as 35 per cent. of the coal was lost. This has been quite abandoned, and the pillars are now made very large, quite a common size being two, and often three, chains square. They should be made of such a size as to prevent the risk of creep when the floor is soft, or of the cracking and fissuring of the coal, known as "thrust," which happens when both floor and roof are hard. There does not, however, appear to be any common system regulating the dimensions of pillars, as nearly every conceivable size and shape can be found in practice, the procedure at each colliery depending on the individual opinion of the manager. Mr. Atkinson, in a report to the New South Wales Government, quotes numerous instances in seams varying from 2 feet 2 inches to 8 feet thick and at a depth varying from 210 feet to 1800 feet, where amounts of from 59 to 95 per cent. of the coal is left in pillars after the bords and walls have been driven. In the best modern practice, never more than 30 to 35 per cent. of the coal is removed in the "whole" workings. If more than 40 per cent. is taken out there is great risk of "creep," while, if 50 per cent. is removed, the latter catastrophe seems inevitable.

It was customary some time ago to work these pillars years after they had been formed, but it is now more common to commence to remove them after a very short interval, before the roof has had time to settle down, and while the driving of bords still proceeds only a short distance away. In this manner the percentage of large coal has been materially increased, and the pillars are scarcely crushed at all, this being especially noticeable where both the coal and roof are tender. The work is concentrated, ventilation is easier, and the dead charges are reduced, for the roof has rarely fallen in the bords or walls, and, consequently, no cost is incurred for ridding or cleansing them. Indeed, "ridding" out the fallen roof is seldom resorted to where the breakdown is serious, because no coal is obtained by the operation, and, consequently, the whole of the cost is dead loss. Where the roof has fallen, a narrow place is generally turned away skirting the débris.

Another practice which was introduced by the celebrated viewer Buddle, about the beginning of the century, is the method of dividing the colliery up into what are known as "panels," or "districts" (Fig. 210), these consisting of an area of from 30 to 40 acres, surrounded on all sides by a rib of coal, called a "barrier," these barriers being holed through at points where roads are necessary. This system of panels is particularly advantageous with a tender roof and soft floor; only a small area of the seam is opened at once, the roof does not weight so badly, nor require so much timber, and more round coal is produced. In addition, the risk of creep is, to a certain extent, prevented, or it may be confined to the panel in which it arises. The risk of explosion is decreased, as each district has its own current of air, and should anything happen in one, there is a smaller probability of it extending to the others.

The preliminary work of driving the bords and walls is called "working in the whole," the removal of the pillars, which follows

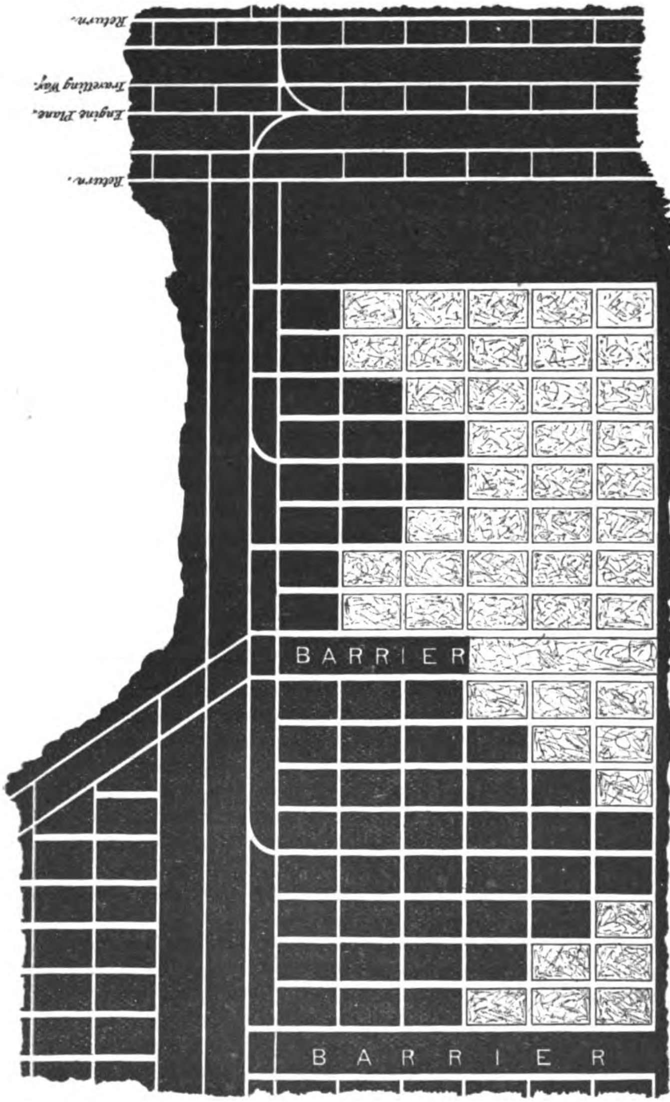


Fig. 210.

afterwards, "working in the broken." In the latter it is of the utmost importance that a proper line of operations, usually a diagonal one, should be adhered to, as if portions of a pillar lag behind, or become surrounded by broken workings, the coal is very much crushed, and quantities are very often lost. The tonnage price paid for getting the coal in the whole is always larger than that paid in the broken. The working of the "broken," immediately following the "whole," seems desirable in every case, except where the seam makes a lot of gas, and has a hard roof that does not fall readily, because under these conditions large open spaces are formed and filled with gas, and this gas may be suddenly driven out into the airways when the fall of roof does happen.

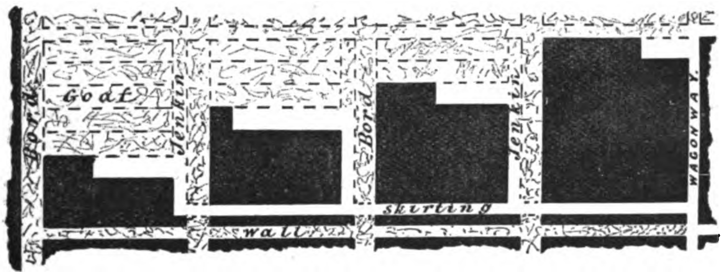


Fig. 211.

The removal of the pillars is carried out by a series of drivages, technically called "jenkins" and "skirtings;" the former is a place driven in a pillar in a bordways direction, while the latter is a similar place driven headways way, although, as a rule, any place driven alongside the fallen roof is called a skirting. At Eppleton Colliery the pillars, which are 44 yards by 33 yards, are worked by driving a fast skirting out of the waggon-way, the length of four pillars, as shown in Fig. 211, leaving 6 feet of coal against the fallen roof in the headways. A jenkin is then carried up the pillar alongside the old bords, and then lifts or "juds" are driven right across, these being 5 yards wide. As soon as one of these reaches the fallen roof on the west side of the pillar, a second is commenced out of the jenkin. Several pillars are attacked at the same time, the lifts in each lying back in step fashion, as shown. The roof is kept up in the juds by a series of chocks or cogs, formed of timber 22 inches long by 4 inches square, placed 4½ feet apart, and, say, 6 feet from the coal side. The space between the loose side and the chocks is secured by ordinary props and laggings, these, except three rows at the face, being drawn every night and the roof allowed to fall behind.

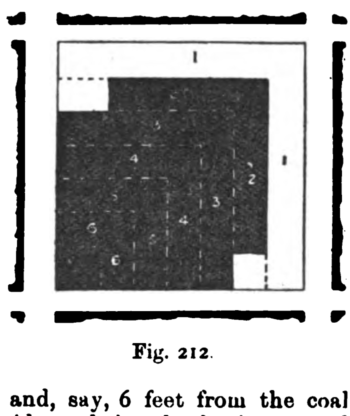


Fig. 212.

With pillars 44 yards square at Murton Colliery in a seam 4½ feet thick and 490 yards deep, lifts of equal width are driven simultaneously from the bord and the wall until they meet, when second lifts are commenced by the side of the first (Fig. 212).

Further lifts are taken as indicated by the numerals, and the square shape of the pillar is thus retained until the end.

At Eppleton Colliery, with large pillars 66 yards square, the process of removal is carried out by driving a jenkin up the middle, splitting the pillar into two halves, and then taking 5-yard lifts right and left. This is the system recommended by Mr. G. C. Greenwell. If the pillars have, in the first instance, been made large enough, he says the whole of the wings on each side may be brought back simultaneously, chocks being used in double rows for the support of the roof, the back row, or that next to the gob, being shifted between the front row and the coal as the face advances.* The numerous methods of removing the pillars in the northern coalfield, under the varying conditions met with in different seams, have been described by Messrs. R. A. S. Redmayne and H. F. Bulman in two excellent papers, to which the student is referred for further particulars, † but the latter differ from Mr. Greenwell, and state that the system most in favour, and most generally adopted, is that of driving lifts right and left, from every headways course halfway across the pillar.

In Fifeshire, where the pillars are from 30 to 50 yards square, they are often removed by driving roads through the centre of the pillar both ways, cutting it into four pillars, which are taken out in turn.

The objections to the bord and pillar system are the difficulty of ventilating the workings, the amount of coal which is lost (a thin piece has always to be left on the sides of the bords and walls which are fallen), the small percentage of round coal produced, and the large charge for narrow work.

With the exception of wide bords, not only has a yardage rate to be paid on narrow bords and winning headways in the whole, in addition to the tonnage price, but the skirtings and jenkins in the broken are also subjected to a yardage rate. In order to give the uninitiated reader some idea of these charges, Mr. Redmayne ‡ quotes the following prices, which are a fair average of those generally paid, although rates vary with differences in the seam and at different collieries :—

					s.	d.	
Whole Work:	Winning headways,	2	yards wide,	. . .	1	10	per yard.
	,,	3	,,	. . .	1	3	,,
	Walls, N. and S.,	2	,,	. . .	1	9	,,
	,, ,,	3	,,	. . .	0	6	,,
	Bords,	2	,,	. . .	1	4	,,
	,,	3	,,	. . .	0	10	,,
Broken Working:	Skirtings,	2	,,	loose at an end,	0	7	for 10 yds.
	Jenkins,	2	,,	fast at both sides,	0	9	,,
	,,	2	,,	loose at an end,	0	7	,,

It is also obvious that the driving of so many narrow places, and the cutting-up of the mine into a number of comparatively small blocks, must reduce the percentage of round coal, and increase the quantity of slack; while if the pillars stand any length of time after they are formed before being worked, their corners and sides invariably become crushed and fissured, with the inevitable result that further quantities of small coal are produced.

* *Mine Engineering*, 200. † *Brit. Soc. Min. Stud.*, ix., 101 and 174.
‡ *Loc. cit.*, ix., 107.

Lancashire Method.—In the Lancashire coalfield, with steep seams dipping 1 in 3 to 6, a system is employed resembling both bord and pillar and longwall. A pair of roads are generally driven from the shaft direct to the deep, and out of these, levels, 30 yards

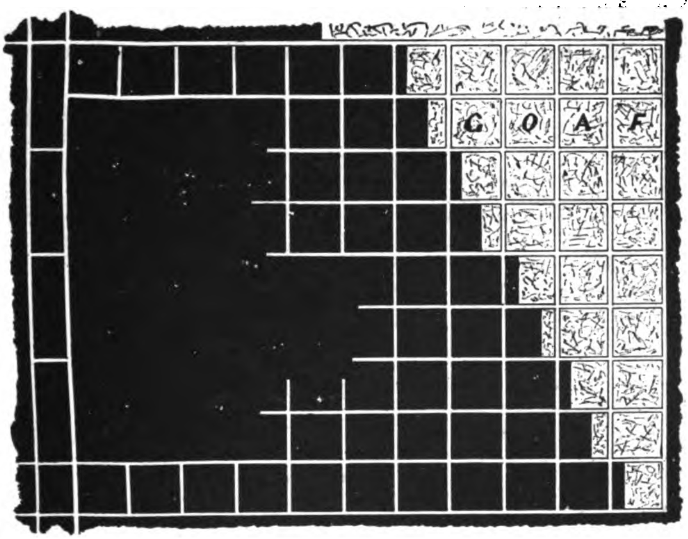


Fig. 213.

apart, are driven to the boundary (Fig. 213). Each pair of levels are somewhere about 200 yards apart, and the coal is left solid between. On reaching the boundary, the two sets of levels are connected by a road, and the coal between is divided up into pillars by a series of drivages crossing each other at right angles. All the pillars are not cut off before commencing to remove the coal, but are gradually formed, leading the face as shown by the illustration.

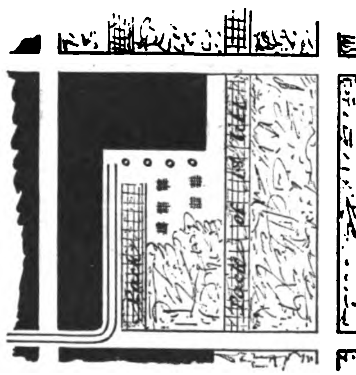


Fig. 214.

The pillars are removed by lifts taken uphill. These lifts vary from 12 to 15 yards wide, and are taken forward like a longwall face. A line of rails is carried by the side of the solid coal, and a pack-wall built on the other side (Fig. 214). Two rows of chocks, about 2 yards apart, are always kept parallel with the face, and at the same time a third row, 6 feet further back, is being withdrawn, trees or props being set all round them while such is being done.

In some instances the pillars are cut off much larger, and are removed by lifts as before, but here several proceed at the same time, one leading the other, the face having a stepped appearance similar to Fig. 225.

Longwall Method.—In this system the coal is extracted in a long face, which is gradually moved forwards. The space behind the working is filled in with packing, and what are called "stall roads" are made into the face at intervals. These stall roads are cut off at regular distances by levels, generally branching obliquely out of the

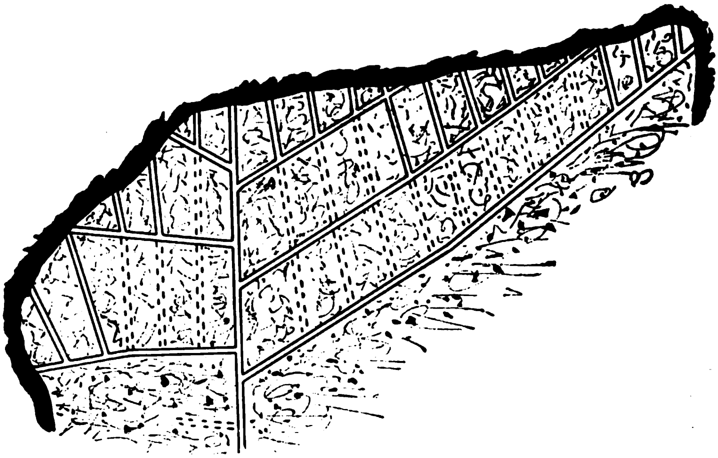


Fig. 215.

main roads; by such means the length of gob roading to maintain in repair is kept within reasonable limits, and, in addition, the distance which the coal has to be hauled is reduced. This is the ideal longwall, and its carrying out in practice is well represented by Fig. 215, which is a reduction of a portion of the working plan of a colliery. The working roads through which coal is drawn are shown in full lines, while those which have been cut off and abandoned are represented by dotted ones.

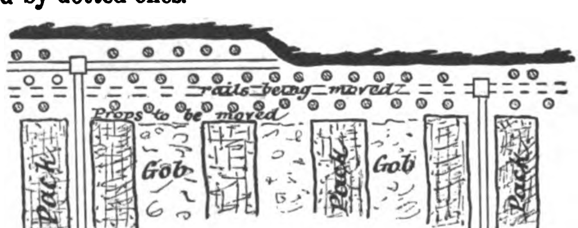


Fig. 216.

The system of working is very easy, the miner undercuts the coal all along the face, supporting it in the meanwhile on sprags. The roof at the rear of the workmen, where the coal has been got down, is generally kept up by a double row of props, those in one row alternating with those in the other. Behind these comes the goaf pack. When the sprags are taken out, the coal is either shot down or falls on its own account. It is loaded up into tubs, a line of rails being laid along the face; the rails have to be taken up and relaid with each advance. The details between two stall roads are shown in Fig. 216.

Perhaps a more vivid impression is given by the two photographs (frontispiece) taken in the mine by Mr. A. Sopwith, who has kindly allowed their reproduction here. The upper one shows the miner holing the face, with a cocker sprag on his right hand. The other is a view up the face, which is holed and ready to be got down, the miner in the foreground being engaged in drilling a shot-hole. The line of rails and cogging are clearly shown.

The weight naturally comes on along the line of face, and when this is continuous, as in Fig. 215, it is sometimes very expensive to maintain. In such cases, the stalls are often arranged to lead each other a short distance (Fig. 225). If the mine is level, the stall roads will be brought into the middle of each wall, but with inclined seams, they will be carried nearer the deep side, as this facilitates the removal of the coal. When the stalls are so arranged the weight is localised, and prevented from spreading all along the face. Several disadvantages are, however, introduced: supervision is rendered difficult, undercutting is not so convenient, one "fast" or cutting side is introduced, and machines cannot be employed. In addition, the pressure on the sharp corners is great and breaks up the coal there, producing a large quantity of small.

As a rule, the seam itself does not supply sufficient material to fill up the whole width across the face, and, in such cases, the packs are built leaving what are called "wastes" between. In seams liable to gob fires, the packs are best set draught-board style—*i.e.*, first a waste and then a pack, each waste being successively closed by having a pack built in front of it, wastes then being formed opposite the back row of packs. In this way, although the gob is not stowed solid, yet a continuous stopping of pack material is built across the face.

The stowing material is obtained, not only from the stall roads, but also from the main roads. As the gob gets compressed, the roof sinks down, and the roads become too low to allow the passage of men and horses. Recourse has to be made to what is known as "ripping," which consists in shooting down the roof stone until sufficient height is obtained. Part of this is always built on each side of the roads, while the remainder is carried into the face, and used there.

The direction of the face is determined by several conditions. In some districts divisional planes or "cleat" exist in the coal; they usually cross each other at right angles, but one set is always much better developed than the other. If the working face is parallel to the main cleat (Fig. 217), the coal is said to be "on the face"; if it is perpendicular to the cleat (Fig. 218) it is called "on the end"; while if another direction is followed, and the face advances obliquely at an angle of 45°, it is said to be "half on."

The main object of working coal is to produce the greatest quantity of large coal in the best condition, and this quantity and condition are materially influenced by the direction of the face respecting the cleat. In a longwall face, owing to the compression of the gob, there is always a considerable amount of weight on the coal at the face; such pressure, indeed, in many instances, gets down the coal without the aid of explosives.

If the coal is worked "on the face," the lines of fracture produced by the above-mentioned force coincide with the lines of cleat, and consequently the coal readily breaks. If the coal is a good strong hard variety, the labour of getting it is reduced, and the quantity of large coal is satisfactory; but if, on the other hand, it is soft, a large amount of small coal is produced. In such cases, it is far better that the coal should be got perpendicular to the cleat, or "on the end."

The direction of the face is, however, influenced by another point, namely, that of the inclination of the seam, which, in many cases, determines the direction irrespective of other considerations. In longwall workings, where the inclination is moderate, the direction of the face is generally at right angles to the dip, as all the weight is then thrown back on to the gob, the packs are easily and readily made, and the coal descends from the working places by the influence of gravity. Where the inclination is steep, the face will be carried half on—that is to say, at an angle of 45° with the inclination.

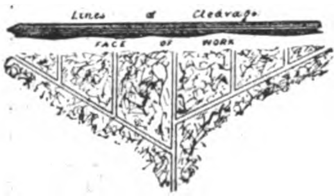


Fig. 217.

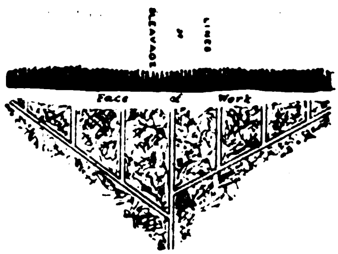


Fig. 218.

The application of the longwall system to seams varying in thickness, from 2 feet 9 inches to 8 feet, and in inclination from 14° to 20°, presents several difficulties which have been pointed out by Mr. E. B. Wain, who has described the methods adopted with success at Whitfield Colliery for overcoming them.* Not only is there a tendency for the roof to slip and break away from the face and take the working weight off the coal, but the packs on the higher side of the roadways are also disturbed by the slipping of the roof.

As soon as the preliminary headings have passed the limit of the shaft pillar, a certain amount of coal is worked out to the depth of the level, and after the first packs have been built, the opening out stall is carried forward nearly in the line of full dip. The amount of coal worked out below the level is often about 10 yards, but depends largely on the direction of the first breaks in the roof, and in order to make the area over which the first breaks occur, as large as possible, a certain amount of coal is also taken out from the rise side of the main level. As a result, the packs are compressed in their original position, and their tendency to slip down-hill is reduced. Fig. 220 illustrates in plan the details of opening out. Especial care is exercised in the building of the first packs. Chocks or cogs, 3 feet square, formed generally of old railway sleepers, are built along the

* *Fed. Inst.*, iv., 24.

higher side of the level at intervals of about 5 yards, and, as soon as possible, a temporary jig brow is put to work into the face, which must to a certain extent be worked concurrently with the opening out of the level, although, in order to keep the continuous line and direction of the face so necessary for the success of the system, it is moved as slowly as possible. Cross pack walls at right angles to the sides of the level are also formed, and are found to be a most important factor in preventing any downward slipping of the packs.

The coal is holed for a depth of from 4½ to 6 feet, and is commenced to be got down from each gate end. As soon as sufficient space is formed, holing re-commences. The line of face is arranged to dip slightly inbye, and the greatest care is taken to so arrange the packs and the timbering that sufficient travelling weight is kept on the face to break down the coal after it has been holed, without the

Fig. 219.

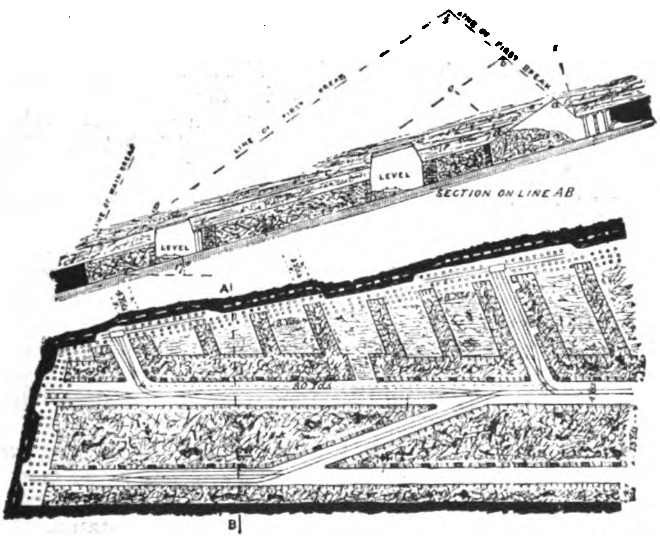


Fig. 220.

necessity of using explosives. The props must be set in proper line to assist in breaking the roof parallel to the face, and the three rows are set one behind the other exactly at right angles to the face, instead of triangulating them as is general in other districts. The packs are carried forward as near the face as possible immediately after the fallen coal has been loaded out; they are carefully built of the strongest available material, and are carried solid up to the roof and firmly wedged, but sufficient space is allowed between adjacent packs to allow the roof to break down in the wastes, and so relieve the pressure on the coal face.

The influence that the width of coal worked out below the level has on the proper settling of the roof will be understood from an examination of Fig. 219. If only a narrow breadth of coal is got out on the lower side of the level, when the road is ripped to make height, all lateral support is taken away from the mass of broken roof, *a b c*, which has a tendency to slip downhill. This tendency would also be increased if sufficient coal were not worked out *above* the level, as the roof would in such case break away along the line *d e*. By working sufficient coal away, both on the lower and upper sides of the level, the breaks are made to take the lines *a f* and *f g*, when the extra resistance to the sliding of the mass due to its greater base line, prevents any downhill movement and induces a more direct vertical pressure, which tends to consolidate the packs. The tendency of the roof to slip, is also reduced by building the pack on the higher side of the level, in such a manner that a greater resistance is offered to the pressure of the sinking roof on the road side, than on the rise side of the same pack.

The length of the stalls, or the distance between two roads, in any system of longwall mining is governed by a variety of circumstances:—

(1) If the coal is to produce its best yield and be worked economically, it is advisable that the face should move forward regularly every day, but if such is to be done, the distance between two stall roads must not be too long. In the Midlands, from 30 to 50 yards has, by general consent, been found to give the best results.

(2) On the other hand, the distance between the stall roads must not be too short. The more these roads are multiplied the higher is the expense of maintenance, because a greater length has to be kept open, and a further charge for the larger quantity of ripping required is also incurred.

(3) The coal has to be got out of the face into the roads, and unless the height in the stalls is such as will allow tubs to be brought in and loaded there, it is advisable that the stall roads should be as near together as possible.

(4) The stall roads must not be too far apart, as it is only possible to have two tubs in the stall at the same time—*i.e.*, one from each end. For a large output it is, therefore, necessary to either multiply stalls or decrease their length.

(5) The length of the stalls is also influenced in a very marked manner by the custom of the coalfield, as to whether the men work singly or in sets. In the Midlands, four or five men take a stall, and, consequently, its length is somewhere about as before stated. In the North of England every man is for himself, which necessitates the roads being close together, with a multiplicity of working faces; indeed, a common arrangement is that shown in Fig. 221, which can scarcely be called true longwall at all.* Headways are turned out of the main roads at intervals of 30 yards, and after they have been driven 10 yards, lifts 8 yards wide are taken right and left and carried 15 yards up, or half the distance between the headways. A line of rails is laid next the coal side, and a row of chocks on the other side. After the first lifts are driven up a few yards the winning places are widened out to 6 yards, and driven forward this width, stone packs 6 feet wide being built on each side, leaving a 6-feet road between.

By general consent, it is now admitted that in longwall every piece of coal, except the shaft pillars, should be taken out. At one time it was pretty common to leave pillars of coal on each side of the main roads, which were supposed to reduce the cost of repairs, and no doubt

* *Brit. Soc. Min. Stud.*, x., 192

did so when the mines were shallow. As they got deeper it was found that such pillars offered little protection, unless they were made inordinately large, and that better results were obtained by taking out the coal altogether.

The method of working that has been considered—viz., working away from the shaft, and carrying the roads through the gob, is the one followed in the great majority of cases; but another method, called "working homewards," is rarely employed, although it is often recommended as a cure for all evils relating to explosions. In it roads are driven out to the boundary, the coal first worked there, and gradually brought back towards the shaft, leaving all the gob, water, gas, &c., behind. It is scarcely necessary to say that, with anything like a large royalty, such a plan would involve the outlay of an enormous sum of money, as all the yardage in narrow work would have to be paid for practically before any coal was won. The output of the

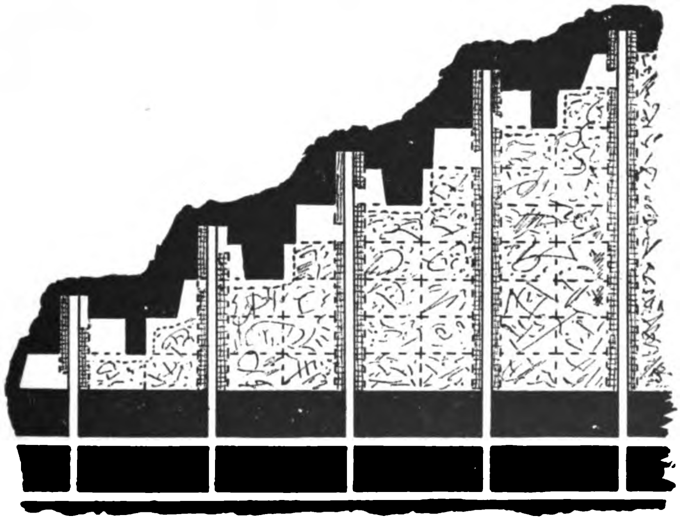


Fig. 221.

colliery would be a low one for many years, and the interest on capital outlay would more than compensate for any saving resulting from the smaller employment of timber and repairs. In small isolated cases, under special conditions (such as an exceptionally bad roof), the method of working homeward is applied with much success. The capital outlay required for the driving of the narrow headways can be materially reduced by dividing the royalty into panels and working back those nearest the shafts, while others are being opened out further away. The main roads are pushed out, and at intervals of from 100 to 150 yards pairs of winning headways are sent away at right angles until the boundary is reached. A connecting road is then driven between each two sets of headways, and the coal between them brought back in a longwall face towards the main roads, only leaving sufficient to form pillars for the support of main roads.

The longwall system was first practised in the Shropshire coalfield centuries ago, and in spite of the prestige attached to the bord and pillar method as coming from the North of England, where the collieries were larger and better engineered, it slowly but surely made its way into favour, until, at the present time, it is employed probably in more instances than all the other systems put together. It would be going too far to say that every seam can be worked by longwall, but the system is applied under such varying conditions of roof, thickness, and inclination that there are strong arguments in favour of such an extreme statement.

Its advantages are so numerous that they can only be briefly alluded to here. It enables a colliery to be opened with less capital expenditure, owing to the absence of yardage charges except in the limited area included within the shaft pillar, and to become remunerative in the smallest possible time. The maximum output can be obtained in the minimum time, as the face is opened at once without waiting to cut up the coal into pillars. The yield per acre is greater because no coal is lost in leaving the thin ribs or small pillars which so often have to be cut off in other systems, and the maximum percentage of round coal is secured. The latter assertion is sometimes disputed, but it is difficult to understand why, when we remember the large amount of small coal which must necessarily be produced in other systems by the driving of so many narrow roads, and by the cracking and fissuring of the edges of the pillars after they have been formed and before they are worked, combined with the fact that each pillar is relatively small compared with the whole area of the mine; everything seems to point to the production of more small coal than if the coal were worked out of the solid, as it is in longwall.

Ventilation is easier, the workmen are concentrated, and the expense of supervision reduced, while the cost of timber and maintenance of roads is less. The latter may not be apparent to the uninitiated, as it may naturally be thought that a road through the solid should take less to maintain than one through the gob, and probably this is so in the majority of cases. But in longwall mining the length of roads under repair for any given output is less than those necessary under any other system, and although the cost per yard may be higher in the former case, yet the cost per ton of output is less. A further advantage in seams giving off large quantities of explosive gas is that shot firing can almost entirely be dispensed with by holing the coal to such a depth that the travelling weight on the face is in itself sufficient to bring down the coal directly the sprags are removed.

Double Stall Method.—In the South Wales coalfield large areas of steam coal have been mined by the system known as the single or double stall.

In the ordinary system of opening work, the two main roads are set away from the shaft along the strike of the seam, but in some cases in order to save yardage charges, a face of coal some 8 to 12 yards wide is taken out, and the middle part of this stall is well and completely packed with rubbish, leaving a roadway on each side next to the solid coal, one forming an intake and the other a return. The sides of these roads are faced with the larger stones obtained from the ripping, and timber is also used where necessary. At intervals of about 100 to 120 yards headings are opened out to the rise—*i.e.*, at right angles to the main levels. These are usually made 10 or 12 yards wide, and are packed with goaf in the centre, leaving a roadway on either side as previously described. Out of the headings, stalls are set off right and left, these proceeding along the strike of the seam and parallel with the main roads. These stalls vary in width according to the nature of the roof and floor, the depth of the seam from the surface, and the amount of rubbish yielded by the seam, but under ordinary conditions are about 12 to 15 yards broad and are driven 20 to 24 yards apart (Fig. 222). Two systems of opening these stalls are adopted, named respectively the single and double road method.

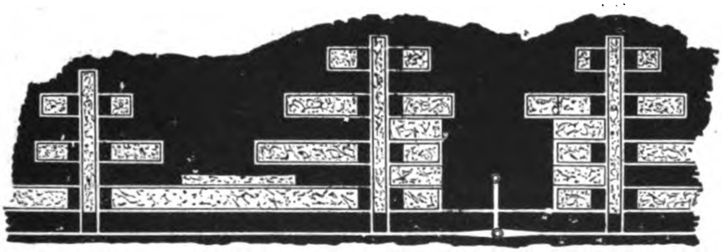
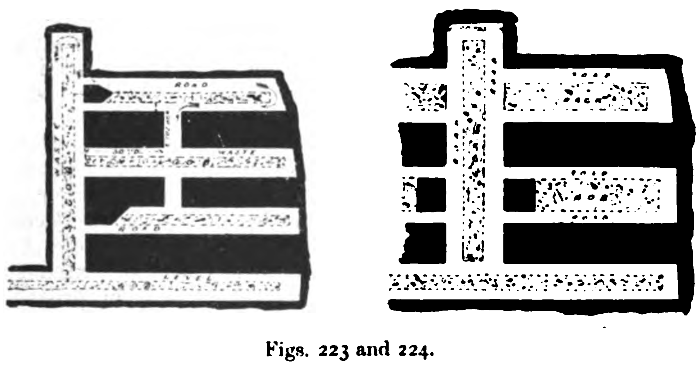


Fig. 222.

Single road stalls are opened in several ways which are illustrated in Fig. 223. In the first case a narrow road 6 feet wide is turned off the heading for a short distance, and is then opened out and carried forward the full width of 12 yards. The centre is stowed with refuse, and a tub road maintained along one side of the rib and an air course along the other. After each stall has been driven 30 yards, a connecting road is put through into the adjoining stall so that the air current may circulate properly, cutting off a pillar of coal which remains to the end as a protection to the main heading. These



Figs. 223 and 224.

stalls are continued until they meet with the second set of cross headings. The rib of coal left between successive stalls is now worked back towards the heading, and everything is cleared out except the pillar left for the support of the heading. These are ultimately removed after all the coal in the stalls and ribs has been worked, a commencement being made with the top or innermost one. They are, however, often so crushed as to be worthless. In the second method the stall is turned away full width to commence with, but only one tub road is maintained, while in the third modification two narrow headings are first driven cutting off a small pillar of coal; these are connected and the stall afterwards carried forward full width. The subsequent proceedings are similar in all the methods.

In the double stall method the headings are taken about 20 yards wide, and the centre packed with rubbish as before; but two tram roads are maintained, one on each side, and stalls are opened off on both sides of the heading, instead of only on one side as in the single road stall system. In the general system of opening, two narrow roads 6 feet wide are turned off about 16 or 18 yards apart, and after proceeding 15 to 20 yards are joined and continued on as a double stall, as shown in the lower portion of Fig. 224, having a road along each side and leaving a rib of coal between each pair of stalls. The advantages are that more men can work in each place, and as there are two roadways the output is increased over a given area. The stall from one heading meets the opposite one from the other cross heading (Fig. 222), and as soon as this happens the two men, who are working at the face, separate, one going to the right and the other to the left hand, each working back half the width of the rib. The other half is taken out by the adjoining stall, and consequently the ground is quite cleared. In some few cases the stalls are opened full width from the headings as shown in the upper portion of Fig. 224.

The stall system is one which is being replaced by longwall in the South Wales district, but, at the same time, one which is superseding pillar and stall in some instances in the northern coalfield of England.

Breast mining in the United States is very similar to single road stall. The stalls are opened out narrow and then carried forward 7 yards wide for a distance of about 80 yards, when the ribs between the stalls are brought back towards the heading. Experiments are being tried in many mines in the Pittsburg region, where coal-cutting machines are employed, of forming wide stalls and very narrow "ribs," and taking out nearly all the coal in one operation; but it is only under favourable conditions of roof and cover that this can give satisfaction.

Working Steep Seams.—Steep seams may be worked to the deep, which allows an easy stowing of rubbish, and results in a saving of pit work. Except where the seams are inclined at a greater angle than 50 to 60°, the method of sinking vertical shafts and cross-cutting the measures is very expensive, and only a small area is won; but if a main engine plane is driven straight down, it can be extended at any time with additional engine power. It has been proved by actual experience that from 8 to 10 per cent. more round coal is produced by working to the deep than working to the rise, which is probably accounted for by the fact that the weight is thrown off the face in working to the deep. It, however, possesses disadvantages if water be present, and an additional one in that the gradient is always against the load. In rise workings gravity brings the coal down to the levels, where it can be collected in sets and hauled along the main engine plane, but additional labour is necessary in self-acting planes.

In some parts of the Bristol coalfield,* where the measures are steep, the area is subdivided into a series of panels, and everything worked to the deep. Each bank has a separate engine and engine-man. The system is costly, but under certain conditions and no water, is safe and produces coal in good condition.

Perhaps the best way in seams of medium inclination is to win the coal by an engine plane driven straight to the deep, and as this is in

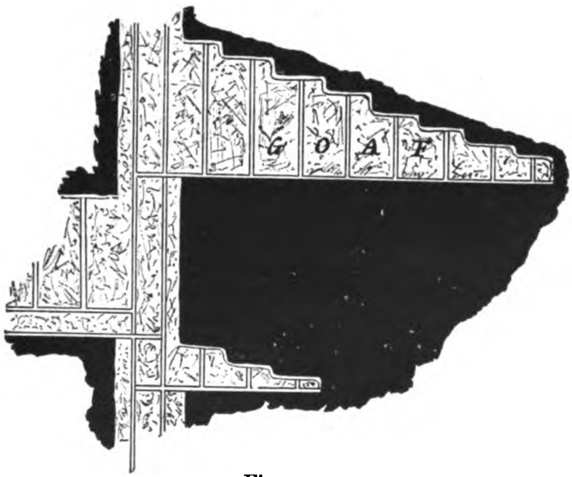


Fig. 225.

advance of the workings, all the water is collected there and pumped to the shaft. Levels, right and left, are branched off at intervals at about 100 yards and the coal worked to the rise (Fig. 225). Self-acting inclines bring the coal to the level, which is then taken to the engine plane and hauled to the pit bottom.

In the North Staffordshire coalfield† all seams lying at an angle of over 45° are classed and worked as "rearers." They are opened

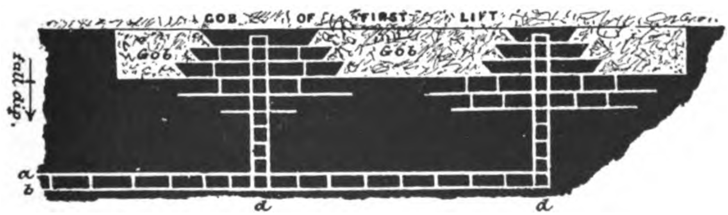


Fig. 226.

out on the pillar and stall system, and are exhausted from the rise downwards. They are worked in breadths or panels, which are usually from 120 to 150 yards wide, measured from the base of the last exhausted recovery down to the new winning levels. Each recovery is made by sinking the shaft vertically and driving a cross-

* *So. Wales Inst.*, xii., 363. † *Fed. Inst.*, iv., 48.

cut to intersect the seam at the required depth. At the point of intersection, levels *a* and *b* (Fig. 226) are set out on either side, and are driven to within 100 yards of the boundary. At these points, pairs of roads, *d*, are driven full rise to within 10 yards of the top of the breadth, and one of each such roads is made into what is called a "cage-dip." Owing to the inclination of the seam, the tubs cannot be led direct from the working places to the main levels, but have to be conveyed down the dips on a cage, which consists of a horizontal platform, placed on a triangular frame made to suit the inclination of the seam (see Fig. 286). Generally, only one cage is employed in each dip, and is counterbalanced by a weight sufficiently heavy to overbalance the cage, rope, and empty tub, but to be overbalanced by the cage and full tub. A series of such cage-dips are constructed at distances of 200 yards apart. When they have reached to within 10 yards of the previously exhausted area, three levels some 12 yards apart (Fig. 226) are started right and left, and are driven a distance of 100 yards, pillars being cut off in the usual manner by cross-cuts. The removal of the pillars is always begun at the end pillar of the topmost level, and the upper workings must be kept in advance of the lower ones. The workings of each upper pillar usually lead those of the one immediately below by 15 yards, the face being maintained in a regular line of about 50° from the line of full dip. The details of removing the pillars are shown in Fig. 227. A shoulder 5 feet in breadth is taken off at the bottom end, *a*, a second shoulder, *b*, is started, and these two are gradually worked upwards, the first, *a*, leading the second, *b*, to the top of the pillar. As the coal is broken off it falls into the level where it is loaded into tubs. Until the gob fills the excavation, the men erect scaffolds to work upon, and the face of the pillar is kept at a slant of about 45° for safety and convenience. After the top pillar has been partially worked away and the gob formed, the second pillar is treated in a similar way, until it is nearly breaking through into the gob above, when a shot *d* is put in of sufficient strength to move the gob and to cause it to slide into the vacant space. This is called "shooting the gob." In some instances where blasting is dangerous, the gob is caused to slide by chipping away the thin rib of coal with an instrument called a "bodger," which consists of a thin wooden shaft, 15 feet long, with a steel spike about 12 inches long at one end. The workman stands behind the timber near the face of the level, and works away at the thin piece of coal at the top of the rib until the gob forces its way through.

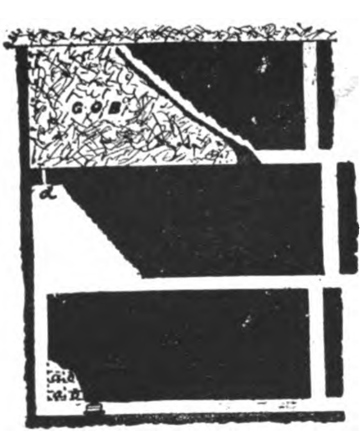


Fig. 227.

In California, with a seam from 10 to 11 feet thick, divided into two bands by a parting 6 to 18 inches thick, and lying at an angle of 60°, a method of angle work has superseded the ordinary system of driving stalls to the rise with satisfactory results.* The coal undergoes less breakage as it descends the shoots, and there is also a saving in timber. After an engine plane has been driven direct to the dip, levels or gangways (*a*, Fig. 228) are commenced along the strike of the seam, and out of these at intervals of 30 feet, gangway shoots, *b*, are driven at right angles with the strike of the seam 40 feet up the pitch; a cross-cut, *c*, 6 by 5 feet, is then driven parallel with the gangway. From this cross-cut, chutes (shoots) are driven at the same distance apart as the gangway chutes (30 feet) at an angle of 35°, and cross-cuts put through every 40 feet, dividing the ground up into a series of rectangular pillars. After a panel of five or more shoots is driven up the required distance, work is commenced on the upper outside pillar; when all the pillars on that line are drawn, the next series are attacked, and this is continued until the panel or block is worked down to the cross-cut, *c*. At intervals of about every 80 feet, it is found advantageous, as the pillars are drawn, to build a row

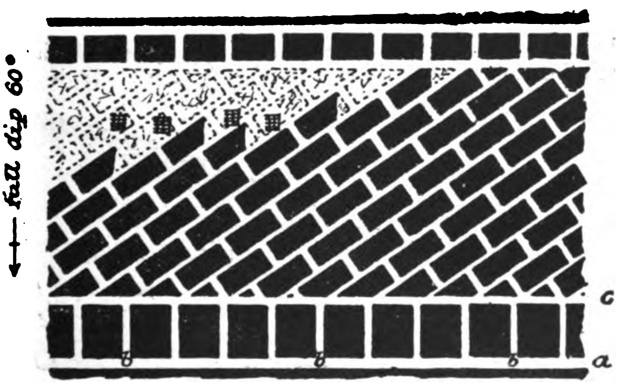


Fig. 228.

of cogs parallel with the strike of the seam. These serve to save the crushing of the pillars and to prevent accidents from falls of rock.

In Belgium and the North of France, where the seams are not only highly inclined, but very much distorted and broken up, the general practice is to sink a vertical shaft, and drive cross-cuts at regular distances apart. At the points of intersecting the seams, levels are taken right and left. These are driven along the strike of the bed, and as the inclination is anything but a regular one, are usually very crooked.

In the thin, very highly inclined seams, the coal between the successive levels is removed by the method known as "gradins renversés," or inverted steps (Fig. 229). The face is divided into a series of steps, and advances in the direction shown by the arrow *a*. There is one workman to each step, and he chips away the vertical face of coal before him, having the solid coal above his head. Shoots through the gob convey the coal to the lower level. The method of timbering will be understood from the illustration. The system of working is in

* *Coll. Guard.*, 1898, lxxvi., 970.

every respect identical with that known to the metal miner as overhand stoping.

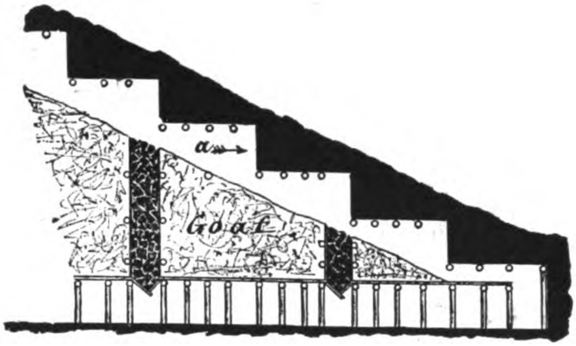


Fig. 229.

In the more moderately inclined seams, say up to 40°, the method called "tailles montantes," is employed (Fig. 230). It is a system

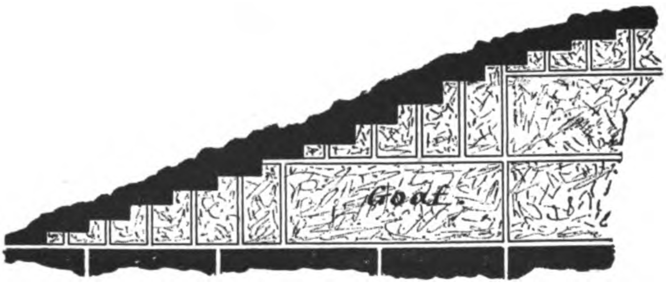
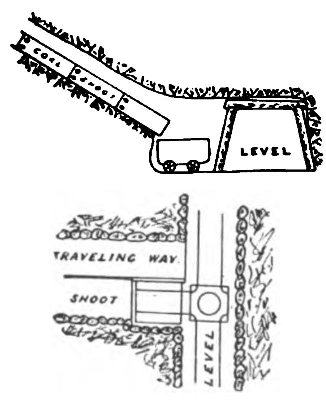


Fig. 230.

of pure longwall. A number of stepped faces, about 20 yards wide, are carried up paralled with the strike of the coal, about 4 or 5 yards in advance of each other. Each stall is served by a road kept through the gob, but these are cut off every 55 to 65 yards by a horizontal cross-level. Figs. 231 and 232 show in elevation and plan the detailed arrangements of the roads into each stall when the tubs are taken into the face. Half of the road serves as a travelling way for the miners, the remaining portion being used as a shoot. The rails in the levels are broken opposite each shoot, and a turn plate placed there, in order that the tubs may be readily run beneath the shoot, and be out of the way of other tubs proceeding along the level. In many cases the tubs are



Figs. 231 and 232.

taken direct to the working places, self-acting inclines or winches being employed.

Other moderately inclined seams are worked by the system called "tailles chassantes" (Fig. 233). A road is carried up from one level to the other, and branch roads put off right and left, about every 15 to 20 yards, measured along the inclination of the seam, taking out the coal for a distance of from 50 to 100 yards on each side of the main incline, the face, as before, presenting a series of steps, but its direction in this case is parallel with the inclination of the seam; at intervals diagonal roads are put up through the gob, cutting off the level roads as illustrated.

The relative advantages of the two latter systems have been exhaustively compared by Mr. Cambessédès,* whose conclusions may be briefly summarised as follows:—When working towards the rise (tailles montantes) weight is favourable to the bringing down of the coal, and produces a sensible reduction in the cost, amounting in certain cases to as much as 25 per cent., while in all cases where such working places are served by shoots through the gob there is a greatly diminished cost in the driving and propping of such roadways com-

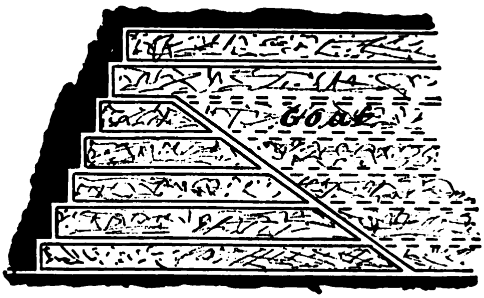


Fig. 233.

pared with the system of forward stalls (tailles chassantes), which are served by ordinary tubs of average carrying capacity. At an inclination of from 5° to 8° up to from 20° to 22° it seems preferable to employ the latter system, and to construct a self-acting incline through the gob, which can serve several levels; indeed, if the tubs are to be taken into or near the working face, steep inclinations above 30° to 35° are unfavourable to working towards the rise, because the tub is apt to throw out part of its contents, and because the cost of repairs to the rolling stock is large on account of the violent usage it receives. In a seam giving off large quantities of fire-damp, the method of forward stalls (tailles chassantes) is advantageous, because the gas tends to accumulate in the superior angle of the stall, and the workmen who are distributed along the face are away from the fiery zone, as the gas can pass away to the upper level, while in working towards the rise (tailles montantes) fire-damp has a tendency to extend along the working face, where the hewers are employed. Should the face be other than perfectly straight, a dead end may be formed, which the air current clears with difficulty. In the system of tailles montantes the stalls are divided into two parts, and the operations of the workmen are carried on more independently of each

* *Soc. Ind. Min.* (3e Serie), ix., 551.

other than those of the men employed in tailles chassantes. As a result, in workings of the former system a greater number of men can be employed with less inconvenience to each other, thereby realising for that method all the advantages of rapid working as:—reduced cost of timber and maintenance; a larger proportion of round coal, and sometimes reduced cost of getting; the haulage staff better employed; and fewer slips and falls. These advantages are, however, minimised, by the fact that when the tubs are taken to the face, more plant is required with tailles montantes than with tailles chassantes, and there is a greater amount of wear and tear. In the former case, the length of the inclined plane is continually altering, and the brake wheel has been moved at a cost, in some instances, of about 9d. per yard. Not only so, but it is difficult to regulate with exactitude the length of the ropes each time the pulley is raised, and as a result, collisions are frequent and the rolling stock deteriorates rapidly.

The extra cost of working seams lying at angles of from 30° to 50° is considerably larger than that of moderately inclined ones, probably as much as one-half more, in some instances frequently a third, but over an angle of 50°, unless the seam is thick, tender, or liable to spontaneous combustion, it can generally be mined cheaper than if it was inclined between the above-named limits. There are some compensating advantages connected with the working of steep seams which are absent in flat ones, the most important one being the ease with which faults are recovered. In beds of moderate inclination a fault throws the measures up or down, and a recovery of the seam is only possible by an alteration in the level of the roadways, which entails considerable expense. In steep seams the throw of a fault is sideways, and all that has to be done when one is met with, is to turn the level to the right or left hand, a less troublesome and less expensive matter than lowering or raising it.

Working Thick Seams—South Staffordshire.—No matter what system of working is adopted, the invariable rule in the Ten-Yard seam is to drive out to the boundary and bring back the work, leaving the gob behind. Two main gate-roads proceed along the strike of the seam, serving as haulage roads, and the distance between them varies from 33 to 45 yards, being always such that in the operation of getting coal these preliminary drivages will form a portion of the chambers, and, as it is called, "come in to work." Where a large area is to be won, roads are branched out right and left of the main roads, and coal gotten at the extremity of these, even before the former have proceeded much past them, the only precaution to be adopted being, that the coal so worked should be a sufficient distance from the shaft not to affect it by any subsidence. While this portion is being worked out, the main roads proceed on their course, and branch roads are again sent out at suitable distances, and when they reach the boundary, either of the lease or of the district, work is opened as before.

The methods of working commonly employed may be divided into (*a*) square work, and (*b*) longwall, the whole thickness being removed at once. True longwall is, however, unknown in the thick seam. It might preferably be defined as bord and pillar, the large blocks being pillars. If so, the system of working is the same as the one pursued under the same title in the Northern coalfield; the removal of the pillars being similar with modifications occasioned by the greater thickness. The coal is sometimes worked in two divisions by a modified longwall system, but although this possesses some advantages, yet the numerous practical drawbacks, such as the increased quantity of small coal produced, the inferior mineral obtained when working the lower slice, and the frequency of gob fires, have resulted in its general abandonment, except in a few isolated special cases.

(*a*) *Square Work.*—In this system the coal is worked out in a series of rectangular chambers, separated from each other by ribs of coal, internal support for the roof being afforded by a series of square pillars of solid coal. The old method of opening a side of work was to drive a series of stalls 10 yards wide, leaving 10 yards of coal between each, and then a second set of 10 yard stalls at right angles to the first, the result being that pillars 10 yards square were formed. This operation would be carried out in the bottom coal, the top coal being got by the method described a little further on. Practically, however, opening a side of work in this way is a thing of the past. To do it with any success requires an exceedingly strong roof, and even then coal is not got out so clear as it should be. At the same time, it is advisable to drive the stalls, in the first instance, at least 5 yards wide, and so save the cost of narrow work.

With an average roof a convenient size for the openings is 10 yards wide, and for the pillars 8 yards square, and in such case the ordinary gate-roads opening out a district will be driven, leaving a piece of coal 33 yards wide between them. On reaching the boundary of the district the two gate-roads will be connected by a cross-drivage (*a*, Fig. 234). This will be widened out by "side-laning," which consists in treating the side of the road as a longwall face, and holing it out to a depth of 10 yards, as shown at *b*. While this is being done a second cross-drivage, *c*, about 5 yards wide, will be carried between the two gate-roads, cutting off a block of coal 8 yards wide. The side gate-roads will then be side-laned off to 10 yards wide, *d d*, and a stall, *e*, driven through the block of coal remaining, the position now being that two pillars 8 yards square are surrounded on three sides by openings 10 yards wide, and on the fourth side by an opening 5 yards wide. All this has been carried in the lower 6 or 7 feet of coal.

In the back opening the top coal will now be got down in sections, slice after slice being removed vertically. The whole distance across this opening is not attacked at once, only a certain portion of its length being worked at a time. The top coal is got down by cutting vertical grooves up through the overlying measure of coal, leaving between each length of 6 feet what are called "spurns." These spurns are narrow webs of coal holed through in the upper part. When the layer that is being attacked has been cut through in this manner on both sides, the spurns are reduced by the aid of a pick, and are then finally "jobbed" (knocked) out with a "pricker," which is a long instrument very similar to a boat-hook. A spurn is always left at the face, and when this is removed the whole mass falls, and is then in a position to be taken away by the loaders.

While this is going on, a third cross-cut will be driven between the two main gate-roads at a distance of 13 yards from the last one (*a*, Fig. 235). The opening (*c*, Fig. 234) is then widened out to 10 yards, as shown at *b* (Fig. 235), the main road side-laned off as before, *c c*, and a middle thurling, *d*, 10 yards wide, driven across, forming two more pillars 8 yards square. While this is being done in the bottom coal, the top coal has been got down around the two pillars shown in Fig. 234. A fourth cross-drivage is made between the two gate-roads at a distance of 13 yards from the last one, and the pillars there cut off, as already explained, so that at this stage of the operation the side of work considered will have the appearance shown in Fig. 236—viz., six pillars, each 8 yards square, surrounded by a series of openings, 10 yards wide. The top coal by this time will be removed all over the side of work, except on the three sides of the last two pillars, and will

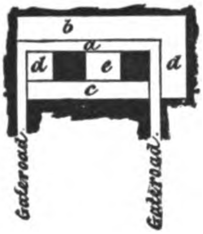


Fig. 234.

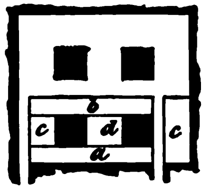


Fig. 235.

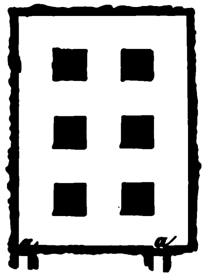
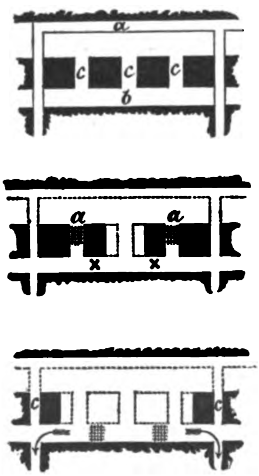


Fig. 236.

gradually be got down there until nothing remains. Fire-dams will then be put in at the points *a a*, and a new side of work started, cutting off a rib of coal 8 yards wide.

(*b*) *Longwall in One Division.*—Gate-roads are first driven out $7\frac{1}{2}$ feet wide, leaving 40 yards of coal between. The cross-holings are 45 yards in the clear, so that the commencement of each district is to subdivide it into pillars, 40 yards by 45 yards, such dimensions allowing of all the roads coming into work. Upon reaching the boundary of the district, the removal of the coal is commenced by widening the $7\frac{1}{2}$ feet gate-road (*a*, Fig. 237) to 8 yards, this being carried on all across the face. While such is being done, a narrow stall, *b*, 4 yards wide, is driven parallel with it, cutting off a rib of coal 21 feet in the clear, and then this rib is split into pillars, 7 yards square, by a series of cross-drivages, *c c c*, each 4 yards wide. The block of coal between two roads is thereby divided into four pillars and three openings. This work is carried out in the lower 6 feet of coal, and while it is being done the top coal in the 8 yards back opening is got down by cutting through and dropping down the successive layers.



Figs. 237, 238, and 239.

The removal of the pillars is carried out as illustrated in Fig. 238. Cogs of timber and stone, *a a*, are built in the stall next to the gate-road, and the central stall widened from 4 to 8 yards, a slice being taken off the pillars on each side. The top coal is got down in the opening so formed in the usual manner. The cogs are then removed, and placed in the position shown by the X. The remainder of the pillars are then got out, together with a portion of the two pillars on the side of the original gate-roads. Fig. 239 now shows the position of affairs. The two pillars remaining in this block, together with the two half pillars of the adjoining blocks, are removed in a similar manner, cogs being built at *c* for this purpose.

During the whole of the above operations, half the coal produced goes down one gate-road, and half down the other, as shown by the arrows, the tubs being taken straight into the face. While this has been going on, another row of 7-yard pillars and 4-yard openings have been cut off in the bottom coal, and the pillars removed in a similar manner. This operation is repeated, until such time as fire breaks out. A rib is then cut off, dams put in, and workings again opened on the other side of it.

For the success of this system it is necessary that the coal should have a soft roof, and one that comes down quietly without much weight. In some parts of the coalfield there is a very hard roof which will bear a large amount of weight without collapsing; however, in the words of the collier, "when the weight does come on" nothing can stop it. Such a roof is very unsuitable for this system.

The advantages claimed are: the greater first yield and total clearance of coal.

The disadvantages are: the large amount of slack produced (this being due to the quantity of gunpowder employed), and the smaller total yield per acre. A greater quantity is obtained per acre than by the first clearance in the square-work system, but, after the lapse of considerable time, the ribs and pillars left in this latter method of working are cleared out. In many cases, the remnants of the thick coal are worked a third time, thus obtaining a further yield. The total produce of winning the broken is about one-third of the quantity obtained by the first working, of which one-third will be coal, and two-thirds slack. The expense of winning the broken mine is somewhat greater than that of getting the solid coal.

In every system of thick coal-mining, dip work is advantageous, as the falling roof-stone rolls away from the workmen.

Pennsylvania.—The system of working the Mammoth Bed, which sometimes attains a thickness of 60 feet, as described by Messrs. H. M. Chance* and Franklin Platt,† is similar to the double stall method of South Wales. Either from the bottom of the shaft or out of a slope, if no shaft is sunk, a main road, called a "gangway," is branched out right and left, but for the sake of not weakening the roof, the two openings are not placed quite opposite each other but nearly so. Gangways are not driven truly along the strike of the seam, but are graded slightly (about 6 inches in 100 feet), in order that the full waggons may be moved easily, and water drain to the slope where the pumps will be situated. A parallel road some few (10) yards away, called a heading, is driven for the purpose of ventilation.

As soon as the gangways have proceeded so far that the subsidence

* *Second Geo. Survey of Pennsylvania. Report A. C. Coal-Mining.*

† *Ibid. Report A 2. Coal Waste.* The chapter on Mining is by Mr. J. P. Wetherill, and is an expansion of a paper originally contributed to *Amer. Inst. M. E.*, v., 402.

produced by working the coal will not affect the slope, stalls or "breasts" are opened off at or about right angles—*i.e.*, up the rise. These are the working places, which are separated from each other by a solid rib of coal. They are usually driven for a distance of from 80 to 100 yards, and are never holed through into the gangway above, but are driven up to within 10, 15, or 20 yards of it, leaving a rib of coal, called "the chain pillar," for support. Breasts are opened off the gangway as fast as room is provided, and when the first breasts are exhausted the men are moved forward. The width of the breasts is governed by the strength of the roof, the firmer this is the greater the width. Breasts vary from never less than 6 yards to never more than 12 yards wide. When the coal is quite flat the breasts are opened at right angles to the gangway, but where the dip is too steep to allow a waggon to be used in the breast, if so driven, it is opened at an angle to the gangway, thus decreasing the inclination. The inclination of the bed usually limits the length of the breasts from 300 to 500 feet, and coal lying at a greater distance from the gangway is mined from a second series of breasts opened from a second gangway driven above the first one.

By the driving of manways and "chutes" (shoots), the rib of coal between the gangway and heading is divided into pillars, called "stumps," which are always made larger than usual where the roof is strong. They form the supports which keep open the gangway, the main entrance to each district which must be preserved. Where the roof is soft, the breasts break down in short lengths without throwing much weight on to the adjacent coal, but with a hard tenacious roof a considerable extent of workings may remain open, to collapse suddenly, producing a crush which may extend to the gangways, unless the stumps are made large, say 15 yards; more often they vary from 7 to 10 yards.

The distance to which the gangway is driven on each side of the slope, or, in other words, the lineal distance worked from a single opening, is dependent on the cost of haulage and on the cost of keeping the gangway open. Endless rope and chain haulage are not used, but if the coal is hard and the roof good, it is often cheaper to mine coal lying 2 miles from the slope than to open a new one, while if the coal is soft and the roof bad, it may be cheaper to open a new slope than to attempt to keep 1 mile or less of gangway open.

The methods of opening the breasts vary with the nature of the roof, the quantity of ventilation required, and the steepness of the seam. Between the angles of 25° and 30° the mined coal will slide on the floor of the breasts, but not at any violent rate. From 25° down to 15° the coal will not move unless sheet-iron plates are laid on the floor. For this reason up to 30° the breasts are worked empty, that is to say, the coal is loaded as it is got; over that angle the coal when mined rushes down the breasts with considerable force, and would dash into the gangways unless prevented by some obstruction, which takes the form of a strong "battery" or regulator, built of round timber props partially covered with planks, leaving an opening through which the coal can be run out as required. Roads are kept up the sides of the breast by the use of inclined props called "jugglers," which are notched into the floor and side and are covered with 2-inch planking. These form the intake and return airways, the whole width between being kept full of loose coal. When the breasts are worked out, the pillars are robbed by taking off from each as thick a slice as possible.

In very steep breasts it is impossible for a miner to keep up to the working face, as he has nothing to stand upon, and it is therefore necessary either to leave the loose coal in the breast or to erect some artificial support. A common method of opening out work in such cases is illustrated in Fig. 240. The breasts are opened by driving in two shoots for a distance of 8 to 10 yards, connecting them by a cross drivage, and then carrying the working forward its full width. Four strong props, *a*, are set just above the pillar so cut off, and against these, two log batteries are built, in each of which is left an opening, say 4 feet square, that will permit large lumps to pass through freely. Roads are kept up each side of the breast by the use of inclined props ("jugglers"), shown in position in Fig. 241, which is a section across a breast. The surplus coal may be drawn out at the bottom through the opening in the battery, but is more frequently sent down the man-ways; the loose coal is allowed to remain undisturbed until the breast is driven to the limit.

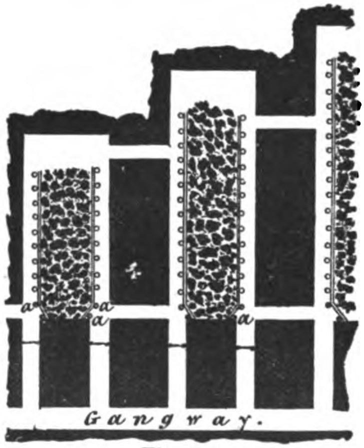


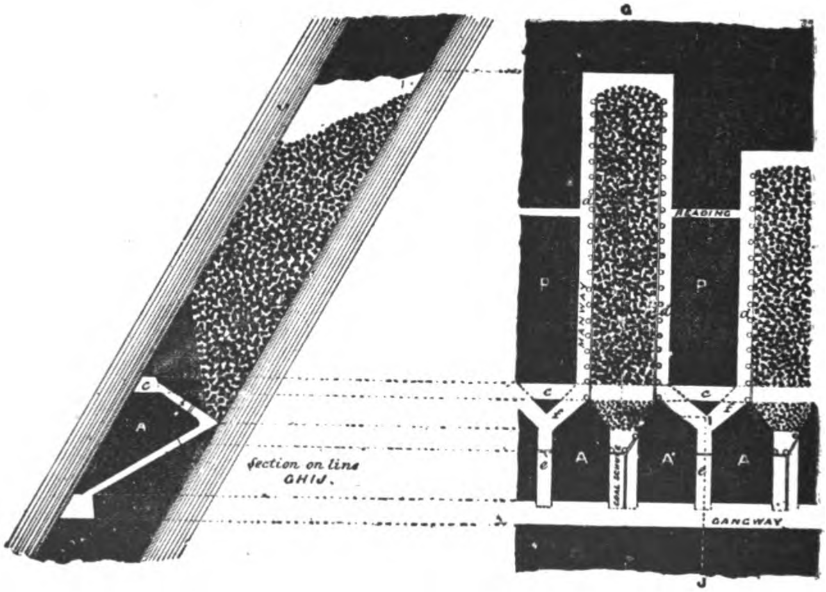
Fig. 240.

Fig. 241.

The advantage in this system is in having two chutes, as the coal may be rapidly drawn from the breast if there is any danger apprehended of its being covered by falls; it also frequently happens in two-chute breasts that when one passage becomes blocked by coal the other will continue open, and that in time the movement there will free the coal in the other. The disadvantages are numerous. Stoppage of both chutes are common, and as a consequence, ventilation is not only suspended in the breast directly affected, but often in all others past it. Unless an additional man-way is driven through the stump pillar between the breasts, the men have to travel through the battery chutes. With two chutes the coal is drawn from the *side* of the breasts, and the movement often unseats the jugglers and breaks in the man-ways.

For these reasons breasts are often started with one chute in the centre. Where this crosses the heading three strong props are placed along the centre line, and the breast is afterwards widened out to its full size and carried forward. The props at the heading form the battery, and also a stopping to direct the air current into the breast man-ways. Should anything break down in the latter, the stopping can be removed and the air current sent direct to the inside breasts.

Man-ways are driven through the pillars between each pair of breasts. An elaboration of the above, introducing a return airway (Figs. 242 and 243), is highly recommended and largely adopted where the seam is steeply inclined, the coal free, and apt to give off quantities of gas. For greater security the gangway is driven along the roof of the seam, this position also allowing the coal chutes to be driven at a smaller angle, giving the loaders greater control over the movement of the coal. The main chute is driven 9 to 10 feet wide for a distance of 8 or 9 yards where the battery is placed. From this point up, the breast is widened out to its full dimensions in a distance of 5 to 7 yards. A space of about 3 feet wide is partitioned off from the coal chute, serving as a man-way for the starter to reach the battery from the gangway. A man-way chute, 6 feet by 6 feet, is driven up in the centre of the pillar for about 8 yards and then branched off right



Figs. 242 and 243.

and left ("slant chutes"), joining each breast where it is of full width. The main feature of the plan is an air course, *c*, driven against the top above the gangway, and connected with the manways *ee* between each breast, by the passages *ff*. This air course is not generally in use, but only when the breasts are exhausted, or repairs are necessary to the man ways *dd*. Where the coal is not very strong and liable to run, that is to say, break away from the solid without mining, this plan possesses many advantages; the breast can be worked in the bottom bench only, and the excess coal run down the slant chutes. When the breast is finished the loose coal it contains can be drawn out at the *three* chutes.

Where the seams are not very thick and the coal is soft, especially when the impurities are large, breasts are worked "on batteries," that is to say, rows of props are set across the stall every 15 to 20 feet as it progresses, and planks nailed to them, forming platforms, on which the men can stand up to their work. The clean coal is passing away through the breast man-ways, and the refuse thrown back into the space occupied by loose coal in the systems previously illustrated. This method was used in hard, clean coal, but in the absence of refuse, which is partly packed against the batteries or plank dams, shots throw down the coal with such force that the props, &c., are often swept away: the danger of this, especially in a clean seam, where the breast would be empty below the battery, and the damage to the coal by smashing has led to its abandonment in such cases.

In seams pitching 12° to 13°, breasts are worked as "on batteries," only batteries are not required, as the men can stand up to their work without support; the chutes will be laid with sheet iron. Where the inclination is still smaller, the waggons will be taken direct to the breast, a good tramroad being kept up on one side. In the latter case the resemblance between anthracite mining and the double stall method of South Wales becomes very apparent.

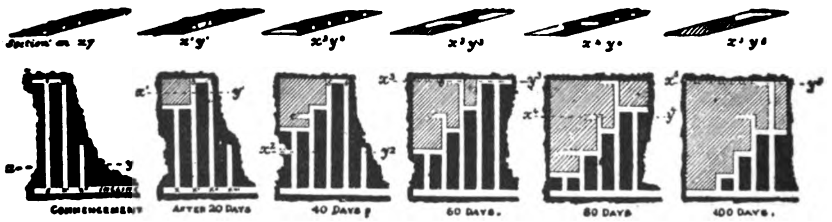
When the gangways and breasts have been opened out to the furthest distance that economical working will allow, the pillars between the breasts and the stumps are robbed or reduced, beginning at the farthest distance and bringing the work back to the outlet or slope. This procedure, by removing the pillars which support the roof, often brings on large subsidences or "caves in."

France.—Both the methods already described differ in one important feature from the mining of thick seams as practised in France, as the only stowing material, if any, used in the chambers is the small quantity produced from the bands of inferior coal or dirt intermingled with the seam, and there is rarely any attempt to use even this small quantity in a systematic manner. On the Continent, complete stowing of the workings is the rule rather than the exception, and huge quarries at the surface are worked for the sole object of supplying material, which is sent down into the mine and used for gobbing up the workings. Care is taken that the circulation of the tubs is as nearly automatic as possible; they gravitate from the screens, where they are emptied of coal, to the quarry, where they are filled with rock, and, after being raised to a suitable height by mechanical means, gravitate to the pit top where they are lowered into the mine. The workings underground are generally to the deep of the pit bottom, and the tubs of rock are delivered to the highest point of the working place before being emptied, in order that the gobbing material can *fall* into the required situation. Shovelling it into position is out of the question owing to cost.

Then, again, the thick seams are divided up into slices, each of which is taken out by a separate working. Two plans are adopted—in one the slices are horizontal and are taken *across* the bed of coal (from roof to floor) from inclined planes driven from one level to the next above it, the development and opening out of the levels and inclines being similar to that adopted in the rearer coals of North Staffordshire. In the second method roads are driven along the strike of the seam at regular intervals apart, and the successive slices are removed by a series of inclined stalls driven to the deep and parallel with the roof and floor of the seam.

In hard coal, the inclined method of working is preferable for a seam dipping less than 15°, unless it be irregular or contain old workings, or unless it be of too great a thickness, when the method of horizontal slices should be resorted to. In seams dipping 15° to 30° the inclined method is also advisable, especially where the coal contains bands of refuse, but the horizontal method is the only one applicable to deposits of irregular form, or to seams dipping more than 30°, when the inclined slice becomes too dangerous, while owing to the fact that the working places are level it also possesses the advantage of rendering haulage easy.

The method of working by inclined slices at Blanzy Colliery in a seam 15 feet thick, dipping 1 in 5, as described by Mr. L. Mathet, consists in dividing the bed into two equal parts, taking the lower one out first, and then following on with the upper layer before the first is finished. The method of opening out, and the details of the working places, are shown in Figs. 244 to 249. A commencement is made by opening out in the bottom slice on one side only of an incline driven along the dip of the seam, two narrow roads (xx', Fig. 245), 10 yards apart, and continuing them until the boundary or the extremity of the district is reached, when they are connected by a cross-road, 1,



Figs. 244 to 249.

2, driven parallel with the floor. The stall so formed is then worked backwards towards the incline, and the space behind the workmen packed with refuse. The gobbing material is brought in along the higher level, and is lowered into the working places by small winches worked by compressed air, which also serve to pull up the tubs loaded with coal to the levels from whence they can be conveyed to the incline by horses. At the end of twenty days a piece of the lower slice of coal, represented by shading in Fig. 245, has been removed, and a third level road, x'', has reached the boundary and has been connected with x' by the cross-stall 3, 4. The coal here is also worked back towards the incline, until at the end of forty days the lower slice has been removed to the extent shown by the shaded portion in Fig. 246, while a fourth winning headway, x''', has been driven to the boundary and connected with x'' by the stall 5, 6.

The development and winning of the lower slice still continues, but at this period workings are also opened in the upper lift. All the stalls have hitherto been driven parallel with the inclination of the bed, but it is obvious that if the road (c, Fig. 246) be started from the level x' and be driven horizontally it will soon reach the roof of the seam. It is then continued to the deep, over the gob of the first lift, and a face opened, and also brought back towards the incline, as will be seen from the sectional elevation (Fig. 247), which represents the progress made at the expiration of sixty days. A second horizontal road is then started (*e*, Fig. 247) to remove the prism between the second level, *x'*, and the roof adjoining the boundary of the district. Similar operations are carried out in the levels which have by this time been driven further to the rise, and at the end of eighty and one hundred days the works present the appearance shown respectively by Fig. 248 and Fig. 249.

Working Seams Lying near Together.—In the South Staffordshire coalfield, when the distance between two seams does not exceed 6 feet, the general practice is to work the lower one first by longwall, carrying gob roads in the ordinary manner. When the boundary is reached the roads are ripped down into the upper seam, which is then taken back longwork towards the shafts. In many cases it is found that by such procedure the upper seam not only makes a greater percentage of large coal than it would have done if it had been cleared off first, but that the cost of production is less, as the undercutting is easier.

In the southern part of the Warwickshire coalfield all the seams come together, being only separated by a small thickness of partings, amounting to as little as 2 feet between each seam. The method of working has been described by Mr. E. F. Melly.* A pair of dip roads are driven in the lowest of the seams to be worked to a distance of not less than 500 or 600 yards. A cross-drift is then cut through all the four seams (shown by dotted lines in Fig. 250), and they are each

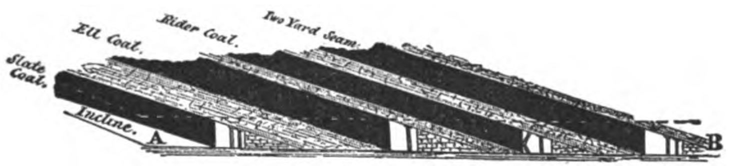


Fig. 250.

opened out by level headings to a distance of from 150 to 200 yards on each side, cross-cuts at each end, and generally one in the middle, connecting the four seams for ventilation. In this way, eight different stalls, or working places, are at once made, each of which may be partly holed every day, so that 50 to 60 tons should be delivered to the flat A B from each one, and to this point an incline rope, which takes from 15 to 20 tubs at a time, delivers the empty tubs.

Each face follows behind the other, and as only a very short parting exists between the seams, there is considerable breakage, as the faces cannot possibly proceed at a greater speed than, say, 2 yards per week, and as the distance at which the face of one seam lies behind another is about 10 yards, the coal in each case has only five or six weeks in which to settle down or deteriorate before being worked.

The main flat A B is made to last a long time, generally two or three months, and the faces adjoining the road are allowed to hang back a little, as making a new flat is rather an expensive business.

In Fifeshire, where the Jersey coal seam sometimes runs to 15 feet thick, and consists of two layers of coal separated by about 4 feet of

* *N.E.I.*, xxxiii., 151; and *Brit. Soc. Min. Stud.*, x., 104.

spoil, the method of working has been described by Mr. A. Burt,* and consists in removing the lower portion of the seam first by longwall and the upper layer afterwards. A heading is first driven to the rise in the bottom coal, and at intervals of from 12 to 15 yards ordinary roads are branched off along the strike (Fig. 251), and a long wall face carried forward at an angle with the line of full dip. To get sufficient height in the working roads, the middle band of dirt is always ripped down, and sometimes when the seam varies in thickness part of the top coal is also removed. The dirt produced from the fireclay holing of the bottom coal, and that obtained from ripping the stall roads, is used to carefully pack the gob which is completely stowed, no open spaces being left. The sides of each road are carefully built up with stone for a width of 2½ feet, and at intervals chocks 2½ feet square are used to strengthen such buildings. A cross-section of the face in the bottom coal workings is shown in Fig. 252.

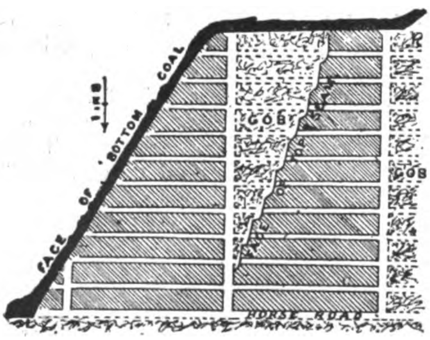


Fig. 251.

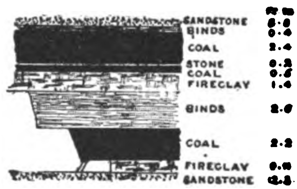


Fig. 252.

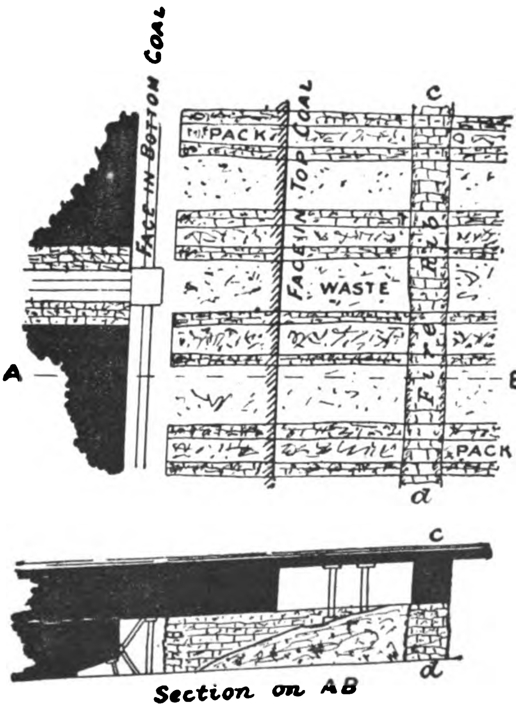
The working back of the upper layer of coal commences at the second heading, which is driven as usual in longwall working for cutting off the stall roads. As soon as this has cut off all the roads out of the first heading, the working of the top coal commences at the top end or innermost part of the second heading. The first place is taken a few feet back before the second is started, and so on, each stall leading the other a distance of about 10 feet (Fig. 251). The coal worked in this operation is taken *back* to the first heading along the same roads which were made in working the bottom coal, these being ripped a second time if necessary. The holing of the top coal is made in the waste of the first working.

In the Saar district, Rhenish Prussia, a seam, consisting of 3 feet of bottom coal and from 4 feet 6 inches to 5 feet 3 inches of top coal, separated by a rock band, having a mean thickness of 2 feet 5 inches, which was originally worked in one operation, is now got by a method identical with that described above. It is stated that the working cost has been reduced by 5½d. per ton; that the measures come down regularly both in the forward workings and in the face coming back, while accidents from falls have greatly diminished; that less timber is

* *Fed. Inst.*, xiv., 194.

required; that all the coal is taken out, while formerly pillars were cut off and lost, and frequently a portion of the top coal had to be left to support the roof; and that the ventilation is improved.

The main coal at Moira Colliery, Leicestershire,* which is 14 feet thick, is worked in two divisions. The main roads are driven out some 40 to 50 yards apart in the solid to the boundary on the bottom of the seam, and when this has been done the coal is brought back in two lifts, each 7 feet thick, by longwall working homewards, the lower face leading the upper one by a distance of about 10 yards. Figs. 253 and 254 show in plan and section the arrangement of packs, wastes,



Figs. 253 and 254.

and jig for each stall, and the position of the two faces. Each road brings back 20 yards of coal on either side. As the main coal is very liable to spontaneous combustion, and also gives off moderate quantities of gas when first opened out, constant watchfulness is required in order to detect any smouldering material in the back workings, and as an additional precaution walls composed of stones and dirt, *c d*, are built across the stalls in the bottom coal workings at intervals not exceeding 20 yards, sealing up the wastes and preventing access to the goaf behind. A rib of coal, some 3 to 4 yards wide, is left in the top coal over each of these cross walls.

* *Coll. Guard.*, lxxvii., 106.

Spontaneous Combustion.—Some seams of coal are particularly liable to spontaneous combustion, the first signs of which are given by a peculiar smell, termed "fire stink." This undesirable state of affairs is produced by three agencies:—(*a*) oxidation of the organic constituents; (*b*) iron pyrites; (*c*) pressure. The first is undoubtedly the main one, but is assisted materially by the other two.

(*a*) *Oxidation of the Organic Constituents.*—Richter's* experiments satisfactorily demonstrated the high importance of this action, and it may be looked upon as being the most effective of the three. Coal absorbs oxygen, one part combining with the carbon and hydrogen, forming carbonic acid and water, while the other enters into combination with the coal, and proportionally increases its weight. This alone would fix careful attention on this action, as it is found that, before combustion, coal so inclined emits large quantities of carbonic acid gas. Heating results from the absorption of oxygen, and absorption is favoured by heating, moisture, fine division, and absence of light; everything thus combines to favour decomposition.

(*b*) *Iron Pyrites.*—This substance on decomposing yields, first, ferrous sulphate, and secondly, ferric sulphate; the former makes its appearance in the form of colourless fibres, protruding here and there from the face of the coal, while the latter is of a brown colour, and is more frequently observed. These products may suffer further decomposition, sulphuric acid being sometimes formed, and as their volume exceeds that of the original pyrites, disintegration of the coal is effected, together with a small heating in close proximity to each lump of pyrites. The heat generated is quite incapable of commencing a fire, but it may help, in a great degree, the action of other agents. Ferric sulphate is reduced to ferrous sulphate by contact with small particles of carbon, and hence may act as a carrier of oxygen to the organic constituents of the coal.

(*c*) *Friction from Slippings.*—Pressure from the roof on pillars cracks them, and grinds the irregular sides of these fissures together, thus producing heat and a considerable quantity of fine coal. Now, small coal does not absorb more oxygen than large coal, but it does so more rapidly, and the temperature rises very quickly. Really solid pillars never fire, it is only when they are being crushed that combustion occurs. The heat acting on the small coal produced by the grinding action, may also subject it to the process of slow distillation, and produce a quantity of bituminous matter, which, on the addition of further heat, suddenly bursts into flame.

Development.—The oxidation of iron pyrites cannot be looked upon as the primary agent in producing combustion. The amount of heat that would be given out by the oxidation of the quantity of sulphur in any coal can be easily estimated, and, on calculation, it is speedily recognised that this heat could not produce the results attributed to it, even if the pyrites existed in isolated nodules; another argument in favour of this is the very slow nature of the process; the heat produced is consequently dissipated, and only a small heating of the particles takes place.

There can be little doubt that the decomposition of iron pyrites is eminently favourable to spontaneous combustion; owing to the disintegration produced, it allows the coal to be more readily per-

* *Metallurgy* (*Fuel, &c.*), Dr. Percy, 1875, 299.

meated by currents of oxygen, and the heating produced—small though it may be—favours the action of such currents.

When the first agent is considered, every circumstance seems to combine to render the action successful. Heating, moisture, and absence of light are all conducive to the oxidation of the organic constituents of coal; it is in seams most free from pyrites that spontaneous combustion takes place. The constitution of the coal seems to be of great importance; it is only in bituminous varieties that this undesirable state of things is found.

Little can be added to what has been already said on the heat produced by friction; the principal argument in favour of this view is the one already given—viz., if fire be found anywhere it will be in the cracks of pillars. No doubt this is perfectly true as regards some underground fires, but spontaneous combustion is frequently found occurring in heaps of coals above ground, and this coal may contain a very small percentage of pyrites. To account for the fire under such circumstances is impossible, unless the oxidation theory is admitted; and, in the opinion of the author, this action, in the majority of cases, is the primary agent, although either of the other two in conjunction may greatly facilitate it.

Prevention.—This can only be done by the loading up and removal of all fine slack and refuse. A vigorous current of cool air must be circulated through the workings, cooling the surface of coal over which it sweeps. The practice of reducing the quantity of air passing cannot be too strongly condemned; such procedure *increases* the risk of combustion, because sufficient air is always left for oxidation, and, owing to the small volume, the air gets heated higher than the surrounding strata, and consequently aids, instead of impedes, the risk.

There is a point at which a vigorous current of air is inadvisable; if combustion has broken out the quantity of air should be reduced, but until that point is reached a diminution in quantity only acts detrimentally.

In longwall workings, close and effective stowing of the gob with roof stone is the best preventive; if sufficient material is not available to completely fill the excavation, the packs should take the form of square cogs, and be arranged draught-board fashion. In Warwickshire, the sides of many of the gob roads are plastered with a layer of well puddled clay several inches thick. In thick seams, as there is practically neither roof nor sides to timber to in the workings, the only method of dealing with a fire is to isolate it by damming off the affected area.

If a fire occurs in a fast road, or in the gob in a thin seam, an attempt should always be made to dig it out. As an additional safeguard, lines of water mains are often laid along all the principal roads, these pipes being connected to the water behind the tubbing in the shaft. High pressure water is invaluable at collieries liable to spontaneous combustion; if a fire is attacked vigorously at its commencement it is often mastered, but when it attains fair proportions, it may not only occasion enormous expense, but be a source of continual trouble and danger.

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MAN. GEO. SOC.: *The Method of Working "Rearing Mines" at Leycett, Staffordshire*, W. J. Grimshaw, xiv., 155; *On Sinking of Surface owing to the Working of Coal Mines*, W. J. Grimshaw, xiv., 455; *Longwall System of Working Coal*, W. J. Grimshaw and H. Phillips, xv., 312, 330, and 341; *The Longwall System at Sovereign Pit, West Leigh*, J. Hilton, xvi., 270; *Working Coal by Longwall*, W. E. Garforth, xviii., 302; *Subsidence Caused by Colliery Workings*, J. Dickinson, xxv., 583.

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A Month's Visit to the North Staffordshire Coalfield, A. W. Grazebrook, xiii., 127; *Double Stall Working in a Thin Seam*, E. Graham, jr., xv., 88; *Mining Anthracite Coal in Pennsylvania*, H. W. Hughes, xvi., 156; *Jellieston Colliery, Ayrshire* (*working three seams of coal together*), W. G. Mitchell, xxi., 80.

AMER. INST. M. E.: *Pillars of Coal*, S. H. Daddow, i., 170; *Longwall System of Mining*, J. W. Harden, i., 300; *What is the Best System of Working Thick Seams?* O. J. Heinrich, ii., 105; *Fires in Mines, their Causes and Means of Extinguishing them*, R. P. Rothwell, iv., 54; *An Outline of Anthracite Mining in Schuylkill County, Pa.*, J. P. Wetherill, v., 402; *Coal Mining in the Connellsville Coke Region of Pennsylvania*, J. Fulton, xiii., 330.

SO. WALES INST.: *The Steep Measures of South Wales*, G. Robson, i., 234; *The Longwork System*, R. Bedlington, ii., 125; *The Working of Thin Seams of Coal*, H. Cossham, ii., 255; *On the Large Proportion of Coal Lost in Working*, A. Bassett, ii., 180; *The Longwall System*, T. Hedley, iii., 148; *The Pillar and Stall, Double Stall, and Longwall Systems of Working Coal in South Wales*, J. Naysmith, iii., 185; *The Longwall System of Working Coal as practised at Letty Shenking Colliery, Aberdare*, J. Williams, iii., 232; *The Comparative Systems of Mining in the North of England and South Wales*, G. Brown, v., 10; *The Different Methods of Working the South Wales Steam Coal*, George Wilkinson, xi., 129; *The Working of Steep Seams*, M. G. Johnson. xii., 363; *Working Thin Seams in the Radstock District*, J. M'Murtrie, xii., 424; *Subsidence Caused by the Workings in Mines*, W. Galloway, xx., 304.

MID. INST.: *On Various Methods of Working Coal in Yorkshire*, J. E. Mammat, i., 25; *On Results of Different Methods of Getting Coal*, R. Miller, i., 37; *On Different Methods of Working Coal*, P. Cooper, i., 44; *On Different Methods of Working Coal*, G. Fowler, i., 64; *On Longwall and its Modifications*, C. Hodgson, ii., 124; *On the Method of Working the Silkstone Seam at Normanton, with some Remarks on the Winning of Deep Coal*, W. E. Garforth, viii., 29.

N. STAFF. INST.: *On Cleavage Planes, and their Influence on the Economical Working of Coal*, G. G. André, ii., 132; *Mining in North Staffordshire*, J. Worgan, vii., 58, and C. Gordon, vii., 80; *On Pit Fires: a Consideration of Careful Special Packing as a Preventive*, S. Spruce, viii., 38; *Method of Working Coal at Whitfield Colliery*, H. Wright, viii., 59; *The Erection of Stoppings, with a view to isolate part of a mine on fire*, A. R. Sawyer, viii., 100; *Gob Fires and Pit Stoppings*, R. Oswald, viii., 198.

ANN. DES MINES: *Méthodes d'exploitation des couches de houille puissantes*, F. Delafonde (8e Série), xix., 253.

ENG. AND MIN. JOUR.: *Working Twin Seams*, W. S. Gresley, lxix., 559, 589, and 621.

FED. INST.: *A General Description of the South Staffordshire Coalfield south of the Bentley Fault, and the Methods of Working the Ten-yard or Thick Coal*, W. F. Clark and H. W. Hughes, iii., 25; *The Longwall Method of Working as applied to Seams of Moderate Inclination in North Staffordshire*, E. B. Wain, iv., 24; *The Opening-out and Working of the Rearer Coals of North Staffordshire*, E. Craig, iv., 48; *The Support of Buildings*, W. Spencer, v., 188; *The Spontaneous Combustion of Coal*, J. Settle, v., 10, and H. W. Hughes, v. 392; *The Methods of Working Minerals in Fifeshire*, A. Burt, xiv., 190; *Notes on Rearer Workings*, J. Cadman, xiv., 392.

CHAPTER VII.

HAULAGE.

Primitive Methods.—During the present century no branch of the various operations in coal-mining has improved more than haulage. In the olden times, carrying the mineral on the shoulders of men or women was the method universally employed, and is still carried out in places where civilisation is imperfect. The practice is, however, adopted in one instance in our own country, where the conditions are such that any other system would be impracticable—viz., the ironstone mines of the Forest of Dean. The earliest improvement consisted in the introduction of sledges, which are now employed to a limited extent, for hauling coal from the working places in thin seams to the roadways, as it is impracticable to lay a line of tramway along the face. In the thin seams of the Somersetshire coalfield, where the coal is 14 to 16 inches thick, roads 4 to 5 feet high are carried up to the face at distances of about 40 yards apart, and along these tubs are brought. In the face the coal is loaded on to an ordinary plank about 12 inches broad, and 6 feet long, one end of which is fastened to a piece of chain having a hook at the end farthest from the plank. The chain is passed between a boy's legs and the hook connected to a ring on a leather belt fastened round his waist. The plank is dragged to the way-end, and its load placed in the tub waiting there.

At this point, it may be stated, that it is a great advantage to have only one loading. Every time coal is emptied from one tub to another, breakage results, and, in addition, it costs money and labour.

Rails.—At the present time, practically all the rails used are of the flange pattern; bridge and angle designs having been abandoned. The sections employed have gradually got heavier, owing to the more permanent nature of the ways, and the desire to make haulage work as smoothly and with as few hindrances as possible. There can be little doubt that the wear of a rail is largely influenced by its composition, but the shape of the section and disposition of metal in the different parts is of greater moment. The use of heavy rails does not necessarily ensure long wear.

The designing of rail sections has of late received considerable attention, especially in the United States, and several papers on the subject have been contributed to the Amer. Inst. M. E.* These refer to the heavier sections employed on railways, but are none the less true, if applied to the designs in use in collieries. The chief points brought out are, that the head should have as broad a wearing surface as possible, and should not be too deep. If too much metal is

* *Certain Conditions in Manufacture of Steel Rails*, F. A. Delano, xvi., 594; *Steel Rails and Specifications for manufacture*, R. W. Hunt, xvii., 226 and 778; *A System of Rail Sections in Series*, P. H. Dudley, xviii., 763.

in the head, the temperature at the finish of the rolling process must be high, which produces a metal loose in structure that rapidly wears away in use. On the other hand, if the rail is finished by colder rolling, the compactness or physical hardness of the metal is increased. It is evident that the smaller the section the deeper will the effect of the compression of the rolls penetrate, and the finer will be the grain of steel.

The American Society of Civil Engineers appointed a Committee to draw out some standard rail sections, and a report of the progress made, has been published.* Ten different sets of designs were prepared, the following dimensions averaging as nearly as may be to the individual sections, if any wide deviations which appear in one set of sections only be neglected; *Head*, 12 inches radius, top corner $\frac{1}{2}$ inch, lower corner $\frac{1}{16}$ inch, vertical sides, percentage of metal 41·5; *Neck*, $\frac{1}{2}$ inch top and bottom fillet radii, sides either straight or 12 inches radius (there appears to be a diversity of opinion on this point), percentage of metal 21·0; *Base*, 37·5 per cent. of metal, width same as height of rail, sides vertical, with $\frac{1}{16}$ inch top and bottom corner radii, angle of head and top of base alike, 13° (about $4\frac{1}{4}$ to 1). The width of the head is 0·54 and the depth of head 0·287 of the total height of rail. Fig. 255 shows a section of rail weighing 30 lbs. to the yard, designed on these lines, which the author is employing largely on main roads at a colliery where the total load of coal and tub is 25 cwts. It replaced a rail weighing 39 lbs., in which, however, the arrangement of material was bad. The disposition of the material, so as to obtain the greatest wear with the least weight, is of the greatest importance, as the rail account at large collieries is quite enough without wasting more money on putting steel into parts where it is not wanted

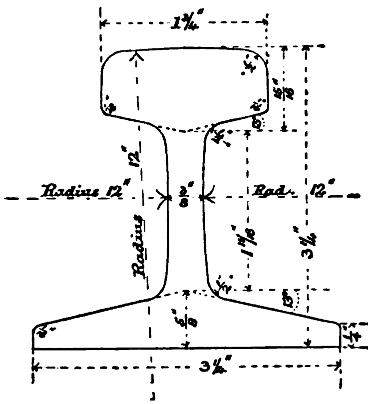


Fig. 255.

Mr. P. H. Dudley† prefers to place the line of the radii for the sides of the web above the centre, so as to make the lower portion of the web thicker, for the following reasons:—To more nearly equalise the heat of the section between the base and the head, permitting colder rolling; to lower the neutral axis, better equalising the strain of the metal between the base and the head, and checking the tendency to permanent set; to check the tendency of the web to bend near the base of the rail under heavy traffic.

The following specification‡ is recommended when ordering from manufacturers:—

The section of rail, when rolled, shall conform to the template furnished; with an allowance in height of $\frac{1}{64}$ inch under and $\frac{1}{32}$ inch over permitted.

* *Eng. and Min. Journ.*, 1891, li., 319.
† *Amer. Inst. M.E.*, xviii., 781. ‡ *Ibid.*, xvii., 238.

The length of rail shall be......feet; a variation in length of one quarter of an inch longer and shorter will be allowed.

The rails must be free from all mechanical defects and flaws, shall be sawed square at the ends, and the burrs made by the saws carefully chipped or filed off, particularly under the head and on the top of the flange.

The rails shall be smooth on the heads, straight in all directions, and without any twist or kinks, particular attention being given to having the ends without any drop.

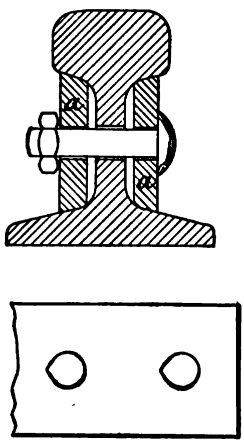
The steel to contain as high a percentage of carbon as the makers are willing to put in.

In the working places the lightest weight possible of rails should be employed, just strong enough to carry the loaded tubs.

Length of Rails.—In the workings, the usual length is 6 feet, or sometimes 3 feet when a longer length is inadmissible. The length should be such that the weight is small, in order that the workmen can easily move them about, as it is here that the greater quantity of rails are lost by falls. For laying the main roads no purpose is served by short rails, and for such situations, their length nearly approximates to those employed on surface railways.

Gauge.—The most general gauge is 24 inches, although it varies from 18 inches to 30 inches. With narrow gauges the operation of tipping the tubs sideways is facilitated; indeed, the objection to a narrow gauge is the ease with which tubs are overturned.

Methods of Laying Rails.—Two considerations have to be borne in mind here. In the working places, especially where the longwall system is used, rails are being frequently taken up and relaid in another position. This happens every time the face advances, and as a result, the way is not put down with much regard to evenness of road.


Figs. 256 and 257.

On the other hand, greater care is taken in laying the rails in the main road, because the line is a permanent one, and must be kept in good condition, in order that resistances to traction may be reduced to a minimum. Care is taken to make the gradient as regular as possible; the rails are kept perfectly straight, or, if curves are necessary, they should be bent by a machine similar to those used on railways. At many large collieries an experienced platelayer is employed, who superintends the laying of the main roads.

In laying curves, the gauge must be a little wider than on straight lines.

Fish-plating.—To obtain a rigid and straight joint on the main lines, side strips of steel called "fish-plates" are fitted on each side of the web (*a a*, Fig. 256) where the rails meet; holes are punched through the web and through each fish-plate, and bolts placed in them and screwed up tight. To allow for expansion, the holes through the rails should be oval, and to prevent the bolts turning round when the nuts are being screwed up, either the holes in one fish-plate are punched square, or the bolts made oval for a short distance under the head and then round afterwards, or one fish-plate is punched with holes of a pear-shaped section (Fig. 257), and the bolt made of a similar form just under the head. The remainder of the bolt is made round, and, passing through the oval hole in the rail, permits the latter to move a short distance.

It is important that the fish-plates should be rolled to correspond with the slope of the head and top of the base of the rail to ensure perfect fit.

Sleepers.—To give the road a solid foundation the rails are laid on transverse supports called "sleepers," which may be constructed of wood, iron, or steel.

Wood.—The length, breadth, and thickness of wooden sleepers depend on the gauge of the road and the weight of the load; from 3 inches to 4 inches deep by 6 inches broad is a common size. The wood employed is generally Scotch fir or larch; the former is cheapest in first cost, but the latter has greater lasting capacity.

To secure the rail to the sleeper a hole is generally punched through the base, and a flat-headed nail driven through it into the wood. The objection to this is that the hole weakens the rail to a very great extent, and breakages often result at the point where they are punched. For this reason a hooked nail called a "dog" is preferred. One of these is driven on each side of the rail. Here a point must be noticed; the hook on the dog is at right angles to the other part, while the base of the rail is sloping. As a result the dog must not be driven vertically downwards, but on a slope (*a*, Fig. 258), in

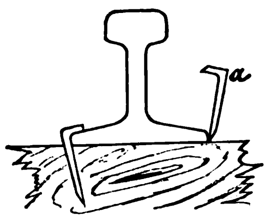


Fig. 258.

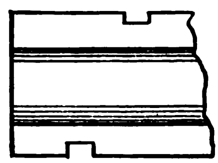


Fig. 259.

order to obtain as large a bearing surface as possible between the hook of the dog and the base of the rail.

The objection to dogs is that they do not prevent the rail moving longitudinally like a nail does when put through a punched hole. The difficulty is completely overcome by cutting a small notch out of the base of the rail where the sleepers are to be fixed, and to prevent these being opposite each other and weakening the rail those on one side of the base lead those on the other side from 1 inch to 1½ inches (Fig. 259). The notch is not more than a ¼ inch deep, and is taken out of the thin edge of the base, instead of through the thickest part, as is done when holes are punched for nails.

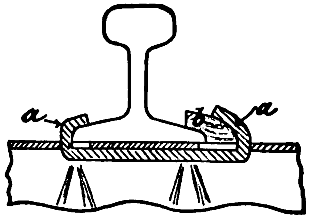


Fig. 260.

Iron.—Wrought-iron sleepers have been largely employed. They consist of a flat strip bent round at each end to grasp the base of the rail, with a block (see Fig. 262) riveted on at such a distance away that it clutches the other side of the rail. These sleepers last a long time and are easily repaired, but are comparatively heavy, and are easily bent.

Steel.—Of late years the use of light steel sleepers has become general. In one form, Colquhoun's patent, the rails are fastened by punching two holes in the sleeper, one on each side of the base of the rail. A steel clasp, or chair, is passed through these holes; the inner end firmly grasps the base of the rail (*a*, Fig. 260), and the whole is secured in position by a wooden key, *b*. The sleepers weigh about 14 lbs. each, and, as they are not very thick, are made of corrugated steel to give extra strength. Owing to the narrowness of the clasp, joints cannot be made on the sleepers, and fish-plates have to be employed.

Bagnall's sleeper is made extra wide, and rail joints may be made on it. A central concave corrugation passes from end to end, and, although the sleeper is narrowed in the middle to reduce weight, room is found for two convex corrugations, one on each side of the central concave corrugation (Fig. 261). The jaws, or chairs, four in number, thrown up for the purpose of securing the rails, are strengthened by corrugations at the back; the sides and end of the sleeper are turned down, thereby preventing lateral displacement, especially on curved lines.

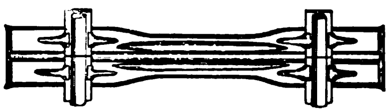
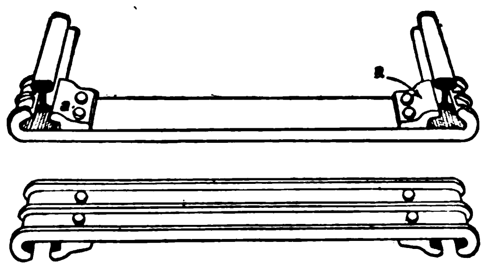


Fig. 261.

In Hipkins's sleeper, the edges are also turned down all the way round, but the top is flat. Instead of providing four small chairs at each end, only two are thrown up, but they are large ones, and each is strengthened by corrugations.

Both Bagnall's and Hipkins's give satisfactory results. Being made of steel they are very light, weighing only about 12 lbs., but, unfortunately, this lightness introduces a serious disadvantage. They are



Figs. 262 and 263.

constructed of such thin material that even a small amount of corrosion, such as would be of little moment on a thicker plate, seriously reduces their strength. In addition, as they are made out of one piece of material, should any of the projecting jaws be broken off, a not infrequent occurrence, the sleeper becomes useless. The satisfactory wearing results obtained from ordinary sleepers made from flat strips directed attention to the question as to whether their construction could not be improved without sacrificing any of their good points, and with a reduction in the weight and a gain in their stiff-

-ness. Such considerations led Mr. R. Mantle to design the sleeper shown in Figs. 262 and 263, where stiffness is secured by three longitudinal ribs about $\frac{3}{8}$ inch broad. The iron or steel rolled to this section is cut into lengths, the two ends bent round to grip one edge of the flange of the rail, and two brackets, *a a*, riveted on at such a distance as is necessary to grasp the other side of the rail. Steel, unfortunately, corrodes somewhat easily, and these sleepers are preferably made of iron, which can be of the commonest quality. They are light, stiff, convenient, and inexpensive.

Switches.—At junctions of roads, switches, or turn-outs have to be employed. For permanent situations these are best constructed by the blacksmith and platelayer, copying those adopted on railways, employing guard or check rails on all curved portions (see Figs. 326 to 329).

In the working places, and for temporary purposes, where turnouts are moved from time to time, a more rough and ready arrangement is required. An ordinary form consists of a movable rail about 6 feet long (*a b*, Fig. 264) pivoted on the centre *b*. This rail can either occupy the position *a b*, or that shown by the dotted line *a' b*. Where the curve is not a sharp one this device acts admirably, but in quick turns it is not so successful, as it throws a certain length of straight rail where there should be a curve.

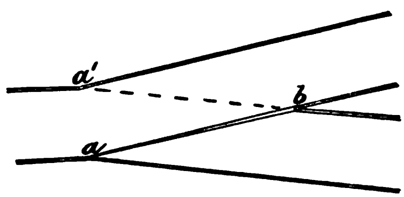
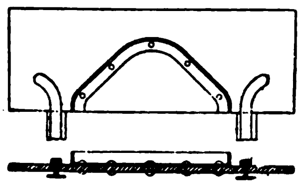
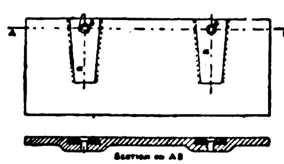


Fig. 264.

The more general practice is to employ castings for a portion of the switches. Middle beds and wing pieces can be bought of any radius and to any gauge. This construction is very handy, easily laid and removed, and generally applicable under any conditions.

Plates.—To readily turn tubs about at junctions where the space is limited, the rails are made to terminate, and a plate of wrought or cast-iron about 3 or 4 feet square placed in the gap. The tub can readily be turned about in any direction, but to guide it into its proper way, with a minimum of trouble, an angle-iron guard is usually secured to the plate by means of set pins, and the rails leading from it are opened out for a short distance (Figs. 265 and 266).


Figs. 265 and 266.


Figs. 267 and 268.

The continual passage of the flange of the wheel over one spot on these plates gradually wears a groove in them, especially where there is a lot of traffic, as at pit bottoms, where they are usually employed. To remove an entire plate takes considerable time, and when removed, the iron is good for nothing but scrap. To obviate this, loose wearing pieces should be introduced. These consist of two wedge-shaped plates (*a a*, Figs. 267 and 268), level with the top of the plate, which is recessed to receive them. The sides of the recess are inclined towards each other, so that the wearing pieces are in a manner dove-tailed, and when slid into position in the front end, are secured there by nails, *b b*, passing through them and the main plate. When worn out they can be replaced in two minutes.

Turn Tables.—As the labour of turning a tub on plates is considerable owing to the friction, revolving tables are substituted. These consist of a circular frame and top plate, which, in its commonest form, runs on four wheel rollers.

The movement with the above is comparatively easy, but has been rendered still more so by the employment of ball bearings. In Hudson's turn-table, a series of balls, about 3 inches diameter, are arranged in an annular groove (*b*, Fig. 269) and on this the top plate *c* rests, being pivoted on a pin, *a*, in the centre. A very simple automatic catch locks the table in any desired position. At Lye Cross Pit, South Staffordshire, the line of rails riveted on the table top are packed up 1½ inches at the end to receive the waggons, and a stop is attached to prevent the tubs running over it, but so arranged that by slight pressure on a foot lever the waggons are released. A stand-post and lever are also attached to the outer edge of the table, the lever being arranged to work the catch and also to pull the table round. The advantages are, ease of turning, the automatic catch, and the fact that no lubrication is required. Unless turntables of the ordinary wheel roller type are well greased, the labour of turning the tubs on them is considerable.

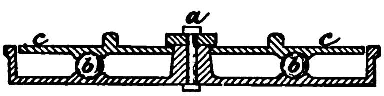


Fig. 269.

TUBS.—The general English practice is to make the body rectangular, and construct it either of wood, wrought iron, or steel. This body rests on a framework, generally of wood—almost invariably oak —or sometimes of iron. To this frame are attached the pedestals forming the bearings for the axles of the wheels.

Bodies.—If wood is employed in the body it may be elm, larch, or poplar. The latter is the cheapest and considered most economical, but elm seems preferable, as its wearing capacity is great. The advantages of wooden tubs are their low first cost and the ease with which small repairs are made; their disadvantage is the large amount of repairs necessary, when the seam is anything but flat and the rolling stock subjected to rough usage. They are usually constructed by cutting the side and end boards to the required lengths, putting an angle-piece of sheet-iron at each corner, and bolting the boards to it. This piece of angle-iron should extend along each corner from the top to the bottom, and preferably should have the lower ends bent back on each other to close the angle, so that a bolt can be fastened through it and the bottom of the tub. This binds the body and bottom firmly together, and adds considerably to the strength. The bolts should have half-round heads placed on the outside of the tub, with the nuts inside. If the boards are not tongued and grooved together, this construction allows the removal of any one broken piece without disturbing the others, but it is now common in many mines, especially fiery ones, to use a metal tongue between the boards, in order to prevent the small coal filtering through the spaces which would otherwise exist.

Wrought-iron and steel bodies are largely employed; with the latter metal the weight is less, but corrosion is far more rapid than with wrought-iron. With rectangular tubs the body is generally made of three plates, two forming the sides and ends and the other the bottom. The latter should always be made slightly thicker than the former, as it has to stand the continual blows given by material thrown into the tub. The connection between the bottom and sides is made with angle-iron, which should have unequal sides, say 3 inches by 2 inches, the longer side being placed vertically. By doing so, corrosion is prevented at the point where the angle-iron ends. A small quantity of fine coal collects in the corners, gets wet and rots the plate. If the angle-iron is made so high that this small accumulation does not reach above it the action is stopped.

A band of flat strip steel runs round the top of the body, and the joint should always be made at one of the ends, never at the sides. Rivets sometimes come out, and the end of the band projects. If the joint be made at the side, serious injury may be caused to horses through the projecting part catching them. For the same reason, rivets should have snap heads placed outside, and be knocked down on the inside.

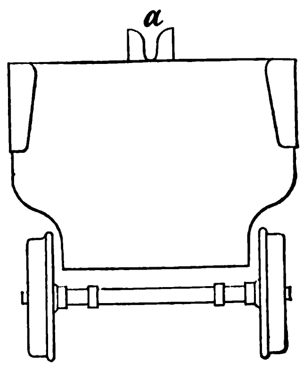


Fig. 270.

The usual form of tub employed on the Continent of Europe is shown in Fig. 270. The advantage of this special shape, is that the carrying capacity is increased without increasing the *height*, for, by bending in the sides at the bottom, practically a distance equal to half the diameter of the wheels is added to the body of the tub, and yet the total height above the rails remains the same. With the Continental thin seams this is important, although, of course, the cost of manufacture must be considerably more than an ordinary rectangular-bodied tub. With this construction equilibrium is very stable, as the centre of gravity is low. They are made entirely of steel, the only wood employed being the buffers, which are situated at each end, and run right across the plate. In general, seven plates are used in the manufacture, two on each side, one at each end, and one in the bottom. The side plates are riveted together, and the end plates secured to the side and bottom ones by angle steel. The frames or feet are channel steel (the pedestals lying in the grooves), and are bolted to the bottom plate.

Seamless steel tubs stamped out of a single sheet by an hydraulic press have been introduced by Graham, Morton & Co. The sheets which are oblong are first heated, and are then pressed by a die into a mould, the surplus pieces, which are produced during folding, being bent back over the ends of the tub, a portion of which is therefore three sheets thick, as will be seen from Fig. 271, which illustrates one of the many designs produced. The sides are generally corrugated, and the ends are stiffened by a piece of channel iron riveted along the top.

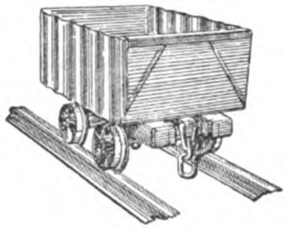


Fig. 271.

In the thin nearly vertical seams at Niddrie, Scotland, the bodies of the tubs are not set at right angles to the axles, but at an angle similar to that of the strata, and will consequently pass along levels, the sides of which are formed by the roof and floor of the seam. If the bodies were square a triangular piece of rock would have to be got off each side of the level to provide clearance space.

Frames.—The body rests on a frame, either of wood or iron. The former consists of two longitudinal pieces running the entire length, and connected either by two cross baulks, or by two iron strips. These bearers project past the body and form buffers, which should be lined up with the object of preventing those on two successive tubs getting interlocked when passing round curves, as, if they do, derailment inevitably ensues. The buffer end is generally widened out by adding on the inside two pieces of wood and placing a wrought-iron hoop around, but the better practice is to employ a cast-steel or malleable cast-iron shoe (Fig. 272).

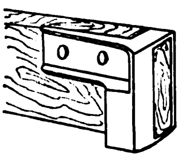


Fig. 272.

A still better plan is to use iron frames; they cost a little more, but wear better, and are a little lighter. Here the buffers are formed by a strip of wood running across the end of the tub, and cross-buffering never occurs. Figs. 273 and 274 show a tub body and iron frame-work employed at Bell End Pit, South Staffordshire.

Height.—The height of a tub is governed by the thickness of a seam, but they should not be too deep, or the breakage of coal is great. In low seams, if the tub be decreased in height and the space between it and the roof increased, there is neither the incentive nor the necessity to break the coals to get them into the tub. To remove the necessity altogether, one end of the tub is frequently made hinged, or loose, or either one end or a portion of it is left permanently open. Unless this is done many of the larger pieces of coal would have to be broken up, as there is seldom space enough between the top of the tub and the roof of the seam to allow of their being put into the tub except through an open end.

Size.—The only advantage of large tubs (carrying 20 to 45 cwts.) is that the useful weight (load) is large compared with the weight of the tub. The disadvantages are, they are awkward to move about, requiring large horses to haul them, and when derailed, several men are required to get them on again. The latter objection can be removed to a certain extent by the employment of small hydraulic lifting jacks, which can be readily carried about. Except in the thicker seams, the employment of large waggons underground means correspondingly large roadways, which are not only costly to maintain, but to make, as a portion of the roof or floor has to be removed to obtain headway, and the use of the endless rope or chain necessitating a double line of rails in the roadways becomes impracticable in many cases. The inclination of the seam also exercises considerable influence on the decision, as large weights on steep gradients are most difficult to deal with in, or near to, the working places where engine power is not available. For these reasons, except in the anthracite mines of Pennsylvania and in South Wales, we rarely find large tubs, the preferable size, perhaps, being those carrying 12 to 14 cwts.; they are easy to handle, capable of being put on the rails by one man, and with any ordinary gradient can be moved by a pony.

Wheels and Axles.—Wheels may be constructed of cast-iron, cast-steel, or forged steel, the former being rarely employed.* Their size should be as large as possible, with a view of reducing friction. The height of the roadways governs the diameter of the wheel where rectangular-bodied tubs are used, but by adopting the Continental form already referred to, a large wheel can be employed in a thin seam.

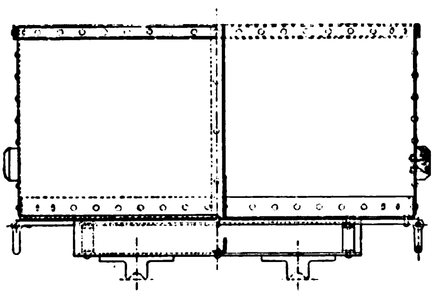


Fig. 273.

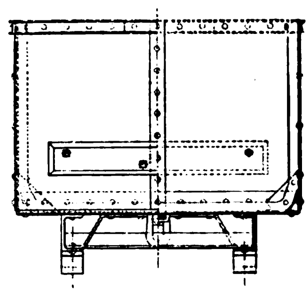


Fig. 274.

An improvement of value has been the introduction of Eyre's solid forged steel wheels, which are perfectly weldless, bosses, body, and rim being forged out of a single steel bloom. For the same strength as cast-steel wheels they can be made much lighter, may be either fast or loose on the axle, wear very well, and are practically *unbreakable.*

At the present time, axles are made of ordinary round bar steel, which is rolled to such perfection that it requires no turning. While the diameter should be as small as possible to reduce friction, strength is of far more importance. Weak axles are a constant source of loss.

Two entirely different methods are used for connecting wheels and axles. In one case, the wheels are loose and turn freely on the axle, in the other they are firmly fixed on the axle, and both are forced to revolve in the same direction with the same velocity. The loose wheel and axle are employed on vehicles travelling on ordinary roads, which are very uneven and where motion takes place in anything but straight lines, and as the roads in older collieries nearly approximated to these conditions, loose wheels were at one time largely employed on underground railways.

* This remark applies to ordinary castings. *Chilled* cast-iron wheels are used at many collieries with marked success.

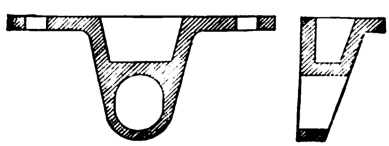
Their advantage, and the only one they possess, is the small resistance they offer in passing round curves. Naturally a wheel on the outside rail passes over more ground than one on the inside, and if both wheels have to travel at the same velocity, a grinding action between them and the rails must be set up.

At the present time, colliery roads more nearly approximate to surface railways, and as a result, wheels fast on the axles are becoming more and more employed. On the straight, there is less friction than with loose wheels. Their great advantage is their absolute trueness of gauge. Loose wheels are kept on the axles by cotters, and washers have to be placed against these to prevent excessive wear. No matter how carefully they are looked after the gauge is scarcely ever correct, and the cost of repairs to loose wheels, if cotters and washers are included, is much greater than with fast wheels.

Drawbars.—Tubs are connected together through drawbars, which are preferably riveted to the bottom of the tub. Indeed, the connection between iron and iron should always, wherever possible, be made by rivets; if bolts are used, sooner or later they work loose. In the construction of tubs, two points should be observed: strong drawbars and strong axles. Nothing is gained by making either too weak, and one breakage will minimise all the gain resulting from the decreased first cost.

Where tubs run in sets, drawbars, similar to those used on railway waggons, are employed; the coupling chains are always attached, and ready connection can be made. With some haulage clips, links on drawbars cannot be used; in such cases, a piece of flat steel is used with a hole through each end.

Pedestals.—Two types are employed, one for loose wheels, the other for fast ones. The general design of the former is shown in Figs. 275 and 276. With fast wheels, as the axle cannot be threaded



Figs. 275 and 276.

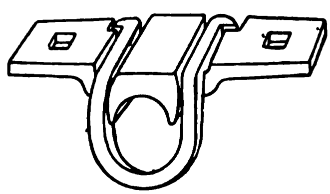


Fig. 277.

through a hole in the pedestal, the bottom part of the casting is omitted, and a wrought-iron guard-strap passed around. To allow of automatic lubrication this strap is bent on one side and leaves the under part of the axle exposed directly below the bearing (*c*, Fig. 282).

In many instances, owing to the severe strain thrown on this gland, one or both of the nuts of the bolts holding it in position may be torn off. In such cases should the strap be displaced there is nothing to prevent the axle jumping out of its bearing. To prevent this, Mr. Drury has designed a pedestal having two recessed grooves into which the upper ends of the strap are dropped (Fig. 277).

To reduce weight, the pedestals are best made of steel, and, as will be noticed, are cored out wherever possible, but care should be taken to see that the castings are smooth and free from adhering sand. Some manufacturers are negligent in this respect, and, as a result, the axles are soon cut badly.

To still further reduce wear and tear, and more especially to diminish friction, the pedestals are sometimes lined with a thin layer of magnolia or other anti-friction metal. Any ordinary pattern of pedestal can be used with a very slight modification, the footstep being cast with a recess about $\frac{1}{8}$ inch deep running straight through longitudinally, and nearly to the edges transversely. The roughness of the interior of this recess ensures the magnolia metal having a firm hold. The faces are cleaned and the molten metal poured in, which, after cooling, may be trimmed up and scraped smooth. With such bearings, the wear of the axles is reduced to a minimum, less lubrication is required, and the tubs are easier to handle. The pedestals last indefinitely provided the lining is occasionally renewed.

Lubrication.—A great deal depends on efficient lubrication, which with loose wheels is nearly impossible, except at great cost. With them, the tub has to be turned over and liquid oil poured into the bearings. This not only means considerable labour cost, but the waste of oil is great.

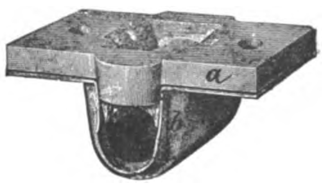


Fig. 278.

Numerous forms of self-oiling wheels and pedestals have been designed, the majority of which have been described by Mr. Emerson Bainbridge,* but few of them are satisfactory in practice.

In the pedestal manufactured by the Hardy Pick Co., the top part (*a*, Fig. 278) is identical with those of ordinary construction, but is fitted underneath with a steel dish, *b*, stamped out of one sheet of metal, which keeps the axle in position and at the same time prevents any dust or dirt getting into the bearing. This steel dish is shaped to hold a piece of hair felt which is soaked in oil and placed in the gland encircling the bearing as illustrated.

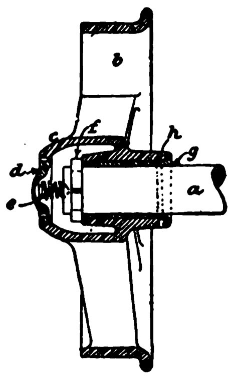


Fig. 279.

For wheels loose on axles continuous lubrication can be secured by casting the wheel with an oil chamber in the hub. In Rowbotham's wheel, *a* (Fig. 279) is the axle, *b* the wheel, and *c* the hollow hub. The oil chamber is fitted with the cap *d* screwed in as shown, in order that the collar *f*, which lies in a circumferential groove, turned round the axle at or near its extremity, can be placed in position after the axles have been threaded through the boss of the wheel. This collar is larger than the axle and prevents the wheel slipping off. The hub of the wheel is bushed with a metal ring, *g*, and to prevent loss of oil at the back of the

* *N. E. I.*, xxv., 215 ; xxvii., 8.

wheel, and to keep out dust and dirt the back of the bush is bevelled to receive a packing, *h*, of cotton, wool, or other suitable material. The cap *d* is provided with an oil hole through the centre, which, under all working conditions, is closed by a small stop per composed of a spiral spring, *e*, having a button at the outer end pressing against the inside of the cap, and at the inner end a con cal point fitting into a similar shaped recess in the end of the axle.

The reservoir is easily charged with oil, by inserting the end of a syringe in the hole and forcing in the button. The conical ends of the plug or stopper prevent it getting displaced during such action, and immediately the contents of the syringe have been discharged into the reservoir and the instrument withdrawn, the spring forces back the button and closes the outlet hole. These wheels have been in use several years with satisfactory results. The attendants have to judge by external appearances whether the reservoir needs recharging, but on the least signs of the wheels becoming dry, or on the tub not running freely on down grades, they can be put out for oiling, which can be done by a lad with a syringe while the tubs are standing on the rails at the pit top, much quicker than a tub with ordinary loose wheels could be turned over and oiled out of a can. Not only is there a considerable saving in oil but effective lubrication is secured.

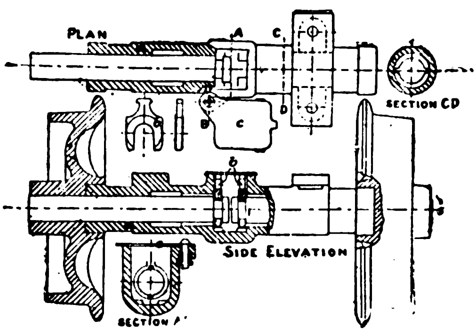


Fig. 280.

A wheel of somewhat similar design has been largely adopted by the Anaconda and surrounding mines in Montana.* The axles are made in halves, and have the wheels pressed on one end, while the other enters into a cast-iron sleeve (*a*, Fig. 280), which for part of its length at each end is bored to fit the axle, while the centre for two-thirds of the length is counter-cored to provide ample oil space. The sleeve enters about $1\frac{1}{2}$ inches into the hub of each wheel, with a sufficiently close fit to prevent a loss of oil. The inner end of each half axle is provided with a groove, in which is placed a small fork-shaped brass casting, *b*, straddling the axle and serving to hold it in position. At the centre the sleeve is enlarged, and provided with an opening of sufficient size to allow the forks to drop in, while a pressed steel cover, *c*, is hinged over this opening, and can be readily slipped on one side to permit oiling, or, when it be necessary, to take out the forks and remove the wheels and axles. By having the axle in halves, a small variation in the gauge is allowed when the wheels pass around curves. Each sleeve is provided with two lugs, which take the place of ordinary pedestals, for attaching the sleeves to tub bodies. All the parts are made to exact gauge, and are absolutely interchangeable.

* *Eng. and Min. Journ.*, 1898, lxvi., 161.

For wheels fast on the axles by far the greater number of lubricators consist of revolving bushes or corrugated wheels which work in a small tank or reservoir, and supply a quantity of grease to each bearing as the tubs pass by. Brushes soon wear out, and for such reason iron corrugated wheels are preferable, two of which, one beneath each bearing, are generally arranged to revolve, and sometimes to travel forward a slight distance also, in a semi-circular trough fixed between the rails.

In Dunford and Emen's greaser, *b* (Fig. 282) is the wheel, and *c* the pedestal gland, bent on one side to expose the under side of the axle, *a*, of an ordinary tub. A corrugated steel wheel (*d*, Fig. 281),

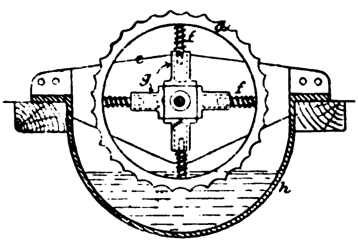


Fig. 281.

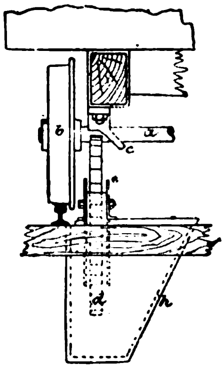


Fig. 282.

revolves in a trough, *h*, partially filled with grease, and at each revolution raises in the corrugations a sufficient quantity of grease to efficiently lubricate the axles. If the wheel were rigid, and could only revolve at a fixed height, it would soon get broken, because of the varying heights of the axles which pass over it, due to the wear of the tub wheels and pedestals. For such reason the corrugated wheel is provided with four short arms, which do not continue to the centre, but enter and slide into four cases, *g*, containing four spiral springs, *f*, which hold the wheel in position, but at the same time allow it to be depressed, or moved forward, or, indeed, to have an eccentric motion about its centre. Two side plates, *e*, carry each wheel, and are provided with slots, to allow of the wheel being easily raised or lowered. Each wheel is in a separate trough, provided with one bevelled side to incline the grease towards the wheel, and as the troughs are not connected with each other the greaser can be arranged to suit any width of gauge, while it automatically adapts itself to wheels varying 2 inches in diameter.

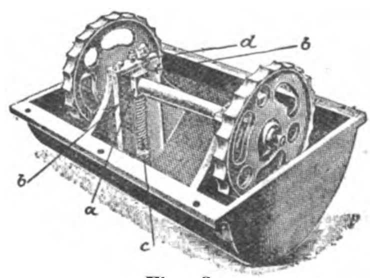


Fig. 283.

In the greaser made by W. G. Allen & Sons, two wheels run loose at the end of an axle provided with two projecting bosses (*a*, Fig. 283), which work up and down in guides, *b*, forming part of the trough containing the grease. As the axle is continuous, each greaser has to be made to suit the rail gauge in use, but as the whole apparatus is self-contained there is little liability for it to get out of order. The axles are supported, and the corrugated wheels kept up to their work, by two spiral springs, *c*, working between each pair of guides, while adjustment to the required height can be obtained by the set pin, *d*. Although the wheels of this greaser may not appear to be so resiliant as those of the one previously described little or no difference is observed in practice, while its first cost is considerably smaller.

In Bowman's lubricator a tank at the side of the rails is employed for containing the grease, with pipes leading under the rails to two boxes which are fitted with cylinders and pistons, the piston-rods of which are hollow, and surmounted by arcs or bows. The bows are kept in position by means of spiral springs in such a manner that, when a tram passes over them, the axle depresses the bows and causes a small column of grease to rise through the hollow piston-rods to the apex of the bows; this adheres to, and is taken away by the axle. The bows instantly rise into position again, ready to repeat the operation on the passage of another axle.

The advantage of this class of greasers is that they can be put down anywhere, and are quite automatic. In a long haulage plane, they can be placed at intervals where necessary, and considerably reduce both the power required and the cost of lubrication. Care must be taken that the tubs pass comparatively slowly over them, and that the troughs are not too full of oil, or the axles will carry away too much grease which drops off after the tubs have travelled a short distance and results in considerable waste.

In the paper before referred to, Mr. Bainbridge states that the cost of greasing tubs at eighteen different collieries, varied from 0·075d. to 0·821d. per ton raised. Oil gave the worst results, no doubt owing to the quantity of waste. With grease and corrugated wheels, the cost varied from 0·075d. to 0·289d. per ton. It will be noticed that this result is over one half-penny less than the maximum, and shows that some efficient method is very desirable. A low cost may possibly mean that the tubs are badly lubricated.

SECONDARY HAULAGE.—At all collieries, even where the most modern haulage arrangements are adopted for conveying the mineral along the main roads, some secondary system of haulage has to be employed for collecting the coal from the working places into one of the main sidings, and for returning the empty tubs from this point and distributing them among the workings. The distance from the ends of the haulage system proper to the working places should be kept as short as possible, but even with the best of roofs and the strongest of coals, it would be unwise to fix haulage machinery as near to the workings as is desirable. From 100 to 150 yards with a good roof to from 300 to 400 yards with a bad one may be taken as the limits. The work of secondary haulage is performed by men, horses, or semi-portable engines, and as only one or two tubs are moved at a time over comparatively short distances, where hindrances are the rule owing to continual movements in the road and railways, it is more expensive than haulage along the main roads.

So much depends on the conditions under which secondary haulage is put to work, that it is difficult to compare one system with another, or to lay down any rule as to which is the most economical. Even where comparisons can be carried out under the same conditions, the result only proves that one system is superior to another under the conditions existing during the experiment; under other circumstances the result may be reversed. The whole subject has been reviewed by Mr. Galloway,* whose paper brought out a discussion interesting to all mining engineers, and further contributions † on the same subject.

Men.—Except for short distances and on easy gradients, the pushing or "putting" of tubs by boys or men is little employed. Under favourable circumstances it affords a ready means of concentrating single tubs at sidings near to the working places from whence they can be conveyed in sets of two to six by horses to the ends of the main haulage planes, and in such cases compares favourably, as to cost, with haulage by horses.

Horses.—Horses are connected to the tubs, either through the medium of a pair of shafts, or a tail-chain joined to a stretch-bar, to which two side traces are attached. Each of these systems has its advantages. With downhill gradients a horse cannot hold back the load when connected to it by a chain, and, therefore, to prevent the tub running away and overtaking the horse, the wheels have to be "lockered," which is done by pushing a short bar of iron through the spokes, and preventing the wheels turning. This is very objectionable, especially on undulating gradients, and causes considerable wear and tear. Shafts are dangerous to horses, as they catch the timber and hamper movement, particularly so in narrow and heavily-timbered roads; they also prevent the horse getting out of the way of the moving train of tubs if the weight overpowers the animal. Up hill there is no difference between chains and shafts.

Feeding.—The chief item of cost in horse haulage is that due to feeding, as not only may an excessive charge be incurred, but the condition of the animals may be so reduced as to unfit them for performing the maximum amount of work. The problem is to keep them in the best condition at a minimum cost, which can easily be done by a proper selection and mixing of food. It may be stated that, however concentrated the nutriment may be, small quantities never afford satisfaction, as hunger is not appeased until the stomach is filled, and, therefore, in addition to foods supplying waste of tissue (oats, beans, &c.), some bulkier body has to be given. This is the reason why hay and straw are found in the feed.

Some prefer to give hay in its uncut state, placing it in a rack where the horse may nibble at it as it prefers, whilst others cut it up with straw into the state of chaff and mix it with hard corn. The latter procedure seems best. Horses going out of the workings into the stable are hungry, and bolt their food. If the manger contains hard corn only, this being small in bulk, is rapidly consumed, passes into the stomach without being properly masticated, and the animal does not obtain the nourishment it should do. Hay is then attacked, and, being in its natural state, has to be pulled from the rack, pieces are dropped on the floor, trampled under foot and lost, thereby occasioning waste. On the other hand, if hay and straw be cut up and mixed with the hard corn, the manger contains an increased

* *Fed. Inst.*, xii., 257. † *So. Wales Inst.*, xx., 343, and *Fed. Inst.*, xv., 136.

bulk; then, if the horse takes its food voraciously, the first pangs of hunger are soon appeased, the remainder is consumed in a leisurely manner, and the full benefits of the nutritious matter are obtained. In addition, waste is minimised with properly constructed mangers.

Regarded from the standpoint of cost compared with benefit, bran is quite out of place as a food. Its chief use is as an appetiser, and for its corrective and laxative properties Sometimes it is given as a mash at week ends, when a horse has to stand in the stable all the next day, while others mix a small quantity with each feed. As it seems preferable to avoid extremes with such regular bodies as those of colliery horses, the latter course is generally adopted.

Respecting the different varieties and mixtures of hard corn, every one interested in the management of colliery horses should refer to a paper by Mr. C. Hunting,* in which the constituents of various foods are fully described, and the whole question gone into. It was long considered that oats alone were sufficient. Mr. Hunting points out that this is correct to a certain extent, as they contain more proportionate quantities of nutritious elements, but for very hard work, such as underground horses have to do, the consumption of muscle is far in excess of the waste of any other tissue, and food containing a heavy proportion of nitrogenous or flesh-forming material must be given. If the choice were limited to one article, oats are superior, but an equal weight of a proper mixture of beans and maize gives better results than oats alone; better in a double sense, because not only is its flesh-forming capacity greater, but it is considerably cheaper. Peas are often used as a substitute for beans, as they run a little cheaper, but are very heating, and should only be used with care.

Mr. Hunting strongly advocates the use of a mixture of green food during a short time in the summer, but some discretion is required in its administration. Under no circumstances should it be sent down the pit when soaked with rain. It should not be allowed in-bye, where a tired horse may gorge itself when waiting at a siding.

A horse's stomach is relatively small compared with the bulk of its body, so that it cannot retain sufficient food to maintain the animal for long intervals. Mangers should therefore be established at the siding to which the horses travel, so that they can eat small quantities while waiting there.

Cost of Feeding.—At a colliery where the horses are on an average 15 hands high and 80 in number, the cost of feeding during the years 1885–1892 has varied from a maximum of 12·25s. per horse per week to a minimum of 8·66s., the average for the whole of the time being 10s. 2·891d. Two samples of feed are given below :—

	Jan., Feb., and March, 1888. Cost per horse per week, 11·44s. Lbs. per day.		Jan., Feb., and March, 1890. Cost per horse per week, 9·75s. Lbs. per day.	
Beans,	2·577	7·135	3·204	7·349
Maize,	2·922		2·615	
Oats,	1·636		1·530	
Bran,	9·398		8·239	
Hay,	13·762		14·499	
Clover,	1·426		0·549	
Straw,	1·767		5·759	
Total,	33·488 lbs. per day.		36·395 lbs. per day.	

* *N. E. I.*, xxxii., 61.

Cost and Life of Horses.—Figures relating to the purchase of horses at the same colliery for a period of thirteen years give the average cost of each one as £21 4s. The average life for the same period practically amounts to about eight years, but the percentage of deaths from accidents to horses employed being rather large—6·198—during the last six years, the life may better be taken at nine years, which is the figure given by Mr. Hunting in the paper already referred to, where the life of horses, on an average at twelve collieries, amounted to that length of time. Mr. Hunting gives the average number of deaths in each year for twenty-one years: horses, 4·70; ponies, 3·08 per cent.

Cost of Corn Cutting and Ostlers.—At the colliery under notice, the feeds are all prepared and mixed at bank by two men, and the cost per horse per week equals 5·296d. Two men are employed cleaning and attending the horses down the pit, both on the day and night shifts, and during the daytime one of the men goes round the different parts of the pit and sees that the horses are supplied with corn and water, while the other cleans out stables, &c. The cost per horse per week is 1s. 9·153d.

Shoeing.—With pit horses rough shoeing is done, old scrap iron being used up in many cases, but against this has to be set the trouble and time the blacksmith is put to in going into the workings, often a considerable distance, when a horse casts a shoe. The average charge may be taken as 6d. per horse per week.

In two most interesting papers by Mr. J. A. Longden,* the following directions are given:—Never pare the sole or frog, and only cut enough of the horn off at the lower end of the hoof to allow the shoe to bed properly; above all, reduce the weight of the shoe to the lowest possible point, and do not employ "calkins" on either heels or toes. Three nails on the outside and two on the inside are quite enough for the fore-feet, and they should never be placed near the heels. He gives the cost of shoeing ponies at Clay Cross and Blackwell Collieries, Derbyshire, at 3·23d. per horse per week.

Taking the average of many years, the total cost incurred for each horse per week is as follows:—

	s.	*d.*
Keep,	10	2·891
Repairs to harness,	0	2·538
Cutting and preparing feed,	0	5·296
Ostlers,	1	9·153
Brushes and currycombs,	0	0·228
Veterinary surgeon and medicine,	0	3·058
Shoeing,	0	6·000
	13	5·164

Arrangement of Stables.—Pure water and plenty of ventilation are essential. The stables at Lye Cross Pit are shown in Figs. 284 and 285. Each horse has a stall 7 feet long by 6 feet wide, and a corn-manger, 4 feet long, made with specially shaped bricks. A water bosh is placed between each two stalls, and a 2-inch main-pipe with down branch pipes delivers water to each bosh, which has a hole and plug in the bottom to allow of easy emptying.

* "Shoeing of Pit Horses," *Brit. Soc. Min. Stud.*, iv., 104; *Ches. Inst.*, ix., 273.

The stables at Eppleton Pit are most elaborate. Each pony stands in a distinct arch, 5 feet 6 inches wide by 6 feet long, the brickwork between each stall being 18 inches thick. A passage is provided behind the mangers with communications to each stall, through which the horse's food is introduced, thereby not only facilitating the work, but removing all source of danger to the attendant through the kicking

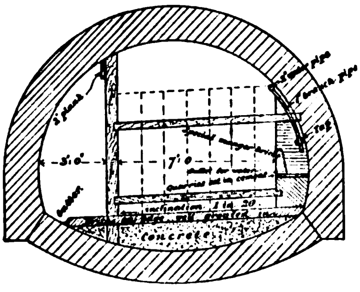


Fig. 284.

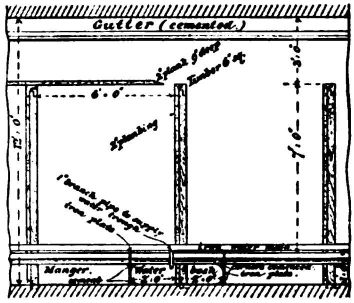


Fig. 285.

of the horses. The floors are laid with blocks cast out of furnace slag, on such an inclination that sock readily drains away, a gutter for this purpose being placed in the centre of each stall, which in its turn passes into the main channel running down into the central arch, out of which the stalls branch on either side. The mangers are also constructed of specially shaped bricks. Water troughs are not provided in each stall, but a large one is placed in the main arch near the entrance. The ponies drink on their entry to and exit from the stables.

Cost of Horse Haulage.—Given a considerable output and long life, there can be no doubt of the economy of mechanical haulage, but the saving is not so apparent if limited quantities are dealt with. At small collieries, the capital outlay with interest and upkeep is so large and the quantity dealt with so small, that horse haulage compares most favourably with mechanical means, especially where the gradients are in favour of the load. An instance of this is given by Mr. H. F. Bulman* where the cost of leading 4407 tons an average distance of 1870 yards was 4·7d. per ton, or 4·4d. per ton per mile.

Upon the relationship of gradient to load the success or otherwise of horse haulage entirely depends. On level roads, or where the inclination is slightly out-bye, the amount of useful work performed by a horse is in strange contrast to that where the conditions are reversed, and the gradient is against the load. Lye Cross Pit supplies a very good instance of this. One stage measures 125 yards long, the first 35 yards being practically level, the remaining 90 rise out-bye at an inclination of 1 in 12. Two horses are employed to haul coal this distance, each one making 42 journeys a day, a total distance travelled of 5·96 miles. The load of coals taken each time is one ton; the useful effect of each horse for this stage is, therefore, one ton led 2·98 miles—*i.e.*, half the distance travelled. The stage immediately succeeding the foregoing one is 200 yards long, and practically level.

* *Brit. Soc. Min. Stud.*, xi., 176.

One horse serves this distance, making 21 journeys per day, travelling 4·77 miles. The load of coal is 4 tons, so that the useful effect is 4 tons led 2·38 miles, or 9·52 tons led 1 mile. A better illustration is afforded by another stage, where a horse makes 38 journeys per day, travels 4·75 miles, the load of each full set being 7 tons. The useful effect is therefore 7 tons led 2·37 miles, or 16·59 tons led 1 mile. The road had a slight gradient in favour of the load. At this pit, when the average distance each ton was led by horses was 480·3 yards, the cost per ton was 4·195d., equal to a cost per ton per mile of 15·37d.; when the average distance was 774·7 yards the cost per ton per mile was 11·25d.

At Cwmaman Colliery* on a total of 12,615 tons, the absolute cost varied from 4·9d. to 6·4d. per ton, equal to an average over the whole pit of 16·2d. per ton per mile.

Messrs. Forster and Simpson † have taken out the costs of "putting" and "driving" at twelve collieries in the North of England, six worked on the bord and pillar system, and six on the longwall method, and with a fair proportion of thick and thin seams. "Putting" is understood to mean the conveyance of single tubs from the face to certain collecting points; and "driving," the haulage by a horse or large pony from such collecting points to the engine planes, the tubs in this case being drawn in small sets. In working out the costs, all maintenance (comprising feeding, attendance, shoeing, veterinary surgeon and harness), wages to putters and drivers, and interest and depreciation on capital, was taken into account. With putting, the average of the twelve cases gave 27 tons per day led 180 yards, by each pony, at a cost per ton of 1·584d. for wages, 0·50d. for maintenance, and 0·068d. for interest, &c., total 2·152d. With driving, an average of 30 tons per day were led a distance of 423 yards at a cost per ton of 0·531d. for wages, 0·615d. for maintenance, and 0·087d. for interest, &c., total 1·233d. The average total cost of putting and driving an average distance of 603 yards, therefore worked out at 3·385d. per ton. These figures may be taken as representing the cost under the favourable conditions of easy gradients and good roads which exist in the Northern coalfield.

Not only is the useful effect reduced by adverse gradients, but the lives of the horses are considerably shortened; in a short space of time they become worthless, and the cost of up-keep is a serious matter. A little consideration will explain the reason why gradients have such influence in haulage on rails, far more so than in surface work with ordinary carts. With well lubricated bearings and wheels on rails, the resistance to motion is slight, and a horse easily moves heavy loads under favourable circumstances. Down-hill gradients are therefore favourable to a good performance of useful effect, but where the inclination is against the load, the small resistance is against large weights being moved, as the load has a greater tendency to run back than if the surface on which it rolls was rough like an ordinary road. In the former case, the friction is so small that the horse has practically to contend with the full weight of the load divided by the gradient, while in the latter, the greater friction reduces the strain. Mechanical haulage therefore becomes a necessity with heavy gradients, as even where these are in favour of the load, the strain of

* *So. Wales Inst.*, xx., 347. † *Fed. Inst.*, xv., 137.

returning the empties becomes so great that the advantage gained with the load is nullified.

Semi-Portable Engines.—When the gradients are against the load, the employment of some form of engine power becomes essential. As the direction and length of the roadways are continually changing, and as the situations in which they have to work are confined, small and compact self-contained semi-portable engines are generally employed. They usually consist of a pair of short stroke engines, geared down, and driving one or two drums on the second motion shaft. The drums are provided with foot brakes, and can generally be thrown in and out of gear by clutches. As a rule, they are arranged so that they can be mounted on wheels of the same gauge as the colliery railroads to allow of their being run from point to point. The motive power is generally compressed air; steam is inadmissible, and electricity does not so conveniently lend itself to the continual starting, stopping, and reversing which must take place.

The use of such engines is far more general on the Continent than in Great Britain, especially in the working of the thicker seams, where the greater portion of the coal is got to the dip. These small winches pull the full tubs up from the workings on to the level, and also lower the tubs containing the gobbing material to the face.

At Llanbradach Colliery, Mr. Galloway used portable winches, and dispensed with horses altogether, when the cost, under by no means favourable conditions, amounted to 4·310d. per ton hauled an average distance of 581 yards. This cost included all wages underground, wear, and renewal of ropes, coal burnt beneath boilers on surface, stoker, engine-driver of air compressor, stores, oil, &c., and general repairs, but did not include interest on capital and amortization, which was given at £313 4s. per annum.*

SELF-ACTING INCLINES.—With mines having the necessary inclination, gravity supplies the motive power for the haulage, and self-acting inclines, or jig brows, are employed, the principle of which is that the loaded tubs running down-hill will haul the empty tubs up. A certain gradient is necessary, as the weight of the full set has to overcome the friction of the two sets, the drum and rollers, *plus* the weight of the empty set and rope; the latter is variable and greatest at the start. Roughly speaking, a gradient of 1 in 36 is required with wheels and axles of ordinary size; but the length of the road plays an important part, owing to the greater weight of the rope, therefore, as the plane gets longer, the gradient must also increase, to overcome the increased resistance. A flat part has to be provided, both at the top and the bottom, to make up the sets, and it is advisable that the gradient at the top of the incline should be greater than it is at the bottom, as the set then easily gets into motion.

Arrangement of Rails.—Nothing gives better results than two lines of rails completely from the top to the bottom, which is only possible when the roof is sufficiently good to allow of a double way being kept. If it will not stand such a width, three rails are carried from the top and bottom, with four in the middle where the tubs pass each other. These are the common arrangements, but rails may be arranged in many different ways.

Where the roof is so bad that a double road cannot be made, even

* *Fed. Inst.*, xii., 273.

in the middle, two lines of rails are used, one inside the other. The tubs run on the outer line, and haul up a dead weight travelling on the inner gauge. At the point of meeting, the rails of the outer gauge are raised up and those of the inner depressed, and the dead weight passes underneath the tubs. The weight of the balance must be less than that of the full set, but more than that of the empty one. The working capacity of such an arrangement is one-half that of a road laid with a double line of rails. For inclines where intermediate landings are worked, this arrangement gives excellent results, and in many cases, under such conditions, as much mineral can be jigged down with this system as by any other.

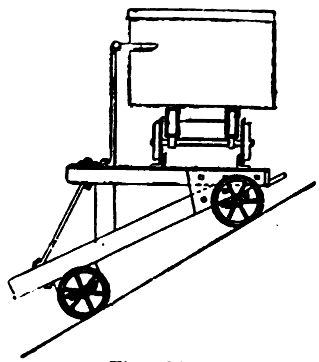


Fig. 286.

In stall roads going into the working place, the common practice in steep mines is to make a full set going down one road haul up the empty set in the next adjoining roadway. Where the inclination is great (above 35°) the tubs have to be placed on special carriages (Fig. 286) to throw the coal into a horizontal position. If this were not done the load would be emptied as it passed down the incline.

Blocks or Stops.—Arrangements are always made at the top of inclines to prevent the tubs prematurely running down before the set is made up. The common form of blocks is shown in Fig. 287, but where the inclination is steep, the top part, *a*, is stretched across the whole width of the rails, and the two wheels of the tub rest against it. A much stronger construction is necessary where the tubs are gathered together to form sets, as severe blows are often delivered which the ordinary stop is incapable of withstanding. In such cases the block illustrated in Fig. 288 is employed at Lye Cross Pit, where there is a double road, but only half the arrangement is needed for a single way. Two round bars of iron, *a a'*, are pivoted at *b b'*, and when shut are held in the jaws, *c c'*, which, in their turn, can describe the arc of a circle about the centres, *d d'*. The stops, *a a'*, are fixed at such a height that the wheels (*h*) of a tub cannot jump over them. The blocks are opened by moving the jaw, *c*, about its centre, when the weight of the tubs pushes the bar right over. The jaws are kept at the proper level to receive the bar when it is brought back by a stirrup of iron, *e*, and in order that the bar may slide into the jaws, and not hang below them, two short pieces of rail, not shown in the figure, are set in the middle of the way on a slight inclination, so that the bar may ride easily on them. The bars have to be brought back into position, and closed on the jaws, after the tubs have passed, which a man easily does with his foot. The whole of the ironwork is firmly bolted to strong pieces of timber framed together. If the sets are

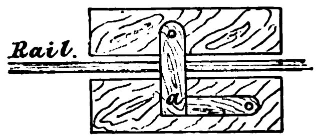


Fig. 287.

always jigged on the same side a balance block can be used (see Fig. 309). Mr. A. R. Sawyer * describes a good block arrangement which

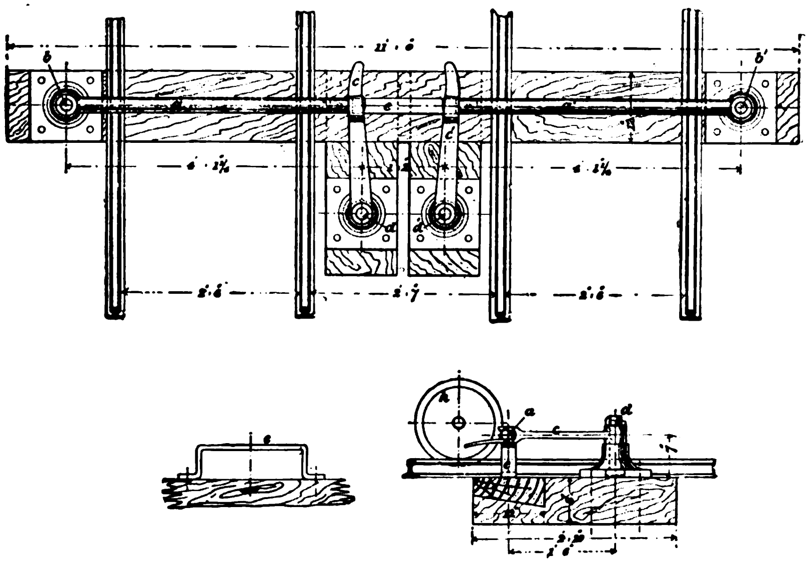
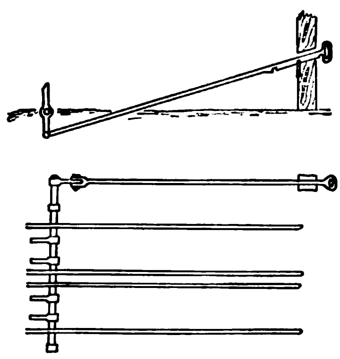


Fig. 288.

is opened and shut by hand at a distance, the working of which will be easily understood from Figs. 289 and 290.



Figs. 289 and 290.

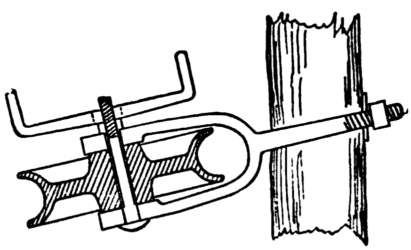


Fig. 291.

Drums and Pulleys.—In permanent situations, and on long inclines, drums similar to those on winding engines are fastened on a shaft, the empty rope coiling on one, and the full rope on the other. A brake has to be provided to retard the descent, and to keep the velocity from getting too great. These drums occupy a considerabie

* *Miscellaneous Accidents in Mines*, 1889, 153.

amount of room, and in confined situations pulleys become necessary. These may either be fixed on a vertical or horizontal axis, and may be made for working with a chain or rope. Chains are very convenient; they can be easily added to, if the plane lengthens, or are shortened with equal ease. They can also be transported much easier than wire ropes, but they are heavier, more liable to breakage, and require a steeper inclination, owing to the greater friction. If ropes are employed either a clip, or a C pulley with several coils on it (see p. 251) may be used, while for chains, the throat of the pulley may either be fitted with Y grips or feet, and in the latter case several turns are passed round it. For short inclines, with only one or two tubs jigged at a time, small hand jig-wheels are employed (Fig. 291), which can be readily moved about from place to place, and are usually secured to a prop.

Brakes.—All-round ones are preferable on small wheels, the brake-ring being of cast-iron, and the strap of wrought-iron. Some material, such as a wooden curb, should be placed between; in the smaller wheels, a lining of hemp rope, attached to the brake-strap by bolts, gives excellent results, but care should be taken to counter-sink all the pin-heads.

Mr. Malissard-Taza describes an ingenious fan-brake on a self-acting incline plane at Bilbao,* which consists of four radial blades, about 6½ feet wide by 16½ feet diameter, two band-brakes being also provided for safety. The fan brake works slowly at first as the tubs move away, gradually increasing in speed until the journey attains the rate of 10 feet per second, after which motion is uniform, owing to the resistance of the air. The advantages are:—absence of continuous friction of brake-strap, with wear and tear, uniform velocity, speed capable of any regulation and variation by addition to, or removal from, the arms of the fan, and less attention while the journey is running, none being required except on the arrival of the waggons at the top of the incline.

Rollers.—In every system of haulage small rollers should be placed at intervals, to keep the ropes and chains from dragging on the ground, as, if they do, not only is the resistance to be overcome much greater, but wear is rapid. The rollers employed are small cylinders on a spindle, and may be either constructed of cast iron, steel, or wood. Cast-iron ones possess no advantages, and rapidly wear out. For surface and exposed situations wood is not to be recommended, as it cracks and splits under climatic influences. Underground, the same objection does not hold good, and wood is often employed, it being contended that it is better that the rope should wear the roller than the roller wear the rope; the latter may happen if steel of a hard nature is employed.

Provided rollers are cast true, and the shell made as thin as possible, there should be little longitudinal rubbing due to differences of speed between the roller and the rope. The sideways motion, due to the swaying of the rope as it drops on to the roller and seeks its normal position, where it has probably worn a groove, can be practically prevented by corrugating the face of the roller, as has been done by Mr. George Spencer. By the use of corrugations not only is the roller strengthened, but the bearing surface for the

* *Soc. Ind. Min.* (2e Série), xiv., 1065.

rope is greater, so that the wear is less, while there is the further advantage that the rope gets a better bite, and starts the roller revolving more quickly, thereby diminishing the slip. The casting can be made of less weight, and flanges at the ends omitted.

Junctions.—In steep mines, where intermediate hanging-on places are worked, the continuity of the rails has to be interrupted at such places. The branch roads pass away level, or nearly so, and at the joining place an iron plate is laid, which is bridged over by rails that can be lifted in and out of position (Fig. 292).

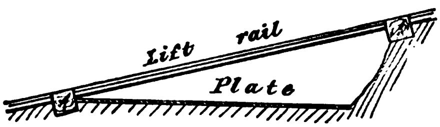
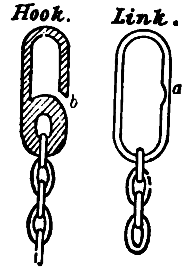


Fig. 292.



Figs. 293 and 294.

The alteration in length of the jigging-rope is either obtained by adding on a piece of chain provided with large links opposite each intermediate landing, or by employing as many pieces of chain as there are branches, all of which have to be joined together when tubs are sent down from the top of the incline. The normal position of affairs is that the chain, consisting of a number of pieces joined together, each of which is equal to the length between two successive landing-places, extends in one continuous length from the bottom of the incline to, and around, the brake wheel at the top. Each time the incline is used two tubs must be sent down, one after the other, in order that the chain may be always returned so as to occupy the same side of the road. When any attendant wishes to jig a tub from any branch, he brings it out on to the landing and disconnects the *upper* portion of the chain, as the couplings are so arranged that they are always opposite the branches when the chain is at rest. The top end of the piece of chain extending to the bottom of the incline is first passed round a small brake pulley, with which each landing must be provided, and then connected to the full tub, which is jigged down bringing up an empty one, but, of course, on the opposite set of rails. In order, therefore, to bring the chain to its normal position, a second journey must be run; the attendant afterwards removes the chain from the brake-wheel and couples it up again to the upper portion. If he were to neglect to do so it would be impossible to run journeys from the upper landings.

The several pieces of chain can be joined together either by shackle connections, which are rather cumbersome and do not pass readily round the brake-wheels, or by the especially shaped hook and link (Figs. 293 and 294), which are the feature of the so-called "cut chain" haulage of Fifeshire.

Transmission of Power.—One of the first questions to be considered in mechanical haulage is that of the position of the engines.

1st. They may be placed underground, and the steam generated there also.

The objections to placing boilers underground are the great danger of the fires igniting fire-damp, or the coal in proximity to the boilers or flues, and the insecure foundation afforded by the general run of strata.

2nd. The engines may be placed underground, and steam generated at the surface and conveyed down the shaft to them.

This practice has, in some few instances, caused fires, by the small coal which accumulates on the pipes becoming so heated as to burst into flame. A loss, which increases with the depth and the presence of water in the shaft, results from the radiation of heat from the steam-pipes, however well they may be coated with non-conducting composition. In some instances the loss may reach from 8 lbs. to 15 lbs. of steam pressure, while better results show not more than 4 lbs. or 5 lbs. Putting aside the inconvenience of using steam, if it can be cheaply generated—as, for instance, by the waste heat from coke ovens—a good performance of useful effect is given.

At Broomhill Colliery, Northumberland,* steam is conveyed to a pump 1414 yards from the boilers at bank. All pipes are coated with a non-conducting composition; the loss by condensation is 21·06 per cent. The pressure at the pump is 13 lbs. below that in the boiler at bank.

Mr. Baure † states that experiments at Bézenet Colliery, France, with an engine situated underground, 1200 feet away from the boilers, with pipes about 3½ inches diameter, showed a loss of 18½ per cent. Two receivers were placed in the length of pipes, one at the top of the pit (206 feet from the engine), and the other at a further distance of 984 feet.

In carrying steam large distances, the pipes should be covered with a non-conducting composition, and rest on supports fitted with a roller (Fig. 295), so that they can move easily to and fro. Stuffing-box

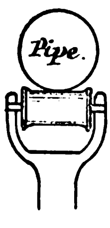


Fig. 295.

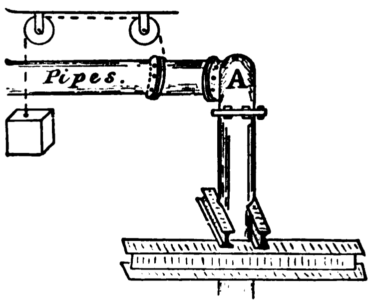


Fig. 296.

expansion joints should be used throughout at intervals of from 40 to 50 yards. The secret of the success of transmission seems to be due to providing two fixed points in each length of pipe and forcing expansion to take place equally in both directions. In horizontal lengths the pipes are clamped half-way between two expansion joints, but where they are on an incline the fixed points are placed nearer

* *N.E.I.*, xxxv., 159; xxxvi., 13. † *Soc. Ind. Min.* (2ᵉ Série), xiv., 297.

the lower end. In addition, steam should never be turned out of the pipes. With these precautions little difficulty is experienced from expansion, but the greatest nuisance is in getting rid of the condensed water, for although steam traps, or separators, may be placed in the range, they only *collect* water out of the pipes, and it has to be still discharged into the roadways. The invention of what is called the "steam loop" partially removes the above complaint.

At Elemore Colliery, Durham, where the length of the column is 224 yards, expansion joints are entirely dispensed with in the shaft. The arrangement at the surface is shown in perspective in Fig. 296, the part marked A being a knuckle-piece, the pipe going through two right angle bends. The dotted line represents a chain passing over wheels, holding a block of metal, weighing about 10 cwts., which checks the too sudden fall of the pipes in the shaft during contraction. The horizontal length of pipes in the drift is 40 feet, calculated to allow for a movement or spring of from 11 to 12 inches, which is the greatest amount of expansion when carrying steam. At every third pipe (each 9 feet long) in the shaft, supporting girders are fixed below the flange to allow 1 foot of slide. If it were not for these, the pipe column would bulge on expansion. The column of pipes is free to move in a vertical direction, and the whole weight is supported by a pair of larger girders fixed at the main seam level. The advantages of the arrangement are that expansion joints are completely done away with, and the trouble attending them, as, for instance, the leakage of steam, which seriously affects the roof and sides of the mine. This is most noticeable at the beginning of the week when steam is being got up, and when, owing to contraction, it finds vent at the expansion joints (where such are in use) until the column is thoroughly heated again.

3rd. The haulage engine may be placed on the surface, and the ropes carried down the shaft.

This is the practice most in favour and is unquestionably the best. With any method of haulage where the rope travels at high speeds and is continuous from the engines to the end of the plane perhaps the advantages are not so apparent. Ropes working in the roadways of mines are apt to get injured, and are more liable to break in the shaft and cause damage; but with any of the slow speed endless rope systems, where the shaft rope is only used to transmit power from the surface to a series of pulleys situated near the pit bottom and is not liable to injury or breakage, most satisfactory results are obtained. It adds the wear and tear of another rope to the expense, but such a rope can be placed in position in a very short length of time compared with that necessary to fix pipes either for steam or compressed air. The cost of excavation for engine-houses underground is always more than on the surface, as the men work shorter hours and get more money.

Transmission of power with wire ropes for very long distances or circuitous routes is not to be recommended, the useful effect being small, and the wear and tear considerable.

Compressed Air. — Transmitting power by compressed air has already been described. The great advantage of employing this agent is that a certain quantity of pure air is delivered into the mine. This, however, practically ceases to be of any benefit if it occurs at or near the pit bottom, where main haulage engines are generally placed.

In cases, however, where engines have to be worked at considerable distances away from the pit bottom, this method is very advantageous.

Electricity.—This subject has also been considered. Its employment offers advantanges for quick speed haulage at points a long distance away from the shaft. The convenience and ease with which it can be applied are its chief recommendations. It is not too much to say that a man could lay a greater length of electrical mains in one day than he could pipes in a week. In non-fiery mines, no possible objection can be brought against this system, and by employing every safeguard possible, its use should not lead to danger in any way.

Different Systems of Haulage.—Having decided on the position of the engines, the different systems of haulage that are in use may now be considered. These may be divided into four heads:—

(*a*) *Direct Haulage*, where the gradient of the road is sufficient to allow the empty tubs to run into the workings and to draw with them the haulage rope.

(*b*) *Tail-rope System*, where a second, or tail-rope, of lighter make has to be used to haul the empty tubs and the main rope into the workings, the gradient not being sufficient.

(*c*) *Endless Chain System*, where an endless chain passes from the engines along one side of the road, round a pulley at the far end, and back again on the other side of the road to the haulage engines; the empty tubs are attached to one-half of the chain, and the full ones to the other; the former proceeds towards the workings, and the latter towards the shaft.

(*d*) *Endless Rope System*, the difference between this and the one last named is that a rope is employed instead of a chain.

DIRECT ACTING HAULAGE.—This system is employed for hauling out of workings to the deep of the pit bottom. It requires a single line of rails, and a gradient against the load sufficient to allow the empty tubs to run back themselves, to carry with them the rope, and to overcome the friction of the drum. As with other machinery, the engines should consist of a pair. Only one drum is required, which should be capable of being thrown out of gear and of running loose on the return journey.

Size of Engines Required.—The number of tubs in a loaded train, or "set," is regulated by the size of the engines and by the pressure of the steam; the size of the engines depends on the quantity of coal which has to be hauled each day.

To illustrate the method of calculating the size of engines required, it will be best to assume some case. Resistance to traction is due to three causes—(1) Friction of axles on pedestals and wheels on rails, proportional to weight; (2) Imperfections of road-laying—*i.e.*, bad joints and crooked ways, proportional to weight and square of velocity; (3) Resistance offered by air currents.

The former has by far the largest effect. With a well lubricated turned axle and large-sized wheel rolling on a smooth rail, friction is small, but colliery tub axles are generally rough, unturned ones, and can seldom be kept perfectly lubricated; it, therefore, is generally considered that an allowance of $\frac{1}{30}$ of the weight should be made for friction.

Let it be assumed that 75 tons an hour have to be hauled up an incline 1500 yards long, having an average inclination of 1 in 20; that the tubs weigh 6 cwts. each, and carry 12 cwts. of coal; that the pressure of steam at the engines is 65 lbs.; and that the average speed of the set is 8 miles an hour.

Eight miles = 14,080 yards, so that the speed per minute = $\frac{14080}{60}$ = 234·6, and each journey takes $\frac{1500}{234 \cdot 6}$ = 6·4, say, 7 minutes, to travel one way. The time in and out will, therefore, be 14 minutes, and allowing 3 minutes at each end for changing makes 20 minutes. Three journeys per hour should thus be got out; but there are always delays, and it will be best to rely on, say, $2\frac{1}{2}$.

As 75 tons per hour have to be delivered, each set contains $\frac{75}{2 \cdot 5}$ = 30 tons of coal, and as each tub holds 12 cwts. there will be 50 tubs in each journey. Fifty tubs weighing 6 cwts. each = 15 tons, therefore the gross load is 30 + 15 = 45 tons; but as the inclination is 1 in 20, the net load will be $\frac{45}{20}$ = 2·25 tons = 5040 lbs.

For this, a plough steel rope $2\frac{5}{8}$ inches circumference, weighing $7\frac{1}{4}$ lbs. per fathom, will be sufficient, and its total weight will be 750 × $7\frac{1}{4}$ = 5437·5, say, 5440 lbs. The net load on the engine will be $\frac{5440}{20}$ = 272 lbs.

As the gross weight of the set is 45 tons, the resistance due to friction (taking this at $\frac{1}{30}$) = $\frac{45}{30}$ = 1·5 tons, or 3360 lbs. For ropes the friction had better be taken at $\frac{1}{10}$, as in an experiment made with a piece of rope weighing $16\frac{1}{2}$ lbs. held on two well-oiled pulleys, 10 feet apart, a pull of $1\frac{1}{2}$ lbs. was necessary to start motion which gives the friction as $\frac{1}{11}$ of the load. In practice the pulleys are frequently choked with dust and dirt. The frictional resistance of the rope is therefore $\frac{5440}{10}$ = 544 lbs.

The total load on the engine is, therefore:—

Due to set,	5040	
„ rope,	272	= 9216 lbs.
Friction of set,	3360	
„ rope,	544	

If it be decided to have a drum 6 feet diameter and a pair of engines having a stroke of 3 feet, as the pressure of steam is 65 lbs. the size of the engines can be found by the rule:—

Area of cylinder (a) × pressure × twice the length of stroke = load × circumference of drum.

In this case:—

$$a = \frac{6 \times 3 \cdot 1416 \times 9216}{65 \times 2 \times 3} = 445 \cdot 43$$

which is the theoretical area of the two cylinders; to overcome internal resistance and friction of engine 30 per cent. of this amount should be added—*i.e.*, 133·63, so that the area of the two cylinders becomes 579·06, or each of these = 289·58 square inches.

The diameter is, therefore:— $\sqrt{\frac{289 \cdot 58}{\cdot 7854}}$, practically $19\frac{1}{4}$ inches; or, to avoid being under power, say, a pair of 20-inch cylinders by 3 feet stroke.

The quantity of material a pair of engines of given dimensions will haul in a certain time can be easily determined by applying the converse reasoning to the foregoing.

MAIN AND TAIL-ROPE HAULAGE.—In this method, a lighter rope, called a tail-rope, has to be employed to haul back the empty set from the shaft to the workings, such addition being caused either by the gradient being undulating, or not sufficient to allow the tubs to run back of themselves. Fig. 297 illustrates the theory of

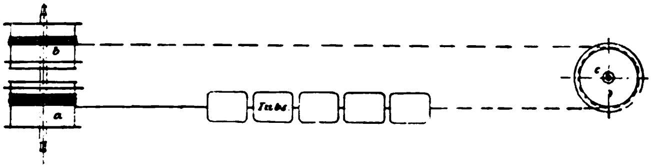


Fig. 297.

the system. Two drums are employed; on one, *a*, the main rope is coiled, and the other, *b*, contains the tail rope, which passes from it to the extreme end of the plane round a pulley, *c*, and is finally attached at the back of the set, or journey. The main rope hauls the tubs towards the pit bottom and at the same time draws out the tail rope. As the latter only has to haul the empty tubs back again, its size is much less than the main rope, but it has to be twice as long.

Devices for throwing Drums In and Out of Gear.—Each drum on the engine is alternately thrown out of gear and allowed to run loose, but should be provided with a brake to prevent it travelling too fast and paying out slack rope. This can be accomplished in several different ways: either the drum may be loose on the shaft and driven by clutches, or fixed to the shaft and a sliding-carriage employed, throwing the drums in and out of gear. If clutches are employed, they may be the same as those used for, and described under, endless-rope haulage. With drums running loose, and travelling at high speeds, wear is considerable, and they should be bushed with some metal, such as brass, which allows them to turn with little friction, and is capable of renewal. Allowance for wear should also be provided on the shaft, which has to be nicely turned. This arrangement possesses an advantage, inasmuch as both drums can be placed on the same shaft, while with a sliding carriage they must be on separate ones.

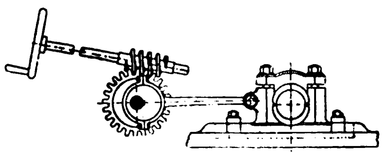


Fig. 298.

Sliding carriages are generally moved by an arrangement of levers, but even with compound levers a considerable amount of force is required. At Elemore Pit, the sliding carriages (Fig. 298) are moved by an endless screw gearing into a cog-wheel, on the same shaft of which is keyed an eccentric, with its link going to the carriage. As the screw is turned, the cog-wheel and shaft revolve; consequently, the eccentric draws its link forward, and pulls the sliding carriage out of gear.

Methods of Working Branches.—In branch, or subordinate roads, a return pulley is necessary at the far end, and a separate length of rope is required for such, both ends of which reach to the junction with the main road. Joints are provided in the main-road ropes, and the branches are worked by disconnecting portions of the main-road ropes, and attaching the ropes of the branch road to them, connections being made by ordinary sockets and shackles.

Three methods are adopted for changing the ropes under normal conditions; such cases where the rope overhauls itself—that is to say, where it runs in-bye without the aid of engine-power—are matters of detail, and do not affect the main systems. In two of these the ropes are changed when the set is at the branch; in the other when it is at the pit shaft.

Fig. 299 illustrates one method of changing when the set is near the branch end. A shackle connection is provided in the tail-rope, and so arranged that it arrives opposite the branch at the same time as the set does—that is to say, it ought to do; but here, as in every other method, it is found advisable to have a winch, with a chain and hook fixed at the way-end, to winch up the main rope to meet the branch rope, as it often happens that they do not quite face each other, which is not at all surprising, considering the great length of rope in use. The main road tail-rope is then disconnected at the points *a* and *b*, and the shackles of the branch rope, *a′* and *b′*, attached in their place. As soon as the engine has started again,

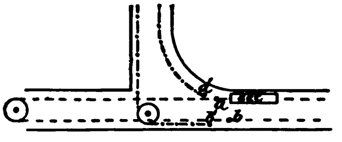


Fig. 299.

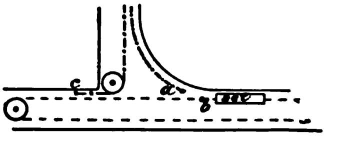


Fig. 300.

the empty set leaves the main road and goes into the branch one. A slightly different method is illustrated in Fig. 300, the changing also being made when the set is at the branch. The end *a* replaces *b*, which is then brought on a little further by the engine and connected to *c*. Here the tail-rope always remains entire.

In the other method the ropes are changed when the set is at the shaft. Joints in the main rope are so arranged that when the set is out-bye, all the shackles are opposite the different branches (Fig. 301). Suppose there are three branches, A, B, and C, B being ready for an empty set. The full set, which is standing at another branch end, say A, having been hauled to the shaft, A's branch rope is disconnected from the main rope, and B's branch rope connected to it. The engine is then started and the empty set at the shaft hauled in-bye into the branch B without stopping at the branch end. Nothing can be more simple and expeditious than this method. To facilitate matters and save time, if it be desired to bring a set out from C, the ropes can be partially changed while A's set is running.

In the latter system, no stop takes place from the start to the completion of the journey, as the ropes are changed at the branch at the same time as they are at the shaft; while in the other two methods, stop has to be made at the branch end, or in all two stops are required, as the ropes have also to be changed at the shaft. Where time is an object, the advantages of the third method are self-evident.

The rope is automatically disconnected from the set when it reaches the shaft either by a knock-off link (Fig. 302), or preferably by the arrangement shown in Fig. 303 As drawn, the hauling rope which is attached to the short length of chain, *a*, will pull the set along, but at the detaching point at the out-bye or shaft end, a horizontal striking bar, which is stretched across the road, catches the lever, *b*, moves it backwards in the direction shown by the arrow, lifts up the link, *c*, and detaches the set, which runs down an inclined "kip" to the shaft.

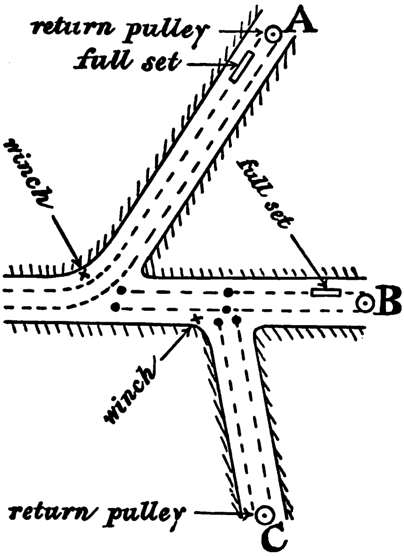


Fig. 301.

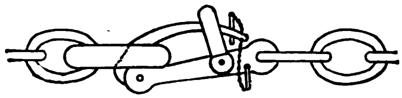


Fig. 302.

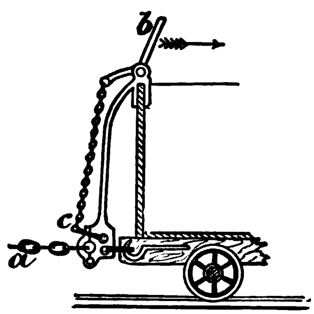


Fig. 303.

ENDLESS CHAIN.—This system differs from the foregoing in the fact that a double line of rails is necessary; that a chain is employed travelling over the top of the tubs, and, as the name implies, is endless; that the speed is small, not more than three miles an hour; and that the tubs are attached singly at equidistant intervals, depending on the quantity required to be hauled.

Attachment of Tubs.—Where the gradient is small, the weight of the chain resting on the tubs is sufficient to drag them along, but for steeper inclinations a Y-shaped fork, catching a link of the chain, is firmly riveted to the end of each tub (*a*, Fig. 270).

Driving Pulleys.—For giving motion to the chain, two different forms of pulley are adopted. In one, a series of Y-shaped jaws, with the groove at the bottom just wide enough to take the link edgeways, are arranged at intervals around the circumference. The chain only passes half round the pulley, the necessary grip being obtained by the links of the chain catching in the forks.

In this system, as with the endless rope, it is absolutely necessary for efficient working that small guide ("leading-on") pulleys should be arranged just before the chain (rope) reaches the driving wheel, so that it may be accurately led on in the proper place.

Instead of fixing forks in the throat of the pulley, a series of pieces of square iron (*a*, Fig. 304) may be placed alternately on opposite sides. This iron is bent back at the top to clip the rim, and at the other end passes through a hole in the throat of the pulley and is secured on the underside by a nut.

With the ordinary form of fork no allowance is made for the lengthening of the links of the chain due to wear. When everything is new they are fixed at correct intervals, grip the chain, and prevent any slip. With wear, the links lengthen, and do not properly fit the jaws. This inconvenience has been overcome by an arrangement due to Mr. Briart, which consists of a series of Y-shaped grips of steel screwed into the periphery of the pulley (Fig. 305). As the links of the chain lengthen, the grips are unscrewed, so as to increase the distance between each, thus fitting the altered length of the links of the chain.

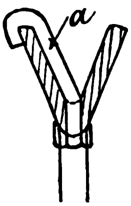


Fig. 304.

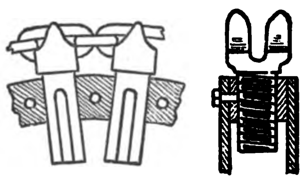


Fig. 305.

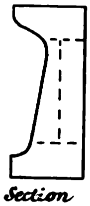


Fig. 306.

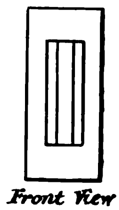


Fig. 307.

The better plan appears to be to use a series of blocks of steel, called "feet," arranged at intervals around the circumference of the pulley, and coil the chain two or three times round to get the necessary grip. These feet are of an inverted cone shape in section (Figs. 306 and 307), with the object of preventing the chain from climbing, and, owing to the recess between each, the circumference of that part of the pulley on which the chain works is in plan like a polygon, preventing any possibility of slip. They also take any wear, effecting considerable economy from this source. They are secured to the throat of the pulley by bolts with counter-sunk heads, which may either pass through holes in the feet, or, preferably, through a slit running down the centre, as the latter allows a little adjustment.

Taking up Slack.—It is just as essential with endless chain as with endless rope that means should be provided for automatically taking up the slack produced by lengthening during wear. This is a point often neglected; indeed, the common practice is to allow the chain to extend until it is only kept on the pulley with great difficulty, and then to cut out a piece. Far better results are given by any of the tension arrangements described under endless rope haulage.

Working Branches and Curves.—The chief advantage of the endless chain is the ease and small amount of labour with which branches and curves can be worked. With branches, all that has to be done is to arrange a series of pulleys one above the other on a vertical shaft, each one working a chain. Even with the most regular output, the quantity coming from any branch is seldom the same as that from its neighbour, and hindrances may often occur in any one of them. If all these pulleys are keyed on the upright shaft, the stoppage of one branch means the stoppage of all. To allow any of them to remain idle while the others are working, only one, and that the driving pulley, is keyed on the shaft; the others are loose, and arranged to be thrown in and out of gear by clutches, similar to those used in endless rope haulage.

When the tubs approach a junction or the delivery end, they are easily detached by arranging a small guide pulley close to the roof, and passing the chain over it (Fig. 308). At this point the chain is lifted out of the fork on the tub, and detached without any manual labour, and if the rails are arranged on a slope, the tub still continues moving under the influence of gravity, passes under the upright pulleys, meets the chain again further on, and automatically re-attaches

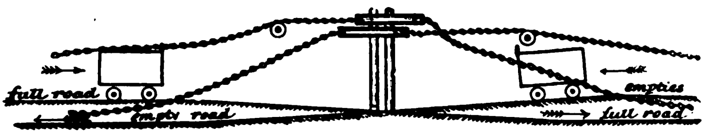


Fig. 308.

itself. Curves are worked on the same principle; the tubs detaching and attaching themselves, and gravitating round the curved portion. With an endless rope automatic detachment can be secured, but in only one type of clip can the tubs re-attach themselves.

Means of Minimising Breakages.—Unfortunately breakages are common occurrences with the endless chain. The proverb is quite true "that a chain is not stronger than its weakest link." The result of a breakage on a steep incline may be very disastrous, as the tubs run downhill, sweeping everything before them. To prevent this, it is usual to apply on the loaded road a balance-block arrangement

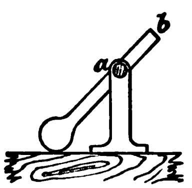


Fig. 309.

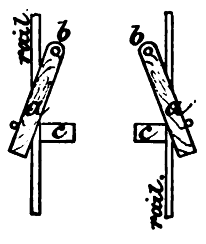


Fig. 310.

Fig. 311.

(Fig. 309) pivoted on a point, *a*. In its journey each tub depresses the end, *b*, and passes over the obstruction, but immediately they have gone by the block falls into the position shown, and stops the tubs running back.

Where the inclination is not steep, the arrangement illustrated in Figs. 310 and 311 can be employed. In their normal position two blocks, *a a*, pivoted about pins at *b*, lie across the rails, as shown in plan, but are pushed aside by the wheels of the tubs up a small greased inclined plane, *c*, to descend again immediately the tubs have gone by, and so block the road.

The chain is carried above the surface of the road on the tubs, that is, so long as it is entire; if broken it trails on the ground. If, therefore, a series of Y-grips be arranged in the centre of the way, they do not catch the chain so long as it is whole, but directly it breaks they come into action and firmly hold it.

ENDLESS ROPE HAULAGE—Driving Appliances.—The methods employed for driving may be divided into (*a*) clip pulleys; (*b*) conical wheels; (*c*) grooved wheels.

(*a*) *Clip Pulleys.*—The general construction of these is such that therope is conducted into a groove, in which are placed sliding jaws, which are pushed downwards, causing them to grip the rope firmly and prevent slipping. They occupy little space, are convenient, side friction is entirely avoided, and as the rope only passes half round the pulley the bending action is not great.

A good form of clip pulley is Barraclough's. One side of the pulley is entirely separate from the other, connection being made by bolts, while any required distance between the two parts can be maintained by set pins, placed at intervals around the circumference. By such means, the pulley can be altered to accommodate any size of rope in a few minutes. All round the circumference are a series of taper pockets opposite each other, inside which work two sliding jaws (*a*, Fig. 312), which are hollowed at the bottom and sides to receive the rope.

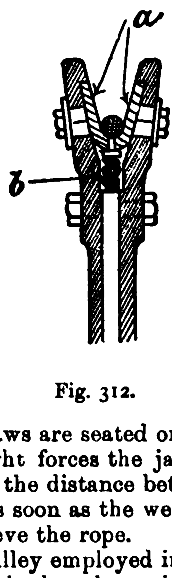


Fig. 312.

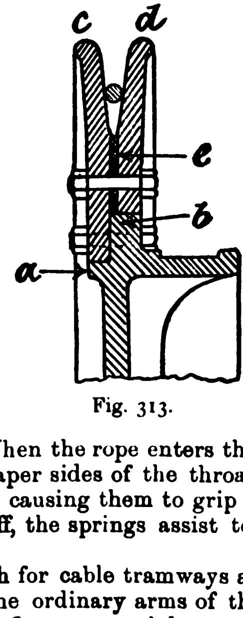


Fig. 313.

These jaws are seated on springs, *b*. When the rope enters the pulley, the weight forces the jaws down the taper sides of the throat, and so narrows the distance between the jaws, causing them to grip the rope, while, as soon as the weight is taken off, the springs assist to release and relieve the rope.

A pulley employed in Scotland, both for cable tramways and mine haulage, is that shown in Fig. 313. The ordinary arms of the pulley terminate in a horizontal and vertical flange, *a* and *b*, to which are respectively bolted the taper throat rims, *c* and *d*, a piece of wood, *e*, being interposed between. It is stated that no injury whatever is caused to the rope, and Mr. D. Ferguson* gives some figures which seem to bear out that view.

It is, however, difficult to see how any clip pulley can work without flattening the rope; their very principle of action is to grip

* *Min. Inst. Scot.*, vii., 145.

or wedge the rope, and the greater the load, the greater the wedging. There are, of course, good and bad clip pulleys, and probably the latter predominate; at any rate they are responsible for a great deal of prejudice. At a colliery with which the author is connected, one of the best known forms of clip pulley was originally used for driving rope haulage, but was removed and replaced by a taper C pulley. Considerably more than three times the work is now being obtained from the driving ropes.

To avoid the flattening action, and to dispense with the complications of springs, loose flanges, &c., a pulley has been designed having a serpentine groove in the throat, and so long as this remains in the curved state, and does not wear *straight*, good results are obtained.

(*b*) C *Pulleys.*—To avoid the flattening of the rope, C pulleys are employed, which originally consisted of a pulley with a C-shaped throat, around which the rope was coiled several times to give the necessary grip and prevent slipping. Here flattening is certainly avoided, but another disadvantage is introduced in the shape of side friction. On their adoption, it was found that the pulleys wore in rather a peculiar manner; their dished form was soon lost and the diameter of the coming-off side became less than the going on side. Most are, therefore, now made slightly conical, the diameter of the going-on side being larger than the coming-off side.

The throat of the pulley is made parallel (Fig. 314), but loose wearing segments, *a*, are bolted in. These save large sums of money. A pulley costs from £15 to £20, while the segments can be obtained for £3; in addition, they can be changed in a short time and are

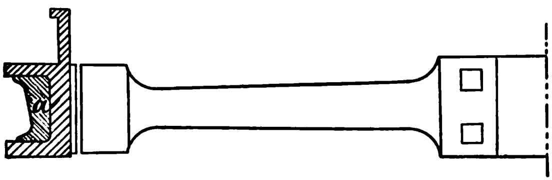


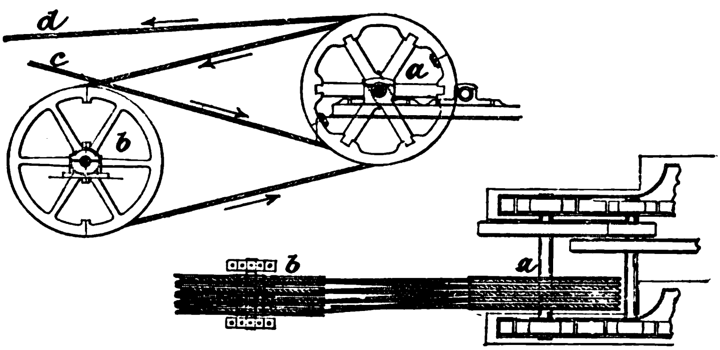
Fig. 314.

easily handled. Pulley changing not only requires far longer time, but considerably more men. Pulleys should always be purchased in halves; in such state they can be transported and got into place with half the expense they otherwise would. Loose wearing segments and pulleys in halves have materially reduced the cost of modern rope-haulage.

As to the amount of taper necessary, experience is the only guide, but the heavier the load the greater it must be. If properly proportioned these pulleys work very smoothly; the rope practically does not slip downwards, but follows a serpentine path from the time it goes on at the top until it comes off at the bottom. Side friction is, to a certain extent, avoided, as practically none exists between the successive coils, but where the rope leads on the pulley there is a small amount against the upper coil, which is an objection. Also, to obtain good results the speed must be rather slow; practically, it would hardly be possible to go more than three miles an hour.

(*c*) *Grooved Pulleys.*—In order to get rid of side friction and prevent the slipping which takes place on taper C pulleys, a series of parallel grooves are put in the main driving pulley, and a similar pulley with one groove less, placed some distance away, the rope being wound from one to the other, each coil having a separate group to work in. As each coil only passes half round the circumference, and as the second pulley is not a driver, but a follower, the rope has little grip, and consequently several grooves have to be employed on each pulley. To meet this objection, the rope is frequently taken from one pulley to the other in the form of the figure ∞, but although this reduces the number of coils, the rope is bent backwards and forwards, for it passes under and over the pulley. This injures it, and shortens its life, as compared with a rope always coiling round a wheel in the same direction.

Another method to lessen the number of coils, is to drive both pulleys as on most cable tramways. No matter, however, whether both pulleys are driven, or whether one is a follower, they only work properly when the grooves are of equal diameters. When new, this condition is possible, as the pulleys can be turned in a lathe. The greatest strain during working naturally comes on the first groove, which is therefore subjected to more wear than the second, while the latter also wears far more than the third, and so on. By such action the grooves not only increase in depth but do so unequally. From



Figs. 315 and 316.

the time the rope passes into the first groove, to the time it leaves the last one, no slipping can result. It is also evident that when the wear in the grooves has progressed to such an extent as to make a difference in the diameters of the first and the last one, the speed of the rope is governed by that of the groove having the smallest diameter (the going-on side), and a point on the circumference of the largest groove will obviously travel faster than this. As it is impossible for the rope and *part* of the pulley to travel at different speeds, a grinding action between the pulley and the rope is set up, and the latter rapidly wears out. To show the extent of the wear in the grooves, it may be stated that after three years' wear, those in the leading drum of a cable tramway line measured respectively, $2\frac{1}{2}$ inches, $2\frac{5}{8}$ inches, $2\frac{5}{8}$ inches, $2\frac{7}{8}$ inches, 3 inches, and $4\frac{1}{16}$ inches deep.

When the grooves are fixed together as in ordinary pulleys, each groove tightens one coil of rope on the other, until when the last groove is reached, the strain may break the pulley or the rope.

For such reasons, instead of the second set of grooves being made in one solid pulley keyed fast to the shaft, a number of separate pulleys running loose on a bearing have been adopted at Lye Cross Pit. A pulley, 7 feet diameter, having five grooves, is keyed on to the third motion shaft (*a*, Figs. 315 and 316), and four loose pulleys, *b*, are threaded on a shaft 15 feet away. The in-going rope, *c*, is led on to the underside of the first groove on pulley *a*, coils half round it, and passes on to the first loose pulley at *b*, and then back again to the second groove on pulley *a*, and so on, until it finally leaves the last groove on *a* and passes away at *d*. By such means the wear on the driving rope is reduced to a minimum, for the second set of loose pulleys can move at varying velocities, and so accommodate themselves to the different speeds required by the unequally sized grooves of the solid driving wheel. The objection is that, as only one pulley is driven, a large number of grooves have to be employed to move heavy loads.

The Walker differential pulley adopted at Bell End Pit completely gets over all difficulties. Briefly described, it consists of a series of loose rings (*a*, Fig. 317) threaded on to an ordinary pulley, these rings being grooved to receive the rope. Both pulleys have loose rings, and both are driven, the second pulley having one less groove than the first. The flange, *d*, on one side of the pulley is removable, and secured in position by a series of bolts, *e*, india-rubber washers being provided at *g* and *h* to prevent the bolts becoming loose during working.

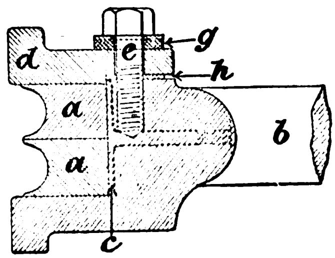
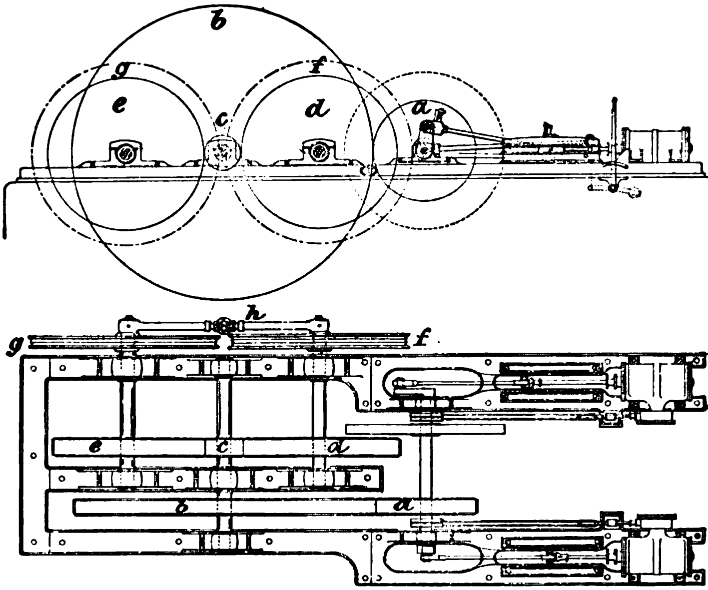


Fig. 317.

The peculiar point appears to be that all the grooves are loose. At first sight it would be thought that at least one fixed groove must be provided to obtain the required grip; but this is not necessary. The explanation appears to be that the pressure of the rope in the groove of each individual ring is transferred to the underside of the ring, hence the friction is just as great there as it would be under the rope if the pulley had solid grooves. Each ring adjusts itself to the unequal strain on the rope, or wear in the groove, and constantly accommodates itself to these conditions whilst in motion. This gives each wrap its proportion of duty, and there is no necessity to secure any of the grooves. It is essentially a friction drive, with each ring accommodating itself as explained. The rope never moves on the grooves, as is proved by the fact that when it is at work the impression of the rope is left in the oil at the bottom of the rings, which conclusively shows that no slipping takes place. The bottom and sides of the rings are thoroughly lubricated by automatic grease-cups inserted in a hole, *b*, in the underside of the rim of the pulley, a groove being provided opposite each hole as shown at *c*.

The design of the modern type of endless rope haulage plant, adopted at Bell End Pit, is illustrated in Figs. 318 and 319. It consists of a pair of 16-inch cylinder engines by 2 feet 6 inches stroke. On the crank shaft is a pinion, *a*, 5 feet diameter, gearing into a crown wheel, *b*, 15 feet diameter on the second motion shaft. This is provided with three bearings, and on it is keyed a pinion, *c*, 2 feet diameter, gearing right and left into crown wheels, *d* and *e*, 7 feet 6 inches diameter, each keyed on to third motion shafts provided with two bearings, one of which is carried on a special bed-plate, while the other is situated on a prolongation of the right-hand engine bed-plate. The two third-motion shafts overhang their right-hand bearings, and on the outside is keyed two Walker



Figs. 318 and 319.

differential pulleys, *f* and *g*. The object of this is that at any time required the loose rings can be taken off, cleaned and oiled, or anything done to the rope without interfering in the slightest degree with any portion of the engines. To take the outward thrust, an adjustable strut, *h*, connects the two third-motion shafts; this is made in halves, connected by right- and left-hand threaded screws. Such an arrangement takes off a great deal of the strain, which would otherwise come on to the right-hand bearings.

Arrangement for taking up Slack Rope.—Successful working is influenced to a great extent by the arrangement for taking up "slack," and at the same time putting enough tension on the rope to prevent any slip on the driving pulley. Ropes lengthen with use, and, in addition, the varying inclination of the plane influences their tightness, or otherwise. Tension carriages should always be placed at the lowest end of the road; the full rope is led on to the driving pulley, then to the tension pulley, and passes away as the empty rope. Naturally, the pulling, or full, rope is always tight.

Sometimes this tightening pulley is firmly connected to a screw—it may just as well not be applied at all. What is wanted is some arrangement that gives and takes, and automatically accommodates itself to the varying load. This may be done in many ways. One form is shown in Fig. 320, which, however, is not recommended. Long experience has proved that the life of ropes is considerably decreased when the wires are alternately bent in opposite directions. The better plan is to carry them half round a pulley on a carriage, which can be either weighted and travel on an incline or it may be on the flat with a weight attached behind by a length of chain, this weight exercising a direct pull on the waggon (Fig. 321).

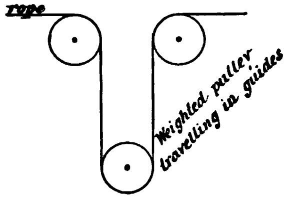


Fig. 320.

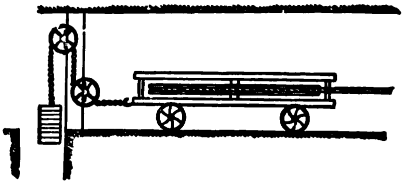


Fig. 321.

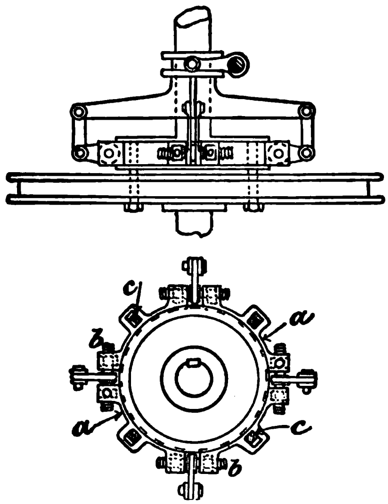
The heavier the load on the rope, the heavier should be the weight on the tension waggon, and *vice versâ*. The weight giving the best results is easily determined by experiment, and when once found need not be varied unless the load on the rope increases. The pulleys on the tension waggons are often made smaller in diameter than the driving wheel, but the far better plan is to make them the same size. Indeed, every main pulley around which the rope coils should be of equal size throughout—one pulley should be a duplicate of another.

In order to avoid the expense and inconvenience of having to cut the rope on account of its stretching during wear, the length of travel of the tension carriage should be equal to a little more than half the circumference of the tension pulley, and the width of the throat of the pulley should be double that of the diameter of the hauling rope. When the new rope is first put on, the tension carriage is braced up as near as possible to the driving pulley, and the rope passed only half round the tightening pulley. As the rope lengthens, the tension carriage goes further back, until it finally arrives at the limit of its travel. Under ordinary circumstances it would then be necessary to cut the rope and re-splice it, but if the above precautions have been adopted an extra coil of rope can be thrown on to the tension pulley, which brings the tightening carriage forward into its original position.

Clutches for Working Branches.—An opinion exists (for which there is little reason) that branches cannot be worked with such ease in the endless rope system as with some others. Indeed, the number of branches may be unlimited, if each pulley is able to be thrown in and out of gear by a clutch arrangement. In some cases, the rope along all the branches and main roads is made in one continuous length, and a stoppage anywhere stops the pit.

Numerous clutches are in use. In the ordinary forms there may be a cone sliding into a conical box, or a large series of lugs on the pulley fitting into a sliding coupling box. The efficiency and life of the ropes (which mainly affect the cost) depend on the speed at which they are run, and the freedom, or otherwise, from jerks or strains, and neither the cone nor claw clutch should be used if the duration of the ropes is to be secured. Supposing the main rope to be travelling at its normal speed and a branch is thrown into gear, with the ordinary clutches the branch rope has to suddenly take the speed that the main rope is travelling at, a very serious strain is thrown upon it, and often something breaks. On the other hand, if it be desired to throw a branch out of gear it can seldom be done without stopping the main rope. Cone clutches often "jam," and cannot be got out anyhow.

Fisher's Clutch.—To overcome these disadvantages, friction clutches have been designed, a very successful one being that invented by Mr. Henry Fisher. It consists of a driving drum firmly keyed on to the shaft. Around the periphery of this drum is arranged a series of segments (*a a*, Figs. 322 and 323), connected by right- and left-hand screws, *b*. An arrangement of levers is provided, by means of which these screws can be turned. If they are turned one way the segments close together and grip the drum; if the other way they open and leave the drum. The number of segments is generally three, sometimes four, and in the centre of each is an oblong hole, in which is inserted a square pin, *c*; the other ends of these pins pass into the arms of the driving pulley. The drum, being keyed to the shaft, is always revolving; the driving pulley is loose, but attached to the friction segments through the pins, *c*. If these segments are tightened on the drum, practically, they become part of it and revolve, carrying with them the driving pulley. The amount of friction, or grip, is determined by the amount of rotation given to the screws, and can be so regulated that sufficient pressure is only exerted to drive the pulley under its normal load. Should a tub come off the rails, or any excessive load be thrown on the rope, the clutch gear should slip. Strain is therefore totally avoided.



Figs. 322 and 323.

The same thing takes place when a branch is thrown into gear. When the segments are first tightened, considerable slip takes place, the branch moves off at first very slowly and gradually increases in speed as the inertia of its load is overcome, until it travels at the same rate as the main rope. As soon as it does this, a very good plan is to slack the segments on the driving drum until only just enough grip is given to drive the branch rope.

The only drawback is its cost. It is very carefully made, the friction parts are bushed with copper to get more adhesion, and there is a lot of fitting work. Its economy and advantages are indisputable, but it is possible to purchase economy too dearly. Many other friction clutches exist which do not, perhaps, give such satisfactory results, but their cost is so much smaller that, except in the more important situations, their use may be recommended.

Bever and Dorling's Clutch.—In this form, what might be called a brake flange is attached to the driving wheel. Inside this flange is an inner split ring. The bearing surface of the ring and the brake flange are each carefully turned. On the driving shaft is a collar, which can be slid up and down, but is forced to revolve with the shaft because it travels over a long key. To this collar is attached an arm, and to one end of the arm a wedge, which, when the clutch is out of gear, only just enters the slit in the split ring. To throw the clutch into gear, this collar is moved towards the driving pulley, and in doing so the wedge is driven into the split ring and expands it, causing it to grip the brake flange and so turn the pulley. The principle is exactly the same as the Fisher and Walker clutch, but as the pressure is only exerted at one point its action cannot be so perfect.

Edmeston's Clutch.—It is like Bever and Dorling's, but the split ring is expanded or closed by a right- and left-hand screw.

Brakes for Branches.—When a branch road is thrown out of gear, if its gradient is a steep one, the tubs may continue moving, even after connection with the main haulage has been broken.

Even when such motion is *towards* the shaft such continuation is objectionable, as, unless the rope were required to stop, it would not be thrown out of gear. Where the gradient is in favour of the load, an ordinary band brake is usually arranged, so connected that it is put on as the clutch is thrown out of gear.

Where the gradient is against the load, and the tubs have a tendency to run back, a most ingenious brake is applied by Walker

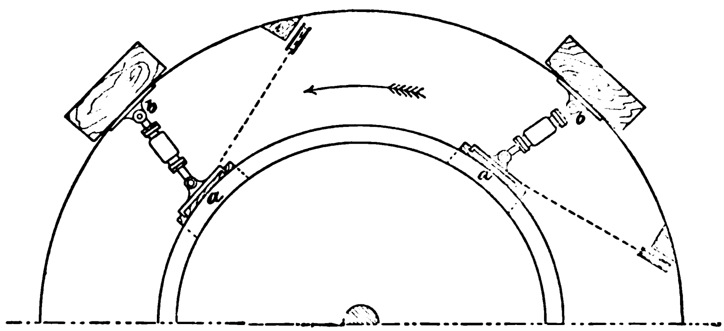


Fig. 324.

Bros., and has been working with great success at Lye Cross Pit. Four brake blocks (*a*, Fig. 324) are arranged at intervals around the pulley, and are pivoted about the points *b*. Each is provided with a right- and left-hand screw to allow for adjustment, and to take up wear. These brake blocks are slightly inclined to the brake rim, and are pushed away from the wheel so long as it turns in its normal direction, indicated by the arrow, but are kept up to their work by the pull of a small weight. When the branch is thrown out of gear, the moment the wheel starts to run back, the arms carrying the brake blocks try to take a position at right angles to the brake rim; but as this is shorter than the inclined distance, the blocks are wedged against the brake and prevent the pulley from running back. As long as the pulley turns in the direction indicated by the arrow in

Fig. 324, the brake keeps off, but immediately it attempts to go the other way, the four arms endeavour to take a position at right angles to the circle *a a*.

Ropes Under and Over Tubs.—Two systems of endless rope haulage are in use. In one the rope travels over the tubs, in the other under them. The advantages of the former are, the rope is always carried above the ground, and is not dragged on it, causing friction, wear and tear, and less life to the ropes, and all the machinery is overhead and can be easily inspected. The disadvantages are, that the tubs cannot be loaded high, as is the practice in some districts, without attaching to the tub means for carrying the rope, which not only leads to complication, but introduces another possible cause of failure. This disadvantage may be, and is, avoided by attaching the rope to the sides of the tubs; but, inasmuch as the pull is not in the centre of the load being moved, frequent derailments result. With the rope over the tub, curves are not easily worked. If any exist, they should be made as sharp as possible, and a good large guide pulley placed at the bend. Practically, every curve with the rope over the tubs requires an additional man, as it is not safe to allow the tubs to work round without supervision. For a day, perhaps, everything may go right; but one accident costs more than a man's wages for a week. If the rope is under the tubs, any amount of curves may be worked easily; but here they should be made as large and of as wide a sweep as possible. Rollers are placed all round the curve, and the clips easily pass round these, *if the rollers are large in diameter*, and placed near together. For good working they must be the largest size allowable. Automatic detachment of the tubs is a very simple matter when the rope travels underneath, but over the tubs it is only possible with the open-topped type of clip.

There is little to choose between either of the systems so far as cost or efficiency are concerned, but possibly in the majority of cases over rope haulage will be found to be the more convenient. This is especially so in wet seams. With the rope beneath the tubs, all the machinery at junctions has to be placed in pits sunk beneath the level of the roadway; they form lodgments for the water and require a pump to drain them, while the water soaking into the ground naturally affects the strata perniciously, thereby injuring the stability of the machinery and necessitating frequent repairs. The ropes drag along the road in places, no matter how many rollers are employed, and not only corrode rapidly, but carry with them into the machinery considerable quantities of sludge, which covers everything and renders careful inspection a difficult matter. Under similar conditions with over rope haulage, the machinery stands high and dry, and the rope seldom touches the floor.

Arrangement of Tubs.—The tubs may be connected to the rope either in sets or singly. On the branches, one tub at a time is attached, but on the main line, from two to four tubs have to be massed together. Where the tubs are run in sets, from ten to twenty are attached to each other, and only one of them connected to the rope. Such a train requires an attendant, and the chief advantage of this system of haulage is lost—viz., regularity of delivery. Where only one or two tubs are attached at a time, the delivery to the shaft bottom is a model of regularity; the tubs come and go with scarcely any attention.

One or Two Road Systems.—The endless rope system proper requires two lines of rails and a wide road. Where the roof is a good one this is not a disadvantage, except, perhaps, in the closing years of the colliery's life. The nature of the roof in some mines prevents the double line system being applied. The difficulty is overcome by running the tubs in sets, and arranging pass-byes at intervals. An attendant travels with each set, and waits at the siding until the train travelling in the opposite direction arrives there; they pass each other, one proceeds towards the shaft, and the other in-bye. Connection between the set and rope is usually made by a screw-clip attached to a bogie carriage (Fig. 325) on which the train-man rides.

Another plan, which avoids the inconvenience and expense of running sets, is to provide two roads, each laid with a single line of rails. In one, the full tubs travel out-bye, while in the other, the empty ones pass into the workings.

For steep gradients, where the load would be too great for a single rope, two may be employed. At Newbattle Colliery, Midlothian,* such a system is adopted, each tub being connected to two ropes.

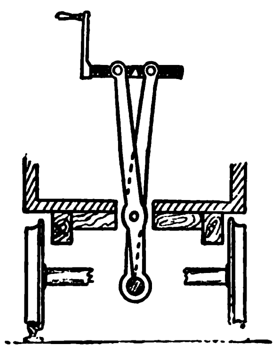


Fig. 325.

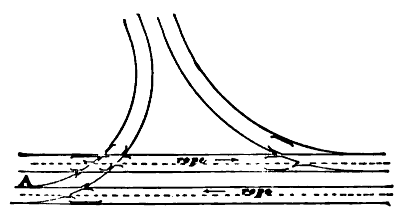


Fig. 326.

Although an elaborate arrangement of friction clutches were applied to allow the ropes to automatically adjust themselves, and each take their share of the load, yet these were found unnecessary.

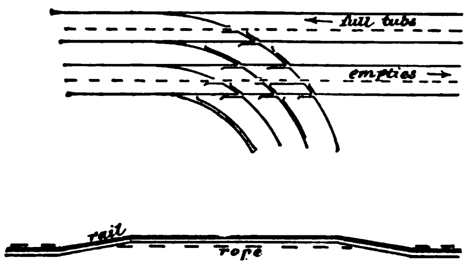
Rails at Junctions.—At main stations, where branches are worked, the usual arrangement of switches and crossings is employed, and as the ropes are either above or beneath the road, no provision has to be made to prevent their being injured.

For junctions, with under-rope haulage, several methods are used; two of the more general ones being shown in Figs. 326 and 327.

In Fig. 326 the empty tubs are taken off the rope as soon as they have passed the switch at A and are then run back into the junction road, as indicated by the arrow. The full tubs from the workings pass at once on to their proper road, as shown by the illustration. Such an arrangement is exceedingly convenient on roadways of steep inclination, as the empty tub can be taken off the rope at the highest point, and will run by gravity into the junction road, while as the full tubs are attached to the rope at the lower side of the crossing, they also gravitate from the junction road on to the haulage plane.

* *Min. Inst. Scot.*, ix., 211.

Under ordinary conditions the plan shown in Figs. 327 and 328 is more compact and easily worked. The illustration explains itself. In both these figures it will be noticed that small breaks or spaces are left in the crossing rails, and in these the rope generally works. Unless some such provision were made, the rope would receive serious injury from the flange of the tub's wheels as they passed from the junction to the main line, as each wheel would have to roll over the rope as it lay on the top of the rails. To prevent any chance of this happening, not only are recesses provided, but the rails at the junction are raised some 3 inches above the general level, as shown by Fig. 328. Just before reaching the junction, a short length of inclined rail is fixed, followed by level rails at the junction, and then another short inclined piece is inserted, throwing down the rails to their original level. At the junction the haulage rope is, therefore, below the lower flange of the cross rails, and tubs joining the main engine-plane can do no injury. When a tub on the engine-plane reaches the junction, the clip, which carries the rope a uniform distance above the floor, lifts the rope out of the groove and lets the tub pass without obstruction, the rope falling back into the recess immediately the tram has gone by. Check and guard rails are used at all junctions, as shown by the figures. A simple and ingenious arrangement has been adopted by Mr. R. S. Williamson, at Cannock and Rugeley Colliery. Only one line of rails is laid into the junction road, and except when tubs are being taken from, or brought to, the haulage plane, the roads there are free from cross rails, and the ropes have uninterrupted passages. An examination of Fig. 329 will make the arrangement clear. The solid lines show the rails in their ordinary position; three of them are hinged at the joints marked on the drawing, and when tubs are to be put on or taken off these loose points are swung round into the positions shown by the dotted lines, as indicated by the arrows *a*, *b*, and *c*. These points are put *over* the ropes, which then work in grooves cut in the wooden sleepers.



Figs. 327 and 328.

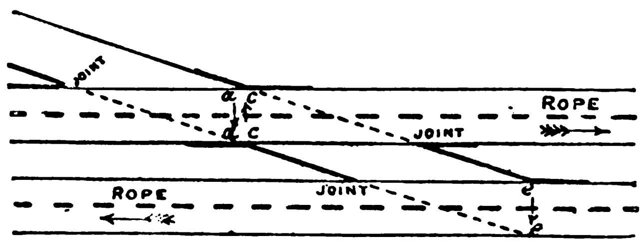


Fig. 329.

For over-rope haulage, no better plan can be adopted than that of raising up the empty road for some distance before the junction, until on arriving there, sufficient height is gained to allow of the construction of a bridge, over which the empty tubs pass either straight on or into the branch (Fig. 330), and *beneath* which the full tubs from the branch are taken. The illustration explains the arrangement, which is preferable to having the crossing on the same level; there is no chance of collision or derailment, and, owing to the height to which the empty tubs are raised, they run freely round the curves, and require scarcely any attention.

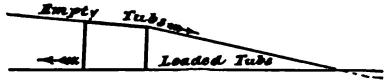


Fig. 330.

CLIPS.—Tubs are attached to the rope in many different ways. A good clip should be capable of easy and ready attachment and detachment, should not injure the rope, have few wearing parts, and act equally well on a downhill or uphill gradient.

Clips for "Under" Haulage: *Screw Clip.*—The common form of clip consists of two plates, an upper and a lower one (*a* and *b*, Figs. 331 and 332), connected together by a screw, *c*, which works through a nut, *b'*, formed by the prolongation of the lower plate. This screw is provided with a handle, so that it can be turned around, but at the lower end, where it passes through *a*, the screw thread is cut away. A connection is made between the plate *a* and the screw *c* by means of a small washer, or collar, *d*, dropped into an opening left in *a* for that purpose, and slipped over the end of the screw, and held there by a cotter. When the handle is turned, the screw either draws the piece *a* towards or from *b*, and so grips or looses the rope. These clips are connected to the drawbar of the tub by a hook or link fastened to the part *e* by a bolt or pin. They are simple, strong, and cost little for repairs. The amount of grip on the rope can be regulated to as much or as little as possible, and for heavy loads on steep gradients they act admirably. They are not easy to attach or detach, and in cases of derailment of tubs cause considerable damage, both to the rope and to the road, as they rarely lose their hold, and are the last things to break.

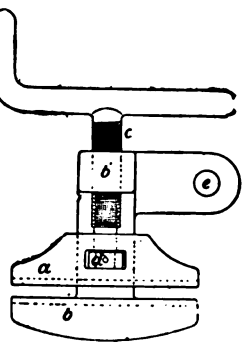


Fig. 331.

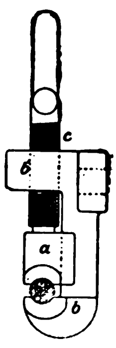


Fig. 332

Smallman's Clip.—The principle of this is the same as that of the screw clip, but the gripping action is obtained in an easier and readier manner. It consists of two plates (*a a*, Figs. 333 and 334), connected together by a bolt, *b*, in the centre; a lever, *c*, turning about a point, *d*, is provided, its shorter arm being enlarged, as shown at *e* (Fig. 334). This slides along wedge-shaped recesses in the side plate, and, as a result, the lower part of the plates can either grip or release the rope. Adjustment for wear can easily be made by tightening the bolt *b*. A very powerful grip is obtained, the rope is not damaged, as it is gripped for several inches, attachment is easy, and the clip passes

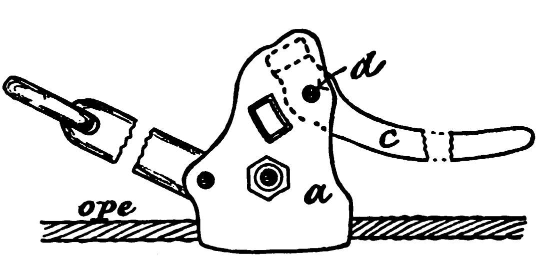


Fig. 333.

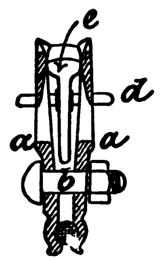


Fig. 334.

freely round curves. It is, however, rather cumbersome, and cannot be automatically detached.

Fisher's Clip consists of a hook having a hinged piece (*a*, Fig. 335), at the far end, which can be doubled back and locked by a sliding collar, *b*; a recess is provided to receive the rope. The hook is placed in the drawbar, and the clip grips the rope by deflecting a small portion of it. It is essential that the hole through the clip should be the same size as the rope and of softer material, so that it wears itself instead of the rope. To allow this, the recess is provided with bushes, *c*, of soft iron, which are kept in position by rivets, and are easily replaced when worn.

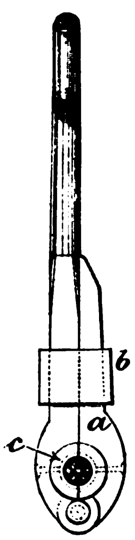


Fig. 335.

With Fisher's or any similar clip, it is absolutely essential that the rope should have a wire core, if not, it stretches too much, and the clip will not hold. The hook part is made of a very good quality of iron, and is the weakest part, so that in the event of the tub being derailed, the hook straightens out and the rope is not damaged. This clip acts equally well uphill or downhill and round curves, and can be easily and automatically detached in the same way as any other clip which is locked by a sliding collar.

Clips for Over Haulage.—In the earlier applications of rope haulage it was thought that the clips would not get sufficient grip on the rope, unless a series of knots or projections were provided on it at regular intervals, but this opinion has long been abandoned, and ordinary ropes employed. Of the large number of clips designed, many are unsuitable through over elaboration in detail; indeed, the chief essential of a good clip is simplicity, while there must be no fear of its failing to act through dirt or wear.

S *Clip.*—Undoubtedly the simplest, and at the same time one of the most efficient, is the plain clamp of round iron, bent to the shape shown in Fig. 336. This fork is pivoted at the *centre* of the tub, and grips the rope a short distance away, along a line which does not coincide with the centre line of the track. As a result of the eccentric arrangement of the fork, the rope becomes slightly kinked, and the clip obtains sufficient grip to move the tub, while the rope is not injuriously affected.

Brown's Clip.—The ordinary Y fork in its common form is unsuitable for rope haulage, but can be adapted to such work by the simple addition of a loose roller to each of the upper branches of the forks. These rollers can turn freely on the forks, but act as cams, because the hole is placed eccentrically, as shown in Fig. 337. The space between the fork is regulated so that the thin side of the rollers will not allow the rope to run between them without turning round until the thick side grips the rope.*

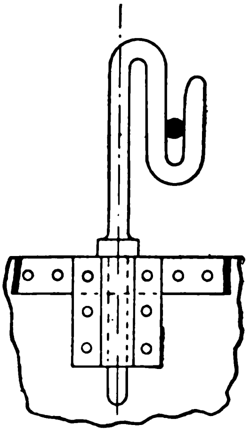


Fig. 336.

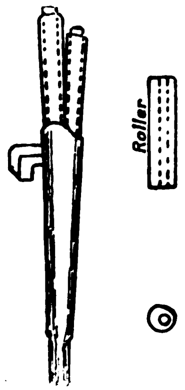


Fig. 337.

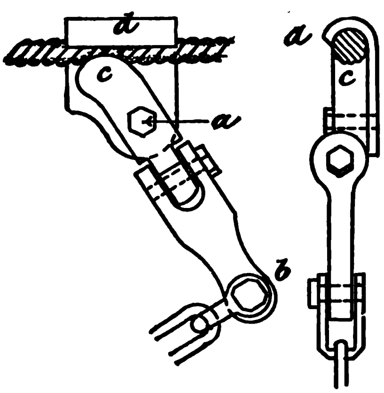
Chains.—A common method of attaching tubs to the rope is by means of a chain, one end of which is hooked on to the drawbar of the tub, the other end passed twice round the haulage rope, and then hooked back on to the chain passing from the tub; as soon as the full weight comes on to this chain the coils get quite close together and form a compact fastening. This attachment is not by any means perfect, although a very convenient one. On undulating gradients, two chains are required—one before and one behind each tub, but both must not be tight at the same time, as in such a case, if the rope was suddenly stretched, the tub would inevitably be lifted off the rails. Wire ropes are in the habit of twisting, and when they do, if the above attachment is used, the chain twists with them, winding up whatever slack portion there may be; consequently, on reaching turn pulleys, or any bend, where the rope is raised higher than its normal position, the tub is overturned, and all succeeding tubs are overthrown until the rope is stopped.

Ward and Lloyd's Clip.—Many of the above disadvantages are overcome by the clip employed at Sandwell Park Colliery. It is exceedingly simple, consisting only of a hinged lever, to the bottom end of which is attached the chain fastened to the tub (Figs. 338 and 339). The lever works about a pivot, *a*, and immediately the weight of the tub comes on to the end, *b*, the rope is gripped between the

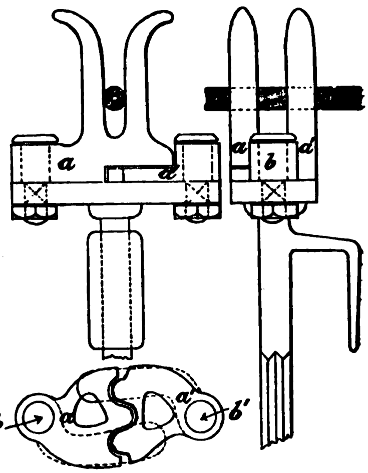
* *Fed. Inst.*, xiii., 147.

top end, c, and the curved plate, d. The lever is hinged, which allows the clip to fall into the guide pulleys when passing round curves. It has now been in use six years, and has given every satisfaction. It is easily attached and detached, but this cannot be done automatically, and on undulating gradients two clips have to be used for each tub.

Rutherford and Thompson's Clip.—The great advantage of this appliance is that it automatically attaches and detaches, enabling curves and junctions to be worked on the gravity principle, in the same way as with endless chain haulage. It does away with one man or boy at each junction, for with an ordinary clip some one has to be employed to take off empty tubs and put on full ones; while with this one, all that is necessary is that some one should be in attendance to space the tubs, and to lift off the clip from the empties, and attach it to the full ones.



Figs. 338 and 339.



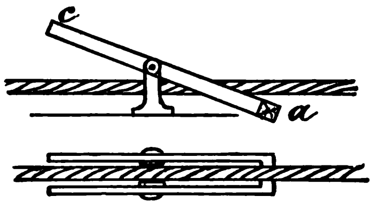
Figs. 340, 341, and 342.

Figs. 340, 341, and 342, which are respectively front and side elevations and plan, show details of the rope gripping apparatus usually employed, which is composed of two Y-forked jaws, *a a'*, mounted and geared together as shown by Fig. 342, so that they can oscillate about the two pins *b b'* as centres. As soon as the clip comes into the same line as the hauling rope, the motion of the latter turns the forks slightly about the centres *b b'*, and causes them to close on the rope and grip it firmly. The stronger the pull, the tighter the grip, hence the clip is well suited for heavy gradients; and as it is attached to the tub through a rigid rod, which is hooked over the top while the other end passes into a small bracket on the front, and as the jaws can move either backwards or forwards, it works well on undulating gradients.

The rope can be lifted out of this clip, or dropped into it again, with as much ease as a chain is lifted out of the Y on an ordinary tub, but inasmuch as these clips are not fixed to the tub but are detachable, an arrangement is employed to prevent them being accidentally lifted off when the rope is disconnected.

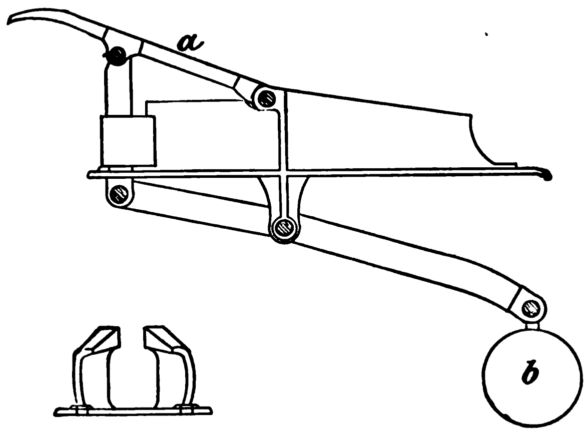
Automatic Detachers.—Little difficulty is found in automatically detaching any clips of such a type as Fisher's, where the grip on the rope is determined by the position of a sliding collar, because if this collar is lifted up, the clip is released. If the rope and clip be conducted into a groove, having sides arranged on an inclined plane, and if the rope is kept down as the clip passes through, the collar is lifted up.

At Nunnery Colliery a very simple appliance is used to perform this action. At the detaching point, two strips of iron are connected at one end by a cross piece, and are pivoted about pins near the centre. Figs. 343 and 344 show plan and elevation of the arrangement. The space between these two strips is wide enough to allow the rope to pass through, but not the collar on the clip. The end, *c*, of the two strips of iron cannot be pressed down because the other end, *a*, is under the rope, consequently the collar of the clip has to slide up the inclined plane and is gradually lifted, releasing the rope.



Figs. 343 and 344.

An apparatus of more elaborate, and perhaps more sure character, has been designed by Mr. J. F. Lee, of Castle Eden Colliery. It



Figs. 345 and 346.

consists of a groove having inclined sides, out of which the rope and the lower part of the clip cannot be lifted, as each side is formed of an angle-piece (Fig. 346). The continuation of the jaws is made by two levers (*a*, Fig. 345) kept up by a weight, *b*, but when the pressure becomes excessive they may be pushed down, the object of this being that the levers can accommodate their height to suit the varying positions of collars on different clips. The rope and lower part of the clip pass underneath the jaws, which taper towards the point of exit; the collar passes up the inclined plane and is lifted, thus detaching the tub. To prevent any chance of failure, the collar of the clip is provided with a flange.

At Skelton Park Colliery* the ropes are attached to a simple hook beneath the tubs, as the gradient is slight, and the weight is sufficient to haul them along. They are detached by an apparatus, consisting of a lever (*a*, Fig. 347) working between split rails, and depressed by

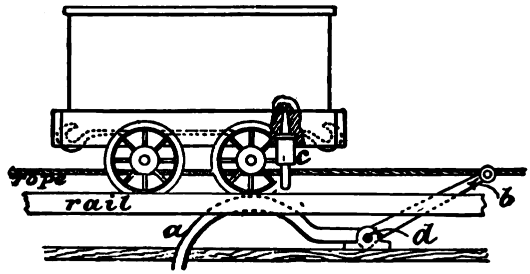
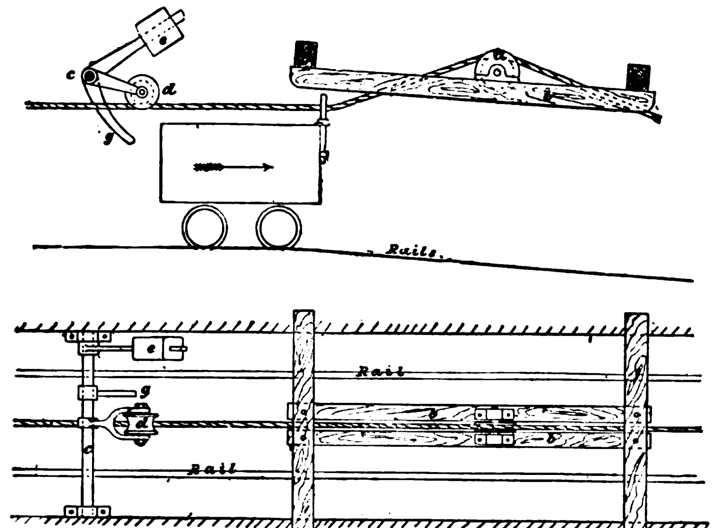


Fig. 347.

the passing tubs. This turns the shaft *d*, raises the lever *b*, and lifts the rope out of the hook, *c*. At the same time, a slight divergence is made in the line of rails, causing the hook to move aside from the rope, which then drops when released by the lever *b*.

With Rutherford and Thompson's clip, detachment is obtained by an appliance which consists of a holding-down pulley (*a*, Figs. 348 and



Figs. 348 and 349.

349), and of two inclined guide-blocks, *b*, one on each side of the rope, the spaces between them being such that the rope can rise up, but that the forks of the clip catch the under side. As a tub and its clip

* *N.E.I.*, xxxi., 105.

CURVE ON ENDLESS ROPE HAULAGE

H.W.Hughes Photo.

JUNCTION ON ENDLESS ROPE HAULAGE

come to the detacher the rope gradually gets higher and higher, tending to lift the clip out of its socket, but is prevented from doing so by the two guide blocks *b b*, which catch the top of the forks. Ultimately the rope is lifted completely out, and the tub runs away. With a clip having a very tight grip, a jerk is thrown on the rope by such action, and to prevent this extending down the road to the tubs further in-bye, a movable holding-down pulley is placed a short distance away which checks vibration in the following manner:—A shaft, *c*, is fixed across the road above the rope and on it are keyed three arms, one carrying a holding-down pulley, *d*, the second having a weight, *e*, at the end of a lever, while the third, *g*, hangs downwards. The action of *d* is to keep the pulley firmly on the rope, and that of *g* to lift the pulley when the tubs are passing, this being necessary, or the clips would catch it and break. The tubs which are travelling in the direction shown by the arrow, push aside the arm which hangs down before them and on doing so, turns the shaft, *c*, round, and lifts up the pulley and weight, which fall again immediately the tub has passed.

Working Curves.—As previously stated, the working of curves when the under rope system is in operation presents little or no difficulty provided pulleys of as large diameter as possible are employed and that they are placed near together. Such a curve is shown in Plate 3. It is, however, obvious that the diameter of the pulleys is limited by the gauge of the railways, because the rope occupies the centre line and the deflecting rollers have to be placed between it and the inside rail of the curve.

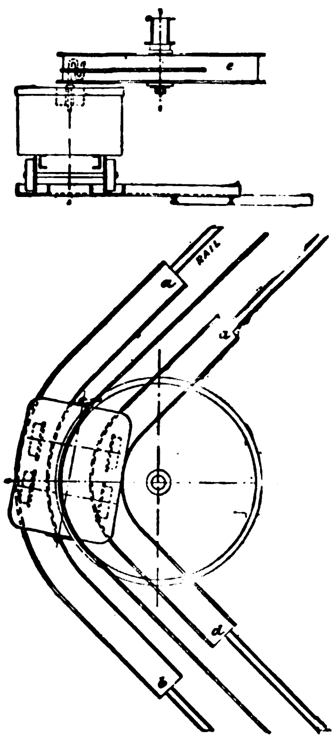
Experience, however, has demonstrated that the wear and tear on a rope passing round such small pulleys is greater than would be anticipated, and that it is due not so much to abrasion, as to the shocks produced by the clips striking violently against the rollers. In the case of pulleys of large diameter, such as are employed in over rope haulage, the clip easily passes on to the periphery which it approaches gradually at a wide angle, but, on the contrary, with small rollers the size of the angle at which the clip strikes the periphery is much more acute. The consequence is that in the former case the clip passes smoothly on to the pulley, while in the latter case it meets with considerable resistance, and is appreciably delayed in its forward movement setting up most injurious shocks along the rope.

Instead of fastening each pulley down independently to the sleepers, they are preferably placed in a frame containing several, such frame extending the length of many sleepers. This is by far the stronger arrangement, and a very necessary one where the load on the haulage rope is a heavy one.

For over rope haulage, the curves are made as quick as is reasonable, and a large turn pulley placed at each. The upper flange of such pulleys is often cut away to a considerable extent, and such a clip as that shown in Fig. 338 readily passes round without being detached from the rope. With these sharp curves tubs often get off the rails and frequently overturn. For such reasons Mr. G. Heckel* suggests the use of two wide troughs of channel iron, *a b* and *a d* (Figs. 350 and 351), bent to fit the curve. The rope is directed by a large pulley, *e*, carried by an ordinary channel-iron joist bedded

* *Coll. Guard.*, 1897, lxxiv., 825.

over the road, and when the tubs pass from the straight to the curve, they leave the rails and are guided by the channel-iron troughs. On reaching the other end of the curve, the troughs act as guides, and the tubs return to the rails automatically.



Figs. 350 and 351.

At curves where the continuing road is on a downhill gradient, when Rutherford and Thompson's clip is employed, the tubs run round and attach themselves to the rope again immediately this comes low enough to grip the clip, but where the gradient rises out-bye other means have to be employed, as the rope tends to get further away from the clip. It is impossible to deflect the rope far enough downwards with a fixed guide pulley, as these have to be placed high enough to clear the clip. The movable one (Fig. 348) is inadmissible here, as the tubs being detached from the rope, are only moving with the force due to the inclination of road, and would not have sufficient power to lift the lever and weight. The ingenious appliance shown in Fig. 352 has been designed to meet such cases. A pulley, *a*, is fixed at such a height as will allow the tub and clip to pass beneath when it is in its normal position. This pulley is not a fixture, but it is suspended from a shaft, *b*, fitted with guide blocks, and connected by crank levers, *c d e*, and *f g h*, and the links *b c*, *e f*, and *h i*, with the rails forming the road at this point. There are two sets of levers, one on each side of the rails. The rails, for a distance of about 12

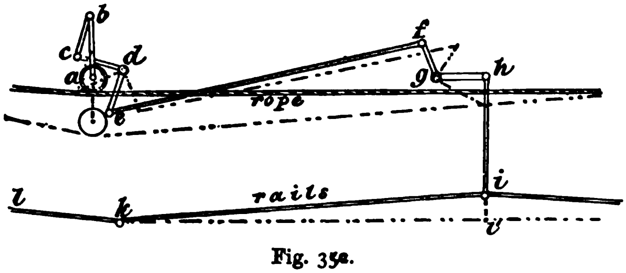


Fig. 352.

feet, are carried on a platform hinged at the point *k*, and by means of a balance-weight take the inclination shown at *i k*. The tubs when detached from the rope run down the slope *l k*, pass beneath the pulley *a*, and continue by the momentum they have gained up the slope *i k*; their weight, however, over-balances the counterpoise. The platform descends about the centre *k*, takes the position *i' k*, pulls down the link *h i*, moves over the two cranks, and depresses the guide pulley *a*, and the rope to such a distance that it is caught by the clip, and the tub consequently moves away. As soon as the tub has gone off the platform, the counterpoise raises it again and the guide pulley, so that the whole appliance is automatic. The points *d*, *g*, and *k* are fixed, the remainder movable. At the moment of attachment of the tubs to the rope, the different parts of the apparatus occupy the position shown by the dotted lines; the travel of the pulley *a* is about 10 inches.

Keeping the Rope down.—Where the gradients vary considerably, especially at the foot of a steep incline, when the ropes work over the tubs and open-topped clips are employed, it is essential that some apparatus should be fixed to keep the rope down, or it would come out of the clip. The pulleys fixed for such an object must move to allow the clip to pass by, and consequently have to be set in specially designed frames. One such form (Fig. 348) has already been described. Another of somewhat improved construction consists of six rollers arranged around the circumference of, and fastened between, two circular sheet-iron plates, the whole arrangement being keyed on a shaft fastened to timbers running across the road (Figs. 353 and 354). The rope is deflected by this compound pulley which does not

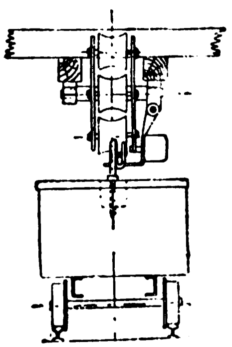


Fig. 353.

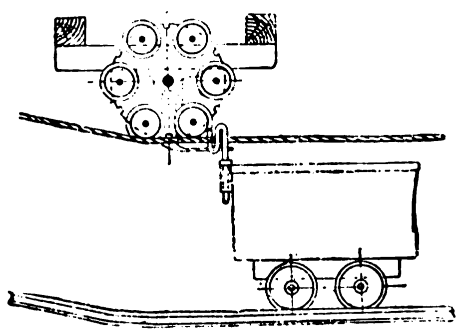
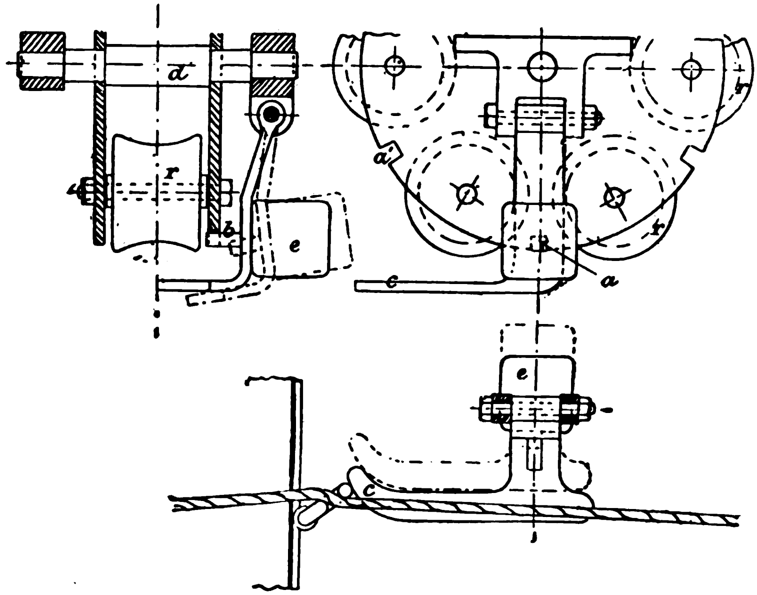


Fig. 354.

revolve under ordinary conditions, being prevented from so doing by the weighted stop, the detailed construction of which is shown in Figs. 355, 356, and 357. There are six recesses, *a a'*, round the circumference of the plate, one between every two rollers, *r r*. The weighted stop *b* under ordinary circumstances occupies the lowest of these recesses and locks the apparatus in the position drawn, but when a tub approaches, the clip first gently pushes the arm *c* of the stop on one side, as shown by the dotted lines, and leaves the set of rollers free to move on their axis, *d*. The clip, therefore, presses the first roller on one side, revolves the whole apparatus and brings down the next recess *a'* into such a position that immediately the tub has passed by, the weight *e* brings the stop *b* into its original position, and locks the frame until the succeeding tub arrives. One or other of the rollers are constantly revolving.

Spacing the Tubs.—If the haulage system is to work smoothly, it is important that the tubs should be attached to the rope at equidistant intervals, more especially so when the gradients are undulating, in order that the load on the engine shall be as constant as possible. Equal spacing can be easily carried out by making each tub, as it leaves the station, strike against a lever and ring a bell so soon as it has proceeded a given distance from the point of attachment. When the attendant hears this signal, he connects another tub to the rope.



Figs. 355, 356, and 357.

Threading the Rope.—It is rather a difficult matter to put on the first rope of a new application of endless rope haulage. As supplied by the manufacturers, ropes are very carefully coiled and should be unwrapped from the *outside*, care being taken that no "slack" is payed out, or the rope will at once kink and spoil itself. If a new rope is replacing an old one, the threading is an easy matter, but one requiring care. First of all, the old rope is cut through, and one end of the new rope attached to the old one, but in between the two ends a swivel must be placed. The object of this is to lessen the twist in the new rope; unless this is done difficulty will afterwards be experienced in the working. The coil of rope is placed on a turntable to which some moderately strong brake power can be applied. The engine is then started and the old rope moves away, dragging the new one into the place it itself had. As new ropes invariably stretch in use, before the two ends are spliced together they should be strained as tight as possible, which is done by attaching blocks, and, at the same time, the tension pulley is braced up as close as can be.

It is always risky to attempt to drag on a new rope with horses;

their movements are very erratic, and it is next to impossible to control the unwinding of the rope from the coil. Under such circumstances there is considerably more chance of an accident. It is, therefore, prudent to first of all thread on any old damaged rope that may be available, which is a simple and inexpensive matter owing to their flexibility, and afterwards employ the old rope to haul on the new one.

Comparison.—If a good representative of each type of haulage is taken, the cost per ton per mile is about the same in all of them. To a great extent, the cost depends on the number of junctions and branches, because attendants have to be provided at these points to attach the tubs. In comparing the cost of one system with another, it is usual to reduce the cost to a uniform distance hauled of one mile—that is to say, if the cost is twopence per ton per half mile, a simple proportion gives fourpence per ton for one mile, but although some uniform distance must be introduced, yet it does not give a fair comparison in every instance. Take, for example, an endless rope or chain plane, exactly a mile from the beginning to the end with no junctions. One man at each end should perform all the labour of taking off and putting on the tubs, and the cost per mile, on the one mile length, would be very small; but if, in another case, there are four junctions in a similar length of plane, each of these junctions will require the services of an attendant, and the labour cost will show very much higher than in the former case, providing the same quantity is hauled, and yet the two planes may be facsimiles, and both be laid out with the same care and labour-saving appliances.

Many estimates entirely overlook some part of the first cost of the plant. Hauling engines cannot be worked without steam, and the extra amount for additional pulleys, fittings, pipes, &c., caused by adding haulage machinery, should be charged against the plant. Then, again, the stores' charges for the machinery should be noted.

The most careful experiments which have ever been made to determine the cost of different systems were those carried out by the North of England Institute.* This was, however, many years ago. The endless rope system was then in its infancy, while little improvement has since taken place in either the tail rope or endless chain systems. This report strongly brought out the merits of endless chain haulage, so far as regards its ease and cost of working, but friction clutches, automatic detachers, improved driving pulleys, and the other similar labour-saving appliances of modern endless rope haulage were then unknown. At that time, a life of one or two years in a haulage rope was considered a very good performance; at the present time 7 to 9 years is by no means an unusual occurrence. At many collieries the rope cost per ton-mile does not exceed 0·2d.

The great advantage of the endless rope system is the perfect regularity of the delivery. The tubs come one at a time at regular intervals, and are easily dealt with; in addition, the full tubs going down inclines assist in pulling the empty tubs up. Both these advantages are common to the endless chain system, but the disadvantages of the latter is the enormous weight of the chain and its liability to break, especially on long planes. For surface work, the endless chain possesses one advantage, inasmuch as it is little affected by the action of the weather, but underground this advantage disappears.

* Vol. xvii.

With the tail rope system the tubs work in sets, and, therefore, travel at a high velocity, 15 to 20 miles an hour being often reached. The delivery is intermittent; a train of from fifty to sixty tubs is brought into the pit bottom at a time, and men have to be there to deal with the set; on its arrival, all is hurry and confusion for a few minutes until the empty set has been despatched to the workings, and then the men have little to do. Should a tub become derailed when travelling at this speed the damage done is considerable. With an endless rope, travelling at only 2 or 3 miles an hour, there is little possibility of derailment, and even if this does occur, the damage done is slight. With the tail rope system, less length of rail is required, but a larger pair of engines are necessary than for endless rope, because in the former case they have to be powerful enough to deal with the *heaviest* load up the *heaviest* gradient, have to travel at a very high speed, and derive no benefit from the counterbalancing effect of gravity on undulating gradients. Their action is intermittent and they require an engineman always in attendance. It has been pointed out that main and tail rope haulage possesses an advantage over the other types, inasmuch as the men may ride in-bye, with the result that their time at the face is increased. The advantage is, however, not a large one, as only a small proportion of the total men employed can be transported in the first set travelling in-bye. This is practically the only one available, as before the second set is ready, the remaining men could walk to their work.

With the endless rope system, the constant attendance of an engineman can be dispensed with by arranging a clutch gear at the bottom of the pit, where the main strap rope terminates. This point is the principal junction of the pit, and men have to be there to attach and detach the tubs. If a signal comes from the workings to stop the main rope, one of these men can easily turn the wheel which disconnects the clutch gear, and the engine on bank may continue running. The author is not aware where the services of an engineman have been dispensed with at a hauling engine, except in the instance of two of the collieries under his charge. By spending £100 on a good efficient clutch gear one engineman looks after three continuously running engines—*i.e.*, hauling, fan, and shop machinery, and not the slightest hitch has ever occurred. The only objection to this system is the possibility of some accident happening to the shaft rope, but an experience of many years does not support such contention.

The author has at work every system of haulage; but the one that stands pre-eminent is, undoubtedly, the slow moving endless rope, with the tubs attached at regular intervals. This appears to be the common experience, as nine out of every ten installations which have been put to work during the last decade or so are endless rope, with the probable exception of the North of England, and even there this system is rapidly gaining ground.

An endless rope can be employed anywhere, although to obtain the best results the roads should be laid out to suit it. The only objection against it is that a double road is necessary to obtain its advantages to perfection, and that double roads are expensive to maintain where the roof is bad. As previously pointed out, even this disadvantage may be, and is, removed by employing two roads, each laid with a single line of rails, one for the full tubs and one for the empties.

Locomotives.—Haulage by steam locomotives is not to be recommended, as neglecting the dangers and the difficulties of dealing with the smoke, steam, &c., the system has the disadvantage of being intermittent in the matter of supply. The engines have to be small ones, and are not only very expensive in up-keep, but are very liable to derailment. There are, however, certain conditions in old mines, or in steep seams of variable dip, when the roads have to follow the strike of the beds and are consequently far from straight, where endless rope or chain haulage is out of the question. Locomotives worked by steam have been applied in English collieries and in the American anthracite mines, but the inconvenience attending their use outbalances any economy they may possess.

Compressed Air Locomotives.—So long as compressed air was produced by wasteful machines and used at pressures of from 40 to 70 lbs., the locomotives which were driven by its agency never gave satisfaction. The Porter Co. of Pittsburg have constructed a great number designed on more intelligent lines. Three of them shipped to Japan for the Yuburi Colliery* may be taken as representatives of the class, although it is obvious that such a variety of conditions is encountered that no two motors of different plants are alike. The extreme length of each locomotive is 14 feet 10 inches, width 3 feet 3 inches, and height 4 feet 10 inches. Its total weight is 12,500 lbs., and there are four driving wheels, 22 inches diameter, which are spaced 4 feet between centres.

The engine is of the usual type resembling that of a steam driven locomotive, the boiler being replaced by a reservoir or tank for carrying the air. The working pressure carried in the main tank is 800 lbs., this is reduced by an automatic valve to a uniform pressure of 140 lbs. delivery to the auxiliary reservoir, from which the air is distributed to the cylinders through a specially constructed throttle valve. This locomotive is also fitted with an apparatus for re-heating the air during its passage from one cylinder to the other.

For the high pressures, the compressors are all built on the multistage plan, in which the air is compressed in three or four stages and the air thoroughly cooled between each stage. The air may be either delivered into a battery of tanks, but more frequently into a pipe line which runs parallel with the railroad. At proper intervals, charging stations are provided where the motor tanks can get a fresh supply of air. The charging station is provided with a universal metallic coupling which fits the check valve on the motor tanks. The whole operation only takes a few minutes, and can be done while the locomotive is waiting at the turn outs before starting on the return trip. It is not, of course, necessary to lay pipe lines along all the tracks, and in mines the main roads alone would be so fitted. The locomotive when charged is perfectly free to run into any branch roads, and all work there can be carried out without pipe lines. In the earlier plants it was general to use storage tanks for charging purposes, these being connected together by pipe lines of comparatively small diameter. It has, however, been found better to dispense with storage tanks, which were necessarily costly and inconvenient to get into position, and increase the diameter of the service pipes

* *Eng. and Min. Journ.*, 1899, lxvii., 623; and 1902, lxxxiii., 376.

which then are made to fulfil the double purpose of conveying and storing the air.

Such locomotives are particularly suitable for gaseous mines, or even in non-gaseous mines where the roadways are low, as naked overhead electric wires would be a source of danger to all persons who had to travel along them. The motors are of the simplest form, are easy to operate with unskilled labour, and take little to keep in repair. They might be compounded at the sacrifice of simplicity, but it would then become necessary to heat the air before each expansion, and there is more economy in wasting a few pounds of coal at the compressor end than in attempting to economise at the motor by introducing complicated parts. Simplicity, however, must not be construed to mean crudity, but rather that the refinements of engineering are sacrificed for purely practical and business reasons.

Electric Locomotives.—The first locomotive worked by electricity was applied in 1882 at Zauckerode Colliery in Saxony. The current is conveyed along the roof of the roadways by a ⊥ iron conductor, and is transmitted to the motor by a conducting piece which slides along the ⊥ iron. The locomotive has worked most satisfactorily ever since its application, and performs the work more cheaply than horses which it replaced. There are many electric locomotives in German mines, and Mr. K. Eilers* states that the cost of tramming with electricity is at Stassfurt and Zauckerode 75 per cent., and at Hohenzollern Colliery 67 per cent. of what it originally was when horses were employed.

So far as is known the only electric locomotive employed in English mines was that introduced by Mr. G. B. Walker at Wharncliffe Silkstone,† where the engine did not depend for its grip on the friction between the wheels and the rails, but got a direct pull on a fixed rope. The latter was fixed at either end and parallel with the road, and passed over a sprocket wheel or friction clutch geared in a suitable manner to an electric motor on a trolley. The road was 500 yards long, the inclination averaged 4 inches to the yard, and the rolling load was approximately 4 tons. The locomotive worked excellently for several years until that portion of the mine was exhausted, the only drawback being the sparking.

In the United States there are numerous plants at work on similar lines to those employed on the overhead conductor system adopted on surface electric tramways, but until some means have been designed to prevent sparking, their use is limited to those mines where gas is absent. As long ago as 1891 Mr. H. C. Spaulding‡ stated that the Thomson-Houston Co. had constructed the largest in that country. The locomotive is 60 H.P., weighs 21,600 lbs., is 3 feet gauge, and has a maximum speed of 10 miles an hour. The armature speed is 1020 revolutions per minute, and the locomotive is 3 feet $3\frac{1}{2}$ inches high, 3 feet $6\frac{1}{4}$ inches wide, and 12 feet $6\frac{1}{2}$ inches long. Since then the American technical journals have constantly contained descriptions of new forms of electric locomotives and of the collieries which employ them. Instances have been quoted where the cost per ton hauled by electric locomotives is only one-tenth of that which prevailed when mules were employed.

* *Amer. Inst. M.E.*, xx., 365. † *Inst. C.E.*, civ., 116.
‡ *Eng. and Min. Journ.*, 1891, lii., 434.

The more recent types* are equipped with two motors of 10 H.P. each, which are of the enclosed multipolar railway type. Each axle is driven by one of the motors through single reduction gearing, these being of steel with machine-cut teeth. Such a locomotive develops a drawbar pull of 1000 lbs. at a speed of 6 to 8 miles per hour, and upon a level track with clean dry rails will haul a train load of 33 tons gross, provided the mine trams have well lubricated axles. All controlling mechanism is arranged so that the motor-man does not have to leave his seat to operate any portion of it. The electric controller is of substantial construction, thoroughly insulated where necessary, and enclosed so as to protect the contacts and wearing parts from dirt and moisture. The controller is arranged so that the motors may be reversed only when the current is shut off. A separate switch is provided, and the motors may be started and run either in series or in parallel, thus enabling the current to be used economically in starting, but giving every opportunity to start heavy loads in parallel when a long distance from the power house where the line voltage is likely to be low. Resistance coils of large capacity and radiating surface are provided for starting the locomotive, and for running at slow speed when desired. The brakes are worked by a screw and hand wheel, which renders the mechanism self-locking in any position in which it may be desired to leave it. The trolley pole is placed at one side of the locomotive, thus bringing the trolley wire outside of the rails, and thereby reducing the danger of electric shock to men and animals.

Benzine Locomotives.—During recent years quite a number of collieries have been equipped with the Deutz benzine locomotive.† These are fitted with 6 or 8 horse-power motors, and generate their gas from combustible fluids carried with them, and are thus of small size compared with those having a receiver filled with compressed gas. The working expense is moderate, owing to the economy of gas motors compared with steam engines. These locomotives are safe in the presence of fire-damp, because ignition and explosion of the working gas are effected within a perfectly air-tight cylinder. On the other hand, a disadvantage of explosion motors applied to locomotives is their slight starting power, the impossibility of their running in the reverse direction, and the vitiation of the underground atmosphere by the exhaust gases.

An 8-horse locomotive complete costs £380. The transmission of motion to the driving shaft and the reversal of the locomotive are obtained by five spur and four chain wheels controlled by friction clutches. Results obtained over a considerable period at the Königs and Laura Works, Upper Silesia, give the average performance per locomotive of 113 ton-miles per diem, and the total yearly expenses come out at £187·9 with benzine, and £178·45 with benzole, equal to 1¼ pence per ton-mile and 1⅛ pence per ton-mile respectively.

Bibliography.—The following is a list of the more important memoirs dealing with the subject-matter of this chapter:—

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* *Eng. and Min. Journ.*, 1902, lxxiii., 490.

† *Coll. Guard.*, 1902, lxxxiii.

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CHAPTER VIII.

WINDING.

The material having been brought to the pit bottom, the next thing is to convey it to the surface. This is done by placing the tubs in a suitable apparatus called the cage, to which one end of a rope is connected, while the other is attached to, and wound round, the drum of an engine at the surface. On reaching the top, the full tubs are taken off and replaced by empty ones, and the cage then descends.

Pit Frames.—As some support has to be provided for the rope, a pit frame, with pulley attached, is used for such purpose. At modern collieries, with large winding machinery running at quick speeds, one stroke of the engine means a considerable lift of the cage, and unless the head-gear pulleys are placed a good height above the surface level, and the engineman is very careful, the cage may be brought up against the pulley, and over-winding take place. In addition, the great majority of collieries are provided with screening appliances, which are inclined so that the coal may run down them, and, as the trucks into which the coal is loaded stand at the ground level, the landing place has to be some distance higher up. A further height is therefore given to the pit frame, and it is quite common to find the head-gear pulleys 60 or 70 feet above the ground. These erections are constructed of different materials. On the Continent of Europe, towers of masonry are employed, but such procedure has never received favour in this country, nor, indeed, a very extended application anywhere else. The material mostly in favour until recently was wood, wrought iron was afterwards employed, and, as in every other branch of engineering, the use of steel is rapidly becoming common.

Before describing the method of construction, perhaps it would be best to refer to the general method of design. The structure, as a rule, consists of six main parts: (1) two vertical upright legs (to carry the weight to be lifted); (2) two front vertical legs (for affording support to the cross timbers carrying the guide ropes); (3) two back legs (to prevent the whole structure being dragged over by the pull of the winding-rope going to the engine). These main legs are braced and connected together by various cross-pieces, added to give general stability to the whole structure. There is nothing particular in the four legs of the front framework, except that they enclose a wider space at the ground level than at the top, the object of such being to prevent them toppling over sideways; but the position of the back legs is of considerable importance. Their bottom ends have to be placed at such a distance from the front legs as will effectually prevent any chance of the frame being pulled over towards the winding engine. The proper position of these back legs is very easily determined, although in many instances they are placed anywhere but in the right position. Often they are carried so far towards the winding engine that additional vertical supports have to be provided underneath them; no advantage is gained by this, indeed it only introduces an element of instability, as the legs may not be strong enough even to carry their own weight. The strain on the pit frame, both as regards direction and amount, is the resultant of two forces. First of all there is the weight—viz., the weight of the tubs, coal, cage, and the rope hanging down the shaft, which is a moving or live load, and, therefore, throws more strain on the structure than if it were an inert mass. The other strain is that coming from the winding-rope, which has to exert sufficient power to lift up the weight hanging in the shaft at a certain velocity. The direction of the pull due to the weight in the shaft is always vertical, but the direction of the one due to the winding-rope may be at any angle to the vertical, its direction being determined by the height of the head-gear and the height of the drum above the ground level, and its distance from the centre of the shaft.

The relative position of the back legs to the front ones is determined by the principle of the parallelogram of forces, and may either be worked out by calculation or graphically. Supposing *a b* (Fig. 358) is the ground level, *c* the pulley, and *d* the drum of the winding engine; *c b* is the direction of the force acting downwards, and *c d* that due to the winding rope and which tends to overturn the structure. Under ordinary circumstances the amount of force acting along *c d* must be equal to that along *c b*. Take the distance *c b* as being equal to the amount of force acting in that direction, and lay off along *c d* a distance, *c e*, equal to *c b*. From *e* a line, *e f*, is drawn parallel to *c b*, and another line, *b f*, is drawn parallel to *c e*. The direction and magnitude of the resultant force will be given by the line *c f*, the diagonal of the parallelogram. In the case under consideration, the back stay should reach the ground at the point *g*, where the diagonal cuts the line *a b*; but, even at the best regulated collieries, accidents happen, and the cage may be drawn violently against the head-gear, or, even without doing this, it is possible for some larger power to be applied along the line *c d* than that due to the weight hanging down the shaft. To be on the safe side it is preferable to lay off along *c d* a distance, *c e′*, equal to twice *c b*, *e f′* and *b f′* are drawn parallel to *c b′* and *c d′* respectively, and the parallelogram constructed as before. The point *g′*, where the diagonal *c f′* cuts the line *a b*, will determine the length of the base of the pit frame. In an actual case of over-winding the weight of the pit frames reduces the likelihood of their being pulled over, and adds to their stability; indeed, it is very probable that unless a detaching-hook is used either the head-gear would be smashed or the rope broken.

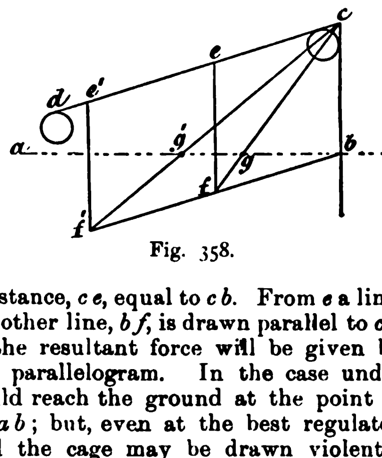


Fig. 358.

Wood.—Where wood is the material used it is generally pitch pine, which should be free from sap and knots. The height and position of the back legs having been determined, the strengths of the required timbers are found by calculation and depend on the height and load to be carried. In side elevation, the front legs are vertical, their position with respect to the centre of the shaft being determined by the size of the pulley, because they come directly under its centre, while the throat of the pulley has to allow the rope to pass down the axis of the shaft. In end elevation, the width at the top is determined by the distance between the centres of the two cages, because each pulley has to lead its own rope on to the centre of each cage. If to the distance between the centres of the cages be added the distance between the centres of the pulleys' bearings, the length from centre to centre of the two main cap pieces is obtained. This gives the width at the top. The width at the bottom is determined by the amount of inclination given to the legs, which is usually 1 in 9 or 10. The main legs, both back and front, are braced and connected together by horizontal and diagonal struts, and often too many are introduced. There is no occasion to add one more than is absolutely necessary, as they only weaken the erection by burdening it with additional weight. The structure often rests on two main parallel sills running from the back to the front legs, but such practice is not recommended. These sills rest on brickwork, and dirt and soil accumulate around them, with the result that they are the first part of the structure to get rotten, and, no matter how carefully they are painted, decay cannot be prevented. The best plan is to put each leg into a cast-iron shoe (similar to Figs. 359–361) resting on a pillar of masonry, and held in position by tie-bolts. Part of the timber is buried in the shoe, and at the point where the iron ends and the timber first becomes exposed to the atmosphere a crevice exists, through which moisture and damp can find its way. Unless this is prevented, the timber will rot more quickly than if it was on wooden sills. To prevent this, the joints should be most carefully filled in with putty and painted, and then a strip of zinc placed all round.

Iron or Steel.—Pit frames have gradually increased in height, and the tendency has also been to raise heavier loads at quicker speeds. It has, therefore, become difficult to obtain timber of the required size and lengths, except at great expense. As a result, wrought-iron erections were first substituted, to be replaced in their turn by steel. The position of the various parts should be the same as if wood were used. On the Continent of Europe a design is employed where the legs are composed of tubular girders braced together by channel section stays, but the general English practice is to construct the legs either of box or lattice girders. A fine example of the latter design is one of the pit frames at Sandwell Park Colliery, the construction of which is shown in Figs. 359 to 361, which are respectively side, front, and back elevations. The general construction and dimensions are given in the illustrations. All the main struts are of lattice girder work, which consists of four angles, one at each corner, connected by diagonal pieces of flat strip; the pulleys are carried by girders, which are of box construction in section, but the sides are lattice work to allow for the adjustment of the pulley carriages. The plates shown in the front elevations are open at the bottom. Plate IV. shows German practice.

As the legs have to bear less weight at the top than at the bottom it is common to make them taper. With a lattice girder, if it tapers, every set of cross-pieces binding the corner angles together is necessarily of a different length, which increases the cost of manu-

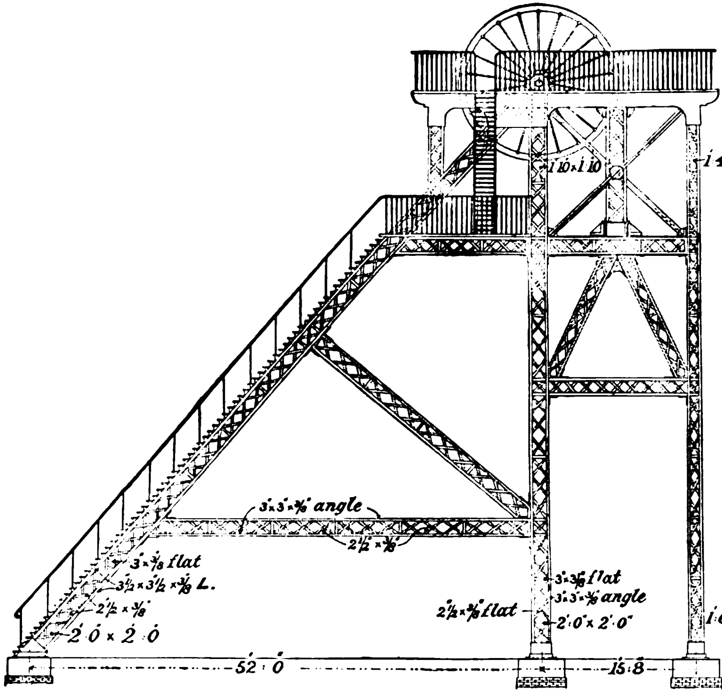


Fig. 359.

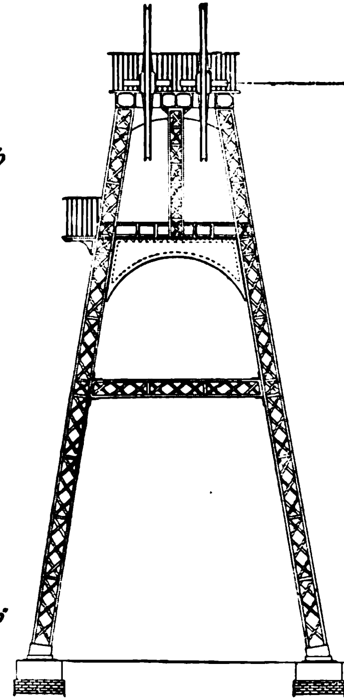


Fig. 360.

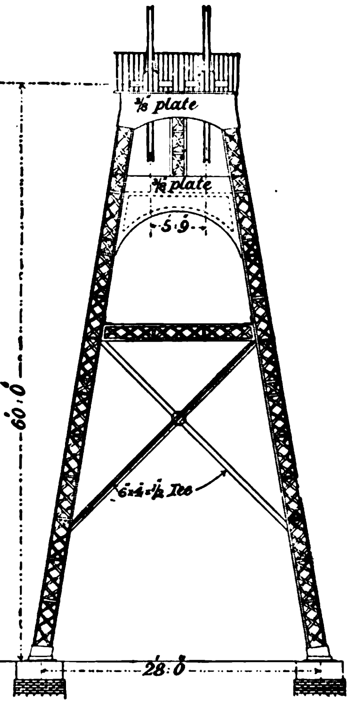


Fig. 361.

facture; to remove this disadvantage, the legs have lately been made parallel throughout. By doing this the weight of the girders is slightly increased, and they are stronger at the top than required, but as the cross-stays in each girder are of exactly the same length, each one can be cut and rivet-holes punched from one template, instead of the innumerable sizes which are required with taper girders. The economy of construction, therefore, far outweighs the extra cost of the small additional weight.

As the lattice girder is rather expensive to make, and as of late years it has been possible to roll very long strips of either iron or steel, the box girder form of leg has been adopted in many cases. The one at St. Hilda Colliery, South Shields, may be quoted as an example. It is 75 feet high and commences at the bottom with a section 18 inches square and finishes 15 inches square at the top. Each member consists of four plates, bound together by angle pieces at the corners. In the main struts, the four plates are $\frac{5}{16}$ inch thick, and the angle iron is $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{5}{8}$ inch.

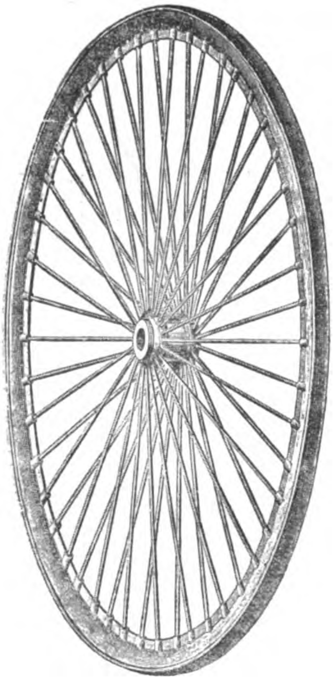


Fig. 362.

Pulleys.—At one time chains were employed for winding, but, except in the rarest instances, none are now to be found, ropes either of flat or round section being employed. Upon the type of rope used depends the shape of the throat of the pulley, such part being the only variable one, their general design being the same either for round or flat ropes. They consist of a cast-iron boss and rim, connected together by wrought-iron spokes (Fig. 362). The shaft, or "gudgeon," is composed of wrought iron, having turned bearings. With a view of reducing friction, the bearings should be as small and the pulley as large as possible. The large diameter of the pulley introduces another advantage, as it reduces the bend of the rope, and it is, therefore, not uncommon to find pulleys having a diameter of 18 to 20 feet. Beyond such size there is a difficulty in making the pulley strong enough to stand a heavy load, and at the same time keeping its weight within bounds. It is very necessary that these pulleys should be as light as possible; if not, with quick winding they have a tendency to spin after the ropes cease running.

When flat ropes are used the groove in the rim must be made perfectly flat, or the rope will be unduly strained. With round ropes the bottom of the groove will be semicircular, of a sufficient size to suit the rope. It is essential that the throat should be made wide enough to allow the rope a certain amount of play, for, as each successive coil is wound on the drum, it is obvious that the position of the rope is constantly changing with respect to the vertical plane of the pulley.

SKIPS AND CAGES.—At one time the mineral was wound from the shaft in what were called skips, which were attached to the winding-rope through the medium of chains and swung loose in the shaft. The Mines Regulation Act, 1872, made it compulsory that guides should be adopted in all shafts over 50 yards deep; and at the present time practically all shafts are provided with guides, and the tubs placed in a framing, called a cage.

Shape and Construction.—The shape of the cage is determined by the size of the tubs and the number on each deck. A common procedure in dealing with large quantities is to place two tubs, end to end, on each deck, and to have four decks. If the tubs are small ones, four may be placed on each deck. Then as to material. Everywhere cages are now constructed of steel. Each time a winding takes place, a certain useless deadweight has to be lifted, consisting of

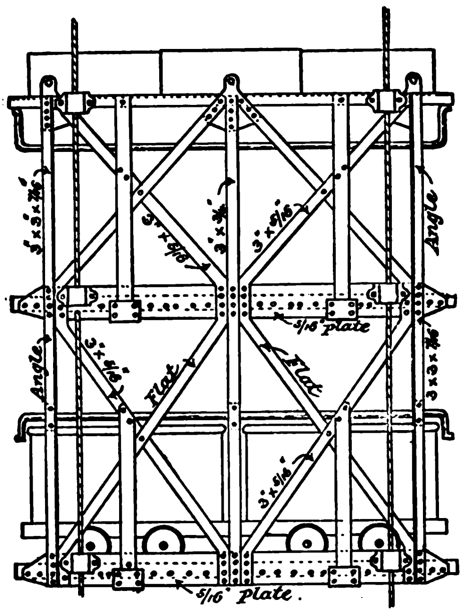


Fig. 363.

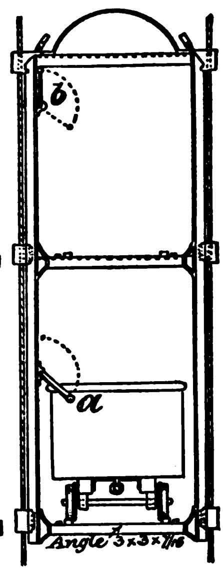


Fig. 364.

the weight of the tubs, the cage, and the rope hanging in the shaft, and it, therefore, becomes imperative, with deep shafts and heavy loads, to use material having the greatest strength and the least weight. Every second saved in the time of winding is of importance. Nothing is gained by having cages too heavy, while everything is lost. A heavy cage knocks itself to pieces, while the cost of a light one is so small, that the gain in output, which results from quicker winding, more than compensates for repairs and renewal. A good example of the modern colliery cage is that illustrated in Figs. 363 and 364. It holds two tubs on each deck, each weighing 7 cwts., carries 52 cwts. of coal, and weighs itself only 30 cwts., so that the useful load is 47·2 per cent. of the total weight. The horizontal frames are composed of angle steel, 3 inches by 3 inches by $\frac{7}{16}$ inch, tied together by two vertical angle pieces and one flat strip on each side. A strengthening plate, 9 inches deep by $\frac{5}{16}$ inch thick, runs along each side of the horizontal frame, and the three uprights are bound together by diagonal struts. The author has employed a cage of exactly similar construction, only lighter, carrying 22 cwts. of coal and an 8-cwt. tub, the weight of the cage and bridle chains being only 11½ cwts.; the useful load is here 53·0 per cent. of the total load.

Means for Keeping Tubs on Cages.—When the tubs are placed on the cage some means have to be provided for keeping them there during the process of winding. This is done in a variety of ways, but by far the commonest, and perhaps the best, is to employ a bar of iron running along the side of the cage, each end of this bar being bent back at right angles. In its normal position it hangs as at *a* (Fig. 364), and locks the tubs, but on arriving at bank it is rotated, the ends describing the arc of a circle, shown by the dotted lines, and taking the position drawn at *b*, allowing the tubs to run off at one side, to be replaced by others, the bar being then pulled down again.

In some instances this bar, instead of being at the side of the cage, runs along the top of it, and when in its ordinary position the ends hang vertically under the influence of gravity. The bar (*a b*, Fig. 365) works about the centre *a*, and is provided with a stop. On reaching the surface, the banksman pushes the hanging piece *c d* to the left hand, and a tooth in it catches the stop *a b*, and holds it in a horizontal position. To release, the end *b* is lifted, and the catch drops to the vertical position, and so keeps the tubs in the cage.

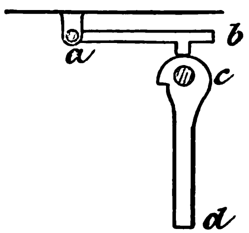


Fig. 365.

ROPES.—Two forms of rope are used at collieries—flat and round. The advantage of the former is that as the rope is wound on the drum, each lap coils successively on the one below it, and the vertical plane of the drum and pulley therefore coincide. A certain amount of counterbalancing also takes place, as the drum varies in diameter. At the commencement of the wind it is small, but as the coils are wrapped on, it increases in diameter, until at the end its maximum size is attained. These considerations influenced at first, in a very marked degree, the choice of ropes for winding purposes, and flat ones were largely adopted. Experience has not, however, justified the selection, the above-named advantages being found to be more imaginary than real. Even with the deepest pits, it is possible to place the winding machinery at such a distance from the shaft that the angling, caused by a round rope coiling on the drum, is scarcely perceptible, or, at any rate, is not very objectionable, and it is also possible to perfectly counterbalance the weight of round ropes by several methods, which are described further on. Excepting in France and Belgium, flat ropes are becoming a thing of the past. They cost twice as much as round ones, and only wear about half as long.

Ropes are constructed of three materials—hemp, iron, and steel.

In English collieries, hemp has never been used to any large extent, and at the present time not at all. On the Continent hemp ropes are numerous, and iron or steel ones rare; aloe fibre is, however, employed instead of hemp. It is difficult to understand why this class of material is retained, for its strength is so small, that a very large and heavy rope has to be employed. The engineers state that its great advantage is the non-liability to breakage, owing to the perfect reliability and uniformity of construction, but statistics do not bear out this claim.

Wire Ropes.—In the early days, no doubt, some wire ropes did fail in an unaccountable manner, but at the present time their manufacture has reached a high degree of perfection, especially in England.

Wire ropes were first constructed of iron, but are now made almost entirely of steel. No advantage is gained by using the former material; it does not wear well, and its tensile strength is so small that heavy ropes are required. Most manufacturers supply steel in three qualities—Bessemer, crucible, and plough. The latter is about 50 per cent. stronger than the former, but only about 12½ per cent. stronger than crucible steel. Crucible steel ropes can be purchased in all ordinary sizes from £32 to £41 per ton, while plough steel ropes cost from £54 to £66. For all situations where a rope is *worn out* and not spoiled, the latter are worth the extra money. Every rope put to work should have a record kept of its performance—that is to say, the number of tons it either hauls or winds. Statements are sometimes made that a rope has lasted so many years. Unless the number of tons is known, such an assertion is valueless, because a rope in another position might have lasted only half as long, and yet have dealt with more tonnage. On inclines, or places where a rope is subjected to severe shocks and strains, it is not advisable to use plough steel, because the rope may be broken and spoiled before it is anything like worn out, but for slow-moving rope haulage, or, especially winding, the highest priced ropes are the cheapest in the end; in the first place, owing to their great strength, a smaller weight is required, and in the second, their life is much longer.

Ropes usually stretch when first started, and probably get more brittle with work. They should be carefully manufactured, and carefully and thoroughly examined. The best signs of the limit of work, are the wearing and occasional breakage of the wires. The principal cause of failure is due to oxidation, especially with steel, and, unfortunately, it is the internal wires which cannot be seen that suffer most from this cause, especially so in wet and upcast shafts. The two points where this action is most active are at or near the capping and at the pulley at the moment of starting to lift, because the strains at such places tend to open the strands of the rope and allow moisture to enter. For this reason the ropes should be recapped at regular intervals not exceeding six months, but recapping pure and simple is insufficient. A length of the rope, preferably equal to half the circumference of the drum, should be cut off on each occasion.

Unless ropes are kept free from rust, they will never last, no matter what material is used in construction. How often oiling is required depends on the conditions of the working places, but although careful and regular oiling should always be done, it is becoming the practice at many collieries to use ropes made of galvanised wires in all situations where corrosion is feared. The grease required for such purpose should be rich in fat and quite free from acids, and, what is of the greatest importance, should not turn hard, or the outside wires will get well greased, while the inside goes rusty. A simple but effective rope-greasing apparatus consists of a cylindrical case made in two halves, and provided with two handles, which are grasped by the attendants, one on each side. Brushes are arranged in the top part and clean off the old grease, while the rope runs through a bath of oil held in cup just below; the grease is thoroughly rubbed in by some loose felt, also saturated with grease, which is situated in the base of the cylinder. There are several elaborations of this design, where the brushes are caused to revolve around the rope as it passes through them, but the results obtained are little better than those given by the simpler apparatus.

The drums and pulleys should be as large as feasible, a good rule being that their diameter should never be less than a hundred times that of the rope. The angle that the rope makes with the pulley should be as small as possible. Ordinary ropes consist of six strands, of seven wires each, twisted round a hemp core; but for special cases where small drums have to be employed, the diameter of the wire is decreased, and more wires and strands used to make up the rope. Except for such purposes, no advantage is gained by this construction, as although the tensile strength of the wires is increased, they are apt to break after a little wear. After a thin wire has worn a little, only a small quantity of material remains, while the same amount of wear on a larger wire is scarcely perceptible.

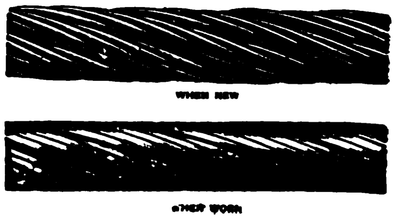
For ropes with hemp cores, if the circumference in inches be squared, the product will practically be the weight in lbs. per fathom. In deciding on the size of rope required, the weight to be lifted is first determined. For a winding-rope such load must include the weight of cage, tubs, coal, bridle-chains, and the rope hanging in the shaft. Each manufacturer issues a card giving the breaking strain of different qualities of ropes, or if the particulars are forwarded, he will readily advise a suitable size. The breaking strain, however, is not the working load. For shaft work the safe load is taken at one-tenth the breaking strain, and for inclines one-seventh. In the former case, men have to travel on the rope, and for such reason a higher margin is allowed. To a certain extent, the purchaser has to rely on the integrity of the manufacturer, for unfortunately the keen competition existing is responsible for much inferior material being thrown on the market, and for quotations being given for ropes at such prices as make it impossible for the article described to be produced in a genuine condition. In cases where the prices quoted are abnormally low, the purchaser should insist upon a specific guarantee being given that the implied conditions will be fulfilled.

All new ropes have a tendency to untwist or spin when first put on, but the practice of allowing them to do so to an unlimited extent by employing a swivel between the cage chains and capping cannot be too strongly condemned. If a new rope has too much spring, the greatest care should be exercised in letting the spin out gradually, because if the number of twists taken out of the rope is too great, the outer wires forming the strands are lengthened and become displaced from their position, with the consequent result that the wires get slack and the original form of the rope is lost. This tendency to spin gradually wears off the rope as the working load deadens the twist.

Ordinary Lay.—As ordinarily constructed (Fig. 366) the strands of a rope are laid in the *opposite* direction to the twist of the wires in each strand, with the result that the wear on the crown of the strand is great and the wires readily break there (Fig. 367).

Lang's Patent.—In England the first successful change from the old construction was introduced by Messrs. Cradock, in 1880. In Lang's patent, the wires are spun in the strands in the *same* direction as the strands are laid in the rope (Fig. 368). There is, therefore, a much larger surface exposed to friction. In working round drums, &c., the wires are bent obliquely, and thus the greatest amount of wear is obtained. Lang's rope wears out; it is only under the most exceptional circumstances that wires break. Fig. 369, from a photograph, illustrates the gradual reduction that takes place in the

Figs. 366 and 367.



Figs. 368 and 369.

diameter. This construction has increased the life of the ropes at least 100 per cent., and no greater argument can be adduced in its favour than the fact that as soon as Messrs. Cradock abandoned their patent rights every manufacturer commenced making ropes of this construction. There seems, however, to be still some "unknown quantity," due in all probability to the quality of the steel rods and the care exercised in drawing the wire, and it does not necessarily follow that ropes constructed on this system by different manufacturers will give equal wearing results. If good ropes are desired, they must be made not only out of good material, but with care also.

Locked Coil.—With the object of increasing the wearing surface, locked coil ropes were introduced in 1885. A series of coils of wire are spirally wound upon each other, all of which, or sometimes only the outer one are composed of special section wires, which when closed together interlock, and present a smooth uniform working surface. The rope in external appearance resembles a bar of iron, but is exceedingly flexible, and has little or no tendency to twist (Fig. 370). At first, there must have been some defect in the manufacture, as the outside coils slipped on the inside ones and the ropes broke up soon. Very good results have since been obtained, and the only disadvantages are the impossibility of splicing and the difficulty of capping. They are valuable for use in any place where the twisting of an ordinary rope is objectionable.

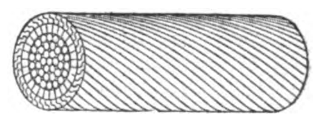


Fig. 370.

Flattened Strand.—As the increase in wearing surface obtained by ropes constructed on Lang's principle was followed by satisfactory results, it seems apparent, that provided the wearing surface could be further increased without sacrificing any of the conveniencies or the certainties of construction of the ordinary rope, still better results are likely to be obtained. The flattened strand rope is formed of strands twisted together like ropes of ordinary construction (Fig. 371), but each strand is oval in section and consequently the outer surface is more cylindrical. The oval shape of the strands is obtained by twisting the outer wires round a triangular or flat core, or round a combination of wires (Figs. 372, 373, and 374). A larger wearing surface is obtained, and consequently each individual wire is subjected to a smaller amount of abrasion. The ropes are very flexible, and can be spliced with as much ease as those of ordinary construction.

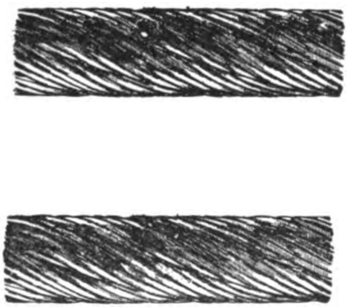
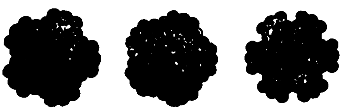


Fig. 371.



Figs. 372, 373, and 374.

Attachment to Cage. — The end of the rope is connected to the cage chains through what is known as the capping, which exists in many different forms. The old plan was to employ two semicircular collars encircling the rope, these being prevented from slipping or drawing off by rivets, which passed both through the rope and capping. The driving in of these rivets necessarily injured the ropes; to remove this disadvantage, a capping with collars driven on (Fig. 375) was adopted. A better plan is to employ a conical socket (Fig. 376). In attaching this, the rope is first of all threaded through the thin end and drawn out a short distance beyond. The ends of the strands are opened, and bent back on themselves, part of each strand being cut away, and in every instance are secured with thin binding wire. The end of the rope is now conical, and is drawn into the socket. As an additional security, a conical wedge is often inserted in the place originally occupied by the hemp core. Except under abnormal conditions, it is impossible to draw the thick end of the rope through the small end of the socket, except by splitting it. If properly constructed of suitable material, such could scarcely happen, but for very heavy loads, collars are shrunk on. At the point where the rope leaves the capping the wires are subjected to a nipping action, and often break. It is, therefore, advisable that careful inspection should be made, and a plan is adopted at many collieries of re-capping ropes at regular intervals, whether they appear to require it or not. In wet shafts, the wires rust inside the capping, and such action cannot be detected. To prevent it, the capping is often run full of lead.

For deep shafts and heavy loads, Mr. W. Heath suggests the arrangement shown in Figs. 377 and 378, where the capping, as generally understood, is dispensed with. The end of the winding-rope is first brought round a small iron drum, *a*, then looped round a ring, *b*, encircling the rope, carried on beneath the drum *a*, and finally returned through the ring *b* again. The end then lies parallel with the main rope, and the two are fastened together by three glands.

Cage Chains.—The cage is attached to the capping through the medium of chains, usually six in number, one at each corner, and one from each centre of the two longest sides. The two latter are often allowed to be slack, and only the corner ones kept taut. There appears no reason why such should be done, as if six chains are required, all should do a proportion of the work. It is argued, that the object of the central chains is to take the weight if anything happens to the corner ones, and, no doubt, it is a difficult matter to keep six chains

Fig. 375.

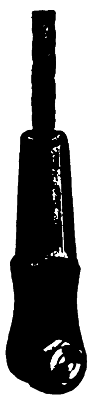
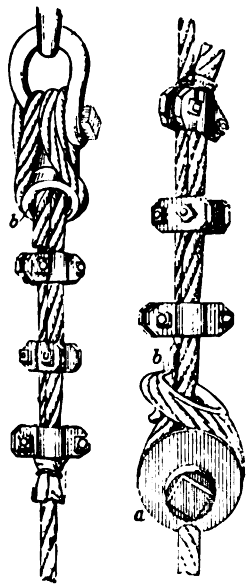


Fig. 376.



Figs. 377 and 378.

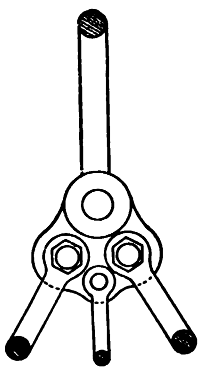


Fig. 379.

of such a length that all take an equal bearing, but the difficulty is overcome by providing the two central ones with adjusting screws, which enable any slack to be readily taken up. These cage or bridle chains should be of the very best quality of iron obtainable, and should be regularly taken off every three or four months and annealed; so much depends on them, that no precaution should be neglected. As a rule, each pair of chains is connected to a larger link at the end farthest from the cage, and each of the three larger links are in turn connected to a still larger link, which is fastened to the capping by a bolt (Fig. 380). With this method, if anything happens to the main link the cage is detached from the rope. The better plan, and common procedure in the North of England and on the Continent, is to connect the link joining each pair of chains to a compound plate, shown in Fig. 379.

The approximate safe working load of chain made from the best qualities of iron can be found by an easily remembered rule:—If W = breaking strain in tons, d = diameter in eighths of an inch: $W = \frac{d^2}{10}$. Thus in a chain made from ¾ inch iron there are 6 eighths, and the safe working load will be $\frac{6 \times 6}{10} = 3{\cdot}6$ tons.

Method of Taking Off Strain.—When the cage is resting at the bottom of the shaft, and is suddenly lifted, the strain on the winding rope is much greater than that due to the load, especially if there is any slack chain. Messrs. Cradock have published a table showing the result of some tests, very carefully made by a dynamometer, from which it appears that the extra strain may amount to over twice the real load, as will be seen from the following extract:—

	Tons.	Cwts.
Cage and four full tubs weighed by machine,	5	1
„ lifted gently,	5	3
„ „ with 3 inches of slack chain,	8	10
„ „ „ 6 „ „ „	10	10
„ „ „ 9 „ „ „	12	10

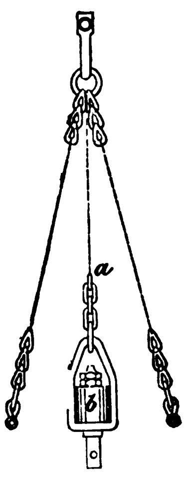


Fig. 380.

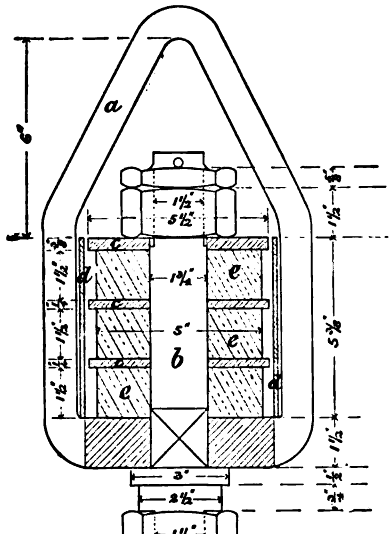


Fig. 381.

The extra strain has an injurious effect on the rope, and numerous devices have been proposed from time to time to reduce it. The author, in visiting Mariemont Colliery in Belgium, observed a simple but effective device, which he has since adopted at Lye Cross Pit. In addition to the ordinary bridle chains, a central one, passing from the capping of the rope to the centre of the cage, is also employed (*a*, Fig. 380). It may be considered as a prolongation of the winding rope, but is *shorter* than the vertical distance from the capping to the top of the cage. To it is attached an apparatus, *b*, shown enlarged in Fig. 381. The central bridle chain is connected to a stirrup, *a*, while the pin *b* is attached to the cage. Threaded on this pin are alternate discs of sheet iron, *c*, and india-rubber, *e*, kept in proper place by the nut and lock-nut at the top of the pin *b*; both india-rubber and sheet iron discs are enclosed in a cylindrical case, *d*, to protect them from dirt, &c. When the lift commences, the central chain, being shortest, does all the work, the stirrup *a* slides on the spindle *b*, and compresses the india-rubber discs, until the central chain lengthens to such an extent that the corner chains come into operation and do their share of work. Instead of this arrangement, volute springs are sometimes employed, and have been used at Mariemont, but were abandoned through unreliability, as they often broke and caused mishap. The weight of such a rope-easing gear, including the central chain, two angle pieces across the top of the cage, and all the fittings caused by the addition, is only 71 lbs., and its cost is small.

In some cases india-rubber blocks have been placed beneath the pulley pedestals, but, being exposed to the weather, the blocks soon

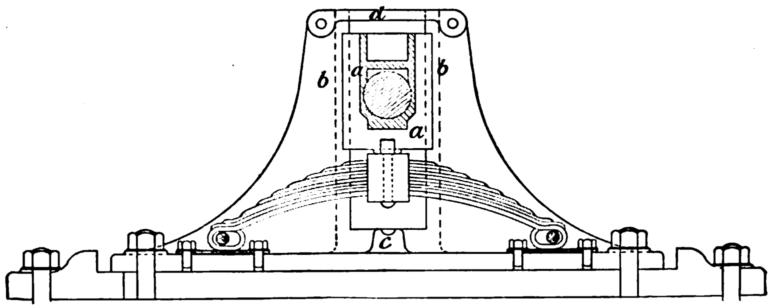


Fig. 382.

become hard and lose their elasticity. A better plan is to place the pedestal on springs similar to those used in railway waggons. Fig. 382 shows such an arrangement at Bell End Pit. The pedestals, *a*, work in guides, *b*, and have a play of about 2 inches. The guides compel the pulley to travel in a vertical plane and prevent it from canting. A stop, *c*, is provided underneath the spring to prevent it compressing too much, and a cross-bar, *d*, is placed over the top to prevent the carriage being sprung out of the guides under abnormal shocks. This arrangement is used in conjunction with the central chain gear just described.

It is rather a difficult matter to estimate definitely the additional life of a rope caused by adopting such arrangements, but some good must result, and the cost of either or both of them is small.

Adjusting Screws.—In the majority of cases the adjustment required to ensure the arrival of one cage at the top of the pit at the exact time that the other reaches the bottom is obtained by moving the spare coils of rope on the drum, but as this is a tedious operation, and by no means an exact one, it is a common practice in Germany to carry out such fine adjustment by means of two screws, about 3 feet long, which are introduced between the cage chains and the capping on the winding rope. The bottom ends of these screws are attached to plates (*a*, Figs. 383 and 384), connected to the cage chains, while the upper ends pass through two holes in a crosshead, *b*, which runs transversely from one screw to the other. There are nuts both above and below the pin *b* on each screw, and consequently its distance from the cage chains can be regulated to a nicety. A long rod, *c*, with an eye at each end connects the crosshead *b* and the capping on the winding rope.

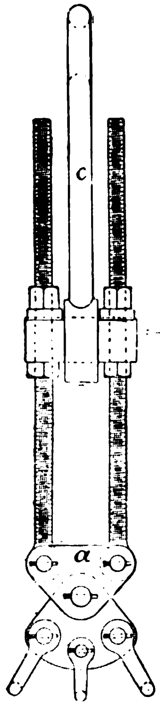


Fig. 383.

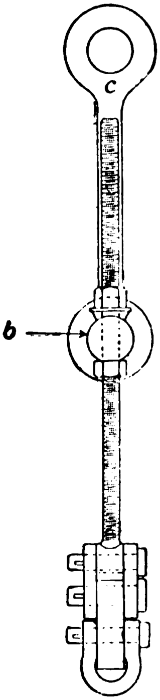
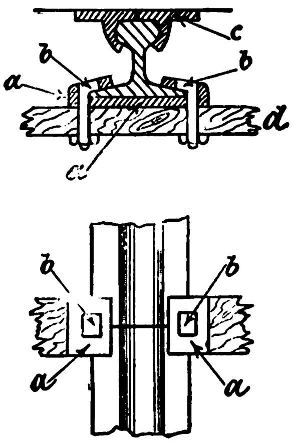


Fig. 384.



Figs. 385 and 386.

GUIDES.—The cages are not allowed to swing free in the shaft, but are kept in the proper direction by guides, which may either be wood, iron rails, or wire ropes.

Wood guides are usually made of pitch pine, are joined together in lengths, and are secured to cross baulks by screws. They are unsuited for quick winding, are costly to fix and keep in repair, but they are rigid, and their first cost is small. For deep shafts and heavy loads, the small advantage in cost is soon counterbalanced by the cost of the upkeep. With few exceptions they are a thing of the past.

Rails.—To obtain the rigidity of wood and to avoid rapid wear, rail guides firmly attached to buntons have been substituted. It is obvious that the ordinary form of chair employed on railways cannot be used, as the head and neck of the rail have to be left clear, in order that the sliding attachment on the cage may pass freely along. As a rule, the flange of such rails is made broader than the ordinary construction, and is fitted into a chair, *a* (Fig. 385 and 386), and prevented from moving latterally by two pins, *b b*, the heads of which are bent round to grip the foot of the rail, and counter sunk in the chair to prevent the guide shoe *c* catching them. The two pins pass through the chair *a*, and are bolted at the far end to the cross buntons of timber, *d*, carrying the whole structure. At Horloz, near Liége, rail guides are fastened together by fish-plates at the *back*, bolted to the rails; the buntons in this case are not placed at the joints.

Rail guides are not only expensive, but require a lot of attention. Mr. Ch. Demanet * gives the following statement of the cost, where the rails weighed 58 lbs. to the yard, were each 9 yards long, and were fished and bolted to oak buntons set 5 feet apart. In the walling, the buntons were set in cast-iron sockets; in the tubbing, iron circles of U section rested on the ribs, and these carried transverse girders, to which the rails were attached. A space of 0·078 inch was left open between the ends of the rails for expansion, and the bolt-holes in the rails and fish-plates were made oval in the usual way.

Cost where Shaft was tubbed.

(a) *Circles.*—Cost of each circle complete, placed in pit, including all bolts and washers, and erecting,	£1 3 2
(b) *Rails.*—@ £5 14s. per ton (4 yards required for each yard of shaft),	0 11 10½
Fixing in shaft,	0 1 5
(c) *Fish-plates,*	0 0 9¾
Total cost per yard,	£1 17 3

Cost where Shaft was walled.

(a) *Buntons.*—Oak Buntons 6′ 10½″ × 6″ × 8″, with eight bolts and washers, and fixing in shaft,	£0 11 7
Rails and fish-plates as above,	0 14 1
Total cost per yard,	£1 5 8

On the Continent of Europe, the common system of fixing rail guides is that due to Mr. Al. Briart, which consists in dividing the shafts by a single series of buntons of H steel girders, which at Mariemont are 14·96 feet long, 0·82 feet deep, and are placed 9·84 feet apart. The utmost care is exercised in getting these buntons in the same vertical plane, and previous to being fixed they are notched to receive the rails, which are each 19·66 feet long, thus giving a slight play between the joints. To secure the rails to the buntons two steel glands (*a*, Fig. 387) are fixed, one on each side of the rail, which they firmly grip, a bolt, *b*, passing from one gland to the other. To prevent any chance of movement, a block of cast iron, *c*, through which the bolts pass, is placed between the rails, and is furnished with a slight projection, which lies in a corresponding groove rolled in the flange of the rail. At buntons where joints occur, two sets of these glands and blocks are fixed, one above and one below; but at the intermediate buntons only one set at the top of the girders is used. In passing through tubbing, the buntons are carried in shoes bolted to the inter-

* *For. Abs. N.E.I.*, xxxi., 28.

nal flanges, the girders being wedged in position with wood keys (Fig. 388).

The entire cost of installing a new set of rail guides on the Briart system at Martinet Colliery, Belgium, to replace wooden conductors which had got into a bad state of repair, and of which the average annual cost of maintenance was £375 6s., equalled £1 9s. per yard, everything included, labour, material, &c.; 732 yards of metal guides were fixed in a little over a month by ceasing work on Mondays only, with one prolonged stoppage lasting ten to twelve days.

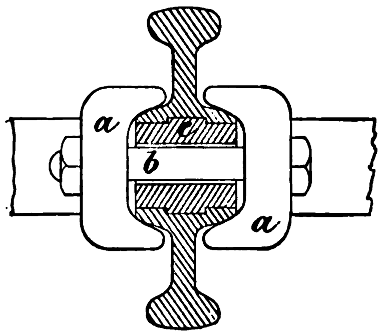


Fig. 387.

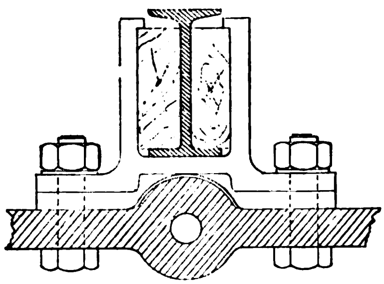
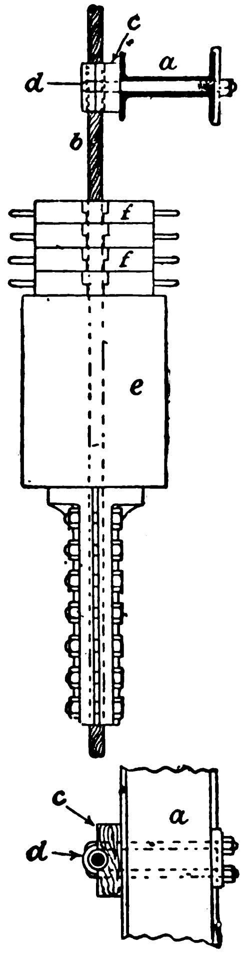


Fig. 388.

Wire Ropes.—In the majority of cases, rope guides are employed, but differ from ordinary wire ropes in the fact, that instead of consisting of a number of small wires twisted into strands, and then into a rope, each strand consists of only one wire, but such wire is of large diameter. At first guides were made like ordinary ropes, but when a little wear had taken place and a wire broke, the projecting piece was caught by the shoe of the cage, and the rope "stripped," causing frequent stoppages. As rope guides have only to sustain small weights, wire of high tensile strength is not required.

Rope guides are cheap in first cost (they can be bought for £16 a ton), are easily fixed, require no attention except oiling, and their wear is almost unlimited. They must, however, be kept taut by proper means. At their upper extremity they should be capped like a winding-rope, and connected to eye-bolts in the head-gear, or they may be secured by the strong gland illustrated farther on. At the bottom of the shaft they should pass by the side of a bunton, and have weights added to their lower end (Figs. 389 and 390). It is advisable to allow a clearance of a few inches between the sides of the buntons *a* and the guide *b*, because the former may get moved out of their correct position by the heaving of the ground. It is an easy matter to insert a wood liner, *c*, between the girder and the guide, which can be readily altered to maintain the correct gauge, while a strap or staple, *d*, passing around the guide and through the bunton serves to keep the guides from swinging about transversely, but does not grip them tight enough to prevent longitudinal movement. Instead of weights, screws are sometimes used. In deep shafts expansion and contraction regularly take place in the guides owing to the variation in temperature, and the length alters considerably from a hot day in summer to a cold day in winter. If screws are used, the guides require constant attention if they are to be kept taut, whereas, if they are weighted, they are always tight, as the tension is always the same.

Never less than three rope guides should be used to each cage when winding proceeds from depths of over 200 yards. When two guides only are employed, one at each side, the cages may not *swing* about, but they are comparatively free to twist about the winding rope as a centre. As has been already mentioned, all ropes tend to spin or untwist, and are only prevented from doing so by the guides. Three guides to each cage, two on one side and one on the other, form a triangle which resists the turning moment of the winding rope as efficiently as two guides on each side of the cage would do, and consequently a fourth guide seems unnecessary. In order to make the base of the triangle as long as possible, the two guides on the one side should be placed as near the ends of the cage as is practicable, and should preferably be situated on the outer side of the cage, while the third guide should be placed some short distance away from the centre of the cage on the other side, so as not to be opposite the corresponding guide of the other cage.



Figs. 389 and 390.

Up to all reasonable depths, a greater clearance than 12 to 15 inches between the corners of the cage, and 18 inches between the *backs* of the two middle guide shoes of the cages, seems unnecessary. Fig. 391 shows in plan the arrangement at Ashton Moss Colliery, Lancashire, where the depth from the banking level to the lowest inset is 945 yards. The shaft is 16 feet diameter with two cages, but a portion of the space is reserved for pump trees. The actual distance between the sides of the two cages is 2 feet 8 inches, but the clearance between the backs of the two middle guide shoes is only 18 inches.

It is a difficult matter to say what weight is needed on each guide rope, but any error in this respect should always be in the direction of overloading. Indeed, some of the objections brought against wire conductors are undoubtedly due to the practice of employing as little weight as possible in order to economise a few tons of cast iron and a few yards of sump room. The more sensible procedure for deep shafts is to use guides of not less than 1½ inches diameter and load them with as much weight as practicable, remembering that allowance must be made for the wear of the guide rope, and that in addition to any dead load which may be put on the bottom, the upper portion has also to carry the weight of the guide rope hanging below it. As a rule, from 3 to 7 tons will be found sufficient for shafts varying from 400 to 900 yards in depth, but these weights must be increased if water accumulates in the bottom of the shaft to the extent of two-fifteenths of the load originally considered necessary, because the effective pull of the weights will be reduced by that amount if they are immersed in water.

Owing to the proper weight being more or less a matter of experiment, it does not seem advisable to cast such weight in one solid block. One large weight is also very difficult to deal with, so that a series of single weights are undoubtedly more convenient, although they are more expensive to cast. The more reasonable plan is attained by combining the two; two-thirds of the estimated weight may be cast in one solid mass (*e*, Fig. 389), and the remaining portion in a series of smaller cheese-shaped blocks (*f*, Fig. 389), which can be added to

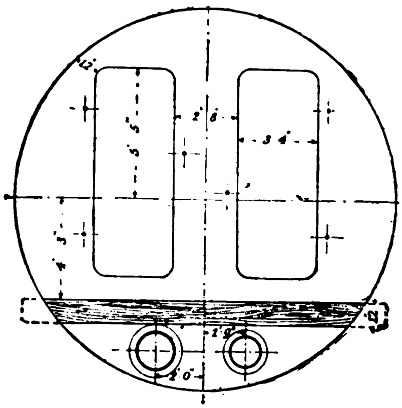
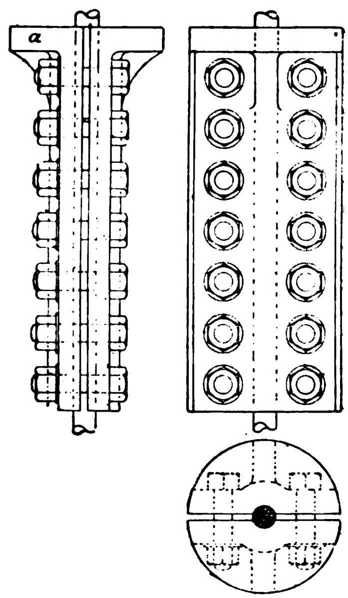


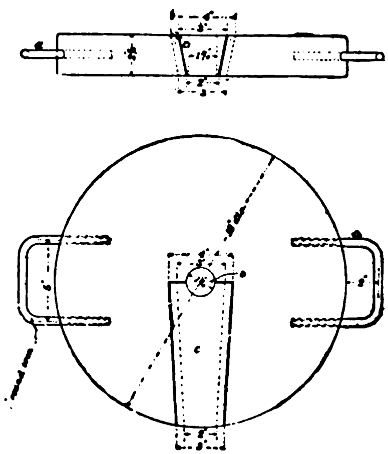
Fig. 391.



Figs. 392, 393, and 394.

the top of the lower weight as required. If the lower weight be cast 23½ inches in diameter, each inch in depth will weigh approximately 1 cwt. The blocks must be cast with a hole through the centre, through which the rope can be threaded, and are best supported in position by the glands shown in Figs. 392, 393, and 394. These consist of two plates, one on each side of the rope, which are drawn together by a number of bolts, and are provided with a semi-circular ledge, *a*, at one end to form a shoulder on which the tension weights can rest. Provided such glands are carefully fitted on the rope there is little probability of their slipping, while they can be easily moved should the guide ropes lengthen under the tension they are subjected to, and the weights get dangerously near the bottom of the shaft.

The smaller weights are conveniently constructed as shown in Figs. 395 and 396. Each one is provided with two handles, *a a*, has a hole through the centre *b*, and a loose wedge-shaped piece, *c*, which when removed allows each weight to be slid on the rope without moving any of the others. This piece, *c*, is not only wedge-shaped in plan, but also in cross-section, and cannot drop out of place when the weight is in a horizontal position. The blocks weigh about 165 lbs. each, and can be handled by two men.



Figs. 395 and 396.

Weights are objectionable at the bottom of any shaft from which water has to be lifted by a tank, or in which dirt accumulates. In the latter case, sooner or later the space beneath the weights gets filled up with mud, and the guides become slack. Weights also occupy considerable space; they cannot be made large in diameter, and consequently have to be correspondingly long. They must also hang some distance above the bottom in order to allow for the extension of the guides by expansion. Consequently, if water has to be drawn by tanks on the cages, only a short portion of the space below the inset can be cleared out, as the cages cannot go past the top of the weights. When the sump-room is limited this is an important matter, and it becomes necessary to adopt some method of tightening the guides as will allow the cage to practically travel on to the bottom of the shaft.

There are several ways of doing this. In all, buntons of suitable strength are first fixed at the lowest point in the shaft, and the bottom ends of the guides firmly secured thereto by glands or eyebolts, the upper ends being carried to bearers on the pit frame. Stretching screws passing through the top bearers and fixed to the guides provide the easiest means for tightening, but have no elasticity, and do not allow for expansion or contraction. In some cases an unequal armed lever is fixed on the headgear; one end is weighted and the other is attached by a sliding collar, beneath a gland on the conductor. Stops are inserted to prevent too much travel, but sufficient play is allowed to provide for the working stretch of the guide. This method is effective, but occupies considerable space, and is unsightly. A preferable arrangement has been designed by Cocker Bros., consisting of two strong springs in a case. These cases, which consist of two parts, the body *a*, Figs. 396*a* and 396*b*, and the cap, *b*, are fixed on a beam in the headgear over each conductor. The body is hollow to receive the springs, *c*, and the cap, *b*, slides easily over and rests upon the springs which project above it. The conductors are attached to a screw-ended main bolt, *d*, which passes vertically between the springs through both body and cap, and is secured by a nut on the outside. Upon the outside of both the cap and the body are corresponding lugs, *f* and *g*, projecting from opposite sides, and between these lugs supporting bolts, *h h*, can be temporarily placed, their lower ends resting in recesses, and their upper ends, which are screw-threaded and provided with adjusting nuts, *i i*, passing into holes through the upper lugs on the cap. When these bolts are in the position illustrated, they act as pillars or supports, and stop the cap from pressing on the springs while the initial slack is being taken out of the conductors by screwing up the main bolt, *d*. After this is accomplished, the supporting bolts, *h*, are withdrawn by slacking the nuts, *i*, and the cap allowed to rest upon the springs, *c*, which are about 20 inches long and have about 5 inches compression in each. Should any undue strain come on the guide, the cap compresses the springs until it rests on the body of the case, and thus damage by excessive overloading is prevented.

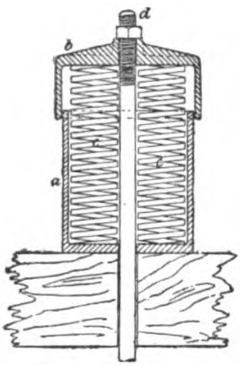


Fig. 396*a*.

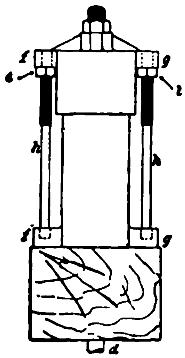


Fig. 396*b*.

Conductors between Cages.—The only objection urged against wire guides, is that the clearance between the cages has to be more than if a rigid conductor was employed. For deep shafts this is, no doubt, true, if the guides are connected to the cage on both sides; but a method is used which entirely removes the disadvantage, and allows the cages with wire conductors to be safely worked with as little clearance as if rail or wood guides were employed. In ordinary cases three conductors will be fixed to each cage, but in the special method two other ropes are suspended down the shaft *in between the cages* and not connected with either of them. These latter ropes are often flat ones, and at the point of meeting may be lined with steel strips passing from one to the other, while the cages are lagged up on the inside. The result of the whole arrangement is that from the top of the shaft to the bottom, the cages are on opposite sides of the central conductors, and cannot possibly catch each other when passing.

Guide Shoes.—Some connection has to be made between the cage and the guides, so that the former shall travel correctly along the latter. If the guides are of wood, the shoe need not encircle them, and the form shown in Fig. 397 is employed. With iron rail guides, which are also rigid, the common form of shoe has already been illustrated in Fig. 385, but with a view of reducing resistance, rolling has been substituted for sliding friction, and at Anzin Colliery, France, the guide shoe is composed of two wheels, one on each side of the rail guide (*a a*, Fig. 398), revolving on a pin bolted to the side of the cage.

For wire ropes, which are flexible, the guide shoe must go completely round them, or any oscillation would throw the slipper off the guide. A common mistake is to make the shoes very much stronger and heavier than necessity requires. If the guides are properly hung, and the centres of the shoes set to the correct gauge, very little strain is thrown on them, and only a comparatively weak connection is required. It is advisable that renewable bushes should be provided for the parts gripping the rope, as all the wear takes place there. A good form is shown in Fig. 399. It consists of a base plate, *a*, bolted to the cage by two pins, *b b*, and has cast-iron bushes, *c*, divided into halves, these being fixed to the base plate by a steel strap, *d*, which encircles them. This strap is kept in position

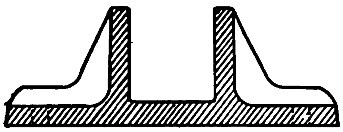


Fig. 397.

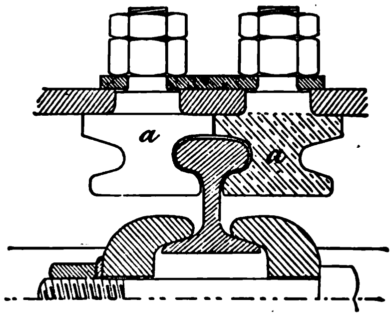


Fig. 398

by two pins, *e e*, also bolted to the sides of the cage. By taking out these two latter pins, the bushes can be changed whenever desired without removing the base plate. As an experiment, the author tried brass bushes, but the result was by no means satisfactory. The first cost was much more than that of cast-iron ones, and their life was considerably less. If the guides are kept well lubricated the wear is slight.

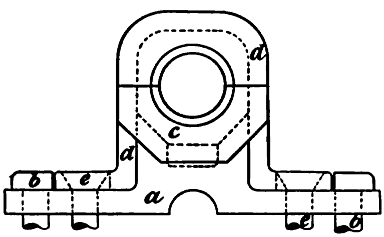
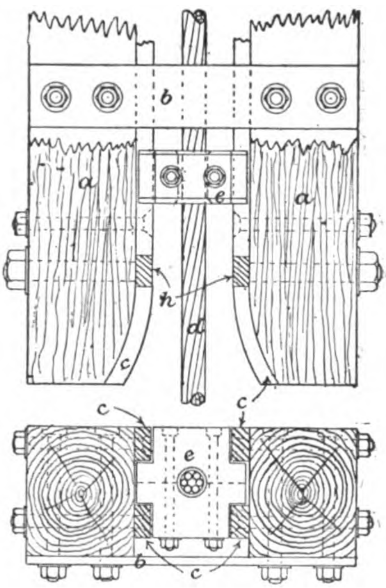


Fig. 399.

Guide Troughs.—While the cage is travelling in the shaft a small amount of oscillation is not objectionable, as there is seldom less than from 6 to 12 inches clearance at the corners, but when passing through the timber framing at the top, or at intermediate hanging-on places, where the clearance space is small, additional means have to be provided to prevent the cage from deviating from a definite line. With rigid guides nothing is necessary, but with wire ropes the general plan is to place a trough opposite each guide at the point where they pass through the frame. The usual construction is to rivet two strips of angle iron to a plate at the back; the angle pieces are belled out at the top and bottom ends of the trough, and the back plate is bent outwards to avoid any chance of the slipper receiving a blow when it enters the trough as it is gradually guided into the proper groove. The troughs are held in position by bolts which pass through the timber framing.

Where the banking level is a considerable distance above the ground, it is by no means a rare occurrence, when storms prevail, for the guides to be blown out of the troughs, and if this happens during winding a serious accident may result. Mr. A. B. Southall has designed a simple appliance, which entirely gets over the difficulty. The troughs consist of two wooden rods (*a a*, Figs. 400 and 401) connected together by iron strap plates, *b*. Two iron strips, *c c*, are fastened by bolts having countersunk heads to each wooden rod on the inner side and extend its entire length. The guide rope *d* passes through a small block, *e*, made in halves and provided with a projection on each side which fit into the recesses on the inner side of the trough (Fig. 401). This block is free to move upwards, but is prevented from dropping completely out of the trough by a stop-plate, *h*, placed at the lower end. In its normal position it rests against this stop-plate, and as the guide passes through a hole in the centre, it is always locked in its proper position in the trough. When the slipper of the cage reaches this block, it lifts it upwards, but on the descent of the cage the block, by the action of gravity, drops into its former position.



Figs. 400 and 401.

Engines.—For winding purposes a pair of engines, with the cranks set at right angles, is the only form admissible. There are, however, two ways of placing these engines, either vertical or horizontal. Vertical engines are becoming things of the past. In the first place the cost of foundations is great. The drum of a winding engine may weigh anything up to 80 tons, and if such a mass has to be placed 30 to 40 feet above the ground, and revolved at a high velocity, the structure carrying it must be correspondingly large. Vertical engines were designed to reduce wear in the pistons, it being considered that if a large cylinder was placed horizontally, the lower half would wear very fast. For the same reason, with horizontal engines it was usual to employ back piston-rods, but both in this case and in the former one, the evil has been proved by experience to be more imaginary than real, and as a result, both vertical engines and back piston-rods are being abandoned. At Harris Navigation Colliery, inverted engines are applied at one pit —that is to say, the drum is placed below and the cylinders above. The cost of foundations is reduced, but it would appear that no real benefit has resulted, as the second pair of engines at the same colliery are placed horizontally.

The all but universal practice is to make the engines direct acting—that is to say, the piston rod is coupled direct through the connecting-rod to the crank keyed on the shaft on which the drum is placed.

The valves regulating the admission and discharge of steam to and from the cylinders are worked by eccentrics, either on, or driven off, the drum shaft. The reversing gear is generally one of the well-known forms of Stephenson's link motion, and is controlled through an arrangement of levers, links, and a horizontal shaft, by a vertical handle placed near the engine driver.

The design and strengths of the various parts is more a matter for the mechanical than the mining engineer. The stroke is usually made twice the diameter of the cylinder, and the connecting-rod three times the length of the stroke. The valves, both steam and exhaust, should be of large proportions. In winding, everything is sacrificed to speed. The engine should be simple, easily handled, and, above all, over its work. On large engines, the double beat, or Cornish valve, has been the one generally adopted, owing to the ease with which it is capable of being moved, but improvements in the design of equilibrium slide valves have brought these types into favour. Corliss valves are employed on recent compound winders.

The proper size of engine to do a given amount of work may be easily found by applying a very elementary formula of mechanics, but simple as the problem is, the determination of the required size is often more a matter of guess-work than of reasoning. In moving a load, an engine has to do two things, and every one is aware that a greater expenditure of force is required to start a load than to keep that load in motion when once started. The greatest work that a winding engine has to do, is to get a given mass into a certain velocity uniformly accelerated from rest, and to raise the load the distance passed over during the time this velocity is being obtained.

The following formula which has been contributed by Mr. H. G. Graves is based on such reasoning, and will be found satisfactory :—

W = the whole weight in lbs. set in motion—*i.e.*, all cages, ropes, tubs, coal, and one-half of the drum and pulleys.*
L = the unbalanced loads in lbs.—*i.e*, coal and the average length of rope unbalanced, if any, between the start and point of maximum speed.
v = greatest velocity attained in feet per second, uniformly accelerated from rest.
t = time in seconds during which v is obtained.
g = gravity = 32·2.
P = average pressure of steam in the cylinders in lbs. per square inch.
A = total piston area in square inches.
S = number of feet of piston travel in time t.

The work done in foot-lbs. by the engine in time t in setting the whole mass in motion and in lifting the unbalanced load is :—

$$W\frac{v^2}{2g} + L\frac{vt}{2}.$$

The work in foot-lbs. yielded by an engine in the time t is the product of the total steam pressure and the distance through which it is exerted. By equating these amounts, the following formula is obtained :—

$$A = \frac{W\frac{v^2}{2g} + L\frac{vt}{2}.}{P . S}$$

* This assumes that all the weight of the drum and pulleys is concentrated at the rim. In reality, the weight and velocity at the radius of gyration should be considered.

To show the application of this formula, the following calculations of an actual instance are given :—2900 tons of coal have to be raised from a depth of 600 yards in eight hours. Each tub contains 16 cwts. of coal, so that $\frac{2900 \times 20}{16} = 3625$ tubs of coal will have to be drawn, and as from the experience of the neighbourhood it is known that in this particular seam 1 tub of dirt is produced to each 20 tubs of coal, the engine will also have to raise $\frac{3625}{20} = 181$ tubs of waste, or a total of $3625 + 181 = 3806$ tubs in eight hours or 480 minutes. The complete journey, including raising the coal, changing the tubs on the cage, and all allowances for hindrances, must be made in one minute, and, consequently, the cage will have to hold $\frac{3806}{480} = 7{\cdot}93$, say 8 tubs. There will be four decks in the cage, each carrying 2 tubs, and, in order to prevent overloading, the inset must be so arranged that never more than one deck can be filled with dirt tubs, which hold 24 cwts. each. The gross weight of mineral on each cage will never exceed 6 tubs of coal at 16 cwts. each and 2 tubs of waste at 24 cwts. = 144 cwts.

The actual weight of a steel four-decked cage with disengaging hook and coupling chains is 80 cwts., and each tram weighs 8 cwts. The total weight at the end of the rope is—cage, 80 cwts.; 8 tubs, 64 cwts.; and coal and dirt, 144 cwts. = 288 cwts. A plough steel rope, $5\frac{3}{4}$ inches circumference, weighs 16 lbs. to the yard, and as the shaft is 600 yards deep and the pit frame 35 yards high, the weight of rope hanging in the shaft is $\frac{635 \times 16}{112} = 90{\cdot}7$ cwts. The maximum weight hanging on the rope is consequently $288 + 90{\cdot}7 = 378{\cdot}7$ cwts., and as such a rope has a breaking strain of 160 tons, the factor of safety is $\frac{160 \times 20}{378{\cdot}7} = 8{\cdot}5$ nearly. This is sufficient for such depths and loads, because the margin between the load (18·93 tons) and the breaking strain (160 tons) is 141·1 tons.

The drum will have a slightly coned part at each end, and be cylindrical in the centre. Each cone will commence at $16\frac{1}{2}$ feet at the edge, and rise to a maximum of $17\frac{3}{4}$ (see Fig. 402*a*). There will be several spare coils of rope on the drum, and, consequently, the diameter of the drum at the first moment the engine starts to lift will be $16\frac{5}{8}$ feet = 52·88 feet circumference. If we assume that the engine attains its maximum speed in 5 revolutions, as the rope during this period has travelled up the slope, the diameter of the drum will then be 17 feet = 53·40 feet circumference, and the space passed through by the cage will be $\frac{52{\cdot}88 + 53{\cdot}40}{2} \times 5$ revs. = 265·7 feet. If full speed is attained in 10 seconds (t in formula), the average velocity will be 26·57 feet per second, and as the acceleration is uniform from zero, the maximum velocity will be double this figure, or 53·14 feet = v.

As the rope starts to coil on the drum when its diameter is $16\frac{5}{8}$ feet (52·88 ft. cir.), and the cone ends at $17\frac{3}{4}$ feet diameter (55·75 ft.

cir.), the average circumference of the coned part is $\frac{52 \cdot 88 + 55 \cdot 75}{2}$ $= 54 \cdot 31$ feet. For the complete wind half the rope will coil on the cone and half on the flat ($55 \cdot 75$ ft. cir.), so that the average circumference during the centre part of the run will be $\frac{54 \cdot 31 + 55 \cdot 75}{2} = 55$ feet. The engine must stop in 4 revolutions, in 9 seconds of time, equal to $4 \times 55 \cdot 75$, or 223 feet. The actual wind is, therefore, performed as follows:—

Revolutions.	Average cir. of drum.	Space lifted.			
5·00 to attain speed at	53·14 =	265·7	feet in	10	seconds.
23·84 at maximum speed	55·00 =	1311·3	,,	24·68	,,
4·00 to stop	55·75 =	223·0	,,	9·00	,,
32·84 revs. give total travel of		1800·0	,,	43·68	,,

This leaves a margin of 16·32 seconds under the minute allowed. As the four decks of the cage will be changed simultaneously in 10 seconds, 6·32 seconds per wind are available for contingencies, equal in 480 winds to 50 minutes during the complete working day.

The steam pressure in boilers is 150 lbs., but a drop of 10 lbs. should be allowed between boilers and stop valve on engine making the absolute* pressure there 155 lbs. $= p'$. If it is decided to use a pair of single-cylinder direct-acting engines and cut off steam at 80 per cent. of the length of the stroke during the five revolutions in which acceleration is taking place, the theoretical number of expansions will be $\frac{100}{80} = 1 \cdot 25$, but the actual expansions will be less, owing to the effect of steam left in the clearance spaces of the cylinder. In this class of engine a factor of 0·85 may be taken, and, consequently, the actual number of expansions is $1 \cdot 25 \times 0 \cdot 85 = 1 \cdot 06$, say $1 \cdot 1 = r$. The theoretical mean steam pressure (p^m)

$$= p' \frac{1 + \log_e r\dagger}{r}$$

$$= 155 \frac{1 + \cdot 095}{1 \cdot 1} = 154 \cdot 2 \text{ lbs.},$$

but the actual mean pressure is always lower on account of steam condensing on the cylinder walls, &c., and the figure so obtained must be reduced by multiplying by 0·85, which gives the actual mean pressure $= 154 \cdot 2 \times 0 \cdot 85 = 131$ lbs. The effective pressure on the piston is the mean pressure less back pressure, and if the engine works non-condensing this can be taken as 5 lbs. above the atmosphere —*i.e.*, 20 lbs. absolute—but condensing it will only be 5 lbs. absolute. These engines will be connected to a condenser, and, therefore, the effective pressure will be $131 - 5 = 126 = P$ in formula.

The two cases for consideration are when the engine runs with and without the load being balanced.

1. When the load is balanced by a rope beneath the cages:—

* Boiler pressure plus that of the atmosphere.

† The hyperbolic or Naperian logarithm of the ratio of expansion.

The total length of rope to be set in motion = twice the depth of shaft (600 yds.) + height of headgear (35 yds.) + distance to drum (35 yds.) = 2 × 670 = 1340 + the rope coiled on drum, which is equal to the depth of the shaft, or a total of 1940 yards. At 16 lbs. to the yard = 31,040 lbs.

The total weight, W, to be set in motion—

Rope,*	31,040 lbs.
2 cages, hooks, &c., 80 cwts. each, ...	17,920 „
16 tubs, full and empty ones, 8 cwts. each, . .	14,336 „
Mineral (6 tubs coal and 2 of dirt), 144 cwts., .	16,128 „
Wood laggings on drum, 80 cwts., ...	8,960 „
Half-weight of drum (26 tons) and half-weight of 2 pulleys (8 tons) = 340 cwts., ...	38,080 „
	126,464 „

The stroke of the engine may be taken at 5½ feet, one-third the diameter of the drum, and as the maximum velocity is attained in five revolutions, $S = 5 \times 2 \times 5 \cdot 5 = 55$ feet. The unbalanced load in this case is minerals only.

$W = 126{,}464.$
$L = 16{,}128.$
$v = 53 \cdot 14$ feet per second taken as 53.
$t = 10$ seconds.
$S = 55$ feet.
$P = 126$ lbs.

$$A = \frac{\dfrac{126{,}464 \times 53^2}{2 \times 32 \cdot 2} + \dfrac{16{,}128 \times 53 \times 10}{2}}{126 \times 55}$$

$$= \frac{5{,}516{,}108 + 4{,}273{,}920}{6930} = \frac{9{,}790{,}028\dagger}{6930} = 1413 \text{ square inches.}$$

With two cylinders this gives 707 square inches for each, but a further allowance of from 15 to 25 per cent. has to be made for friction, If 25 per cent. be added the area becomes 884 square inches, and the diameter of each cylinder will consequently be :—

$$\sqrt{\frac{884}{\cdot 7854}} = 33 \cdot 5 \text{ inches.}$$

2. Where the load is unbalanced :—

The weight set in motion for tubs, coal, &c., will be as before, but as the length of balance rope (600 yds.) is taken away, this reduces the weight by 9600 lbs., and W becomes 116,864.

During the time acceleration takes place the load is lifted 265·7 feet in five revolutions of the drum, and this length of rope, weighing 1417 lbs., is taken off the ascending rope and added to the descending one. The unbalanced rope at the commencement is 600 yards, or 9600 lbs., and at the end of the ten seconds is 9600 - 2 × 1416, or

* The winding rope in the shaft and the balance rope.

† Foot-lbs. of work done in ten seconds. This multiplied by 6 and divided by 33,000 gives 1780 horse-power.

6766 lbs. Half of these two, or $\frac{9600 + 6766}{2} = 8183$ lbs., is the weight of unbalanced rope lifted on the average during the time in which the maximum velocity is being obtained.

The average unbalanced load is consequently 16,128 lbs. of mineral + 8183 lbs. of rope = 24,311 lbs.

$$A = \frac{\frac{116,864 \times 53 \times 53}{2 \times 32 \cdot 2} + \frac{24,311 \times 53 \times 10}{2}}{126 \times 55} = \frac{5,097,375 + 6,442,415}{6930}$$

$$= \frac{11,539,790^{*}}{6930} = 1665 \text{ square inches.}$$

Each piston should, therefore, have an area of 833 square inches + 25 per cent. for friction, or 1041 square inches, and a diameter of—

$$\sqrt{\frac{1041}{\cdot 7854}} = 36 \cdot 40 \text{ inches.}$$

Position of Engine-House.—In nearly every case the direction of the inset governs the position of the winding engine, the drum shaft being generally at right angles to the axis of the inset and cages. The choice, therefore, appears to be limited to two positions, either A or B (Fig. 402). Such, however, is not the case; the cages may still be kept in the same line by placing the pulleys obliquely, shown by dotted lines, and, by doing so, the engine-house may be situated at, say, either C or C[1], or practically anywhere; indeed, by putting one pulley over the other, the engine may be placed at right angles, D, to the axis of the inset.

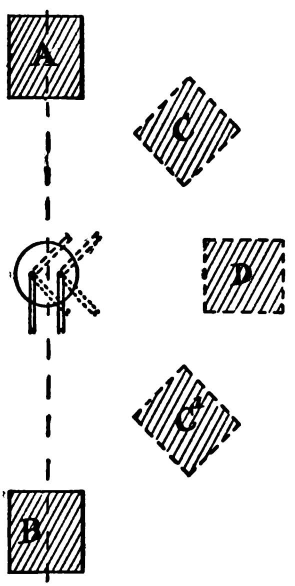


Fig. 402.

Drums.—The winding rope is coiled on a drum, which may be of various forms. The first division is produced by the type of rope adopted.

The ropes are flat ones and coil on themselves; the drum consists of a narrow cylinder of small diameter fitted with horns on each side. Its weight is small and its construction simple.

The other main division is caused by the employment of round ropes. It has been tried to make round ropes coil on themselves, and employ a drum similar to that used for a flat rope, but the experiment did not meet with success. Three types of drum for round ropes are in use: (1) the ordinary cylindrical form, parallel throughout; (2) the conical; (3) the spiral.

* Foot-lbs. of work done in ten seconds; equal to 2098 horse-power.

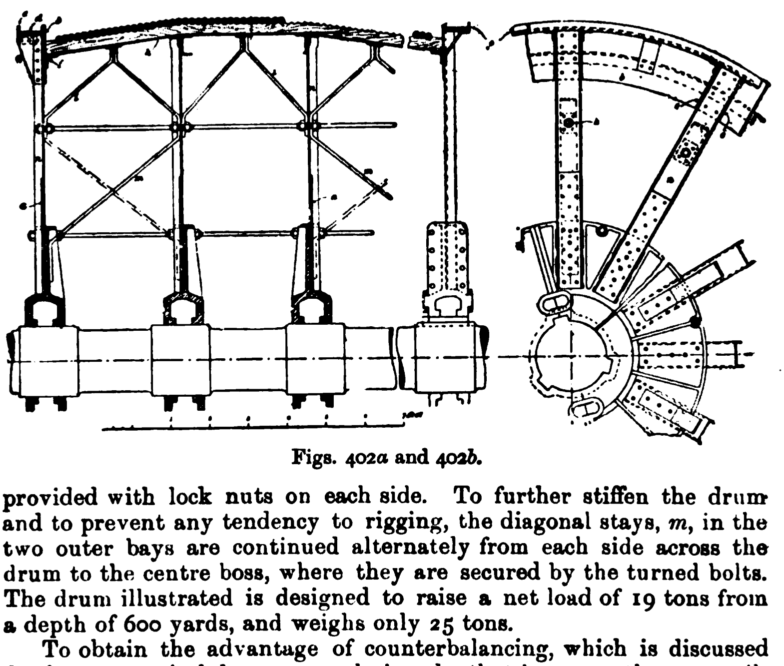
The parallel form is obviously the simplest, cheapest, and least liable to accident. Its only disadvantage is the side friction resulting from the angling of the rope. The successive coils lie side by side, and as they lap on the drum are constantly moving relatively to the centre line of the pulley. An attempt is made to equalise this strain, by placing the drum in such a position that at the commencement of a wind the rope is at the same distance on one side of the centre line as it is on the other side at the conclusion—that is to say, the centre line of the pulley coincides with the centre line of half the drum.

The result, however, is that at first the coils do not lie against each other, but have spaces between, as the rope tries to get into the same plane as the pulley, but after the central point is passed, the rope still tries to keep in the same plane as the pulley, and the successive coils not only lie very close against each other, but a grinding action is set up between them.

This disadvantage is removed in some cases by turning shallow grooves in the circumference of the drum for the rope to coil in. It then winds evenly and grinding is avoided. A cheaper plan, and an equally satisfactory one, is to make the drum *slightly* conical instead of cylindrical, a slope of 1 in 10 being sufficient. The tendency of the rope to get into the same plane as that of the pulley, is thereby counterbalanced by its disinclination to climb the slope, and each coil winds evenly against the other. With either system, and a cylindrical drum, it is impossible to avoid side friction altogether. What is done is to make the side friction of one lap equal to that of another, and not throw all the grinding action upon one or two coils.

If the drum is kept of reasonable diameter, its width increases to an objectionable amount when the depth of the shaft is great, and consequently the usual practice is to wind the incoming rope on the same space that the out-going rope has just previously uncoiled from. In this way the width of the drum can be reduced by nearly one-half and excessive angling of the rope prevented. A rope, however, cannot be wound on a drum down a slope, and consequently if any portion is coned, the total width of such a drum must be greater than the space occupied by the full complement of rope belonging to one cage. The better-designed drums of this class consist of a short-coned piece at each end and a parallel portion in the centre (Figs. 402*a* and 402*b*), and unlike older forms are made of rolled-steel plates and channels, and are built as light as possible. Indeed, a good many err in not being strong enough. Lightness is most desirable, but must not be obtained by the sacrifice of stiffness. The central bosses should be light, the castings cored out wherever possible, and strength obtained by ribs instead of by increasing the thickness of metal. The pockets for the channel steel arms, *n*, twelve in number, are machined out to obtain a good fit, and the arms are secured thereto preferably by turned bolts fitting into bored holes, which give better results than rivets, extra bearing surface for these being obtained by the introduction of short lengths of flat bars, *a*, which are riveted to the webs of the channels near to the central boss. The outer rims of the drum are formed of steel plates, *b*, connected together by butt straps, and riveted to the channel arms. On the outside of these plates a channel steel ring, *c*, is attached by countersunk rivets to form the brake rim;

the brake path is formed by a thick steel plate, *d*, fixed inside the channel rim, which can be renewed when worn out. The brake circle is further supported by gusset plates, *e*, and angles fixed on each side of the channel arms, while a flat bar stay is introduced between each pair of arms. A strong angle ring, *f*, is riveted on the inside of the plates forming the side, and carries the steel plates, *h*, forming the barrel, while shallow wood laggings are fixed outside. It is advisable to employ some such material as wood, in order to provide for the enormous compressive strains which are set up when the rope coils on the drum. The central portion of the periphery of the drum is supported by one or more sets of channel arms, dependent on the width, which are attached to it and to the bosses in the same way as the outer ones. A strong tee ring of steel is riveted to the plates forming the barrel midway between each set of arms, and the compressive strain on the periphery of the drum is taken up by diagonal stays, *i*, attached to the webs of the arms, the horizontal thrust from these being taken up by bolts, *k*, passing through all the arms and



Figs. 402*a* and 402*b*.

provided with lock nuts on each side. To further stiffen the drum and to prevent any tendency to rigging, the diagonal stays, *m*, in the two outer bays are continued alternately from each side across the drum to the centre boss, where they are secured by the turned bolts. The drum illustrated is designed to raise a net load of 19 tons from a depth of 600 yards, and weighs only 25 tons.

To obtain the advantage of counterbalancing, which is discussed further on, conical drums were designed—that is to say, the rope coils on a cone instead of a cylinder. The amount of counterbalancing that can be obtained is small, as the slope of the cone is limited by the fact that if it is made too great, the rope slips off. For this reason, their use has been abandoned. In their place spiral drums have been substituted, which consist of a combination of a cone and a cylinder. The cone is very steep, and on its side is arranged a continuous spiral groove, usually made of semi-circular iron troughs riveted to the barrel. The rope commences to coil at the small end of the spiral, and gradually ascends the cone, finally wrapping on the cylindrical part, the latter being added to reduce the width of the drum and the angling of the rope (Fig. 402*c*). As each groove has to be placed at such a distance from the one immediately above, that the rope going from the lower spiral misses the troughs of the upper one, a considerable amount of space is occupied, and unless several of the coils took place on a cylinder, angling would be very large, and, in addition, for any great depth, the size of the drum would be enormous.

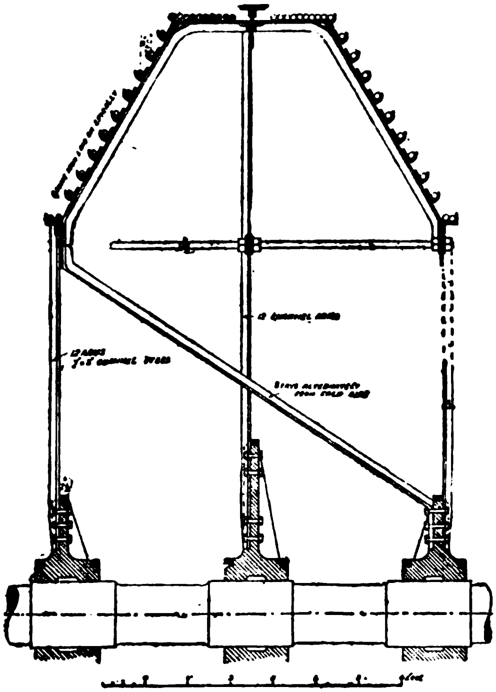


Fig. 402*c*.

Several objections may be urged against spiral drums:—(*a*) As pointed out farther on, counterbalancing is not perfect; (*b*) their enormous weight and cost; (*c*) the disadvantage attending banking when the decks are not changed simultaneously. The cage at the bottom of the shaft is attached to the rope coiling on the smaller diameter of the drum, whilst that at the surface is connected to the larger diameter. When the cages are moved to change the decks, the drum has to be turned sufficiently to wind up on its *smallest* diameter an amount of rope equal to the height of a deck, whilst, at the same time, the cage at the surface is lowered a considerably greater distance, because the rope to which it is attached is coiled on the *larger* diameter of the drum. After the engineman has put the bottom cage in position, he has to lift up the top cage again to discharge its contents, the result being that time is lost in banking.

Their weight and cost is the most serious objection. Their construction is such that they have to be made strong and, consequently, heavy, and a greater proportion of such weight is distributed at the rim, which in its turn is further from the centre, owing to the relatively large diameter than is the case with a cylindrical drum. At a moderate estimate, any spiral drum will weigh at least double that of a cylindrical one for similar work, and cost from 50 to 100 per cent. more to make. They have, however, one important advantage. The incoming rope which carries the load is attached to the small diameter of the spiral, and the out-going rope to the largest diameter. As a consequence, the load being lifted acts at the end of a short armed lever, while the weight assisting the engine acts at the longest possible leverage, with the result that, although the engine has to set a much greater mass into motion, due to the increased weight of the drum, it yet does it comparatively quickly owing to the difference in leverage. At the end of the wind the position of the loads is reversed, so far as leverage is concerned, as the heavy weight is being wound on the larger diameter, with the result that the tendency is to stop the engine, and the driver can slow down without an excessive use of his brake.

This important result can be secured at less cost by combining the several types of drum as illustrated in Fig. 402*d*. The incoming rope first coils evenly without side friction in shallow grooves on the slightly coned smaller diameter, and at the end of a certain predetermined number of revolutions when the engine has attained full speed, it rises in about two and one-half turns on a spiral, and during the remainder and greater portion of the run is coiled on the flat. The opposite takes place with the out-going rope, and it is not until the end of the run that the weight begins to act at the small leverage.

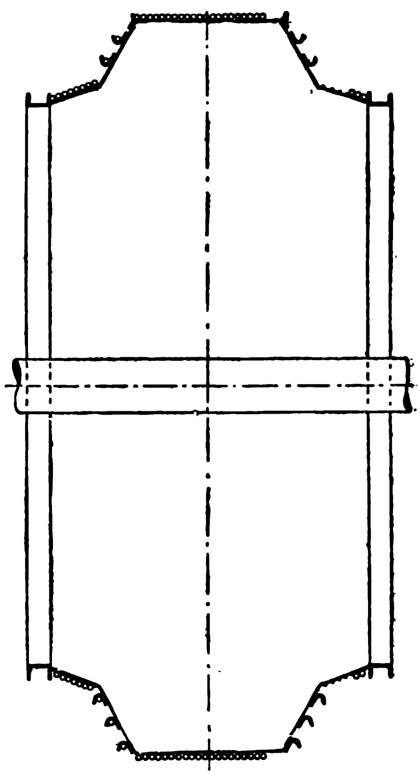


Fig. 402*d*.

Such a drum, which combines the cylindrical, conical, and spiral, is naturally more difficult and expensive to build than a plain one, but much cheaper and lighter than a spiral one. When the weight of the winding rope is counterbalanced this drum materially helps the engine at the start and retards it at the end, an ideal condition of affairs so far as steam economy is concerned.

Brakes.—An efficient brake on a winding engine is an absolute necessity. The rim should be turned up true to get equal bearing surface at every point during a revolution, and is best fitted with a steel wearing liner, which should be ventilated to prevent undue heat extending to the drum sides. At one time straps or bands encircling the circumference of the brake rim were general, but the "post" type, illustrated in Fig. 405*b*, are now more often applied. In cases of emergency, very powerful brakes are required, and to meet the case the brake-strap is connected through a lever to the piston-rod of a small engine, into which steam can be admitted. Such an appliance, unless controlled by a floating lever through a cataract, acts on the "all or none" principle; full power has either to be exerted or not. If steam be admitted to the cylinder, the power applied to the brake is due to the area of the piston multiplied by the pressure, and as neither the steam pressure nor the piston area can be varied, the power exerted is always constant. Immediately steam enters the piston such power is applied to the brake-strap, the result being that when a steam brake is thrown into action the machinery is subjected to very severe shocks, and consequently such appliances are only used in cases of emergency. As a rule, winding engines are provided with two brakes, one applied by the engineman's foot, giving a comparatively light load for stopping the engine at the end of each wind, and the other by steam, the latter only being used on rare occasions. Several devices have been designed to increase the power and leverage of foot brakes, and to do away with those of steam.

Burn's Brake.—The brake-strap does not encircle the drum, but consists of a block of wood (B, Fig. 403), about 24 inches long by 6

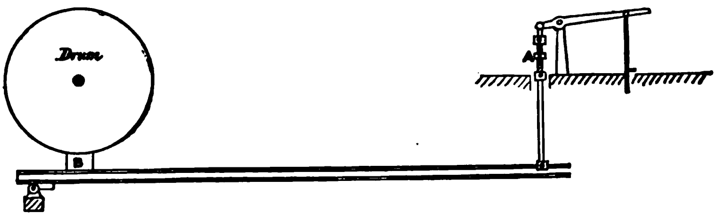


Fig. 403.

inches broad, in which a series of holes is bored and filled with sand. This block of wood is placed at one end of a long lever, the other end being moved up and down by a rod connected to the arm of another lever controlled by the engineman. The block being small in area, and fitted to the rim of the drum, only requires a very small movement to free itself, and the length of the lower lever being nearly equal to the length of the engines, it follows that a large amount of power can be applied. At Bickershaw Colliery, Lancashire, the leverage is about 200 to 1, and as there are two blocks on each drum the power exerted by the engineman is multiplied to a great extent. The action of the sand in the holes is to keep the brake rim free from grease. By the aid of an adjusting screw, A, the brake can be tightened in a few minutes and any wear taken up in the blocks, which are usually renewed about every four months.

Tyldesley Colliery.—A pair of 32-inch cylinder engines are here fitted with a powerful strap-brake, moved by a toggle-joint lever. The engineman exerts pressure through his foot-treadle in the direction of the arrow W (Fig. 404), pulls down the bell crank lever

A, B, C, moves the toggle-joint D, E, F, and gives motion to the lever F, G, H, working about the centre G, the end H being attached to the strap going half round the brake-ring on the drum. The direction of motion in each part is shown by the arrows, and as the engineman puts on the brake, the toggle-joint D, E, F forms a straight line. At the instant this takes place the pressure exerted becomes infinitely large. B, D, and G are the only fixed points.

Pasfield's Brake.—To obtain the power of a steam brake, and yet remove the difficulties previously referred to, Mr. T. Pasfield * has designed a special valve and gearing (Fig. 405), which allows any variation of power to be applied, as the pressure of steam in the brake cylinder is made to increase and decrease in proportion to the amount of force exerted by the engineman on the controlling treadle. The passage *l* leads into the cylinder of the steam brake, which is fitted with a piston and piston-rod, the latter being connected by a link to the lever applying the brake. Steam is admitted on one side of the piston only, and enters and leaves the cylinder by the same passage. The valve-box *a* is fitted with two valves, *b* and c, both connected by gearing to the lever to which the foot-treadle *f* is attached, and controlled by the link *e*. The valve *b*, which admits steam through the passage *g*, is kept closed by a spring, *d*, which just balances it against the steam in the boiler. The relief-valve *c*, unless the brake is in action, is in equilibrium, free to open or shut.

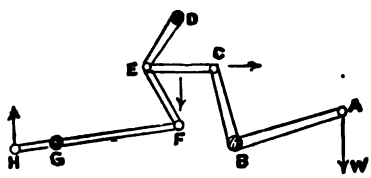


Fig. 404.

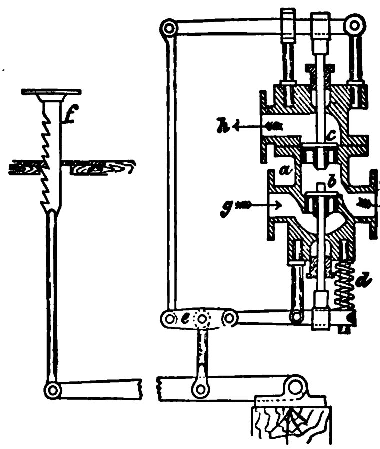


Fig. 405.

When the treadle is pressed down, the steam-valve is relieved of some of the pressure which keeps it closed, and steam enters the cylinder until its pressure is sufficient to again close the valve against the force exerted by the treadle, so that the greater the force exerted on the treadle, the greater the pressure must the steam reach before it closes the steam-valve. At the same time, as the treadle relieves the steam-valve of some of the spring pressure which tends to close it, it brings an equal force to bear on the relief-valve *c* to keep it closed; any increase of steam pressure in the cylinder beyond that intended at once escapes through the relief-valve. Thus, if the force exerted by the treadle to relieve the steam-valve, is to the extent of what amounts to 1 or 2 lbs. per square inch, the steam-valve

* *So. Staff. Inst.*, ii., 112.

admits steam into the cylinder until the pressure there is 1 or 2 lbs. per square inch, as the case may be, and then closes. The treadle at the same time exerts sufficient force to keep the relief-valve closed until the steam in the cylinder has reached the 1 or 2 lbs. pressure, and then allows anything beyond that to escape.

Such a brake, or indeed any other depending for its power on steam pressure, becomes useless when a pipe bursts or anything happens to stop the supply of steam, and it is usual in some cases to fit an additional appliance worked by weights as a safeguard for cases of emergency. The piston-rod of the steam brake is continued through the back cover, fitted with a collar, and connected through a slotted link, *a*, Fig. 405*a*, with a bell-crank lever, *b*, the longer arm of which carries a heavy weight, *c*. This weight, under normal working con-

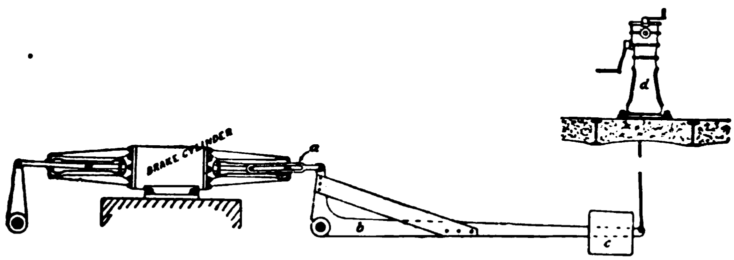
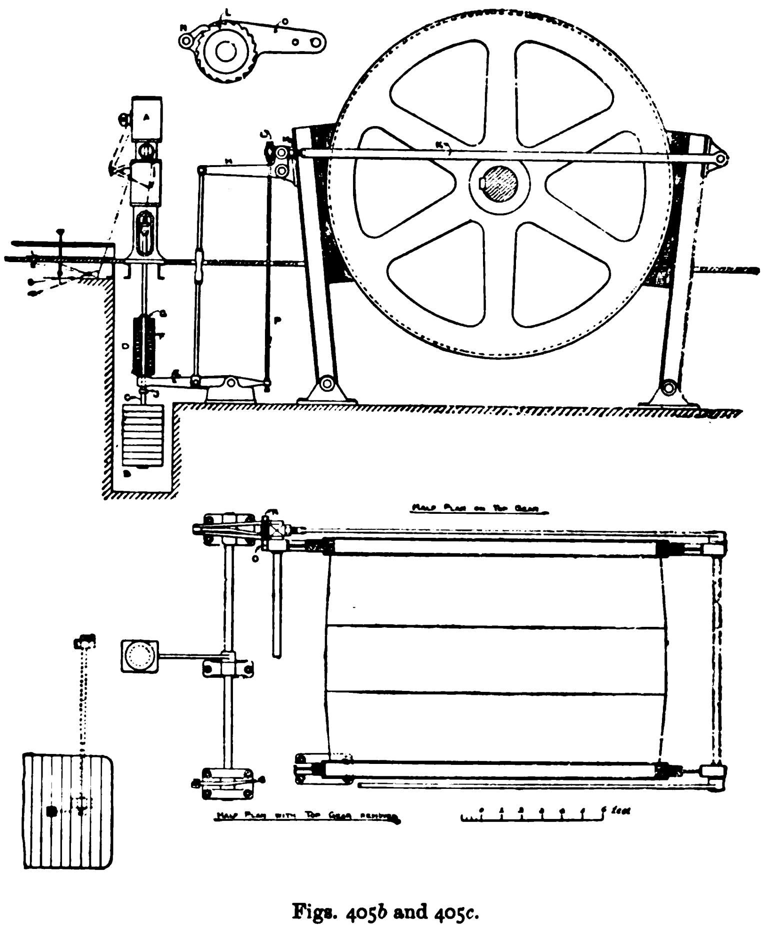


Fig. 405*a*.

ditions, is held up by a small winch, *d*, locked by a ratchet and pawl, which can be released and the weight allowed to drop by the engine-driver. The piston-rod of the brake cylinder can move to and fro in the link quite freely so long as the weight is suspended, and as steam is only admitted to the front end of the brake piston, when steam is shut off, the block on the back end of the piston-rod engages the front end of the link. Consequently, if the engine-man released the weight the brakes would be put on without shock, but any such probability can be guarded against by inserting a friction arrangement which only allows the weight to fall at a moderate speed.

Whitmore's Brake.—An arrangement, designed by Mr. L. F. Whitmore, combines both the weight and steam application, and introduces a further important advantage in providing for the automatic taking up of the wear on the brake blocks, with the result that a certain definite pressure is always exerted by the engine-man when his treadle is in a given position. The brake engine, A, Figs. 405*b* and 405*c*, consists of steam and cataract cylinders, and is fitted with a floating lever gear, by means of which the position of the piston corresponds exactly with the position of the foot treadle. A series of weights, B, are suspended by the rod, C, attached to the crosshead of the brake engine. These weights put on the brake through the levers, E and H, as illustrated, and steam has to be admitted under the piston to raise the weights to take off the brake. Consequently, should any accident occur to the steam main, the brake would go on. As a rule, there are not enough weights provided to stop the engine against full steam pressure, but only enough to hold it against the ordinary winding load, because under working conditions the full load is applied partly by the weights and partly by steam on the top of the piston. The rod, C, is threaded through a spring box, D, which is free to slip up or down. This bears upon the brake lever, E, and



Figs. 405*b* and 405*c*.

the springs, F, contained in the box are compressed between the bottom of the box and the plate, G. The brake lever, E, is connected to the top ends of the brake posts by a cranked lever, H, and tie-rods, &c., and draws them together. The varying load is applied by the compression of the springs, due to the lowering of the weight, B, bringing down the top plate, G, and the spring box, the position of each being controlled by the foot treadle. The farther this goes down the more the springs are compressed, owing to the downward movement of the weights. The maximum load is applied when the plate, G, is touching the sleeve distance piece in the spring box, and the minimum load is applied when the collar, J, is touching the under side of the brake lever, E, as the springs are then fully extended.

This happens when the foot treadle is about position 2, and in bringing this further back to position 1 the piston travels still higher, carrying with it the weights and fixed collar, J, and also lever, E, sufficiently far to give clearance between the brake blocks and the drum rim. The principal advantage, however, lies in the automatic taking up of the wear of the brake blocks, which are always kept in the same relative position for any position of the foot lever. In ordinary circumstance the wear of the brake blocks is adjusted periodically, and immediately after such adjustment probably the whole brake load is applied to the engines by a very short movement of the treadle, this distance extending from time to time as the brakes wear, until another adjustment has to be made. Constant attention teaches the engine-man to apply the brake in a fairly satisfactory manner, but with inattention or change of hands serious strains and, probably, accidents might occur by applying too great a load suddenly. In the Whitmore arrangement a ratchet nut is mounted in the crosshead at the end of the tie-rod, K, an enlarged view being drawn separately. This ratchet nut, L, is fitted with a pawl, N, mounted in the lever, O, which is connected by the rod, P, to an extended arm of the brake lever, E. This comprises the take-up gear, which acts as follows:—On the downward stroke of the brake lever, E, the rod, P, is moved upwards, and, consequently, when the lever and rod, E, are forced down to a certain distance, the pawl will take up another tooth. On the return or upward stroke the rod, P, is brought downwards by the collar at the end of the lever, E, striking on the bottom of the rod, P, which screws up the nuts on the tie-rods, K, to the same extent. It will be seen that the lever is not forced down to the position before mentioned by the same load being applied until the brakes are worn to that amount. The adjustment is small at each operation, and there is only a very slight difference in the position of the brake piston immediately before and after each automatic adjustment.

Counterbalancing.—With an ordinary cylindrical drum, unless some means are taken to counterbalance the weight of the rope hanging in the shaft, the engine is subjected to an enormous variation in the load, especially in deep shafts. If

w = weight of cage and empty tubs = 6270 lbs.
c = weight of coal = 4480 lbs.
r = weight of rope hanging down pit = 6000 lbs.

At the commencement, when the empty cage is at the top of the pit, the weight to be lifted will be:—

$$w + c + r - w \text{ or } 10{,}480 \text{ lbs.}$$

In the centre of the run, half r would have been added to the descending load and subtracted from the ascending one; the weight on the engine is, therefore:—

$$\left(w + c + \frac{r}{2}\right) - \left(w + \frac{r}{2}\right) \text{ or } 4480 \text{ lbs.}$$

At the end of the wind all the rope is acting in favour of the descending cage, and the weight on the engine becomes:—

$$(w + c) - (w + r) \text{ or } -1520 \text{ lbs.}$$

During the complete operation the load varies from 10,480 lbs.

against the engine to 1520 lbs. in favour of it. At the commencement of winding the engine wastes a great deal of energy in setting this mass into motion, and as speed is the main object, the engineman cannot cut off steam when most desirable, but must go on, and finally has to reverse the engines in order to bring them to rest. An enormous amount of energy is therefore lost in the latter part of the run, and such loss obviously increases with the depth of the pit.

Supposing, now, that by one of the methods of counterbalancing, the weight of the rope hanging down the shaft was balanced. If this new factor be denoted by r', the weight to be lifted at the commencement of the run will be :—

$$(w + c + r) - (w + r') \text{ or } 4480 \text{ lbs.}$$

in the centre of the wind it will be :—

$$(w + c + \frac{r}{2} + \frac{r'}{2}) - (w + \frac{r}{2} + \frac{r'}{2}) \text{ or } 4480 \text{ lbs.}$$

and finally

$$(w + c + r') - (w + r) \text{ or } 4480 \text{ lbs.}$$

The weight thus not only remains constant, but is considerably smaller at the beginning than in the other case. This reasoning will be clearly understood if it is remembered that for every decrement in r, an equal increment of r' is added, and as these two forces are equal and opposite at the beginning, they will necessarily be so at the conclusion.

The advantages are perhaps more clearly shown by comparing the work which has to be performed in the actual example referred to on p. 310. With a balance rope beneath the cages, the work done in the first ten seconds is at the rate of 1780 I.H.P., while if the winding rope is unbalanced it is at the rate of 2098 I.H.P. The addition of the balance rope reduces the indicated horse-power by 318, or over 15 per cent.

Having thus proved the great advantage of counterbalancing, the means by which such is secured may now be considered.

Tapering Ropes.—A tapering rope enables winding to take place from greater depths than is possible with ropes of uniform section; the theory of taper ropes is to obtain uniform strength throughout, thinner at the cage end where the weight is least, and thicker at the drum end where it is greatest. Their thickness is such that the section at any part is capable of safely bearing the load on it at that point. With tapering ropes, a smaller initial dead weight is thrown on the engine, as their section at the largest point will be less than that of a rope of uniform section throughout, because a smaller weight has to be supported. The difference between the initial and final load is also smaller, but it increases more rapidly, because the larger diameter is wound on the drum in the ascending portion, while in the descending portion the larger section is being unwound. These ropes cost more than ordinary ones, and owing to the difficulty of manufacture cannot be made so perfect.

Flat Ropes.—This means of winding allows of a certain equalisation, for the radius of the coil of the ascending rope continues to increase, while that of the descending rope diminishes; consequently, as the resistance decreases in the ascending load, the leverage increases, and as the power increases in the other, the leverage diminishes. The variation in the leverage is a constant quantity, and is equal to the thickness of the rope. If the diameter of the drum be made small enough at the commencement, a remarkable uniformity in the load may be obtained, the only objection being the use of flat ropes.

Conical and Spiral Drums.—Results analogous to the preceding may be obtained by using round ropes coiling on conical drums. They may be either smooth, the successive coils lying side by side, or may be provided with a spiral groove. If a conical drum was constructed to give perfect equalisation, the sides would be so steep that the rope would slip off. For such reason scroll drums were designed, which are open to the objections already stated. In addition, the load is seldom perfectly counterbalanced. To obtain satisfactory wear from a round rope, it must be coiled on a drum of large diameter. Such condition limits the size of the smaller diameter, which is usually made so large that if the final diameter was of the proper dimensions to give perfect counterbalancing, the size of the drum would be enormous. For this reason, and to prevent the great lateral displacement of the winding rope from the centre line of pulley, owing to their necessarily large width, such drums are usually made for several coils to take place on the spiral, and the remainder on the flat.

Tail Rope beneath Cages.—With cylindrical drums, perfect counterbalancing can be secured by several methods, such as the attachment to a small drum, keyed on the same shaft as the winding drum, of a heavy chain which is wound up and down in a staple pit, or employing instead of the chain, a loaded waggon running on an incline, but all are clumsy and have given way to the endless rope system, which is preferable to all others if the shaft is free from cross-timbers. It consists of placing beneath the cages a tail rope, equal in diameter to the winding rope, and after conveying this down the pit into the sump, where it forms a loop, it is returned and attached beneath the other cage. When first introduced, it was considered that a pulley must be placed in the sump for the tail rope to pass round, such pulley remaining stationary under ordinary conditions, but free to move between guides and be lifted out of its bearings in case of accidents. In the majority of cases no pulley whatever is used. All that has to be done to keep the tail rope from twisting, is to fix two beams side by side across the pit in the sump, between which the tail rope passes, and another one below put across in the opposite direction, the latter passing through the loop in the rope.

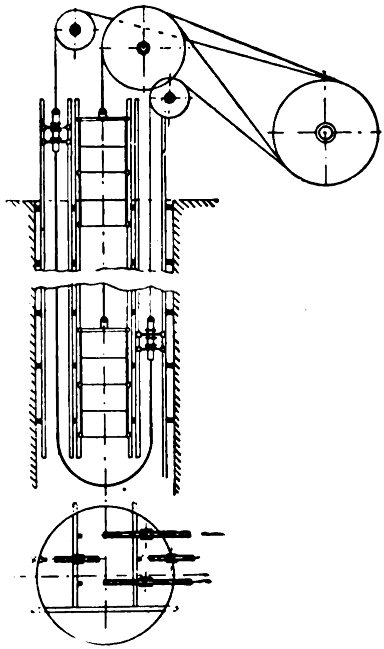
It is perhaps preferable to use a guide pulley in the sump, as old winding ropes can then be used, otherwise a special rope has to be employed, as old winding ropes are not sufficiently flexible. The balance rope is connected to the bottom of the cage by an ordinary capping and bolt passing through a cross-bearer.

By this system perfect counterbalancing is obtained, as a factor is introduced equal and opposite to the winding rope, and gives equality at the beginning and the end. The one solitary objection urged against it, is that a greater weight is put on a tender part of the winding rope—viz., the capping, but if properly constructed and put on, the capping is quite as strong as the winding rope itself.

*Meinicke's System.**—A balance rope is employed in this method, but instead of attaching it beneath the cage it is connected to two auxiliary ropes, which may either be coiled on the same drum as the

* "On Counterbalancing the Weight of Winding Ropes." C. Meinicke, *Ches. Inst.*, xiii., 336.

winding rope, or on auxiliary ones. The auxiliary rope passes over separate pulleys on the head-gear, and the balance rope is equal to the weight of both the winding and auxiliary ropes. At first, the balance ropes, and those for working them, were left to hang freely in the special compartments provided in the shaft but frequent fouling resulted, and it is now judged advisable to guide them in the manner shown in Figs. 406 and 407, which has been found satisfactory. Instead of carrying the small ropes to the drum of the winding engine, they may each be connected by one end with the cage, passed over the small pulleys on the head-gear, and then brought down to the side of the shaft and connected at their other end with the balance rope. Perfect counterbalancing results, and no additional weight is thrown on the capping of the winding rope. This, in conjunction with the fact that the balance rope may be led into any position in the shaft and boxed off, are the advantages, but as it is much more complicated than a tail rope beneath the cages, the latter seems preferable.



Figs. 406 and 407.

Overbalancing.—It is a debatable question whether in winding large loads from great depths the weight of the rope should be over-counterbalanced or not. The work performed in accelerating the load in the first few revolutions is so much larger than that of maintaining full speed during the greater part of the run that, even when an expansion gear is fitted to the engines, they cannot be stopped within reasonable time unless the brakes are applied. In the example given on p. 312 the total work done in the first five revolutions is 9,790,028 foot-lbs., but as soon as the maximum velocity has been attained only the amount represented by $L \frac{v t}{2}$, or 4,973,220 foot-lbs., have to be exerted in each succeeding five revolutions in order to maintain full speed. At the end of the run, after steam has been shut off, this power tends to stop the engine, but it is overbalanced by the energy $\frac{W v^2}{2 g}$, or 5,516,108 foot-lbs., stored up in the moving parts. In ordinary cases the excess, or difference between these two factors, has to be absorbed by the brakes.

If, on the contrary, the balance rope is made heavier than the winding rope, the excess partially balances the weight of mineral at the commencement of the wind, and enables the engines to start away very quickly, but the gain is to some extent neutralised by the fact that a greater mass has to be set into motion. At the end of the run nearly the whole of the excess of the weight has been taken off the descending cage and added to the ascending one. This tends to stop the engine without applying the brakes, and is a distinct gain.

Expansion.—For economical working steam must be used expansively. With a continuously running engine there is no difficulty in doing so, but in the case of an intermittently running engine, working under the conditions which exist in winding, the problem is not so easy. As before remarked, everything is sacrificed to speed. It is essential that the engine should start quickly, should travel at a high velocity, and be quickly brought to rest; it is also essential that the engineman should be capable of putting full steam either on or against the engine, whenever required, and, above all, the machine should be simple. Under these conditions, regular expansion is quite out of the question. Of late years several most ingenious automatic variable expansion gears have been designed, which give satisfactory results. They are so arranged that at the beginning of a wind the engine takes full steam, and they only come into operation when the machinery has attained its maximum speed. The general type consists of "trip gears"—that is to say, by some arrangement the valve is made to trip off the lifting lever, and close before the completion of the stroke.

Comparative experiments made at the Treuil pits of the St. Etienne Colliery* for ascertaining the coal and water consumption, both with and without expansion, during a period of twelve and six working days respectively, with four tubs wound from the 2034 feet level, and two tubs from the 1627 feet level, involving a work of 2,421,659 foot-lbs. and 1,937,327 foot-lbs. of work for each tub, showed that as regards water consumption, there was an economy of 31·5 per cent. in favour of expansion. As regards the coal consumption, the rates of useful effect, with and without expansion, was 0·648, showing a saving in fuel of 35·2 per cent. It is also stated that quite an appreciable saving was effected by the decreased quantity of lubricant used in the cylinders when working expansively, owing to the smaller amount of steam passing through them.

Musgrave Gear.—In Fig. 408, A is the spindle of an ordinary Cornish valve fitted with a dash-pot, O, at its upper end. With ordinary gear, the valve would be lifted by the lever, B, catching the projection, C, but here a bell crank lever, D E, capable of turning about the centre, F, is interposed between the two pieces. Fastened to the upper end of the frame carrying the valve is a pin, G, and spindle, H, on which is keyed an eccentric, K. By means of the link, L, and the rod, M, a rotary motion can be given to the eccentric about its axis, H. At the beginning of a wind, the lever, B (moved by the eccentrics of the engine in the ordinary manner), raises the valve through the bell crank, the spindles rising and falling with the lifter, as if no expansion gear was present. As speed increases, the rod, M, which is in connection with the governor, is moved in the direction shown by the arrow, turns round the eccentric, K, and depresses the end, D, of the bell crank. The lifter, B, then trips off the other end, E, of the bell crank, and allows the valve to close suddenly, any injurious shock being prevented by the dash-pot, O. The lifter, B, continues its upward journey without the valve, and on its return, the

* *Soc. Ind. Min.* (3e Série), x., 73.

spring, N, pushes the bell crank into gear again. Fig. 409 shows the attachment of the gear to the engines. It is worked by a dead weight governor, *a*, driven by a strap, *b*, from the drum shaft, *c*.

In the case of a new installation, it is only necessary that the maximum speed at which the engines are to run shall be determined, and then by a proper relation between the pulley on the drum shaft, and the pulley on the governor, the point of cut-off can be readily fixed. This gear has been applied in numerous instances to winding engines, and the author has inspected its working on several occasions. At Tyldesley Colliery, Lancashire, the drum makes twenty revolutions

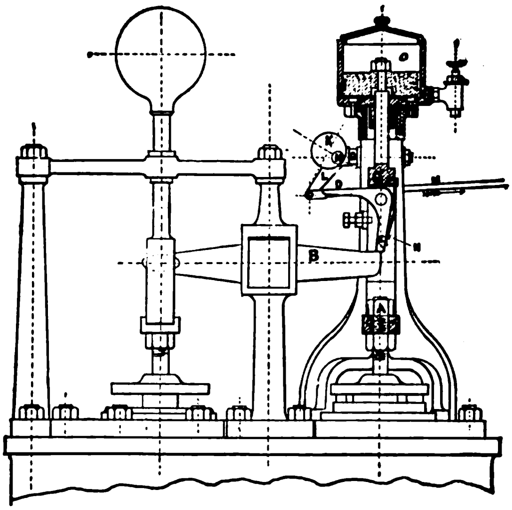


Fig 408.

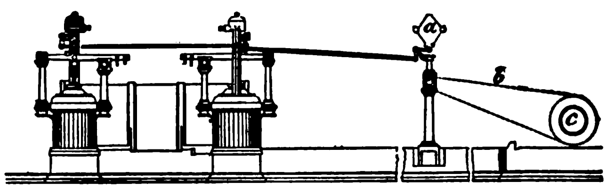


Fig. 409.

and a cut-off of $\frac{1}{8}$ commences at the fourth revolution. The gear does not come into operation until the maximum speed is obtained, and is thrown out of action by the governor towards the end of the wind, when speed falls. Its advantages are, that it has no complicated parts, is out of the engineman's way, and comes in and goes out of action without interfering with any of the parts handled by him, and, at the same time, allows full pressure of steam at the beginning and end of a wind, or at any other desired point during the ascent or descent of the cage; indeed, so far as the engineman is concerned, he is in just the same condition as if the gear were absent.

Grange Gear.—A gear is applied by the Grange Iron Co., which is similar both in principle and action to the one just described, and gives the same results. The only difference is in the arrangement of the parts. The lifter raises the valve through a curved rocking lever, under one end of which a sliding wedge is pushed or withdrawn by a combination of levers moved by a governor. When the wedge is pushed under one end of the rocking lever (which takes place when the maximum speed is obtained), the lifter drops off the other end, and allows the valve to close at some intermediate point in the length of the stroke.

Sulzer Gear.—This arrangement has been applied to many engines on the Continent, and is most ingenious, although rather complicated. Fig. 410 is a diagrammatic sketch. The shaft, *a*, is driven by bevel gearing from the crank shaft, and revolves at the same speed. On it are keyed two eccentrics, only one, that working the steam valve, being shown in the sketch. By the revolution of the spindle, *a*, a motion to and fro in the direction of its length is given to the eccentric-rod, *b c*. As this falls, it catches a projection, *d*, on the bell crank lever, *e f g h*, the fixed points of which are *e* and *h*, and the valve spindle is lifted. On a second shaft, *k*, is fixed an eccentric, which can be rotated by the governor in the direction indicated by the arrow. The rod of this eccentric is connected by a screw to *b c*. In ordinary working, the apparatus stands as shown in the sketch, and the valve is regularly closed and opened. When speed increases, the spindle, *k*, and its eccentric is rotated, and the bar, *b c*, pushed outward, with the result that the projection, *c*, trips off *d*, and expansion results.

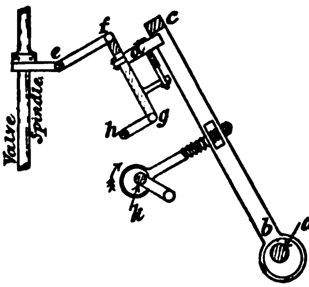


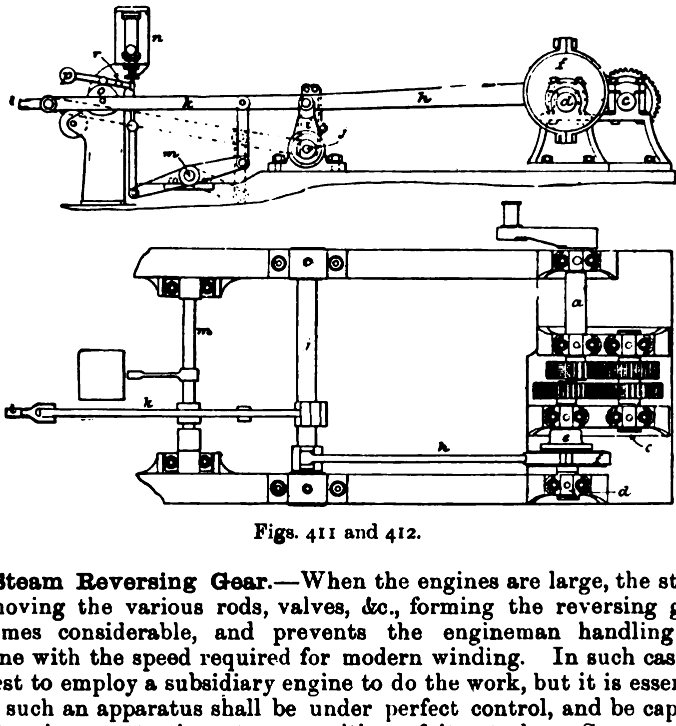
Fig. 410.

Woodworth Gear.—As some engineers contend that expansion gears controlled by a governor reduce the speed of winding to some extent, Mr. B. Woodworth* designed the automatic gear, illustrated in Figs. 411 and 412, which is not put into action by the speed of the engine, and in which the point of cut-off is not fixed, but is progressive—that is to say, the engine takes full steam for the first few revolutions until the maximum velocity is attained, when a cut-off of 0·5 takes place, and gradually increases, until at the end of the winding the steam is cut off at about 0·3 of the stroke.

The gear is driven by a drag shaft (*a*, Figs. 411 and 412), through a train of wheels and intermediate shaft, *c*, to the shaft, *d*, which carries the cut-off eccentric, *f*, connected through the rod, *h*, and arm, *i*, with the rocking shaft, *j*. The latter is provided with a slotted link, which forms part of the rocking shaft, and in which works an ordinary block connecting the swing rod, *k*, driving the cut-off valve through the spindle, *l*. The eccentric, *f*, on the shaft, *d*, is not driven direct by the train of wheels, as it is only connected to them through a stud pin projecting from the driving disc, *e*. It is loose on the shaft, and is brought into action by the stud pin, thus controlling the cut-off gear

* *Fed. Inst.*, x., 470.

in whichever direction the engine turns. The train of wheels is arranged to give a slightly accelerating speed to the shaft, *d*, which advances the eccentric, *f*, through an angle of about 1½° at each revolution of the drum. The gear may be put out of action at will, by shutting off the supply of steam to the small controlling cylinder, *n*, which is connected through levers to the shaft, *m*, and hence through other levers and links to the swinging rod, *k*. The working position is shown by the dark lines, while the dotted lines represent the position occupied when the gear is out of action. Under normal working conditions, the movements in the cylinder, *n*, are controlled by the cam, *o*, driven by a chain from the shaft, *d*, so that it makes one complete revolution for each winding. This cam turns the weighted lever, *p*, about the stud pin, *r*, and operates the valve of the cylinder, *n*.



Figs. 411 and 412.

Steam Reversing Gear.—When the engines are large, the strain of moving the various rods, valves, &c., forming the reversing gear, becomes considerable, and prevents the engineman handling his engine with the speed required for modern winding. In such cases it is best to employ a subsidiary engine to do the work, but it is essential that such an apparatus shall be under perfect control, and be capable of stopping or starting at any position of its stroke. Some steam-reversing engines simply move the eccentric links to and fro, and such types are worse than useless.

Melling's Reverser.—This apparatus consists of a steam cylinder (*a*, Fig. 413), and a hydraulic cylinder, *b*, placed in a tank, *c*, containing water. Both cylinders are provided with a piston, and are placed with the axes in the same straight line, one piston-rod being common to both. The upper end of this piston-rod is connected by levers, as shown with the block in the reversing link on the engines. This block follows the motion of the reversing handle, *d*, to an amount corresponding with the distance the latter has been moved, and then stops, because the valves of both cylinders will by this time be closed through the action of the link, *e*, acting on the valve-rod, *f*. The pistons are thus brought to a standstill, and are locked until the reversing handle is again moved. As the lever, *e*, is connected at one end to the rod coming from the steam piston-rod, and at the other to the reversing handle, it follows that the valves of the steam and hydraulic cylinders receive two motions through the rod, *f*, one due to the reversing handle, and the other, ***in a contrary direction,*** to the movement of the steam cylinder piston-rod.

As the valve of this auxiliary engine is small, it is moved with a much smaller expenditure of power than would be required if the reversing links, &c., had to be lifted direct, and the operation is also performed more rapidly. Both steam and water are brought to the respective cylinders *between* the two valves, and exhausted on the opposite side of the valves, so that they are in equilibrium in all positions, and only require a slight effort to move them.

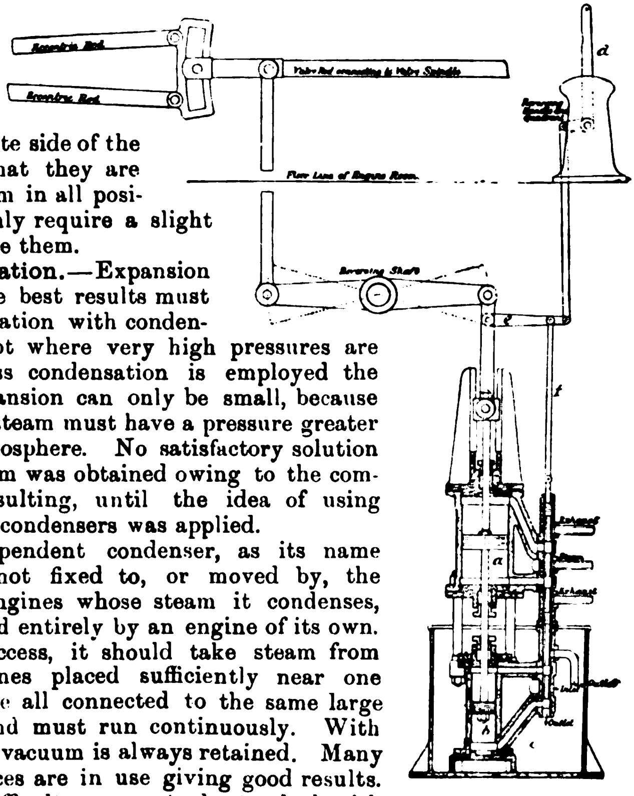


Fig. 413.

Condensation.—Expansion to obtain the best results must be in combination with condensation, except where very high pressures are used. Unless condensation is employed the ratio of expansion can only be small, because the exhaust steam must have a pressure greater than the atmosphere. No satisfactory solution of the problem was obtained owing to the complication resulting, until the idea of using independent condensers was applied.

An independent condenser, as its name implies, is not fixed to, or moved by, the engine or engines whose steam it condenses, but is worked entirely by an engine of its own. To be a success, it should take steam from several engines placed sufficiently near one another to be all connected to the same large condenser, and must run continuously. With it a constant vacuum is always retained. Many such appliances are in use giving good results. The chief difficulty seems to be to deal with the enormous volume of steam which comes from the winding engine at intermittent times. Winding engines are necessarily large, and run rapidly, so that when they are moving, especially if expansion is not used, the volume of steam discharged is very large, far more so than is general with continuously running engines. The condenser, therefore, has a difficulty in dealing with these sudden rushes.

A condenser is a mechanical contrivance into which steam is passed and condensed, thus producing a vacuum. It serves the double purpose of reducing the back pressure from the exhaust side of the piston by removing the greater part of the pressure of the atmosphere, and allows steam to be expanded to a lower pressure in the cylinder than could profitably be done if exhaust was made direct into the atmosphere. As a result, either the consumption of steam is considerably reduced to furnish equal power, or there is a corresponding increase in the work performed by the engine. It introduces a further economy, inasmuch as the hot water produced in the condenser can be used for boiler feeding, and, indeed, with suitable safeguards in the form of oil filters and separators, the condensed steam water may be sent back to the boilers. Such practice is not, however, recommended, as it is next to impossible to remove all the oil, which is a most dangerous substance to introduce into boilers. It is advisable to erect a central condenser in the midst of the steam engines in order to keep the exhaust pipes as short as possible, but a distant position is admissible, and the loss of vacuum scarcely perceptible provided the exhaust pipes are of suitable dimensions. Nearly any vacuum can be obtained, but it must be remembered that with a very high vacuum the horse-power required by the air pumps increases very considerably, and generally a wise limitation is found most advantageous. Under normal conditions the highest saving is obtained with a vacuum of from 11 to 13 lbs.

There are two systems of condensation differing entirely from each other:—(1) Jet condensers; (2) surface condensers, but both should be so arranged that the water and steam move in opposite directions.

In the former, the steam is brought into direct contact with the cooling water within the vacuum chamber.

The condensers employed may either be of the ordinary construction, where an air pump and spray injection are used, or of the ejector pattern where a vacuum is obtained and the steam condensed by a jet of water issuing from a special-shaped nozzle. In arrangements of this type, designed by Balcke & Co., the condenser consists principally of two parts, a large lower chamber with a dome placed upon it, the construction of the chamber being such that a definite quantity of water inside it is always ensured. Fig. 413*a* shows the arrangement where artificially cooled water is employed for condensing the steam. The cool water enters at the dome and falls into the large water chamber. The steam enters the opposite way through the pipe, *a*, and comes into close contact with the water in the large chamber, *b*. It is nearly all condensed here, only a small portion, together with the air enters the dome, *c*, and the vacuum is completed by the inrush of cold water through the pipe, *d*. The cold air which enters with the water is taken away from the top of the dome at *e* by an air pump, which is a necessary adjunct of every condenser. If this air was not removed it would soon set up a large back pressure. The warm water passes from the large water chamber to the circulating pump, *f*, which lifts it to the top of the cooling apparatus. The artificially cooled water is again sucked up automatically through the pipe, *d*, into the condenser cone, the quantity being regulated by a float. The efficient working of such a condenser depends on regulating the entrance of cold water into the condenser after warm water has been pumped out by the circulating pump, and the automatic maintenance of the water level in the large chamber at a predetermined height.

With surface condensers the cooling water remains quite apart from the steam and does not enter the vacuum chamber at all. In them the steam is carried into a nest of pipes having a large external surface which is subjected to a rapid cooling action, either by the flow of a stream of cool water around the pipes, or by allowing a spray of water to fall on and trickle over them, such cooling action being much augmented by the circulation of an artificial current of air. Each subdivision of the surface condenser type has received considerable attention during recent years. The tendency with surface condensers has been to decrease the number of pipes employed and to use a greater quantity of circulating water, which can readily be produced by a good centrifugal pump. Evaporative condensers, with the water trickling over the pipes, give very satisfactory results and use a

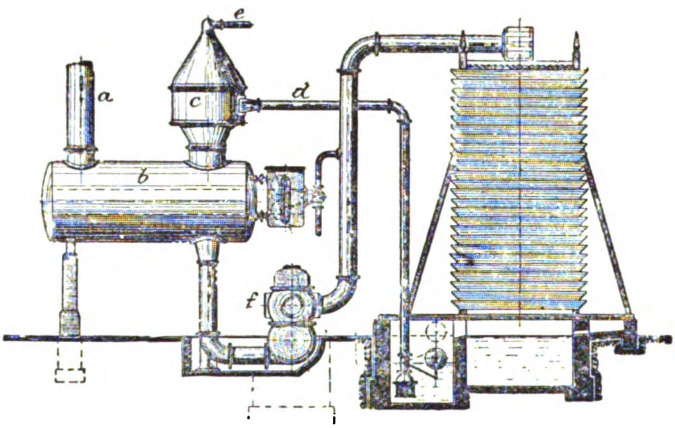


Fig. 413*a*.

remarkably small quantity of water, indeed, some firms who manufacture them state that owing to the quantity of water obtained from the condensed steam itself, the same engine working condensing uses less water than when it is non-condensing. Their cost is, however, large, and this would put them out of consideration in all cases where a good supply of surplus water is available and plenty of ground space at command. In surface condensers proper the water is separated from the steam by thin brass tubes. The cooling water is on one side and keeps the tubes cold while the steam is precipitated on the other side. The pipes are arranged in varying manners dependent on the different classes of water which have to be employed, but the principle is the same in each case. A great deal of attention has been given to this question in Germany, and the whole of the details carefully thought out, with the result that a large number of such plants are in operation with perfectly satisfactory results. They all consist of a high-class steam engine, generally compound, driving a water circulating pump, an air pump, and a special double pump which deals with the condensation water produced from the steam, and with the oil and water separated in the oil filters. Such a plant, erected by Balcke & Co., is illustrated in Fig. 413*b*. The condenser consists of a round tank in which a large number of brass tubes are

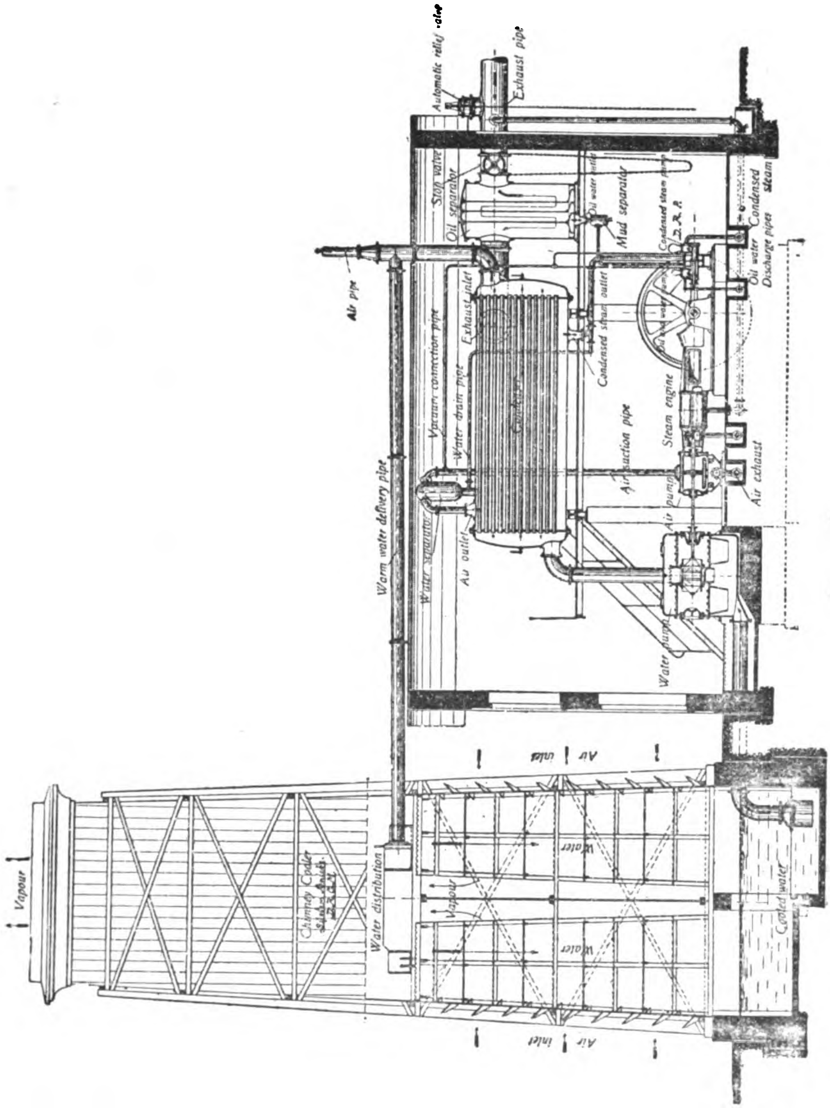


Fig. 413*b*.

placed. The steam flows round the brass tubes while the cooling water flows through them. These tubes can easily be cleaned by a brush after taking off a manhole door. The steam before entering the condenser passes through an oil separator, and after being freed from oil makes a long passage through the condenser in an opposite direction to that in which the water is circulating and is effectually condensed. The air pump removes the air which is contained in the steam or has entered through leakage, and thus maintains the vacuum, while the water condensed from the steam is taken by its special pump, and the oily water by the oil pump, the two latter being combined into one casing or chamber. On them depends, to a considerable extent, both the satisfactory working of the plant and the safety of the system. An enlarged view of the arrangement is given in Fig. 413c. The cylinder of this pump is by means of a special contrivance brought into direct connection with the air pump during the period of suction so that during that time exactly the same vacuum exists in the condensed steam pump as in the air pump and condenser. There are no suction valves. The condensed steam and oily water also flow into the barrel of this pump, but are kept in separate chambers by a diaphragm, and are forced out again by the plunger on its return stroke. A large pump of the ordinary plunger type is worked from a tail rod on the air pump bucket, and effects the constant circulation of the cooling water by forcing it through the

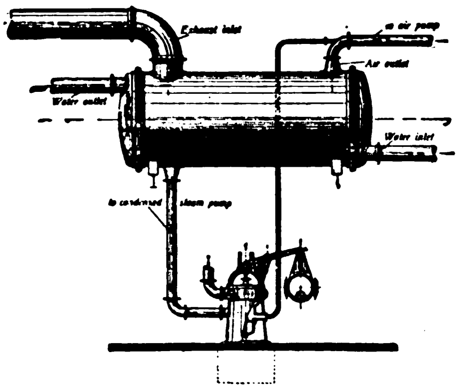


Fig. 413c.

condenser into the cooling tower and sucking it up again when cooled.

The satisfactory solution of the problem hinges about the fact that either a large quantity of water must be available, or that some efficient method of cooling it must be found. Ponds of large surface area are sometimes available, but their construction for the sole purpose of cooling water used for condensation is out of the question, as an area of about 2·5 square feet of water surface is needed per lb. of steam condensed per hour. Many artificial methods are adopted for cooling, all of which consist in splitting up the water into small particles and bringing them into contact with the air. It is only in the details of carrying out this principle that differences occur. Körting's spray nozzle provides a ready means of breaking up the hot condensation water into fine particles, and if a row of these jets be placed over a pond good results are obtained. At Anzin Colliery the hot water from the condenser is cooled by being pumped to the top of a wooden frame erected over the storage reservoir and then allowed to fall through the air. A series of horizontal trays composed of brushwood are arranged beneath each other, and the water in falling from one to the other is split up into small drops, thereby largely increasing the cooling surface. This is the so-called open type cooler, and must be placed in such a position that the draught can readily pass through. When properly proportioned they bring the temperature of the water below that of the surrounding atmosphere, and their cooling capacity can be very easily and cheaply increased.

For a medium degree of cooling such as is required with the waste water from condensers, chimney coolers are in general favour, These consist of a chimney-like superstructure formed by a square or rectangular tower with wooden framework covered with tongued and grooved sheeting boards. The water cooling apparatus proper is built into the lower part of the tower, as shown in Fig. 413*b*, and consists principally of the water distribution troughs, drizzling grooves and nozzles, and drizzling floors or trays. The hot water is delivered at the top, and after being divided into a number of small streams by nozzles is further subdivided into minute drops and allowed to drip from tray to tray, meeting on its way an ascending current of cool air which enters through the side openings. During this process the heat is transferred to the air partly by evaporation and partly by actual warming of the colder incoming air. The function of the chimney portion of the structure is to induce a draught. The air there is warmer than that of the outside atmosphere, and consequently the cool air rushes in at the bottom and ascends against the dripping water. The cooled water falls to the bottom of the tower and is collected in a tank ready for using over again.

Where the ground space is limited, or a very low temperature is desired, fan coolers are employed in which the ascending current of cool air is produced by a fan or fans fixed at the surface level. They are not recommended except under such circumstances, as the cost of the power required to drive the fans may be greater than the saving resulting from the increased efficiency of the cooling process.

A separate condenser having a steam cylinder 9 inches diameter and air-pump 12 inches diameter, both with a stroke of 2 feet, applied to a tandem compound engine having high- and low-pressure cylinders of 19 and 27 inches diameter respectively, by 3 feet stroke, is stated by Mr. H. Bramwell* to produce a vacuum of 25 inches, with a developed horse-power of 1·27 in its steam cylinder. Of the 135·26 I.H.P. produced by the main engine, 56·79 I.H.P. is obtained owing to the vacuum, a gain of 55·52. The vacuum thus yields 40 per cent. of the power expended. The quantity of water passing through the condenser is approximately 5000 gallons per hour. In another example at the same colliery, 39,000 gallons per hour were required to be passed through the condenser equivalent to 30 gallons per hour per I.H.P.

At Zollern Colliery, Westphalia, an independent condenser takes steam from a pair of winding engines, with cylinders 40 inches diameter by 80 inches stroke, a pair of air-compressing engines, a pair of fan engines, a compound compressor engine, a compound fan engine, a com-

* *So. Wales Inst.*, xxi., 158.

pound engine driving the washing machinery, two workshop engines, two boiler feed pumps, and one engine driving the condensing plant. The total load is 2000 horse-power, and the condenser was designed to deal with 42,000 lbs. of steam per hour. Although the vacuum fluctuates slightly no difficulty has been experienced with the winding engine, as after a few days' practice the engine driver was able to handle it with as much ease and certainty as when working non-condensing. About 85 per cent. of vacuum is obtained in the air pump suction pipe.

Compound Engines.—Most economical results are obtained by what is known as compounding engines—that is to say, the engine is supplied with a high- and a low-pressure cylinder, and expansion takes place in each. The steam from the high-pressure cylinder passes into the low-pressure one. The object of using two cylinders is to obtain a higher degree of expansion than could take place in a single cylinder with good results, as the difference between the initial and final temperature of the steam would be too great. A pair of compound engines would, therefore, contain four cylinders, and as simplicity is essential in winding machinery, such type did not at one time meet with much favour.

It has, however, been suggested that winding engines should be constructed in pairs as before, but instead of both cylinders being high-pressure ones, one should be high pressure and the other low pressure, steam passing from the former into the latter through an intermediate receiver. This is the type known as the twin compound, but the difficulty encountered with it was that sometimes it could not be got to start. Such failing was fatal to any application for winding purposes, as engines of such description are practically doing nothing else but starting and stopping. The first solution of the question was obtained by Mr. Wm. Galloway at Llanbradach Colliery.* Successful working followed on the introduction of a reducing valve between the steam pipe leading from the boiler to the high-pressure cylinder and the pipe connecting the high- and low- pressure cylinders, regulated in such a manner as to maintain the pressure in the intermediate pipe, *when the engine was not at work*, as nearly as possible at the same average as the steam in that passage would naturally assume when the engine was working. In order to limit the quantity of steam passing through the reducing valve to the smallest quantity necessary to accomplish the object in view, a screw stop-valve was introduced in the pipe connecting the reducing valve with the high-pressure steam pipe, and a steam pressure gauge on the intermediate pipe itself, for the purpose of enabling the reducing valve to be properly regulated.

An engine of the twin-compound type has been winding coal at the Great Western Collieries, South Wales, since 1892 with satisfactory results.† It has a high-pressure cylinder, 32 inches in diameter, on one side of the drum, and a low-pressure cylinder, 48 inches diameter, on the other side, the stroke of each being 5 feet. Both cylinders are steam jacketed, and are fitted with expansion gear similar to Fig. 408. The total load is over 9·5 tons, the drum is 18 feet diameter, and the shaft 1440 feet deep. The average boiler pressure is 120 lbs. per square inch, and the maximum speed of wind-

* *So. Wales Inst.*, xvi., 111. † *Fed. Inst.*, xii., 282.

ing is 60 feet per second. Total time occupied in winding, 50 seconds. This engine only used 26 lbs. of steam per hour per indicated horsepower, as compared with 37 lbs. used by a high-class ordinary engine having expansion gear, and with 46 lbs. used by a third engine also having expansion gear. The last engine used 74 lbs. of steam per hour per I.H.P. before it was fitted with expansion gear.

With deeper shafts, heavier loads, and increased boiler pressures, four-cylinder compound engines have come into more general favour, as, in spite of the existence of certain unfavourable factors, satisfactory results are obtained under suitable working conditions. In the first place, they must be attached to a condenser, and as this acts on the larger cylinder, the proportional increase in power will be large. Not only does a condenser reduce the back pressure, but it permits the more complete utilisation of the expansive force of the steam. If a condenser is not employed, the final pressure in the low-pressure cylinder must be considerably greater than that of the atmosphere, in order to obtain a free and rapid exhaust. A high initial steam pressure is also essential, and directly the engine has got up speed, some form of expansion gear should come into operation, and be so arranged as to produce a low terminal pressure. The importance of this consideration will be realised when it is remembered that the calculations given on p. 312 show that in the first ten strokes the engine has to exert over 9¾ million foot-lbs. of work, but that in the succeeding ten strokes only 4¼ million foot-lbs. are necessary in order to keep the engine going at its maximum speed. It is therefore evident that, unless acceleration is to proceed, the engine-driver must either throttle the steam or expansion must take place.

In order to reduce cylinder condensation, all four must be steam-jacketed, and, in addition, the interval between successive winds must be made as small as possible. Some rapid method of changing the tubs on the cages should be adopted, because, immediately steam is cut off, the cylinders commence to cool. A reheater receiver, having a volume equal to from 2½ to 3 times the capacity of the low-pressure cylinder, should be placed between the cylinders to restore part of the heat lost by expansion in the high-pressure cylinders, and stop valves should be inserted between the receiver and the low-pressure cylinders to cut off the supply of steam at the same time as the main throttle valve is closed by the driver. All these valves are connected together and controlled by the same handle. In this way the receiver pressure is maintained at some fixed amount, as enables the engines to start promptly on their return journey, and renders unnecessary the employment of a reducing valve under normal working conditions. A reducing valve should be connected to the receiver, but should be arranged to open only when the engines have been standing for some considerable time.

The drum should be small in diameter, and the weight of the rope should be counterbalanced. In this way the number of strokes during each hoist is increased, permitting more regular expansion, while the engine not only gets up speed quicker, but can be stopped in a shorter distance, with the result that steam is kept in the cylinders up to the last practicable moment.

In determining the size of a compound engine to do given work, it is usual to consider that the expansions of the steam all occur in the low-pressure cylinder, because the total steam used can only be that exhausted from such cylinder, and it is immaterial whether the terminal pressure is produced by an early cut-off in the low-pressure cylinder, or if the cut-off happened in a preceding cylinder, and the steam finally expanded in the low-pressure cylinder down to the same terminal pressure. The total power developed by a compound engine having a properly designed low-pressure cylinder is independent of the ratio between the size of the high and low-pressure cylinders, but the smooth and economical working is considerably influenced. It is usual to endeavour to apportion the work of a continuous-running compound engine equally between the cylinders, and the general practice under such circumstances is to make the low-pressure cylinder some three to four times the volume of the high-pressure cylinder, the ratio depending on the initial pressure of the available steam. But with intermittent-running engines, a lower ratio is adopted and more work done in the high-pressure cylinder, a condition which is not favourable to economy, but which increases the starting power. For winding engines a ratio from 2¼ to 3 to 1 is common.

Taking, therefore, the conditions laid down, the example given on p. 312, where 9,790,028 ft.-lbs. of work have to be done with a piston travel of 55 feet, with an absolute initial steam pressure of 155 lbs. and a cylinder ratio of 2¼ to 1, if steam be cut off in the high-pressure cylinder at 75 per cent. of the stroke, the theoretical number of expansions will be $\frac{100}{75} \times 2{\cdot}25 = 3$, and the actual number $3 \times 0{\cdot}85 = 2{\cdot}55$. The average mean pressure will be, neglecting clearance—

$$p^m = p' \frac{1 + \log_e r}{r} = 155 \frac{1 + 0{\cdot}93}{2{\cdot}55} = 117 \text{ lbs.}$$

Allowing for clearance, the mean pressure becomes $117 \times 0{\cdot}85 = 99{\cdot}4$ lbs., and if 9·4 lbs. be allowed for back pressure, the mean effective pressure on the piston is 90 lbs. The total area of the low-pressure cylinders is, therefore—

$$\frac{9{,}790{,}028}{90 \times 55} = 1978 \text{ square inches.}$$

Adding 25 per cent. for friction, gives a total of 2472 square inches for the two, or 1236 for one cylinder, so that the low-pressure cylinder should have an area of

$$\sqrt{\frac{1236}{0{\cdot}7854}} = 39{\cdot}66 \text{ inches.}$$

Calling this 40, the high-pressure cylinder should be about 26 inches diameter to give the desired ratio. A pair of four-cylinder compound engines, with two high-pressure cylinders each 26 inches diameter, and two low-pressure cylinders each 40 inches diameter, all having a stroke of 5·5 feet, will be capable of doing the desired work. In order, however, to obtain more economy in steam consumption, and to permit a higher degree of expansion and a lower terminal pressure, the ratio between the cylinders was increased to 3 to 1 and the low-pressure cylinders increased to 45 inches diameter, the high-pressure ones remaining at 26 inches. The student must remember that, although the size of the low-pressure cylinder is increased and the initial steam pressure remains the same, the mean effective steam pressure is reduced owing to the greater number of expansions, and, consequently, the horse-power developed is the same.

Winding from Great Depths.—It is obvious that the deeper coal seams which have been opened up by modern enterprise require more powerful machinery for winding purposes. To a certain extent the difficulty has been overcome by the employment of a much higher pressure of steam and by counterbalancing, but even then winding engines have tended to increase in size until they reach such a weight as renders them cumbersome. The very circumstances under which they work, such as the intermittent running, the continual starting and stopping, and the necessity for obtaining their maximum speed in the quickest possible time, render it almost essential that their moving parts should be as small and as light as possible, and to no other portion does this remark apply with such force as to the drum. If no other circumstance had to be taken into consideration an easy solution of the problem would be attained by reducing the size of the drum, but, unfortunately, this introduces a further complication owing to the larger number of coils of rope which have to be wound upon it, and the width of the drum has to be so increased that a point is soon reached where the angling of the rope between the drum and the pulley becomes greater than is permissible in practice. Many attempts have been made to overcome the difficulties of winding from great depths, but it can hardly be said that any of them are perfectly satisfactory. The subject was discussed by Mr. B. H. Brough* in 1896, by Messrs. Poussigue, Stassart, and Hrabak, at the Paris International Congress on Mining and Metallurgy, 1900, and by Mr. H. C. Behr before the Institution of Mining and Metallurgy in 1902. The latter paper presented very fully the mechanics of the question, but was incomplete in the absence of information as to the application of the suggestions to practice. Speaking generally, it seems that a great many of the difficulties are over-estimated. At the present time there are no shafts either existent or projected of a greater depth than 6000 feet, and up to that limit no difficulty has yet been experienced by competent engineers in designing satisfactory machinery for winding purposes. The advent of high-pressure steam has placed a very powerful factor in the hands of engineers, making it possible to employ small engines which can run at high piston speeds and attain their maximum velocity in the smallest possible time, even when the loads to be moved are large. Far more practical difficulty is likely to be experienced over the ropes, and with great depths it will probably be found most economical to use a rather low factor of safety and change the ropes more frequently, than to employ a high factor of safety with a longer period of use for the ropes, as such a proceeding would give a smaller size of engine with a corresponding reduction in initial cost. Taper ropes would materially reduce the weight hanging in the shaft and increase the efficiency of the plant. They have been little used in the past and are difficult and expensive to construct, but if a demand arose for such ropes it is only reasonable to assume that manufacturers would meet it.

* *Journ. Society Arts*, xliv., 57.

*Blanchet's Pneumatic System.**—The employment of round ropes is limited to a certain depth, as a point is reached beyond which they will not support their own weight. Taper ropes have theoretically no such limit, but practically they have, owing to the method of construction. To dispense with ropes altogether, Mr. Blanchet successfully applied at Epinac, France, the principle of the pneumatic tube.

The Hottingeur shaft was intended to reach 1100 yards, but, unfortunately, after attaining 711 yards no workable coal was found, and, although the pneumatic system has been used for winding on a small scale, it was never carried out in its entirety; but sufficient experience was gained to prove that the idea could be a practical success. At the same time, the results did not show that it was superior in economy to the system of employing ropes, if counterbalancing be adopted. The expense of the installation was enormous. One tube 63 inches diameter and about $\frac{5}{16}$ inch thick was placed in the shaft. It was made up in about 20 feet lengths riveted together with butt-joints and counter-sunk rivets. At first, it was thought that the tube would have to be bored, but such was found to be unnecessary, although each length was hammered to a perfectly cylindrical form upon a mandril. A diagrammatic representation of the scheme is given in Figs. 414 and 415, the former showing the cage at the bottom of the shaft, and the latter at bank.

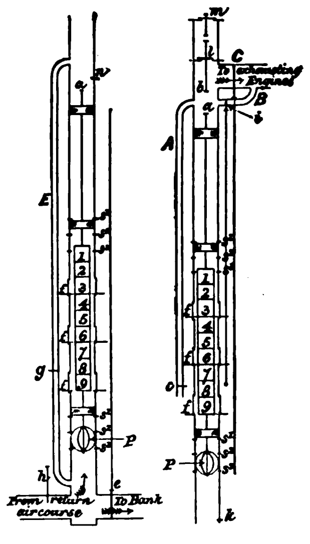


Fig. 414. Fig. 415.

The piston is made in two parts, one at the top of the cage and the other at the bottom, while the former is subdivided into two portions, placed at such a distance apart that in passing the doors through which the tubs are changed, one of them shall always be in an uncut position of the tube; this ensures the pressure remaining constant when the piston passes the doors. The lower part of the piston below the cage carries a parachute, *p*. The cage holds 9 tubs, one above the other; the load of coal carried is nearly 5 tons; and the total weight of the piston, cage, tubs, and coal is about 12 tons.

When the air is exhausted above the piston, the latter commences to ascend, while for descent, exhaustion is stopped, its connection with the exhaust engine severed by means of doors at C, and air allowed to pass upon the top of the piston through the regulator, *c*. To remove the tubs from the cage three double doors, *f*, are provided in the tube, both at the top and the bottom, these corresponding to

* "Tube atmospheric du puits Hottingeur." Z. Blanchet. *Soc. Ind. Min.* (2ᵉ Série), iv., 557, and vii., 273; T. W. Bunning, *N. E. I.* xxiii., 81. "Pneumatic Hoisting." H. A. Wheeler. *Amer. Inst. M.E.*, xix., 107. "Etude historique sur le puits Hottingeur des mines d'Epinac." M. Nougarède. *Soc. Ind. Min.* (3ᵉ Série), vii., 551.

three levels of the heapstead. Three movements of the cage take place to change the nine tubs, and to keep it steady while such is proceeding, three double sets of stops s^1 s^2 s^3 are introduced, and can be thrust into the tube or withdrawn by means of one lever. When the cage is confined between stops s^3 of the two sets, decks 1, 4, and 7 can be handled, while if the cage be confined by stops s^1 of each set, tubs 3, 6, and 9 are discharged.

At the bottom of the shaft the equilibrium pipe, E, goes from the bottom of the tube to a point sufficiently high to be above the piston during the whole time the tubs are being changed. When the cock, *y*, in this pipe is closed, the pressure of air on the bottom keeps the piston up against the top stops, and when the cock is opened, and the main inlet and outlet valves, *h* and *e*, shut, the air below is rarefied, and the cage falls on to the bottom stops. At the pit top, the two pipes, A and B, are provided with stop-cocks, *c* and *i*; the first is in connection with the atmosphere, to allow the cage to descend, while the latter is in connection with the exhausting engines, and is used to move the cage if required while banking is being performed.

When the cage ascends, the doors, *f f* and *e*, are shut, but when it arrives at the top it is made to stop, first, by automatically shutting at *k* the connection with the exhausting engine at C; secondly, by moving the valve, *l*, and admitting some air from the atmosphere, while if the ascent still continues, the valve, *n*, is lifted and the tube opened to the atmosphere. To avoid all shock when opening these valves, the top part of the piston carries a spring buffer, *a*. In the descent, when the cage arrives near the point where it has to stop, it automatically closes the escape valve at *n*.

The apparatus also serves to ventilate the mine. During the descent of the piston, the valve *h* is shut and *e* opened, and all the air contained in the tube is forced to bank, but during the ascent of the piston the valve *e* is shut and *h* opened, so that an amount of air equal to the contents of the tube is exhausted from the mine to be discharged into the atmosphere when the piston descends.

Koepe System.—In its lightest form a drum requires a large amount of energy to set it in motion, and an equal amount to stop it. In addition, for deep shafts the angling of the rope with the pulley is not only a disadvantage and a possible cause of accident, but a source of wear. To reduce this angling, and yet keep the drum relatively small in diameter and in width, the ascending rope is sometimes arranged to coil on the space from which the descending rope has been uncoiled.

To remove the objection to the weight, &c., of large drums, Mr. Fredk. Koepe designed the system where they are dispensed with altogether. The first application was made at Hannover Colliery, in Westphalia, and may briefly be said to consist in the substitution of a single grooved pulley in place of the ordinary drum. The winding rope passes from one cage over its head-gear pulley, round the "drum," and, after passing over the other head-gear pulley, is connected with the second cage (Figs. 416 and 417). The winding rope simply encircles about half the periphery of the drum, in the same manner as a driving belt on an ordinary pulley. There is a balance rope beneath the cages, so that the arrangement may be likened to an endless rope, the two cages being simply points of attachment. The drum pulley usually consists of the two outside cases of an ordinary cylindrical drum, bolted together and securing between them a band of hard wood in which a groove is made to receive the winding rope, the depth of this groove being generally equal to twice the diameter of the rope. Instead of being placed parallel, the head-gear pulleys are angled towards each other, with the object of reducing side friction.

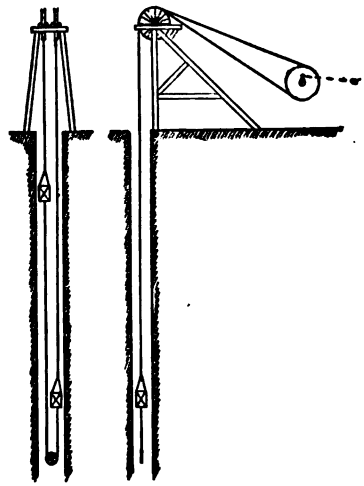


Fig. 416. Fig. 417.

The system has been in successful operation since 1877, and results show that the single winding rope lasts more than twice as long as the two ropes formerly adopted. Experiments made have determined that with a rope passing only one-half turn round the driving pulley, the coefficient of adhesion between steel ropes and wood rim is in practice 30 per cent., which would admit of an excess of 105 cwts. being placed on the present ascending load at Hannover Colliery before any slip can occur. The first application of this system in England was at Bestwood Colliery, Nottingham,* but after seven years' working it was abandoned (in 1890) owing to the slip which took place when the winding ropes were oiled. At this colliery such slip was most objectionable, because winding took place at an up-cast shaft which was cased in all round. The engineman could not see his cages, but had to rely entirely on the indicator. On the other hand, at Sneyd Colliery, North Staffordshire, where the second application of this system in this country was put down, its working has been, and is, most satisfactory.†

The merits and demerits of the system are fully explained in an elaborate inquiry by Mr. L. Trasenster,‡ and later particulars of the results obtained at Hannover Colliery are given by Messrs. Mahlet de Gournay, and Suisse.§

Since its introduction a large number of installations have been made in Germany, and all have been so successful that it is difficult to account for its non-application in other countries. Slip is prevented by using a rope of full size and running it without grease. Sometimes the ropes are coated with varnish or sprinkled with resin occasionally, and there is no instance on record of one breaking. In some cases the indicator is driven by gearing from the pit frame pulleys, and consequently the position of the cages is correctly shown, even should the rope slip on the driving sheave.

* *Ches. Inst.*, xi, 267. † *Fed. Inst.*, xviii., 450.
‡ *Rev. Univ.* (1879), v., 85. § *Soc. Ind. Min.*, (3ᵉ Série), i., 65 and 389.

When the cages reach the landing-place and rest on the stops, the weight is removed from the rope, and sufficient adhesive power does not exist on the rim of the motive pulley to enable the load to be re-started. This can be guarded against, either by dispensing with stops at the top, as is done at Sneyd Colliery, or by continuing the rope past the cages by means of cross-heads, above and below each cage, connected together by cross-pieces passing outside; the bridle chains are hung from the top cross-head, and when the cage rests on the stops the weight of the winding and tail rope still remains on the motive pulley. This was the arrangement used at Bestwood.

A modification of the Koepe system, where a flat rope is employed instead of a round one, has been used for some time at Crone in Westphalia, and a model of a suggested plant on similar lines for winding from a depth of 1312 yards was shown at Düsseldorf Exhibition in 1902. The ordinary objections to flat ropes do not apply here, because no lapping takes place, and the rope lies on an even surface, which is always of the same diameter.

The chief objection to the Koepe system is the probability that if one rope broke both cages would be precipitated to the bottom. If the breakage happened any distance down the shaft it is doubtful whether both cages would fall, because the frictional resistance of the piece coming up the shaft over the head-gear pulleys and around the drum would be sufficient to take up the pull of a moderate load, and, at any rate, may act as a sort of brake, and prevent the second cage falling at full speed. In some instances a brake block has been placed over the pulley, which, in case the rope broke, would be automatically wedged against the pulley, and would prevent the rope from slipping. This fear does not appear to be reasonable. In Germany the law provides that all ropes on Koepe hoists shall not be worked for more than two years, and, as previously stated, a broken rope is unknown. This is not surprising when it is remembered that, with ordinary ropes rigidly attached to a drum, a careless engine-driver may, by picking up the load sharply and with a small length of slack rope, throw a strain on to the rope equal to nearly three times the load, and that if this process be repeated many times during the day it must have a most injurious action on the rope. This cannot take place with the Koepe hoist, because there is not any slack rope, and even if any large load should come on to the rope it simply causes it to slip.

An installation at Viviers Colliery, Belgium, entirely removes this objection. Instead of one rope, two are employed The drum has two grooves, and there are four head-gear pulleys. Each rope passes from one cage, over its head-gear pulley, round one groove in the drum, over the other head-gear pulley, and back to the other cage. Each rope passes half round the drum—in fact, the arrangement simply consists of duplicating the Koepe system. The only difference is in the attachment of the ropes to the cage. It is obvious that it would be a very difficult matter to keep both ropes exactly of the same length, while, if they varied, and one became longer than the other, the shorter rope would have all the weight, and the longer one would in all probability be thrown out of the groove on the pulley, and might cause a serious accident. To prevent this, the ropes, instead of being attached directly, are connected to a tension apparatus which distributes the weight and puts an equal quantity on each. The two ropes, *a a* (Fig. 418), are terminated by an ordinary capping, *b b*, through which is passed an ordinary chain, *c*. This chain is endless and passes round a polygonal drum, *d*, on the top of the cage, but the sides of the polygon are rounded to fit the links of the chain (Fig. 419). This pulley can turn on an axis, and readily permits the chain to adjust itself to any variation in the length of the ropes. Two small cross chains, *e e*, connect the main chains, *a a*, so that in case of the breakage of either of the ropes the other one holds the load; and, finally, in case the chains, *a a*, should break, the cage is supported by a flat metal rope, having one extremity attached to the capping on the winding rope, while the other is connected to the cage. Instead of employing round balance ropes beneath the cages, two flat ones are employed, the strands of each being laid in alternate directions.

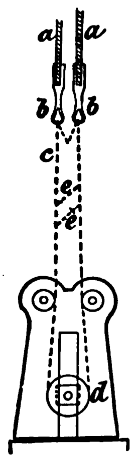


Fig. 418.

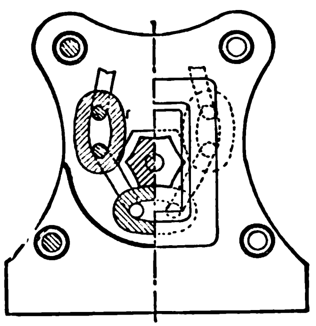
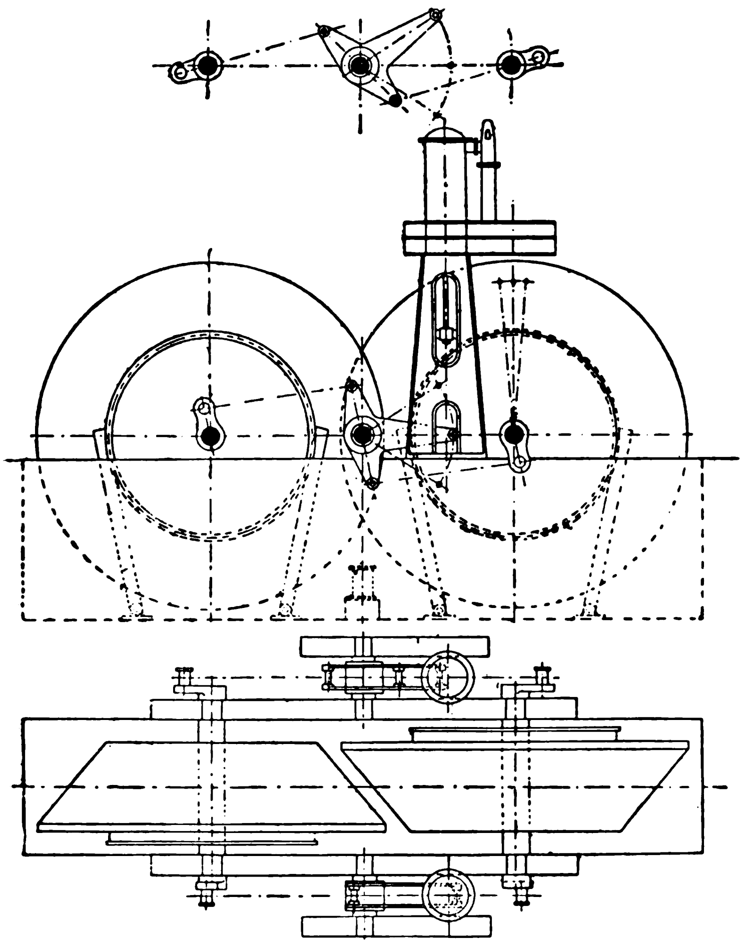


Fig. 419.

By doing this, it is claimed that any tendency to twist is entirely removed.

Whiting System.—The Whiting hoist is a friction drive like the Koepe, but in order to obtain more grip two grooved pulleys, both driven, are used, and the rope is passed several times round each. The arrangement employed in the best practice is exactly that illustrated in Figs. 318 and 319, except that the Walker differential pulleys are driven at a higher speed without intermediate gearing. The first sheave is driven direct by the main connecting-rods, while the second one receives its motion through a pair of parallel rods similar to those used on locomotives. The second shaft has to be slightly inclined to prevent the out-going rope fouling the second Walker pulley, and the parallel driving rods have to be made with a simple compensating device to avoid any risk of their binding. A tightening arrangement for adjusting the length of rope to wind from different levels is employed, consisting of a tension pulley on a carriage and a strong winch for moving this carriage on its track, similar in principle to the tension arrangement of an endless rope haulage installation; indeed, this method is endless rope haulage applied to a vertical lift. There is a tail rope beneath the cages.

Tomson System.—When the engines at No. 2 pit Preussen Colliery, Westphalia, were being designed, it was found, after deciding that spiral drums should be employed, that if the two were put on one shaft in the usual manner, its diameter would be over 30 inches in order to be strong enough to safely carry the working load. The impracticability of employing a shaft of such proportions led



Figs. 420 and 421.

Mr. Tomson* to divide the drum into two, and to place each on a separate shaft. The design of the complete engine is illustrated in Figs. 420 and 421. One drum is placed in front of the other and there are four cranks and four connecting-rods. The latter are not

* *Soc. Ind. Min.* (3e Série), x., 254.

coupled direct to the piston-rods as usual, but to two T-shaped pieces which can rock to and fro on a secondary shaft. The third end of the T-shaped rocking lever is coupled to the connecting-rod of the engine which is a vertical one. The opposite cranks of each drum are set at right angles. The position occupied by the cranks and rocking lever on the right-hand side of the drum, is drawn detached above the side elevation, in order that it may be compared with the position occupied at the same instant by the cranks, &c., on the left-hand side of the drum.

The engine is certainly complex, but it has been working satisfactorily since 1896, and renders possible the employment of a smaller and wider drum without excessive angling of the rope; indeed, each drum may be as wide as the two could be if they were both placed on the same shaft. The total weight of the engine is 460 tons, the drums alone weigh ng 115 tons and costing £1700. The winding speed is comparatively small, the run of 600 yards taking over sixty seconds as a minimum. Such an engine costs at least 30 per cent. more than the most modern type of four-cylinder tandem compound with ordinary drums designed to perform equal work.

Morgan's System.—When it became necessary to wind from a depth of 900 yards at Dolcoath Mine, Cornwall, Mr. W. Morgan decided to employ both an engine and drum of moderate dimensions, and then had to face the question of how the angling of the rope could be

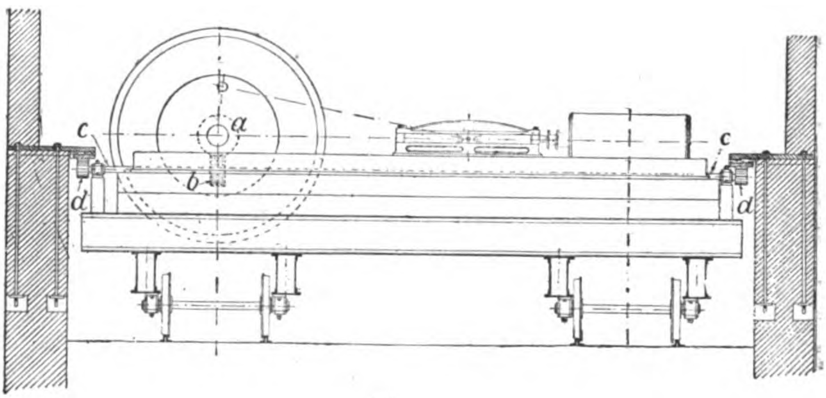


Fig. 422.

prevented with such an inordinately long drum as was required to hold the number of coils that had to be wrapped on it without overlapping. He adopted the novel procedure of mounting the engines on a carriage built up of girders, and fitted with wheels, and causing such carriage with the engine to traverse slowly with each revolution of the drum a distance equal to the diameter of the winding rope. The total travel is, of course, equal to the space occupied on the drum by all the coils of rope, and it consequently follows that all angling is prevented. Other advantages obtained are, the reduction in the size of the cylinders and the length of the stroke, which is rendered possible by the decrease in the diameter of the drum, with a consequent increase in the number of revolutions and in the piston speed,.

thus permitting expansive working to a much larger extent than is generally the case. Indeed, the chief objection to the use of expansion gears on winding engines is the comparatively short time they come into action under ordinary circumstances.

The engine which is shown in Fig. 422 is traversed automatically by the worm wheel, *a*, on the drum shaft gearing into the toothed wheel, *b*, keyed on a shaft, *c*, which runs the entire length of the engine, and which is provided with a cog wheel, *d*, at each extremity geared into a rack built on the engine house wall. The teeth of these cog wheels are equal in pitch to the diameter of the winding rope, and consequently at each revolution of the drum shaft, the engine moves a distance equal to the space occupied by one coil of rope. After the engine had been built and before it was erected, operations were suspended at the new shaft for which it was intended, consequently it is impossible to say whether it would have answered the expectations of its inventors, but there does not seem any apparent reason why it should be impossible to traverse a winding engine at a very slow speed, when we remember that huge cranes in engineering works are readily moved at comparatively high speeds without any difficulty or danger. Messrs. Holman Bros., the manufacturers, showed at the Earl's Court Exhibition in 1899 a working model one-sixth full size, which wound a weight up and down in a perfectly satisfactory manner.

Hopwood and Marshall's System.—In order to remove the prejudice attaching to a traversing engine, and to reduce the cost of construction, Messrs. Hopwood and Marshall suggest that the engine with its long drum should be fixed at right angles to the plane of the winding pulleys, and the rope carried round guide pulleys fixed horizontally near the engine, and that these guide pulleys should be traversed to and fro at the same speed as each coil of rope is wound on and off the drum.

Winding by Electricity.—Small subsidiary hoists, electrically driven, are in common use, and larger plants are now being applied in some cases.

The electrically-driven engine for the Zollern II. pit of the Gelsenkirchen Colliery, Westphalia, is designed to lift a useful load of 4 tons 3 cwts. from a depth of 1640 feet at a maximum speed of 65 feet per second. It consists of two 1400-H.P. motors keyed on the main shaft on each side of the driving drum, which is a Koepe pulley 19·68 feet diameter. Outside the motors powerful main bearings are arranged, having automatic ring lubrication. Two motors were selected in preference to one, because by series or parallel control the maximum hoisting speed could either be 32 or 65 feet per second, while if one motor became unworkable for any reason, the men could be raised from the mine by the other. An accumulator battery consisting of 250 elements is provided, and by gradually switching this in and altering the exciting current of the field magnets, the engine can be run at any speed from the maximum down to 3 feet per second. The gradual application of the voltage is attained by dividing the storage battery into four groups and switching these groups in step by step, using small starting resistances between the groups. In order to subject the groups and cells to as near as possible the same working conditions, the battery is discharged from right to left when one cage is ascending, and from left to right when the other cage is being lifted. A few cells at each end of the battery are charged by a separate small boosting dynamo, and can be switched in individually for the small movements necessary to unload the several decks of the cage. Energy is supplied to the motors as continuous current of 500 volts, and, in conjunction with the storage batteries, admits of an advantageous utilisation of the energy of the primary generator, and the acceleration of the load with a minimum loss. The starting gear consists of two perfectly separated starting resistances. For the maximum speed each motor starts on its own resistance, but for half-speed the two motors are in series and only one starting resistance is used. The starting and reversing arrangements are controlled by an auxiliary compressed-air engine, which is connected by a rack and pinion arrangement to the vertical shaft of the starting resistance, while a second lever, placed beside the switch lever, works a compressed-air brake, but this can only act when the switch lever is in the no-current position.

The winding arrangement at No. 1 pit Preussen II. Colliery, Westphalia, is designed to lift 100 tons of coal per hour from a depth of 765 yards. The total lift is made up as follows:—

Useful load, 4 tubs, 1210 lbs. in each,	2·16	tons.
Cage and gearing,	3·74	,,
Four tubs, each weighing 772 lbs.,	1·37	,,
Rope, about 2395 feet at 4·5 lbs. per foot,	4·81	,,
	12·08	,,

The direct use of high tension alternating current has been adopted as a necessary condition of the modern desire for centralising power, and the possibility of transmitting large currents to great distances without notable loss. The starting and regulating apparatus is also of a much simpler and sturdier character than the complicated arrangement of collecting-rings, brushes, &c., in continuous current machines, which, in spite of the most careful arrangement, are given to sparking and wearing out. The installation includes three primary generators, which, in addition to serving the winding engine, supply current for underground pumping engines and other accessory devices both above and below ground. Each generator is designed for a duty of 550 K.W., and delivers three-phase current at 2000 volts with a periodicity of 50 alternations per second when running at 94 revolutions per minute. Motive power is furnished by a twin-compound steam engine of 800 H.P. The winding engine has a Koepe disc of 19·7 feet diameter, and a rope of 1·77 inches diameter. The speed in drawing minerals is 52 feet per second, and not more than 16·4 feet when raising or lowering men. For the examination of the rope or the shaft it may be slowed to whatever limit may be desirable.

The winding mechanism is driven by a three-phase alternating current motor whose armature is keyed direct to the shaft carrying the Koepe winding disc. The main current of 2000 volts is supplied to the field magnets by the insulated cables shown in Fig. 422*a*, which gives the connections in detail. Safety fuses and a safety cut-off switch, as well as the reversing switch, are also interposed in the main circuits. The latter is worked from a hand lever in the same way as the valves of a steam winding engine; when the lever is in a mid-position the current is cut off from the motor, which is thrown into forward or back gear by a corresponding movement of the hand lever. The starting of the engine and the regulating of its speed is effected by the liquid resistance in the armature circuit. Each of the three phases of the armature circuit is led to electrode plates, which are each insulated and suspended in a cistern through which a solution of caustic soda is kept in circulation, the rate of flow being dependent upon the position of a regulating valve at the bottom of the cistern, so that by proportioning the aperture the immersed

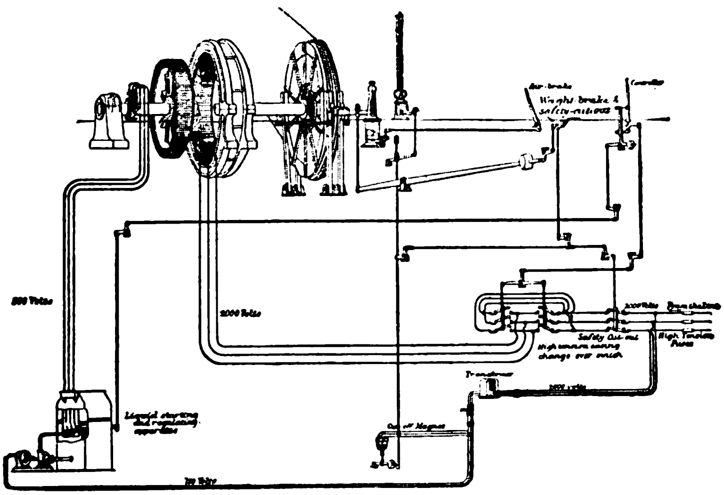


Fig. 422*a*.

surface of the electrode plates and the resistance may be varied within any desired limit.

When the valve is closed the cistern fills to an overflow notch, which gives the maximum of immersion, minimum of resistance, and consequently the highest rate of winding speed. The regulating valve is controlled by a combination of levers from the hand lever that works the main reversing switch. When the latter is notched in position, forward or backward, the hand lever is free to move through a certain distance towards the centre for the purpose of regulating the cistern valve. As the rate of variation of the level of the fluid in the cistern depends upon the discharge of the circulating pump, the latter is so proportioned that the change can be only slowly effected, and the possibility of starting at a higher speed than is compatible with the necessary frictional adhesion of the rope on the winding disc, or the permissible overload of the engine is prevented. The level of the fluid is, however, so arranged that the cistern can never be completely emptied, so that a small area of wetted surface of the plates is constantly provided. This allows the engine to start directly the main circuit is closed by the starting handle. All the parts of the installation carrying currents are railed off, so as to be visible without being accessible to the touch. The different accessory arrangements are placed below the floor, and are inaccessible until the current is cut off. The motor casings, switch, stands, and rods are earthed, so as to be entirely free from electric tension or current of any kind.

The brake arrangements are similar to those of a steam winding engine, a ring of the full diameter of the disc being fixed on either side of the latter. The rubbing blocks are applied by levers worked by a compressed-air engine, which can be worked by hand during the operations of loading and landing tubs. It can also be applied by a lever in connection with the depth indicator in the event of overwinding, the same movement also cutting off the current on the main circuit, and the arrangement of a similar kind applies the brake in the event of the failure of the current by the burning out of a safety fuse. This is worked by a falling weight, which is only held up by an electro-magnet so long as the current passes. The same movement serves to open the safety switch. These accessory appliances are operated by a low tension current supplied by a small transformer. Finally, in the event of the air cylinder failing, another falling weight arrangement is provided which can be applied by a treadle close to the starting lever. This, in like manner, cuts off the current by the safety switch.

Prevention of Overwinding.—Unfortunately, overwinding sometimes takes place, and the cage and its contents are lifted too far, and dashed violently against the timber at the top of the pit frame. To prevent the rope from being broken, and the cage dropped back again down the shaft, detaching hooks are employed. These may be divided into two classes; those which simply detach the rope from the cage, and those which detach the rope, and, at the same time, prevent the cage from falling. The former were first employed, but as additional means had to be provided for holding the cage when released, which involved the introduction of another complication, they have entirely given way to the latter, where one instrument serves both purposes.

There are many efficient disengaging appliances in use, all of which perform their work well, and only differ from each other in matters of detail. Perhaps the best known ones are King's, Ormerod's, and Walker's. In all of them, detachment is effected by passing the rope through a circular hole in an iron plate, or through an iron cylinder, the size of which is sufficient to allow a portion of the hook to pass through in its working state, but not to allow it to fall back again when disengagement has taken place.

King's hook consists of two outside fixed plates, enclosing between them two inner movable ones, which can oscillate about a strong pin passing through both plates and framework. The upper end of both these plates is made of uniform width, except near the bottom, where two projections (*a a*, Fig. 423) are fixed, which prevent the hook from passing entirely through the hole in the disengaging plate. The winding rope is attached to the top shackle, *d*, and the cage to the lower one, *e*. When the two movable plates are placed on the central bolt, *b*, their upper parts close in opposite directions upon the connecting pin of the winding rope shackle, and entirely overlap it, and in such position are secured by a copper pin, *c*. In case of overwinding, when the hook passes into the ring of the disengaging plate, the two projecting pieces, *a a*, are forced inwards, the copper pin sheared, and the jaws at the top forcibly separated from each other, releasing the shackle pin, *d*; at the same time the two projecting pieces are forced outwards, *f f*, and prevent the cage dropping back (Fig. 424). This

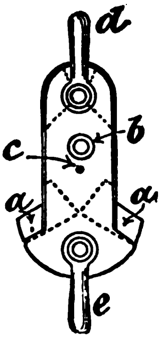


Fig. 423.

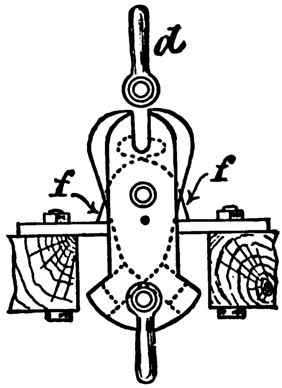


Fig. 424.

hook has been improved by slightly reducing the height of the two outer plates and flanging the top of the two inner ones, thereby thickening them over the point where the shackle pin passes through, and obtaining nearly three times the wearing surface at the place where the working strain comes on.

Ormerod's hook is very similar to the foregoing one. The only objection that can be raised against either of them is that, being constructed of plates, there is a considerable amount of side friction, and

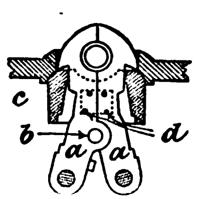


Fig. 425.

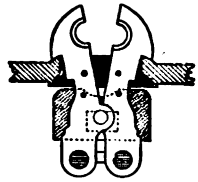


Fig. 426.

unless they are regularly taken apart and oiled, there is a probability that the plates will firmly rust together.

Walker's hook acts on an entirely different principle. In those just described, the weight is utilised to prevent displacement, while here the load is always endeavouring to cause detachment, but prevented from doing so by a hoop encircling the hook. Its construction will be understood from Fig. 425. Two levers, *a a*, are pivoted about the centre, *b*, and kept from opening under ordinary conditions by the collar, *c*, held in position by the copper rivets, *d*, which also secure an additional safeguard, consisting of a tongue passing from one jaw to the other. When the hook enters the plate, the collar is pushed downwards, and the two rivets sheared; the upper part of the jaws open, release the winding shackle, and lock the suspension jaws on the disengaging plate (Fig. 426).

Safety Cages.—The apparatus just described do not safeguard the cage in the event of the rope breaking. To perform this operation, innumerable devices have been designed, none of which have, however, met with permanent success in this country, although many are working in France and Germany. These safety cages usually depend on the action of a grip, which is kept away from the guides so long as the weight of the cage is borne by the rope, but immediately fracture occurs, a spring, which has been kept in compression, is released, and the grips clutch the guides and prevent falling. The objections to such appliances are numerous. At modern collieries, the velocity of the descending cage approaches that of a falling body, and there is always a danger of such appliances coming into action when not wanted. Then again, the result of suddenly stopping a cage travelling at such a speed would be that, unless the safety apparatus was exceedingly strong, in all probability it would break and release the cage, while if it was strong enough, perhaps the guide ropes would be broken. In either case, if men were travelling in the cage, the probabilities are that the shock would be so great that they would be thrown out; indeed, instances are on record where with a detaching hook the velocity of the ascending cage has been so great, when detachment has taken place, that men have continued on in obedience to Newton's first law of motion, and have been seriously injured by being dashed violently against the top of the cage, even after the latter had stopped. Indeed, the high speeds referred to and the general introduction of wire conductors, in place of wood, have made safety cages inapplicable. The best safeguard against ropes breaking is to employ none but those of the very best quality, and to give them careful treatment and regular and efficient inspection.

Safety Props in the Head-gear.—The fact that the rebound of the cage, after the detaching hook has acted in an overwind, has been known to throw such a strain on the cage chains as to break them, and thus drop the cage, leaving the detaching hook suspended on its plate, led Mr. Sebastian Smith* to design an arrangement of catches in the head-gear frame which are closed under ordinary conditions, but which open beneath the cage directly it has passed through them. When these props are open, their front faces project in an inclined direction beyond the face of the head-gear frame and terminate with projecting beaks. Consequently, when an overwind takes place, if the cage chains should break, the cage in dropping would be caught between the inclined faces of the props, and possibly arrested by their wedging action, but should the cage continue descending in spite of the wedging force, and drop to the bottom of the inclines, it will then be effectually stopped and supported by the beaks of the props.

Automatic Contrivances.—Detaching hooks do not prevent overwinding; they only reduce the damage done, and often prevent loss of life. In addition, they do not safeguard the descending cage. Two classes of automatic contrivances are used. In one, some projecting

* *Fed. Inst.*, xii., 564.

lever is fixed above the pit's mouth, which, when struck by the cage, puts on a brake; these are not any more effective than disengaging hooks, as they come into operation too late. In the other type, an instrument is so arranged that, providing the engineman shuts off steam at the proper moment, he is in exactly the same position as if no such appliance existed, as it does not come into action; but if at a determined point in the wind the speed is greater than it should be at that point, the steam is cut off from the engine, and a brake applied.

The Visor.—In this appliance, which has been in use by the Wigan Coal and Iron Co. for some time, a shaft (E, Fig. 427), carrying two beaked cams, E^1, performs one revolution to each wind, such motion being obtained by the bevel gearing endless screw, shown at D and D^4. At each side of this cam is a tappet, F, which is engaged by one of the beaks, if the engines are going beyond the proper speed, such engagement being performed by the aid of the governor and levers, H and G^3. Usually two governors are provided, weighted for different speeds. What takes place is as follows:—When the engine is travelling at high speed, the rise of the governor lifts up the lever, H, and throws the two tappets, F, into the path of the beaks, E^1, on the revolving shaft, E. If the speed decreases at the proper moment towards the end of the wind, the governor falls and throws back the tappets, F, consequently the appliance does not come into action, but if the engines are travelling above their proper speed, one of the beaked cams catches the tappet, F, and raises it; the arms, F^1, cross-head, F^2, and bar, F^3, are raised also, and the pawl, C, disengaged from the catch bar, B^1. Immediately this takes place, the brake is applied and steam shut off. A somewhat similar appliance has been designed by Mr. C. H. Cobbold,* which also acts through a governor.

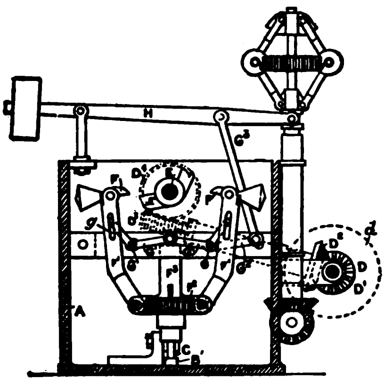


Fig. 427.

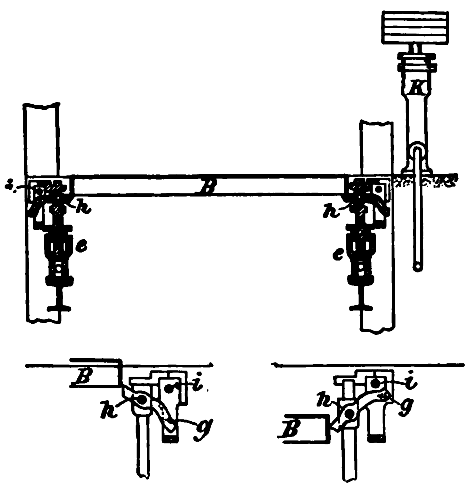
Grimmitt's Apparatus.†—Both the appliances just described are open to the objection that the engine receives a great shock by the sudden application of the brake. In Grimmitt's appliance this difficulty has been overcome by employing a pneumatic arrangement, which buoys up the brake lever for a few seconds after it has been cast loose by the apparatus. As air escapes from a regulating tap, the air-vessel and lever sink lower and lower, gradually increasing the pressure of the curbs on the brake wheel. Several designs of such appliances are used on the Continent of Europe. At all the Lens Collieries the winding engines are fitted with an apparatus which automatically cuts off steam at a determined point at every wind. A tappet on the indicator opens a valve when the cage reaches a distance of some 35 yards from the top, and shuts off steam and applies the brake.

* *Fed. Inst.*, i., 61. † *Ibid.* ii., 243.

Catches at Pit Top.—At the great majority of collieries, some appliance is used to hold the cage while the changing of the tubs takes place.

Keps.—The common form consists of a series of legs, usually four, arranged in pairs on two sides of the cage. They are pivoted on a shaft, and are readily pushed aside by the cage on its upward journey, but have to be moved out of the way again to allow the cage to descend. Such form is shown at *dd'*, Fig. 440. In another form, a series of projecting bolts are arranged in the main timbers at the top, which are pressed outwards by springs, and can be moved back by levers. Such type is not so suitable for heavy loads as ordinary legs, as the wear is considerable, and a greater strain is thrown on the framing at the pit top.

Hydraulic Keps.—With the ordinary form of legs, if the cage is at bank, it cannot descend without being lifted off the props, as the banksman cannot withdraw them while the weight is on. If a three-deck cage is used, and each deck changed independently, seven reversals of the engine have to take place, each deck requiring two,



Figs. 428, 429, and 430.

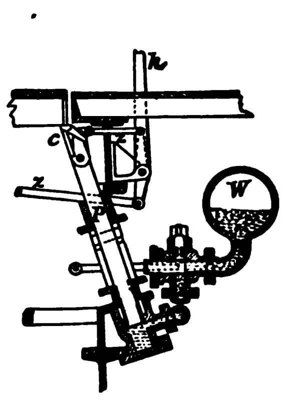


Fig. 431.

and the final lowering of the cage another. This not only occupies time, which is so valuable in winding, but causes considerable wear and tear of the machinery and consumes steam. In addition, slack rope is payed out on to the bottom cage, and as this is usually quickly drawn up, a very injurious shock is given to the rope. Several devices, all coming from the Continent of Europe, have been designed with a view of securing the cage firmly while changing is going on, but to release it again for descent into the shaft, without the preliminary lift of a foot or so, and consequent reversal of the engine.

Frantz's* appliance used at Camphausen Colliery, Saarbrücken, consists of four plunger cylinders (*e*, Fig. 428), provided with stuffing boxes and pistons, joined together by wrought-iron tubes. Each

* *Lehrbuch der Bergbaukunde.* G. Köhler, 1884, 386.

plunger is provided with a double lever, g, having its turning point on the piston itself. One end of this lever projects under a fixed pin, i, while the other serves as a support to the bottom of the cage. The rise of the piston and double lever is caused by water in the accumulator, K. The ascending cage, B, lifts the front end of the lever, g, upwards (Fig. 429), which by reason of its own weight falls back into the horizontal position immediately the cage has passed. When the cage rests on the legs, it is supported by the water in the piston, connection between the plunger cylinder and accumulator being cut off by a tap. When the cage has to be lowered, this tap is opened, and the weight of the tubs and contents presses down the plunger, drives back the water in the accumulator until the lever, g, takes the position shown in Fig. 430. As soon as the cage has passed through, the accumulator again forces the piston and lever into the higher position, and the tap above referred to is closed.

At Camphausen I Shaft, a somewhat different arrangement is in use. The four pistons, p, stand obliquely and have at the top an end (c, Fig. 431), turning round a bolt. When the hydraulic apparatus is not required, these legs, by means of the lever, h, and the connecting-rod, z, can be pushed backwards and forwards just as in the ordinary way. A still greater variation consists in using an air vessel, W, instead of an accumulator. This vessel is filled with water up to the middle, the upper space containing air at a pressure of two atmospheres, which serves the same purpose as the weight of the accumulator, but by reason of its elasticity works more advantageously.

The disadvantage of such apparatus is its complicated nature, liability to get out of order, and the fact that in cold weather the water freezes. The latter has been overcome by employing glycerine in the rams and accumulators.

Stauss Props.—These are an ingenious arrangement of levers, without any complicated parts, designed to secure the same object. With them only one reversal of the engine takes place, that is immediately the cage is brought to the bank, the direction of movement being always afterwards a lowering one. The apparatus consists of two shafts, a and b (Figs. 432-434), fixed in bearings; the legs, c, upon which the cage rests, are threaded on another shaft, d, which can swing about, but is attached by a link to the shaft, a. The shaft, d, is connected to b by a toggle-joint lever, e and f. As shown in Fig. 432, it is impossible for the props, c, to slide in a horizontal direction, as the two levers, e and f, prevent such motion, but they allow the cage to pass through when coming to bank, for, being loose on the shaft, d, they rotate about their axis, and take the position shown by the dotted lines, dropping back on to their seating as soon as the cage has passed. When lowering is desired, the banksman pulls over a lever, moves the link, g, in the direction shown by the arrow, and rotates the shaft, b.

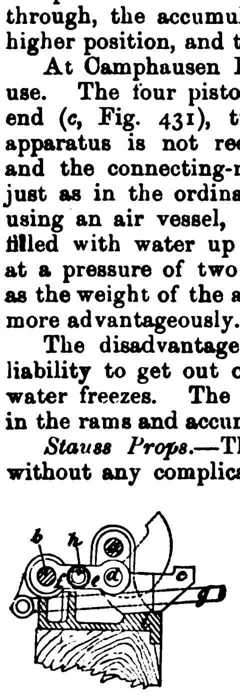


Fig. 432.

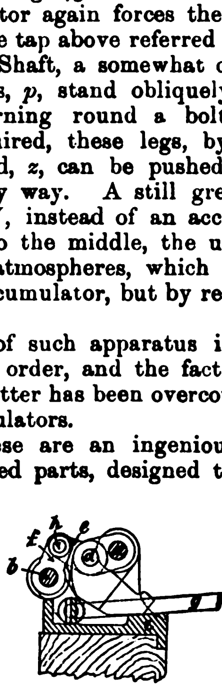


Fig. 433.

This lifts up *f*, until the point, *h*, is a little above the straight line joining *d* and *b*. Immediately this takes place the weight of the cage does the rest, as the props, *c*, slide on an inclined plane, *i*, having a slope of about 9°. The whole apparatus takes the position shown in Fig. 433. The simplicity of the appliance is its chief recommendation, while its cost is not more than the ordinary form of legs. Its wear should be unlimited, as there is nothing to get out of order. At Bascoup it is claimed to effect a saving in time of 15 per cent. With it, 78 to 88 cages per hour have been drawn up, and the three decks changed, from a depth of 268 yards.

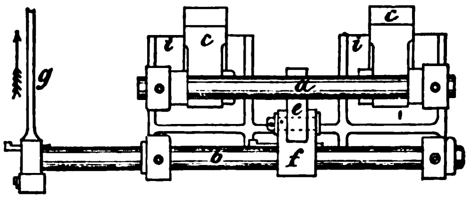


Fig. 434.

Changing Tubs.—In order to avoid moving the cage so many times, it is usual, when it has several decks, to change two of these at the same time. Supposing the cage has four platforms, the first and third will be changed at one operation, the cage will then be moved and the second and fourth decks changed. By doing this, the cage is only moved once, where otherwise it would have to be moved three times. It means more labour, because with only one landing, one set of men will do the work; with several landings, a set of men will have to be employed in each.

One additional advantage is obtained by changing all the tubs at one operation when the cages are fitted with the relieving gear, and the head gear pulleys mounted on springs as shown by Figs. 381 and 382 respectively, as it has been found in practice that when the loaded tubs are removed the springs lift up the cage slightly, but to such an extent that the legs can be withdrawn from beneath it. It can, consequently, be lowered away without the preliminary lift that generally has to be made by the engineman.

Hilda Colliery.—The general method of caging two decks at once is well illustrated at Hilda Colliery, South Shields, where the details have been carefully thought out. The inset is divided into two stages, and all the tubs from the workings arrive at the top level and run down a gradient of ½ inch to the yard, either to the shaft to supply the top platform, or to a drop cage, by means of which they are lowered to the bottom level to supply the bottom deck. A plan of the arrangement of the rails is given in Fig. 435. The empty tubs from the top deck gravitate down an inclination of 3⅛ inches to the yard to the point *a*, and are carried by the momentum they have attained for a short distance along *a b*, and up a slight gradient, *b c*, sufficiently far to clear the points, *b*. Their direction of motion is reversed, and they then run along the line marked "empty tubs," indicated by the arrow, and deliver themselves to the point *d*, where they are made up into sets and hauled away to the workings. The full tubs for the lower decks, after being dropped by the cage, *e*, gravitate to the shaft, and the empty ones towards the cage, *f*, which is connected by a rope to the drop cage, *e*. As the weight of the latter and the full tubs are heavier than that of cage *f* and its empty tubs, when *e* is lowered it lifts up *f* and the empty tubs to the top level, where they are automatically released from the cage, and gravitate away to join those at *d*, which have already come from the top deck.

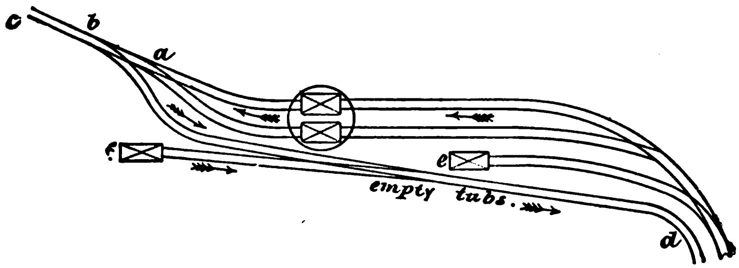
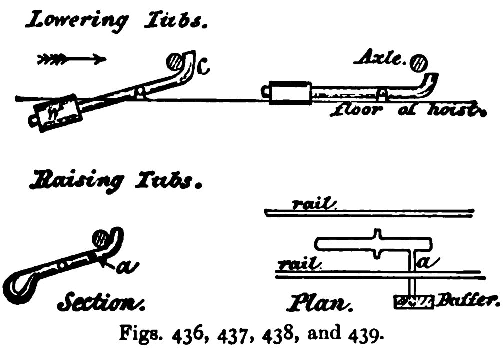


Fig. 435.

The following automatic catches are used for keeping the tubs on the cages during their ascent or descent:—(*a*) During lowering, the tubs run in from the direction shown by the arrow (Fig. 436), the axles being caught by the catch, *c*, maintained in position by the weight, *w*. On reaching the bottom the weight strikes the floor and lowers the catch, allowing the tubs to run off (Fig. 437). (*b*) When raising tubs; the position at the bottom is shown by Fig. 438; on reaching the top the crank lever, *a*, strikes a buffer at the side which liberates the tub (Fig. 439).



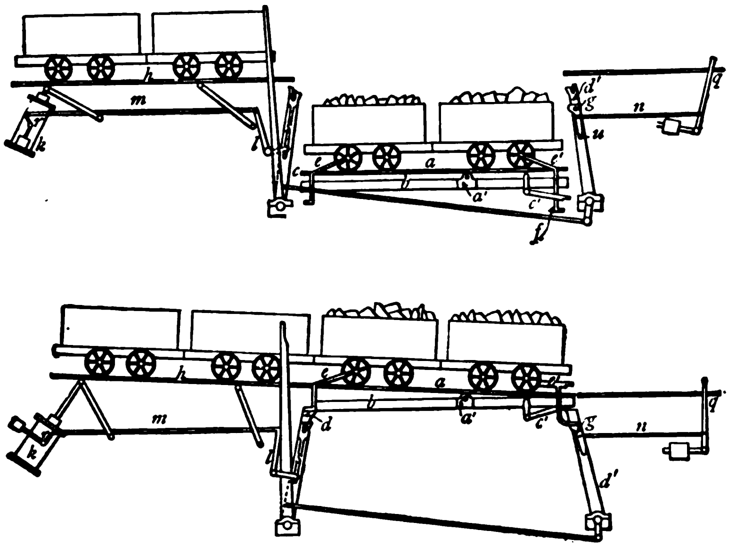
Figs. 436, 437, 438, and 439.

Clifton Colliery.—Mr. Henry Fisher* has designed an arrangement in which the rails (*a*, Fig. 440) are pivoted about a point, *a′*, fastened to the bottom of the cage. In the illustrations, only the bottom part of the cage is shown, the vertical side-pieces and diagonal struts being omitted for the sake of clearness. At one end of the rails are two feet, *c*, and at the other, two levers, *c′*, projecting below the bottom of the cage when it is suspended. When the cage is lowered, the feet, *c*, rest on the props, *d*, and raise the rails at that end of the cage, while at the same time the lever, *c′*, rests on the props, *d′*, and lowers the rails at the other end, the result being that the tubs gravitate away. Before the rails are inclined, the tubs are held on the rails by the stops, *e e′*, which press against the axles, but

* *Ches. Inst.* xi., 212.

simultaneously with the rails, *a*, being inclined, a foot, *f*, attached to the stop, *e'*, rests on the prop, *g*, and raises it to the position shown in Fig. 441, and allows the loaded trams to run away. The prop, *g*, is pivoted about a shaft, *u*, and is connected by a rod, *n*, to a lever, *q*. When the axle of the first loaded tram presses against this lever, *q*, the prop, *g*, is withdrawn from under the foot, *f*, and the stop, *e'*, takes the position drawn in Fig. 440, in time to prevent the empty tubs running through the cage.

In addition to the tub-releasing gear, the empty trams are run on the cage by the aid of a movable platform, *h*, connected with an oscillating cylinder, *k*, to which air or steam is admitted by an ordinary three-way cock, *r*. Simultaneously with the inclining of the rails on the cage, the foot, *c*, presses down the tappet rod, *s*, and gives motion through the crank lever, *l*, to the connecting-rod, *m*, which opens the



Figs. 440 and 441.

tap, *r*, and admits steam to the cylinder, when the platform, *h*, is raised to the same inclination as the rails on the cage (Fig. 441). As soon as the cage is lifted from the props, steam is discharged from the cylinder, and the platform, *h*, falls to the horizontal position. The oscillating platform seems to be an unnecessary complication, as the rails might easily be arranged on a permanent incline.

Fowler's Apparatus.—In the arrangement designed by Mr. G. Fowler for simultaneously changing all the decks, in addition to the cages travelling on the shaft two subsidiary cages, having as many decks as the winding cage, are erected on the front side, and two similar ones on the back side of the shaft. These subsidiary cages rest on plungers which move in hydraulic cylinders. Similar lifts are fitted below ground, and the winding cage stands between its corresponding subsidiary lifts above as well as below ground. Fig. 442 shows the apparatus in the position when the cage has just arrived at bank with its load of full tubs; the platforms, *a a a*, contain the empty tubs, while *b b b* are ready to receive the full ones. The tubs on the lower platform are pushed off by manual labour; simultaneously with this, the empty tubs on the two upper decks are thrust forward by the hydraulic rams, *c c*, and displace the loaded ones on the cage. The catches for retaining the empty tubs are then put into position by the movement of one rod (not shown) and the cage is ready to proceed on its downward journey, the time occupied in changing being exactly the same as if only one deck was in use. The two platforms, *a* and *b*, are then allowed by the hoists, *c* and *d*, to sink; *a* is ready to receive empties, its decks being successively brought by the hoist to the bank level, and *b*, having been allowed by similar means to bring its middle deck to the bank level, can be further lowered for the removal of its uppermost loaded tub. As soon as this is done, the counterbalance weights, W, bring it back into position ready to receive the full tubs

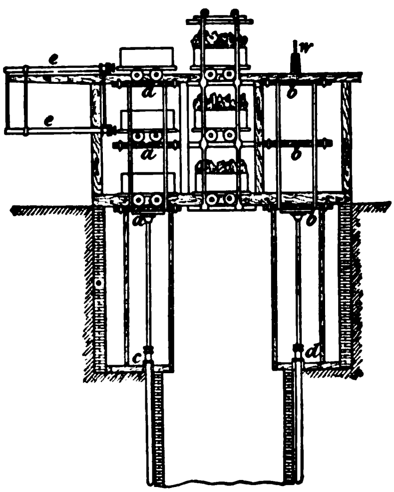


Fig. 412.

again. Time is saved in changing the tubs on the cage, because the operations of taking off the full tubs and putting empty ones on the hoist is performed while the wind is taking place. After nearly twenty years' experience with this apparatus at Denaby Main, Mr. W. H. Chambers, when applying it at Cadeby Main Colliery, Yorkshire, modified the details in several important directions in order to obtain a more rapid and certain movement. The duplicate cages are each supported by three rams, and water pressure is maintained by an accumulator in the two outer rams, while the contents of the central and smaller ram can be exhausted into an open cistern. The subsidiary cages are lowered by opening the exhaust valve of the central ram which so reduces the lifting power that the weight of the cages overcomes the resistance of the outer rams. The rapidity of the descent is controlled by the amount of opening of this valve. Instead of employing separate rams for propelling the empty tubs on to the cage and the full ones off, the pushing rods are supported by rollers and are attached to a vertical travelling beam running on rails which is connected through struts and a rocking lever to an oscillating hydraulic ram. In this way all the pushing rods are bound to move forward at the same instant and with equal speed. Under the old arrangement, it was found that as each ram was independent, they frequently travelled at varying speeds owing to the possible existence of a leaky valve, or a tight cup leather in the stuffing box. The pushing rams are withdrawn by a balanced weight immediately the winding cage has been loaded.

The time occupied in changing the eight tubs on the four decks of the cage is about five seconds. As soon as this has taken place, winding recommences, and while this is going on the subsidiary hoists at the front and back are lifted simultaneously, the former to be filled with empty trams ready for the next arrival of the drawing cage, and the latter to discharge its load of full tubs.

It should be noted that with this arrangement the hydraulic machinery has to be powerful enough to lift the subsidiary hoist and its complement of full tubs, because the winding engine only brings the top deck of the main cage up to screening level.

Tomson's Apparatus.—This arrangement is also a modification of Fowler's idea, but designed to require less motive power to work it. Subsidiary cages in front and at the back of each winding cage are employed, but the two in front are suspended by a common chain passing over a pulley, so that one ascends while the other descends. The back pair are similarly arranged, and all are supported by rams which move in hydraulic cylinders. These cylinders are arranged that the forward one on the right is in connection with the back one on the left, while the other two are also connected crosswise. The connection pipes pass through a controlling apparatus so constructed that :—

(1) Two opposite lying cylinders may be placed in direct communication and the passage of water from one into the other regulated to control the speed of motion.
(2) Either cylinder can be put into connection with the waste pipe, and the cylinder lying opposite to this, or both together or separately, in connection with the pressure service pipes.
(3) The service pipes can be put into connection with a hand pressure pump.

This apparatus is supplied by water under pressure, but owing to the peculiar system of balancing, the hydraulic power is not needed when the loading is normal and is only employed under exceptional circumstances. The descending auxiliary cages are always heavier, owing to the number of tubs on them than the ascending ones, and this provides the motive power.

The controlling apparatus is operated by one man, and consists of a set of valves worked by two levers, A and B. When the levers are in mid position the cages are locked. When lever A is moved forward, the right-hand hoists, front and back, rise, and the others fall. The reverse movement takes place when the lever, A, is pushed backward. When the loading of the hoists is not normal, both levers, A and B, are moved forward or backward, as the case may be, and water admitted to the cylinders from the hydraulic pressure main to operate the lifts. There is a hand pressure pump connected with the controlling apparatus which can be used whenever the chief supply fails.

The rails on the main and subsidiary cages are inclined at such a gradient that the tubs run on and off without being pushed. The tubs are retained on the cages and hoists by suitable stops, which are all operated by the movement of one lever immediately the winding-cage arrives at the banking level. Consequently all the decks are changed at once.

This apparatus effects a considerable saving of water, as the motive power is really obtained from the winding engines owing to the fact that the main cages travel a greater distance than the mean depth of the pit, the actual caging taking place above the banking level at the surface, and below the inset level at the bottom of the pit. The changing is not quite so rapid as when rams are used to push off the tubs, because these have to start from a state of rest under the influence of gravity, and a badly greased tub may delay operations. Neither is the action quite so certain. A ram overcomes any slight obstruction which may prevent the tubs starting on a small gradient.

The more perfect arrangement for very rapid changing appears to be a combination of the Tomson hoists with the Chambers pushing off rams.

Harris Navigation Colliery.—At the downcast pit, two decks are changed at once. The full tubs run off the top deck, in the opposite direction to those going off the bottom deck, and proceed round a circular platform, having a gradient of about 1 in 40, to the other side of the pit, where they join the loaded tubs from the bottom deck, the whole lot then going to the screens. The empty tubs to change *both* decks are raised by a steam hoist to a platform about 6 feet 6 inches high; part of them run straight to the shaft (to change the top deck), while the other part run round a second circular platform with a descending gradient, and reach the opposite side of the shaft, where they are placed on the lower deck of the cage (Fig 443).

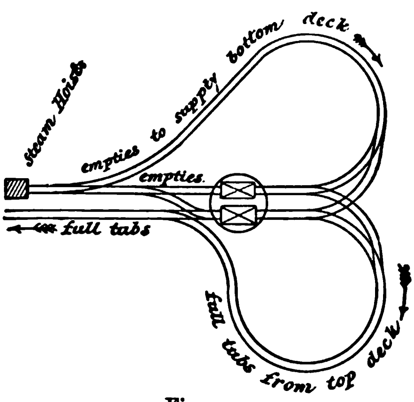


Fig. 443.

The steam hoist discharges its tubs automatically, as a stop is placed in the guides which tilts up the bottom. The cages are also provided with a loose bottom, pivoted about a pin. By an arrangement of projecting pieces and tub stops, similar to those in use at Clifton, tubs automatically discharge themselves as soon as the cage is lowered on to the keps.

Bell End Colliery.—At Bell End Pit, where the shaft only contains one cage, the author is employing a combination of several arrangements. The cage is double-decked, and each is changed independently. The rails are set at a permanent inclination, and the tubs are kept on by a hinged arm, but at the landing-place are released by an automatic arrangement described a little later on. At the bottom, the lower deck is received on a set of Stauss props, the tub is released and gravitates away to a platform. The cage is then lowered without reversing the engine, and the top deck tub released, which then runs to the same platform. The full tubs are now on the cage, which starts away to bank.

The platform referred to is attached to a hydraulic ram and pivoted about a point slightly away from its centre (Fig. 444). When the tubs are on, it therefore takes a certain inclination limited by a stop. The curved guard, *b*, prevents the tubs running through, and the inclined surface will not allow them to pass out during the lift. The hanger-on pulls the lever, *a*, the platform and its contents rise a distance of about 6 feet. On arriving at the top the platform automatically stops through catching the lever, *d*, and cutting off the pressure, and is tilted in the opposite direction, when the tubs run away on the top landing, *c*, and gravitate to the point where they are attached to the haulage ropes; the platform then descends, ready to receive another consignment of empty tubs.

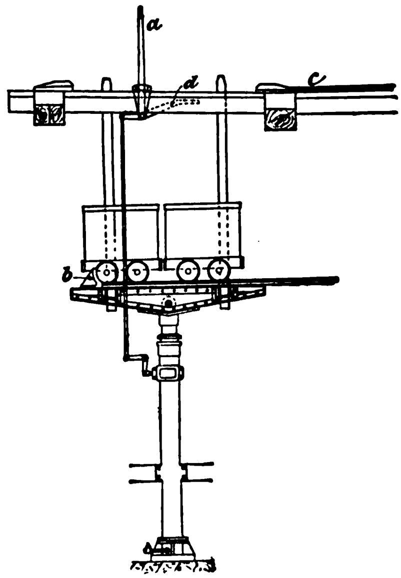


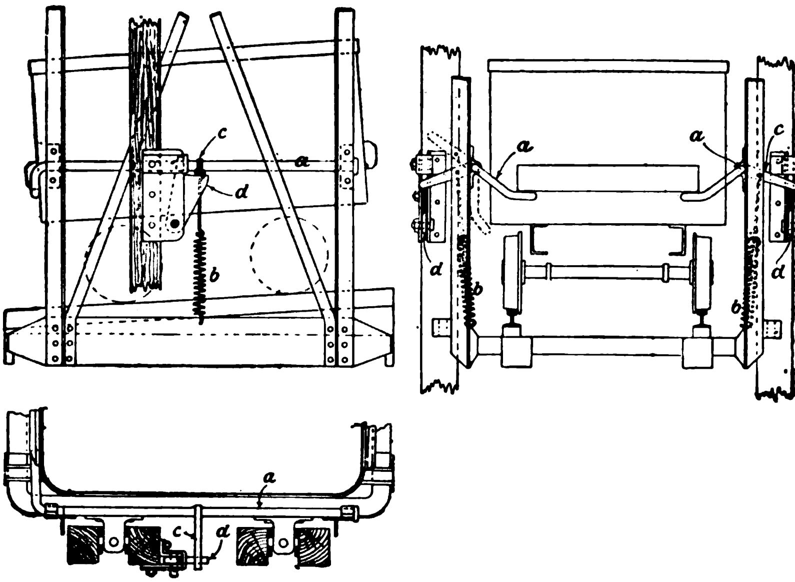
Fig. 444.

The releasing gear employed is that designed by Mr. W. R. Wills.* The inclination of the rails on the cage is such that the tubs will only run forwards, and these are held on and released from the cage by the mechanism shown in Figs. 445, 446, and 447. The L arms, *a a*, revolve in suitable bearings, fixed to the side of the cage, and the angle pieces rest against the front end of the tub, but are prevented from rising too high by a stop (not shown in illustrations), while they are kept in their proper place by a spiral spring, *b*, attached to levers, *c c*, projecting outwards. On the cage being drawn out of the shaft these levers strike against and lift two catches, *d*, which fall back into place again, and on the return of the cage push the levers, *c*, into the position shown by the dotted line on the left-hand side of Fig. 446, and release the tub. By the time, however, that the cage rests on the legs the levers, *c*, have completely passed the catches, *d*, and the arms, *a*, would be closed by the springs, *b*, but

* *So. Staff. Inst.*, iv., 31.

by such time as the tub is on an incline it has moved forward a short distance and the L parts of the arms are locked beneath the bottom of the tub to remain there until it has passed out, when they immediately close and prevent the further passage of the second tub.

At the surface, the cage is lifted until its bottom deck rests on the Stauss props, and the motion afterwards is always a lowering one. The tubs are automatically released by a similar apparatus to the one at the bottom.



Figs. 445, 446, and 447.

Bascoup Colliery.—At No. 5 pit the changing operations are performed with extreme rapidity; at the bottom with the aid of a balance platform, and at the top with Stauss keps; and, by the peculiar arrangement existing there, both are carried on independently of each other.

When the cage reaches the bottom it is received upon a platform (*p*, Fig. 448), counterbalanced with a weight, *w*, equal to that of the empty tubs and the cage. The two empty tubs on the bottom deck are then replaced by full ones, and the extra weight of the load they contain causes the cage to descend with the platform, until the second deck is level with the inset. The tubs on this deck are then changed, and the platform and cage descend again, until the top deck is level with the inset, when the empty tubs are replaced by full ones. The descent of the platform is governed by a brake, *a*, regulated by a hand-wheel, *b*. A catch, *c*, is also provided, which locks the platform at the proper levels, by engaging with the stops, *e*. This catch can be lifted off by an arm, *d*. It will allow the platform to *ascend*, but not to descend until released. Immediately the cage containing the full tubs is lifted by the winding engine, the counterbalance brings back the platform to the level of the inset, ready to receive the other cage.

The changing at the surface is carried out as follows. The bridle-chains are made very long, and before the top cage comes to bank, the bottom cage reaches the balance platform just described. At this point the engine is steadied, and the top cage is lifted until its lower deck rests on the Stauss props. An amount of slack rope is, therefore, payed out on the cage at the bottom by such operation, but through the bridle-chains being long the rope itself is kept straight, and does not "kink"; indeed, not so much is let out as would be expected, for before the top cage is actually raised to bank, the empty tubs on the bottom deck of the cage below ground will be replaced by full ones, and the platform lowered, thus taking up a length equal to the height of one deck. At the surface the bottom deck is also changed first, the cage lowered by moving the Stauss props, the full tubs on the second deck replaced by empty ones, the cage again lowered and the top deck changed. The engineman has only to attend to the operations at the surface, the tubs at the bottom being changed with the balance platform, and by the time the top deck is changed at the surface, all the slack chain and rope has been taken up, and the engine starts away upon receiving the signal from the bottom.

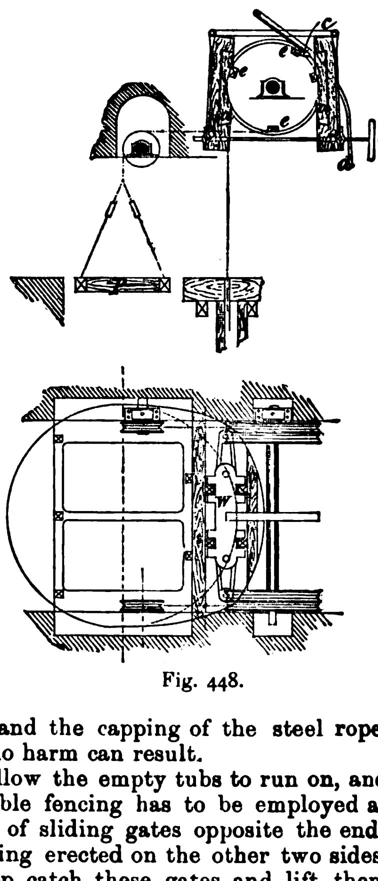


Fig. 448.

At Anzin Colliery a balance platform is also employed, but to remove any chance of the rope kinking when the slack rope is payed on to the cage, a short length of aloe rope is inserted between the bridle-chains and the capping of the steel rope. As this is quite soft and flexible, no harm can result.

Fencing the Pit Top.—To allow the empty tubs to run on, and the full ones off, the cage, a movable fencing has to be employed at the pit top. This usually consists of sliding gates opposite the ends of the cage, a permanent fence being erected on the other two sides. Projecting pieces on the cage top catch these gates and lift them upwards when the cage arrives at bank, but as soon as the descent commences the gates fall to the ground and secure the top of the shaft. As the cage travels at considerable speed when it strikes the fence, it is advisable that the latter should be made as light as possible. The preferable plan appears to be to employ three strips of iron or wood, *a*, *b*, and *c* (Fig. 449), resting on two props, *d*, cut to the shape illustrated. The top strip is longer than the second, the second than the third, and all are guided in a vertical plane by the ropes, *e e*. On the arrival of the cage at bank, the bottom bar is first lifted, then the second, and finally the third. As their weight is so little the shock is infinitesimal.

A combined fence and stop used in the Pennsylvania mines* where the waggons are unusually large, consists of a gate sliding in a frame and partially balanced by a weight, *a* (Fig. 450). The stop, *b*, is a heavy piece of timber, 10 inches by 12 inches, and when the gate is down occupies the position shown on the left-hand side of the illustration. It is pivoted at *c* so that it may swing about this point as centre, while it is counterbalanced by the weight, *e*, attached to the other end, and guided in the proper direction by the strip, *h*. This weight is slightly heavier than the block which it consequently tends to lift at all times. A small pulley, *d*, is attached to the back and at one end of the block, which runs in a groove, *f*,

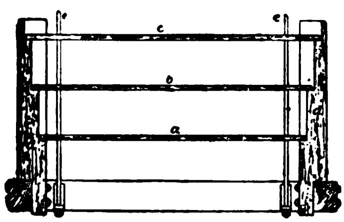


Fig. 449.

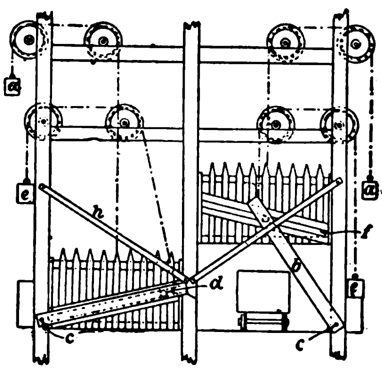


Fig. 450.

formed by two strips fastened across the front of the gate. The excess of weight in the gate over its counterbalance, *a*, is sufficient to cause it to descend when unsupported, bringing the stop, *b*, with it. The ascending cage lifts the gate and allows the stop to fly back. The way is then clear for the tubs to be changed on the cage, the apparatus occupying the position shown on the right-hand side of the illustration. When the cage descends, the gate falls, bringing the stop with it.

The problem is rather more complicated if winding goes on at an up-cast shaft where fan ventilation is employed, because, unless some special means are adopted when changing is taking place, the pit top is open to the atmosphere. A fan produces a partial vacuum in the up-cast shaft, and reduces the pressure there below the atmosphere. Consequently, unless this depression chamber is sealed off, the fan is choked by the air drawn in from the atmosphere, and the ventilation of the mine is seriously impeded.

Pemberton Colliery.—At the up-cast pit, the entire distance from the ground level to near the top of the frame is cased in, as shown in Fig. 451, by two rectangular sheaves of wood, each forming a compartment in which one cage travels. As little play as possible is given between the sides of the cage and the framing, each cage practically forming a piston. At the banking level, small rectangular

* *Eng. and Min. Journ.*, 1899, lxvii., 589.

openings are made, of just sufficient size to allow the passage of the tubs through them; these openings are closed on the inside by a vertical trap-door sliding in two grooves, which is opened by the cage as it ascends, and on the outside by a safety trap-door, balanced by a weight which is lifted by the on-setter. By this method, the loss of air is reduced to a minimum. The bottom deck of the cage is made solid, and to prevent any loss of air when standing at bank, it is provided with a second or false bottom, about 18 inches below the one on which the tubs rest. By this device the top of the pit never becomes open to the atmosphere, even should the engineman raise the cages a short distance above the proper level. To provide a perfect joint, and reduce shock, the inside doors have a gutta-percha band running along the lower side.

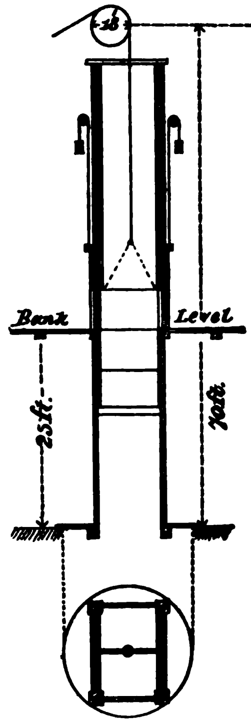


Fig. 451.

Homer Hill Colliery.—Another method of covering commonly employed is well illustrated by that in use at this colliery. The shaft is closed by a pyramidal covering, at the upper end of which is a small movable shutter. The pressure of air on the outside of this pyramid, owing to the vacuum beneath, is considerable, and it is, therefore, counterbalanced by weights, *w* (Fig. 452). When the cage is nearly at bank, the capping on the winding rope first lifts the small shutter, *a*, and it does so easily as its area is small. This to a certain extent takes off the pressure on the main casing, and as the weight of the latter is also counterbalanced, the cage lifts the covering vertically upwards without any injurious shock. As an additional safeguard springs, *b b*, are placed at the four corners.

Neumühl Colliery.—The previously described methods are all subject to the objection that considerable losses of air are sure to happen when the trap-doors are opened, and that this has to be done to discharge the contents of the cage each time it reaches the surface. The total air loss varies from a minimum of from 10 to 15 per cent., and increases with the number of windings, sometimes up to 30 per cent. So long as engineers were content to obtain small outputs from up-cast shafts, or it was comparatively

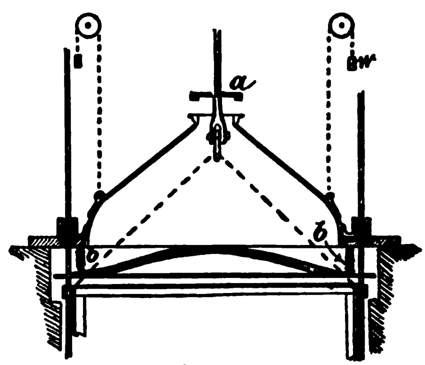


Fig. 452.

easy to sink additional ones for winding purposes, the colliery output could be increased at reasonable expense, but as the depth and the difficulties of sinking increased some efficient means of dealing with a large output at up-cast shafts became more necessary. Air-tight passages leading from the outer atmosphere into a casing erected around the pit top and sealed by a series of air sluices reduced the loss of air to a minimum, but the doors are troublesome to open, and as attendants are needed to open and shut them and to pass the trams through, the cost of handling the coal is increased.

At the up-cast shaft of Neumühl Colliery, Westphalia, Mr. H. Bentrop has patented an arrangement, the prevailing idea of which is that of making the shaft-house air-tight. A building is erected around the pit-top of sufficient size to permit of all the manœuvring and discharging of the contents of the trams, and conjointly with the roof of this house, which is also made air-tight, the head-gear is covered with thin sheet iron up to the pulleys. To allow the rope to pass through small holes lined with wood are made through the pulley casing, and as the swaying of the ropes just under the pulleys is slight, such holes need only be a shade larger than the ropes, and consequently the leakage of air is small. For the passage of men, or special material, sluices are built in the enclosure walls, but these do not serve for the passage of the mineral, for which purpose a series of contrivances have been designed. The winding compartment and the tipping and screening gear remain as easy of access as in an open shaft.

The most convenient arrangement for the dry sluicing of the material is by means of a bunker built into the landing stage. The top is open to the interior of the depression chamber formed by the air-tight shaft-house, but the base is closed by a sliding door. If the material consists of small pieces, and sufficient quantity is allowed to accumulate in the bunker no air can escape even when the shutter is opened to fill a tub, as the material itself closes off the air of the pit from the outer atmosphere (*a*, Fig. 452*a*), but if the material is

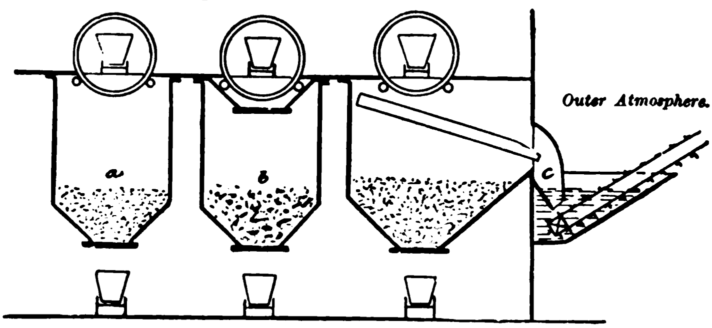


Fig. 452*a*.

large coal or rubbish it is best to employ two or more bunkers having shutters at the top as well as the bottom (*b*). These are filled and emptied alternately, and every bunker has always one shutter closed.

For all kinds of coal that can be loaded up in a wet state, or which is to be carried to a washing plant, the water seal provides the simplest and most efficient method as any loss of air is prevented and there is not any wear or tear. The coal is tipped on to the screens and passed by a shoot into a trough containing water into which a conveyor elevator also dips. The height of the water is regulated to cover and seal the mouth of the shoot (*c*, Fig. 452*a*).

The up-cast shaft at Neumühl is fitted with two cages, each having four decks and carrying two tubs on each deck. The pit frame stands quite free in the air-tight house (Plate IV.). The total air-tight area is 3792 sq. yds., and although this is proportionately large, it has been found after two years' working experience that the amount of air drawn in from the outer atmosphere is very slight. Careful experiments gave the loss at 2·26 per cent.

In cases where it is desirable to carry the tubs and materials into the atmosphere, suitable revolving tables (Fig. 452*b*) are employed. These consist of a drum revolving on a vertical axle consisting of a number of compartments arranged fan-shape, each of which carries a tub. These compartments are isolated from one another, and leakage is prevented between the revolving drum and the sides of the casing

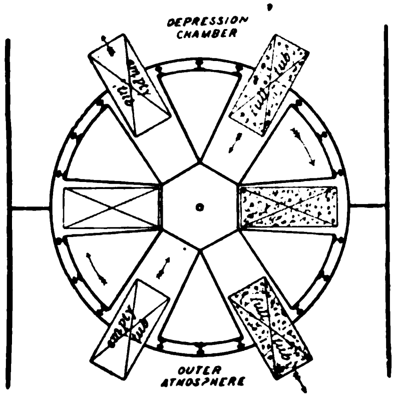


Fig. 452*b*.

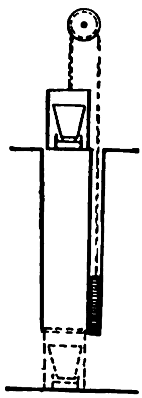


Fig. 452*c*.

by a series of horizontal vertical strips of iron which close the space between the drum and the case. The exclusion of the outer air is effected by the drum casing in conjunction with the drum vanes, the distances between the openings of the drum and the number of vanes being so arranged that always at least two vanes cut off connection with the outside air. When the landing and loading stages are not at the same level the trams can be dropped to the lower stage by means of the sluice brake shown in Fig. 452*c*. This is a simple brake shaft, the walls of which are sealed hermetically from the landing stage half-way down to the loading platform. The cage slides up and down in this casing like a piston, and the construction is such that in every position of the balance cage a tight barrier is placed either by its roof or floor between the depression chamber and the outer atmosphere.

Fencing Intermediate Landings.—Provided winding takes place from one inset only, the sump may be fenced by balanced doors similar to Fig. 110, for these can be opened in a few minutes whenever it is necessary for the cage to descend, as when water is drawn.

Such doors are not applicable when the air current has to pass further down the shaft to ventilate lower workings. In such cases at Blanzy Colliery a wire-rope net with meshes

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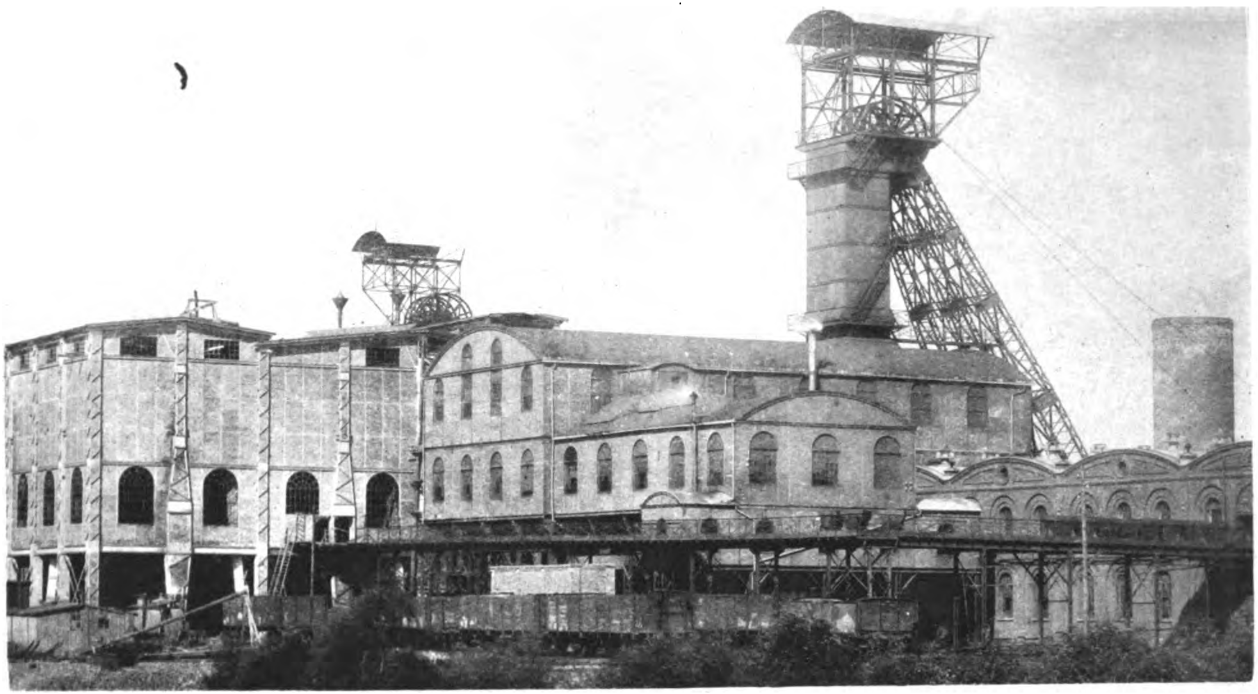

NEÜMÜHL COLLIERY. GERMANY.

4 inches square has been placed some 2 feet below the keps. One side of this net is fixed by permanent bolts to buntons across the shaft, while the others are provided with loops, which can be attached to staples. The net hangs vertically in the shaft when one side is released, so that water winding can readily take place.

A great number of ingenious appliances are in use for closing the openings into those shafts on the Continent of Europe, where, owing to the inclination of the seams winding takes place from several levels.* The majority depend for their action on the pushing aside of a cam or projecting lever which is connected through rods with a swing gate closing the opening into the shaft. This cam has to be moved by the cage, and consequently the gate always remains closed, except when the cage stands at the landing. The fences are automatic, and open and close quite independently of any action on the men's part.

It is difficult to understand why such complicated devices are needed, because the object to be attained can be secured by placing two rods across the landing, the second such a distance from the first as the length of one or two tubs, whichever the cage is constructed to contain. These two rods are connected through cranks and a link, and are so arranged that opening one shuts the other. Both cannot be open at the same time. A diagrammatic representation of such an appliance is shown in Fig. 453, where the shaft is *closed* by a gridiron

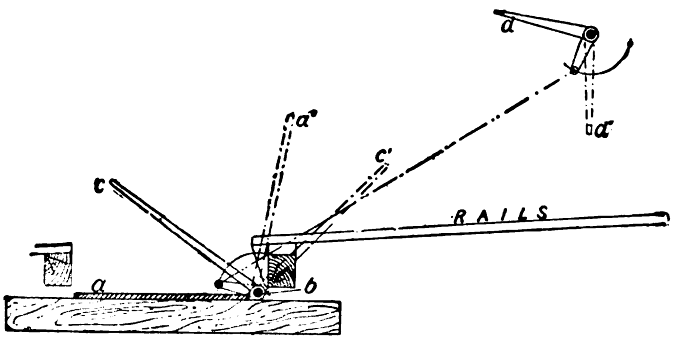

Fig. 453.

platform, *a*, hinged at *b*. When the cage reaches this landing, it cannot pass by, as the shaft is blocked; indeed, the gate takes the place of ordinary keps. As soon as the tubs have been changed, and the cage has ascended, the attendant moves over the lever, *c*, and lifts the gate, thus opening the shaft for the cage to pass through on its return journey, but at the same time closing the inset, so far as the passage of tubs is concerned, because by an arrangement of levers the arm, *d*, drops across the roadway and forms a stop, while at the same time the gate rises and forms a fence across the inset. When the shaft is open, the several parts take the positions shown by the dotted lines and the letters *a'*, *c'*, and *d'*. Whenever the stop, *d*, is up, the gate, *a*, must be down, and the shaft cannot be left unfenced.

* Consult *Soc. Ind. Min.* (3e Série), vi., 1127; and *Coll. Guard.*, 1894, lxviii., 879 and 928; and 1899, lxxvii., 107.

Tub Controllers.—To prevent the tubs running into the shafts, ordinary blocks (Fig. 287) are generally employed, but possess many disadvantages. They have to be opened by hand, and when once open will allow any number of tubs to pass by. Automatic contrivances are much to be preferred.

At Lye Cross Pit the empty tubs are controlled by a projecting stud, *a* (Fig. 454), which stands up between the rails and catches the axle of the tubs. This stud is attached to a lever, *b*, pivoted about a centre, *c*. One end of the lever is weighted, *w*, while the other is attached to a foot treadle, *d*. The weight always keeps the lever in such a position that the stud, *a*, blocks the way, unless the banksman depresses the treadle. This apparatus has two objections—(*a*) As the stud engages the *middle* of the axle, this may get bent; and (*b*), the banksman has to keep his foot on the treadle until the tub has passed by.

For empty tubs the former is not of much importance, as little strain is thrown on the axle, but for loaded tubs the objection is fatal.

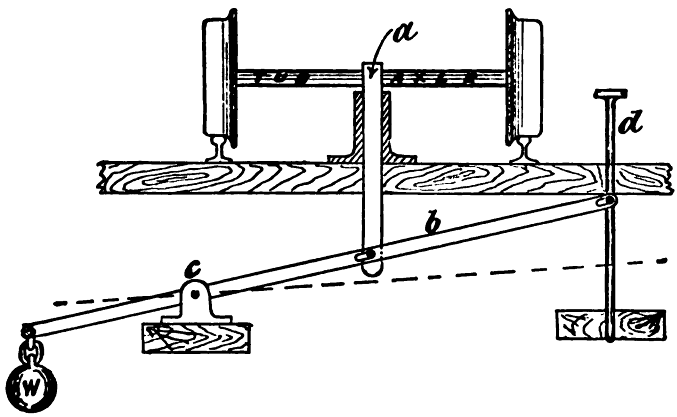

Fig. 454.

The latter is scarcely any inconvenience, as the apparatus is very compact, the treadle can be placed anywhere, and the banksman, having the use of both hands, is left quite free.

To the apparatus used at Bell End Pit for regulating the passage of the full tubs no objection can be raised. It is designed by Mr. B. Woodworth, and can either be arranged to automatically control the delivery of tubs in and out of cages, or for intermittent delivery from inclined planes or platforms without the need of attendants for scotching and releasing the tubs. The apparatus can be opened from any distance by the person requiring the tubs, and all the other movements are self-controlling.

To open the controller, the shaft, *a* (Fig. 455), is twisted and moves the tongue, *b*, causing the sliding bolt, *c*, to project under the lever, *d*, and lowering the stop end at *e*, until the axles run clear, when delivery by gravitation commences. The succeeding axles turn the star wheel, *f*, in the direction shown by the arrow, as they pass by, until the cam point, *g*, comes into contact with the heel of the sliding bolt c at c', and withdraws the same, causing the lever, d, to fall into its proper position and stop the delivery of tubs until it is re-opened in the usual way.

To check any tendency there may be for the star wheel, f, to travel beyond its right position when driven by the axles of the tubs, it is provided with a square boss, h, upon which a spring, i, presses. A small roller, k, is fixed over the sliding bolt, c, to prevent any tilting up of the latter when heavy loads are pressing against the buffer stops.

Either when used on cage decks, or on inclined platforms, two controller boxes are fixed between the rails, so that the buffer stops come into contact with the tub axles as close to the bearings of the wheels as possible; by doing so, there is little risk of bending the axles by the shock of stoppage of the loaded tubs, and, as an additional preventive, elastic spring buffers are also used to equalise the bearings of the axles against the stops. In Fig. 455, the box mechanism shows an arrangement to pass two tubs each time. To pass one only each

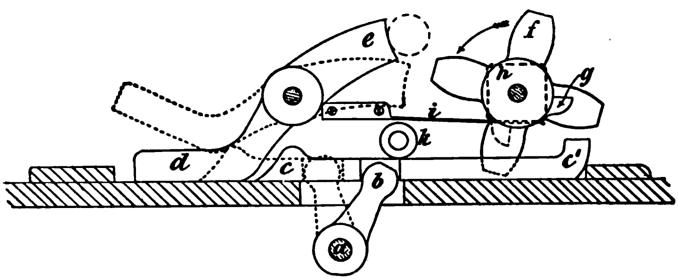

Fig. 455.

time, two cam points, g, are used to one star-wheel boss, while for passing three tubs, a star wheel with six points would be used with only one cam point.

Signalling.—Nothing conduces to rapid winding more than efficient signals. Two systems are employed. The ordinary method consists of a wire carried down the side of the shaft, one end being attached to a lever and the other to the mechanism working a bell. For small depths this system works very well, but where the line is a long one, the power required to ring the bell is considerable, and although balance arrangements are used to take off the weight, the banksman has still to exert a large amount of force, which necessarily takes time.

Instead of these mechanical signals it has now become common to use electrical ones. Undoubtedly, when such were first applied, they were by no means suitable for the rough work of a colliery. The great mistake made consisted in making them far too weak, and not introducing sufficient safeguards; in addition, the men at collieries were quite unused to such appliances, and if anything went wrong an electrician had to be sent for. At the present time none of these objections hold good. It has long been recognised that signals suitable for dwelling-houses are of no use whatever at collieries, and a special stronger type has been designed. The working and keeping in order of such appliances have ceased to be a wonder, and many collieries at the present time simply purchase their stores, and fit up and keep the signals in order themselves.

What are known as single-stroke bells are generally employed—that is to say, the bell only makes one stroke each time a signal is given. The elements of successful working principally lie in having large-sized battery cells, which are almost universally of the Leclanché type, and proper wire in the shaft. One of these wires should undoubtedly be insulated. Sometimes both wires are suspended from a point on the head-gear and hang free in the shaft; then neither are covered. This arrangement possesses some advantages in the fact that it is cheap and requires little labour, and in addition the wires are not damaged by pieces of coal, &c., falling down the shaft, as these simply glance off the wire and do no harm. Sooner or later, however, leakage of the current takes place. The better plan, although the dearer one to commence with, is to employ a properly insulated wire and carry it in grooved boarding down the side of the shaft. No staples or iron should be employed to keep the wire in the groove, which should preferably be made slightly smaller than the diameter of the covered wire, and then the latter lightly tapped into place, the whole being finally covered with a light wooden lid. The insulation prevents leakage, and the wood casing prevents any damage to the insulation.

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Fed. Inst.: *The use of Expansion Gear as applied to Winding Engines*, M. Deacon, vii., 672; *Methods of Closing the Tops of Upcast Winding Shafts*, A. Reid, x., 367; *The Woodworth System of Progressive and Automatic Cut-off Gear for Winding Engines*, B. Woodworth and W. G. Cowlishaw, x., 470, and xi., 111; *A Compound Winding Engine*, W. Galloway, xi., 207; *The Compound Winding Engine at the Great Western Colliery*, H. Bramwell, xii., 282; *Safety Props for Supporting Cages in the Head-gear of Pits in Cases of Overwinding*, C. S. Smith, xii., 564; *The Internal Corrosion of Wire Ropes*, T. G. Lees, xiv., 400; *The Application of Condensers to Winding Engines*, W. Freakley, xvii., 242.

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CHAPTER IX.

PUMPING.

THE amount of water met with in mines is dependent on their depth and on the nature of the overlying strata. Shallow mines are always more troubled with water than deeper ones. The subsidence caused by extracting the material cracks and fissures the ground above, and affords means for the ingress of water. Even when the depth is great, if the strata overlying the coal seams contain large quantities of water, as is often the case, the workings naturally release the water, and it flows into the mine. In some cases, a series of impervious beds are found to exist between the water-bearing strata and the coal measures beneath, and the water met with during sinking may be tubbed back.

The details of pump work should be mastered by every mining student. The very best pump worked and controlled under the most favourable conditions is a source of *loss* at any mine. Pumps have aptly been termed profit-eaters, and every endeavour should be made to see that they consume as little as possible. Valuable assistance in learning the broad outlines of pumping can be obtained from books, but practical observation is absolutely essential. Only by going into the shaft and taking part in the several operations of changing the buckets or clacks, or in rendering assistance while repairs are being executed, can the student learn the numerous small practical points so necessary for the smooth working of all pumping stations.

The great majority of the pumps employed for draining mines use steam for the motive power, and both for convenience and safety it is usual to place the boilers on the surface, which necessitates the transmission of power from the point where it is generated to the pump itself, which has to be placed at the spot where the water is encountered. The power to drive the pump may consequently be generated by a surface engine and transmitted by rigid rods, or steam may be carried direct to an underground engine. These two systems form the two broad divisions into which mining pumps may be divided, and both possess advantages under different circumstances. Either one or the other are universally adopted, so long as the water to be dealt with is considerable, and at or near the bottom of the shaft, but when comparatively small quantities of water have to be dealt with at points some distance away from the shaft, a third system is adopted where the power, which is generated on the surface, is transmitted by some intermediary agent and carried to the pump where it is transformed into work.

SURFACE MACHINERY.—In the majority of cases where large quantities of water have to be dealt with, the engines are usually situated on the surface near the point where steam is generated. Such engines should preferably be direct-acting and compound. The use of gearing between the engine and its pump rods is rapidly becoming a thing of the past, and indeed has few, if any, points to recommend it. In order to divide the strains set up in the several parts, the water is rarely raised in one length to the surface, but by successive stages called "lifts." With single-acting surface engines, the strains set up on the pumping machinery are far greater than when compound engines are employed, as the latter do not vary their speed so much during the stroke; consequently, longer strokes and longer lifts can be employed, which result both in a saving in first cost and in wear and tear.

Pumps.—Numerous types of pumps are used for unwatering mines, but they may be broadly divided into two classes—bucket and plunger. If the engines are placed at the surface, with the former type the water is lifted during the forward stroke, while with the latter it is forced at the backward stroke.

Bucket Pumps.—Suction pumps in mines are similar to those used in ordinary wells, only better designed and on a larger scale. They

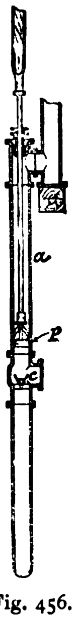


Fig. 456.

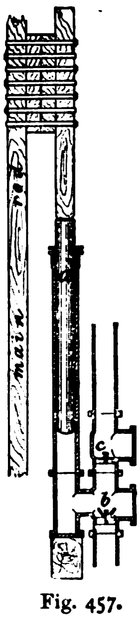


Fig. 457.

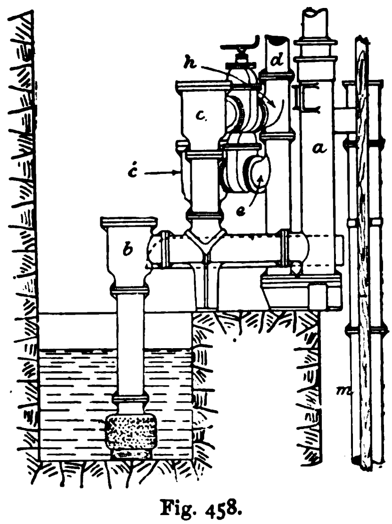


Fig. 458.

consist of a pipe, called the working barrel (*a*, Fig. 456), into which a well-fitting piston, *p*, having a valve or valves opening upwards, is worked up and down by being attached to the pump-rods. The lower end of this working barrel is connected to a suction pipe, through a special piece, containing a valve, *c*, called a "clack." The lower end of the suction pipe is called the "snore-piece," or "wind bore," and is provided with a number of holes at or near the bottom, through which water enters the pipe, and which prevent, to a certain extent, any large piece of solid material entering the working barrel. The combined area of these holes should be larger than the area of the suction pipe.

When the piston, or bucket, makes its up stroke, a vacuum is created in the working barrel, and the pressure of air forces water through the suction pipe and clack into the working barrel. On the return stroke the clack closes, and the bucket valve opens, allowing the water to pass to the upper side of the bucket, to be raised to the surface on the return stroke of the engine. The complete bucket set comprises, commencing at the lower end, the snore-piece, a length of suction pipe, clack-piece, working barrel and bucket door-piece, to which is bolted the pipes for carrying the water to an upper level. Both the clack-piece and bucket door-piece are provided with a door or lid at the side which on being removed permits of ready access either to the clack or bucket. As an additional safeguard, the clack is generally provided with a head so shaped that it can be readily grasped and removed from above.

Plunger Pumps.—In this system the water, instead of being lifted, is forced up by the action of a piston or plunger working up and down through a stuffing-box at the top of a long cylinder. The arrangement of this and the necessary valves is shown in Fig. 457, where the piston, *a*, is just commencing its upward stroke, and is sucking water through the valve, *b*. On the return, the valve, *c*, will open and *b* close, and as the plunger passes downwards, water is forced through *c* to the surface. The arrangement of such a set as adopted by Hathorn, Davey & Co., is illustrated in Fig. 458, where *a* is the plunger, *b* the suction clack-box, and *c* the delivery clack-box. The parts are all cylindrical, and it will be noticed that the suction and delivery clack-boxes are entirely separate, so that the covers may be removed and the valves attended to without much trouble. There are two plungers which deliver into one rising main, *d*, through the branch pipes *e* and *h*, each of which is coupled to a delivery clack-box, while the other side is bolted to a branch on the rising main; and a sluice valve is fixed on each branch, so that either column can be cut off. A relief valve is provided in each plunger cylinder, which is regulated by screws and springs to open when the pressure becomes excessive, while a bye pass pipe closed by a cock allows water to be run from above the delivery valve out of the rising main into the plunger and suction pipes. This is of considerable service when air has by any means found its way into the plunger, or when the suction pipe loses its water, as the working parts can then be run solid with the minimum of trouble; *m* is the bucket set of the lower lift.

With bucket pumps, lighter rods can be employed than with plungers, but wear and tear is large, and the maintenance charge is heavier. Plunger pumps have one disadvantage; unless the column of water is solid at the commencement of the return stroke the ram falls suddenly, and the pipes receive a severe shock. As a rule, most pumping arrangements consist of a combination of the two, with the lower lift worked by a bucket set, and all the lifts above by plunger sets. Engines working bucket sets throughout would require to be larger than if plunger sets were employed, because the weight of the rods with their strapping plates, &c., is more than that of the water. With plunger pumps, all the engine has to do is to lift the rods, as these on their return stroke force up the water, but when bucket sets are employed, the engine has to lift the rods and the water. Bucket sets have one very important advantage, because when an open-topped lift is employed, the rods and buckets and clack can be drawn and changed while the working parts are under water, which cannot be done with plunger pumps. In all mines where the lower set is liable to be flooded, bucket sets should be used for that lift.

Stocks or Trees.—The pipes through which the water is delivered to the surface are called "stocks" or "trees," and, in combination, form the rising main. They consist, as a rule, of cast-iron pipes, generally 9 feet long, shorter lengths of 3 feet and 6 feet being used for making-up pieces. They should be as long as possible, without making them difficult to handle, as by doing so the number of joints is reduced, and there is less liability for air to enter. They should always be cast standing; if not, the probabilities are that the metal will be thicker on one side than the other.

The thickness depends on the size and the pressure to be withstood. A cubic foot of water weighs 62½ lbs., and as it stands on a base of 144 square inches, the pressure per square inch due to each foot in depth is ·434 lb. The common rule, and one erring on the right side, is to allow a pressure of ½ lb. for each foot in depth, or to find the total pressure in lbs. per square inch due to a column of water, its vertical height in feet may be divided by 2. Indeed, some allowance is absolutely necessary in determining strengths, because it is well known that the pressure experienced in pumping sets is variable during different parts of the stroke, and exceeds that due simply to the weight of the water.* The necessary thickness of the pipes is determined by the formula:—

$$t = \frac{d\,p}{5600}$$

where d = internal diameter in inches, t = thickness in inches, and p = the pressure in lbs. per square inch.

The weight of any length of pipes is found by the formula:—

$$w = c\,(D - d),$$

where w = weight per lineal foot, D = the outside diameter in inches, d = inside diameter in inches, and c is a constant = 2·45 for cast iron, and 2·64 for wrought iron.

Of late years, wrought-iron and steel pipes have been substituted for cast-iron ones. For the same strength their weight is considerably less, and they can be made in longer lengths, and yet be much easier handled; 15 to 20 feet lengths are by no means uncommon. They have additional advantages in being cheaper, and not so liable to fracture.

Joints.—The trees are joined together in various different ways. For moderate lifts, the common practice is to face and turn in two concentric V grooves in each flange. A sheet of lead is placed between the two flanges, and when the bolts are screwed together, this lead is forced into the V grooves. The better plan for heavy pressures is to employ what is known as the male and female joint. One flange is provided with a projection and the other with a corresponding recess. An india-rubber or lead ring is placed in this groove, and the flanges screwed firmly together. A modification of this joint is shown in Fig. 459. One flange is provided with a projection $\frac{3}{16}$

* Consult. *N. E. I.*, xxi., 949; and *Brit. Soc. Min. Stud.*, iii., 107, and viii., 138.

inch deep, while the opposite one has a triangular piece cut out which tapers as shown. A packing ring of circular cross-section is inserted in the groove and the two pipes screwed together. The pressure of water from the inside cannot force the packing material past the shoulder at the base of the triangle, as immediately behind it the pipes are screwed together until metal nearly touches metal. Each flange is faced along the thick black line, and is belled out for a quarter of an inch at each end in order to prevent any possibility of the bucket catching when it is drawn out through the pipes.

There has been an increasing tendency during recent years to substitute wrought-iron or steel pipes for cast-iron ones. The latter is less liable to corrosion, but its excessive weight renders it difficult to handle. Wrought-iron or steel pipes can now be purchased more cheaply than cast-iron ones, but great care must be taken to see that they are of proper thickness to withstand the pressure. Wrought iron is not so liable to fracture as cast iron, and, consequently, wrought-iron pipes possess one great advantage over those made of cast-iron for pumping operations where severe and sudden strains often occur, but as the shell of such pipes is moderately thin they are very unsuitable for use where the mine water is acid. The larger sized pipes are formed from plates riveted together like an ordinary boiler, while the better class smaller ones, say, up to 6 or 8 inches diameter, are drawn out of solid blooms by the Mannes mann or other similar processes. Care must be exercised in the selection of ordinary welded tubes for heavy pressures; butt-welded ones should never be employed.

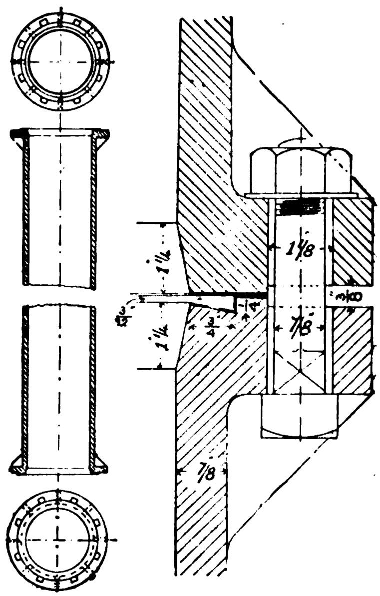


Fig. 459.

Such pipes should have the flanges riveted on. In the smaller sizes the latter are first forged out of the solid and then turned on the inside to the same size as the outside of the pipe, which has also been turned in a lathe. The flange is then heated and shrunk on the pipe and afterwards riveted in position.

Of the many patent joints for wrought-iron pipes, one of the best known is Williams's. Each pipe terminates in a short cone, *a* (Figs. 460 and 461), and is provided with a loose flange, *b*. The joint is made by introducing a double cone-shaped annulus, *c*, and screwing the flanges tightly together. An india-rubber ring is fitted upon each ferrule. The advantages are, the small amount of time taken to make a joint, and the facility with which the pipes can be connected at small angles, whereby, in many cases, the trouble and expense of bends is avoided. They possess an advantage over screwed wrought-iron pipes, as they are not weakened by having threads cut on them, and when galvanised, no part is subjected to corrosion, as is the case when galvanised pipes are screwed.

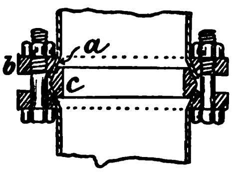


Fig. 460.

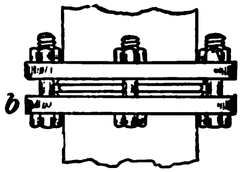


Fig. 461.

Another convenient and cheap connection is Lewis's joint. Each pipe is provided with a loose flange, *a a* (Figs. 462 and 463), while the ends are bent back at right angles for a short distance. The joint is formed by an annular T-shaped ring, *b*, which is placed between two successive pipes with a thin ring of india-rubber or similar packing material at the bottom of the groove, as shown by the thick black line. The loose flanges are then slipped up to the ends, bolts passed between, and screwed up tight. By using an annular ring of triangular section these pipes can be worked along crooked roads without employing bends (Fig. 463).

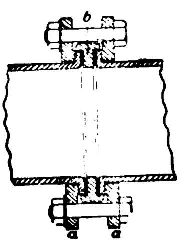


Fig. 462.

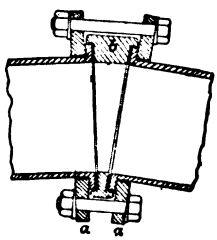
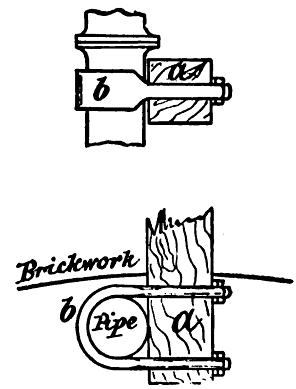


Fig. 463.



Figs. 464 and 465.

Supporting Pipes in Shaft.—The ordinary plan is to provide a main bunton of timber running across part of the shaft, upon which two smaller pieces are fixed at right angles, one on each side of the pipe under a flange. These short pieces are hollowed out to fit the pipe perfectly. It is difficult to see how such support can be improved, and it is invariably employed where there is plenty of room. It, however, requires a considerable amount of space, because the main cross-piece has to be fixed on the outside of the pipe, and as it has to bear all the weight, is necessarily large.

In a shaft where room was valuable, the author applied the method shown in Figs. 464 and 465. A bearer, *a*, was fixed at right angles to the brickwork of the shaft. Wrought-iron pipes were employed, as the flanges on them took up considerably less space than cast-iron ones would have done. One of these timber pieces was fixed immediately below each joint of the pipe. A wrought-iron gland, *b*, with two screwed pin-ends passed round the pipe and through the timber piece, and was firmly bound against the tube by nuts screwed as tight as possible. A main bearer similar to that described in the preceding paragraph was fixed at the bottom of the shaft, this supporting, in a great measure, the weight of the pipes.

Spear Rods.—The buckets, or plungers, are connected to the engine through the medium of what are called "spear rods." In the great majority of cases these consist of wood, although iron and steel are sometimes employed. Since those above have to support their own weight and the weight of all below, the upper rods must be made proportionately large. With plunger-pumps, the rods must be heavy enough to force up the column of water before them. Wooden rods are preferably made of Memel or pitch pine, except at the surface, where they are exposed to changes of temperature. Pine is more readily obtained in long straight lengths free from knots. All the rods should be exactly the same length in order to be interchangeable and should be as long as can be conveniently obtained, preferably some multiple of the length of the "trees," say, 36 or 45 feet. The wood must be straight in the grain, free from sap and knots, and if pitch pine is the wood employed, those logs which have not been tapped for their resinous fluid should be obtained if possible. The safe load for wood spears is 5 cwts. per square inch, but it is often advisable to make them larger than necessary in order to obtain stiffness which is important.

If rods of sufficient sectional area cannot be obtained, they are made up of two pieces, the joints of the one coming into the centre of the other set Single rods are sometimes jointed by cutting the ends slanting with a hole in the middle, the connection being made by an iron plate on both sides and bolts passed through. An oak wedge is finally driven into the hole in the centre to make the joint quite firm (Fig. 466), but this has the disadvantage that the wood is likely to split. The bolts are not passed through the core of the wood, but alternately on either side. The common practice is to cut off the ends of the rods square and to bolt connecting plates on all four sides, details of such a joint, in rods 10 inches square, being shown on Fig. 467. The bolts from one set of plates are halfway between those coming from the other set. The pins have square heads, and are square under the head for three parts of their length to prevent any possibility of their turning round when the nuts are screwed on. In order to make the joint as solid as possible, the holes through the wood are bored about one-sixteenth of an inch longer distance between than the corresponding holes are drilled through the strap plates. When the bolts are driven in, the two ends of the rods are thus forced together solid.

Iron rods are built up of various sections fixed together with bolts or rivets, usually the latter. A general form is composed of two channel pieces, back to back, and two flat strips, one on each side, but every section of compound girder is employed. Solid wrought-iron rods have been used in Germany up to 12 inches diameter, but only, so far as can be learned, up to $8\frac{1}{4}$ inches in Great Britain.

The difficulties of making an efficient joint have been decreased by Harvey's patent, where the rods, which are made in lengths of about 32 feet, are provided with collars (*a a*, Figs. 468, 469, and 470) at each end forged solid. All the collars are turned to the same gauge, but care should be taken that the shoulder where the rod joins the collar should be slightly round and not turned down square, or a breakage will probably result at that point. The clasps, *b b*, are made in halves, and are usually forged in a die, and machined to the same gauge as the collars. These clasps have a hole through the centre to allow a key to

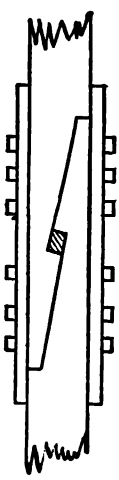


Fig. 466.

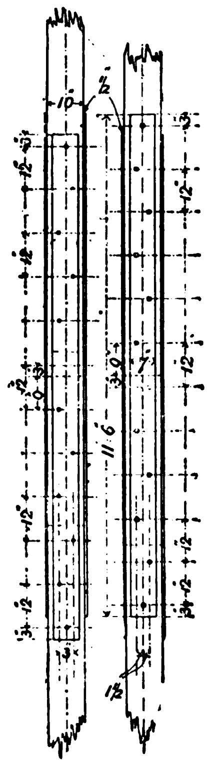
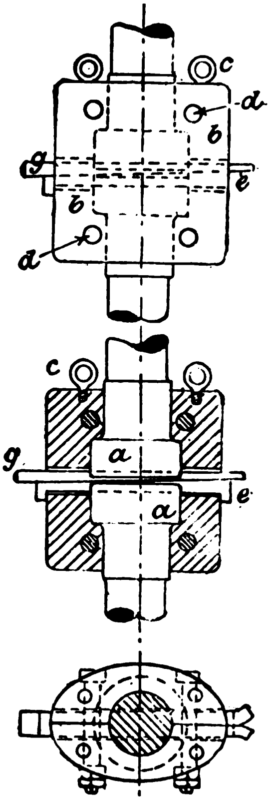


Fig. 467.

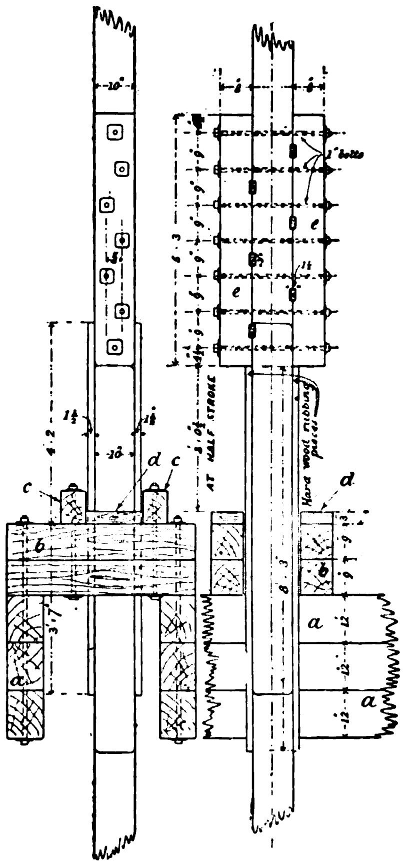


Figs. 468, 469, and 470.

be driven in, and there is a keyway of equal size cut in the end of the collars on the rod. Two eyebolts, *c c*, for lifting purposes are fitted to each clasp and four bolt holes, *d d*, are drilled through each half. In fitting the joint together, two collars of adjacent rods are put against one another, the two halves of the clasp brought round them, and bolted together through the holes, *d d*, by four turned bolts (see plan) having gunmetal nuts. A collar, *c*, is then placed in position in the central hole previously referred to, and a key, *g*, driven firmly in, wedging the two rods apart, and forcing them into their beds in the clasp until the whole joint is practically solid.

The use of iron or steel rods does not appear objectionable if they are made strong enough to prevent crystallisation, and proper means taken to preserve them from corrosion or from the effects of acid water. In shafts where the rods are alternately wet and dry, iron ones are preferable to wooden ones, but the latter are superior to the former if constantly kept moist, or if submerged. In some countries it is often necessary to use iron in place of wood, on account of climatic or other conditions, but in probably nine cases out of ten wooden pump-rods are used, and by far the greater proportion of these are pitch pine; under ordinary conditions nothing can compare with them for cheapness and general convenience.

Guides and Banging Beams.—The effectiveness of pump-rods is materially increased by good staying and guiding, while catch pieces and cross-beams must always be fixed to prevent the rods falling down the shaft in case of breakage. One such set of banging beams must be put in each lift, while guides will be placed at much nearer intervals. Figs. 471 and 472 show in detail the construction of such appliances. The banging beams consist of six oak baulks, *a a*, built into the shaft, three in front and three behind the pump-rod, not touching it, but placed several inches away. Two other baulks, *b b*, are placed across these on both sides of the rod, some 2 inches away, while on the top of the latter two further cross-pieces, *c c*, are fastened. The rod has thus to work through a square opening with a clearance space of 2 inches. To keep all wear off the pump-rods, they are lined with hardwood rubbing pieces 1½ inches thick, while similar lining pieces are also placed on the banging beams at *d d*. The stroke of the pump-rod in this case is 6 feet, so to allow a clearance at half-stroke, catches *e e* are bolted on two sides of the rod, 3 feet and ½ inch away from the hardwood liners *d d*, while for greater security, hardwood keys are afterwards driven into grooves cut both in the catch pieces and the rods. These catch pieces only touch the banging beams when the engine exceeds its stroke, or the rods break.



Figs. 471 and 472.

Connections to Rods.—Owing to the ease with which bucket lifts can be lengthened, it is common to find one of these at the bottom and plungers higher up the shaft. This necessitates attaching the plungers to the main spear rods by some form of connection. In general, water from great depths is not forced or lifted to the surface in one operation, but in a number of stages, each of which is called a lift. It is, therefore, common to find the main pumping-rod going direct to the bottom of the shaft, with plungers attached to it at intervals. These connections are often made by the method illustrated in Fig. 457, or by the better plan of employing a special casting with a serrated edge next to the rods, a series of stirrup-shaped bolts binding the two firmly together (Fig. 473). This connection is suitable for most ordinary situations, but for heavy work the best plan is to fork the main rod (A B, Fig. 474), instead of placing the plungers at the side. The plunger is then fixed in the line of the rods, the latter being continued on either side, joining again afterwards.

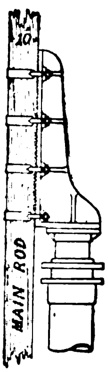


Fig. 473.

Fig. 474.

Valves.—The speed at which pumps may be worked depends in a great measure on the construction of the valves, which should open easily, giving full passage, and close quickly without any shock. Small lifts of the valves are a necessity if the pumps are to work quickly, and indeed are an advantage, as both the shock of closing and the "slip" of water are reduced. "Slip" is the quantity of water which escapes back through the valve before it closes for the return stroke, and with worn or bad valves, the loss is so great that the efficiency of the pump is seriously reduced. The simplest kind of valve is that in which a flap works on a hinge. This is the type used on the buckets and clacks of suction pumps, but it consists of two flaps instead of one (Fig. 475); clack-valves are constructed in a similar manner, but instead of fixing the hinges of the flaps, they work within guides, and the whole is free to move upwards a few inches, thus giving a greater area of water passage at the commencement of the stroke. For pumping dirty or gritty water, the old butterfly valve with leather faces is probably better than any other, but experiments have proved that such type gave 7½ per cent. more slip than a double beat valve.

A valve largely employed for pumps of moderate capacity for lifts of 300 to 500 feet is the single beat one (Fig. 476). The spindle is fitted with alternate discs of india-rubber and sheet-iron, the lift of the valve being determined by the amount of compression of the india-rubber discs.

For lifts up to 300 feet, india-rubber disc valves give good results. An india-rubber disc is fixed over the centre of a grid, and on the water rushing through the holes is lifted at the edges, and immediately shuts again at the return stroke. In the ordinary construction, as the disc drops in the same place each time, it is soon cut away by the bars in the grid. To remove this disadvantage, Jos. Evans & Sons fix a small brass collar (*a*, Fig. 477) in the centre of the disc, *b*, and place it on a spindle. Instead of the passages through the grid being vertical, they are placed at an inclination, with the result that the water flows obliquely, and turns the rubber disc slightly at each stroke, causing it to drop in a different place each time. In their later construction of valve, the holes through the

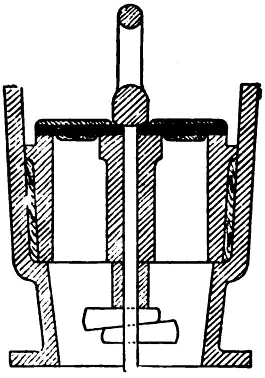


Fig. 475.

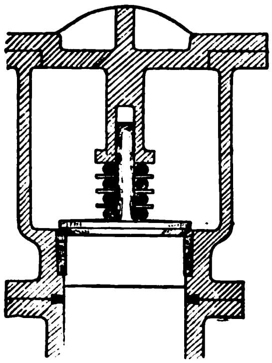


Fig. 476.

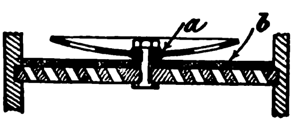


Fig. 477.

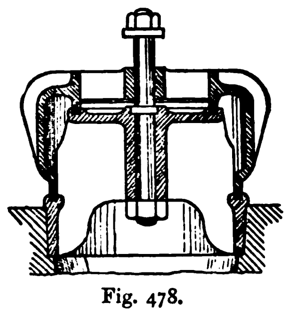


Fig. 478.

seat are made vertical, but the disc has teeth cut all round its circumference, such teeth being inclined; the action is exactly the same as in the former case, but the cost has been reduced. Such a valve is superior to a metal one up to certain pressures, especially where the water is gritty and dirty.

For heavy pressures, nothing gives better results than the Cornish, or double beat, valve (Fig. 478). These have been applied to pumps 9 inches diameter, working under 700 feet head, and have given every satisfaction. For larger pumps, instead of employing one valve, which would be very unwieldy and often get broken, multiple valves are used—that is to say, several double beats are arranged in a cluster. At the Bradley pumping engine, where the plungers are 27 inches diameter, there are seven such valves working on gutta-percha beats in each clack-box.

Valves are generally constructed of brass or gun-metal, except in the case of very heavy pressures where they have been made out of a special quality of steel. The "beats" are usually of gun-metal, but often the upper one is of gutta-percha, or better still a high grade of leather such as hippopotamus hide.

Quadrants and Counterbalancing.—For any type of horizontal engine fixed at the surface, quadrants have to be employed to change the direction of motion. If two lifts are used, quadrants are placed on opposite sides of the shaft, and so connected that one is making the up stroke, while the other is making the down stroke. In such case, the quadrant consists simply of an L-piece, as one balances the other; but where only one lift is employed, the quadrant is made of ⊥-shape, and a balance weight placed on one end. Instead of using wooden quadrants, wrought-iron or steel girders are common.

Almost invariably, the weight of the rods is greater than that of the water in the rising main, and unless they were counterbalanced the engine would run at such an irregular speed as would cause severe shocks and strains throughout all the working parts. In general, the balance is obtained by adding weights to the opposite end of the quadrant to which the pump-rods are attached, while in the case of deep mines, additional balance quadrants or "bobs" are placed at such intervals down the shaft as the necessity of the case requires. A forcible illustration of how great the difference is, is afforded by an actual instance where, taking the top lift only, 130 yards of 10-inch square rods with their strapping plates and the plunger and its connection to the rods, weigh 8·382 tons, while the water in the 9 inches diameter rising main only weighs 4·807 tons, a difference of 3·575 tons. As the engine here is double-acting, if it is to exert the same power, both on the in stroke and out stroke, a weight equal to half the sum of 8·382 and 3·575, or 5·978 tons, will have to be put on the end of the quadrant opposite to the pump-rods.

An ingenious balanced beam was exhibited at the 1889 Paris Exhibition, the design being due to Mr. Rossigneux, which really

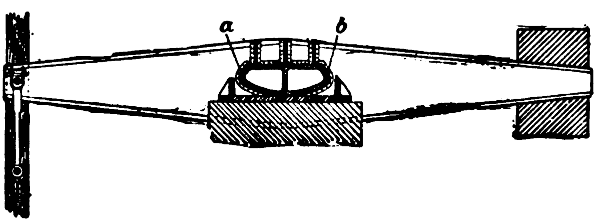


Fig. 479.

acts as a regenerator, helping the weight of the rods at the commencement of the stroke, and gradually exerting more and more resistance until at the end of the stroke the resistance is greatest and the rods are brought slowly to rest. On the other hand, when the engine starts to return, the beam, which at the termination of the down stroke was exercising its greatest resistance to motion in that direction, is naturally in the most favourable position to help the engine, but as the stroke progresses, the beam gives less and less resistance until at the end it gives least of all. This action is secured in a very simple manner. Instead of the beam turning about a fixed shaft as centre, it has a curved bearing surface (*a b*, Fig. 479) rolling on a plane, and consequently the ratio of the lengths of the two arms alters continually throughout the stroke. At the commencement the counterpoise weight is at its lowest position, and the leverage at which it acts is the shortest, while the conditions are exactly reversed at the termination of the stroke. The use of this appliance at Montrambert Colliery, St. Etienne, enabled an engine which was originally under its work, to run at an increased speed with safety.

Cornish Pumping Engines.—This type of engine, which is still largely employed for pumping operations, is illustrated in Fig. 480. It consists of a single cylinder, with its piston-rod connected to one end of a beam, the pump-rods being attached to the other. It is a single-acting engine, steam being admitted to the upper surface of the piston, causing the engine to make its in-stroke. An equilibrium valve is then opened, and steam passes to the lower side of the piston; the pressure is then equal on both sides. The weight of the pump-rods causes the outward stroke. Communication is now opened between the lower side of the piston and the condenser, a vacuum formed, and steam re-admitted to the upper side of the piston. This engine was designed by Watt, and remains at the present time as he left it. The valves are opened and closed at the proper time by tappet rods, regulated by a cataract. Any number of strokes per minute can be obtained, although from the massiveness of the machinery, speed must necessarily be slow; in addition, a pause is made between the successive strokes, during which the valves, or clacks, have time to close, thus reducing any chance of shock. It is a large piece of machinery, very expensive in itself, and also to work, but when once in operation requires little attention, has a very high efficiency, and its wearing capacity is almost unlimited.

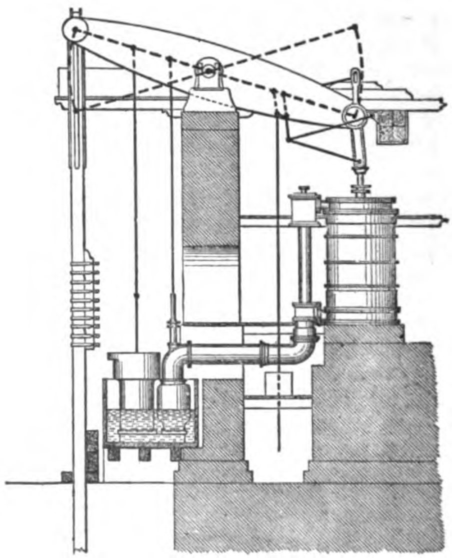


Fig. 480.

In these days of high boiler pressures, the ordinary single-acting Cornish pumping engine is doomed, as it is an engineering impossibility to obtain efficiency with expansion in one cylinder. Even when a moderate degree of expansion is carried out, the action during the stroke is irregular, and great strains are thrown on to the pump. In certain circumstances, however, when all the work of the steam is done on the up stroke of the engine, it is an advantage to have a single-acting engine, and consequently the Cornish cycle of steam distribution has been followed by Mr. H. Davey in designing a compound engine for the Basset Mines, Cornwall. Each of the two cylinders are single-acting, and on steam being admitted to the under side of the high and the upper side of the low-pressure piston, a weight of pump-rods is raised, which on the return stroke is sufficient to overcome the pump resistance, without any help from the engine. The return stroke is effected by opening equilibrium valves, uniting the upper and lower ends of each cylinder. No change occurs during this stroke in the quantity of steam contained in the cylinders, a single transfer to the opposite side of the piston being all that takes place, while in the succeeding indoor stroke the steam thus transferred passes from the high-pressure cylinder to the low-pressure one, and that in the low-pressure cylinder passes to the condenser. In this manner cylinder condensation is reduced to a minimum, because the steam end of the high-pressure cylinder is never brought into direct communication with the low pressure, nor the steam end of the low-pressure cylinder with the condenser.

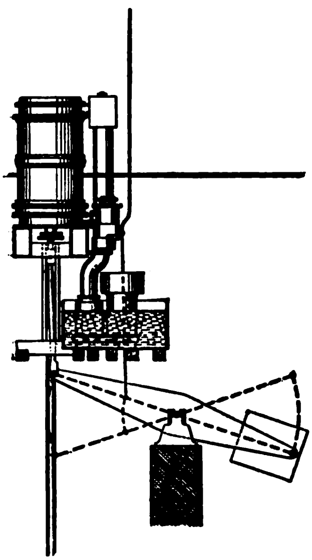


Fig. 481.

Bull Engine.—To reduce the cost of the machinery and erections, the Cornish Bull engine (Fig. 481) is often employed. In it the cylinder is placed directly over the shaft, and the piston-rod connected to the spear-rods. It works in exactly the same manner as the Cornish engine.

Davey Differential Engine.—Pumping engines have been called "profit eaters," and attempts are always being made to reduce both their first and working cost. It is questionable whether the working cost of any engine is less than that of the Cornish type, but its first cost is great, and it is liable to accident, especially in sinking, when what is known as a "riding column" often occurs—that is to say, some obstruction gets in one of the valves in the clack; the whole weight of the column of water is thrown on the engine in the return stroke, and the load acts in conjunction with the steam pressure, instead of opposing it. In nine cases out of ten this means that something has to break, although to reduce the risk, stops, previously alluded to, are fixed at intervals, to prevent the engine going too far either on its out stroke or on its in stroke.

To remove the danger Mr. Henry Davey has designed a gear, whereby a differential motion is communicated to the slide valve which is connected to a lever, one end of which is worked by the engine piston, while the other receives an independent motion from a subsidiary piston controlled by a cataract. The action of the gear will be readily understood from Figs. 482 to 485, and the following description given by Mr. Davey.* The diagrams are not drawn to a scale, but clearly show the action of the gear.

The main slide valve, *g*, is actuated by the piston-rod through a lever, *h*, turning on a fixed centre, which reduces the motion to the required extent and reverses its direction. The valve spindle is not coupled direct to this lever, but to an intermediate lever, *l*, which is joined to *h* at one end, while the other end, *m*, is joined to the piston-rod of a small subsidiary steam cylinder, *j*, which has a motion independent of the engine cylinder, its slide valve, *i*, being actuated by a third lever, *n*, coupled at one end to *l*, and moving on a fixed centre, *p*, at the other end. The motion of the piston in the subsidiary cylinder, *j*, is controlled by a cataract cylinder, *k*, on the same piston-rod, by which the motion of this piston is made uniform throughout the stroke; the regulating plug, *q*, can be adjusted to give any desired time for the stroke.

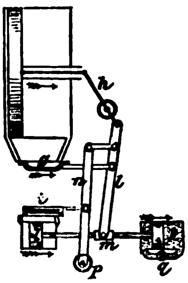


Fig. 482.

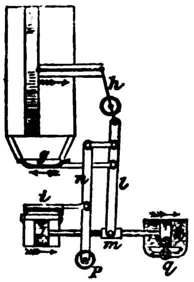


Fig. 483.

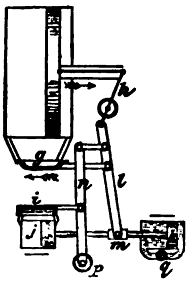


Fig. 484.

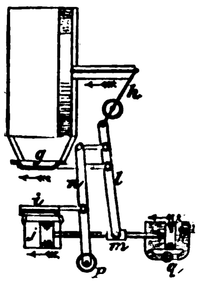


Fig. 485.

The lever, *l*, has not any fixed centre of motion, as its outer end, *m*, is joined to the piston-rod of the subsidiary cylinder, *j*; the main valve, *g*, consequently receives a differential motion, compounded of the separate motion given to the two ends of *l*. If this lever turned about a fixed centre at the end, *m*, steam would be cut off in the engine cylinder at a constant point in each stroke; but as the centre of motion at the end, *m*, shifts in the opposite direction with the movement of the piston, *j*, the point of cut-off also moves, and is dependent on the position of the subsidiary piston at the moment when the slide valve closes. At the beginning of the engine stroke the subsidiary piston is moving in the same direction, as shown by the arrows in Fig. 482, and in the instance of a light load, as illustrated in Fig. 483. the engine piston, having less resistance to encounter, moves off at a higher speed, and soon overtakes the subsidiary piston moving at a constant speed under the control of the cataract; the closing of the main valve, *g*, is consequently accelerated, causing an earlier cut-off. With a heavy load, as in Fig. 484, the engine piston, encountering greater resistance, moves off more slowly, and the subsidiary piston has time to advance further in its stroke before it is overtaken, thus retarding the closing of the main valve, *g*, causing it to cut-off later. At the end of the engine stroke (Fig. 485). the relative positions become reversed from Fig. 482, in readiness for the commencement of the return stroke. A retarding gear is also applied, by means of

* *Inst. Mech. Eng.*, 1874, 261.

which any pause that is required between successive strokes is easily obtained.

The differential gear is usually controlled by a subsidiary engine placed by the side of the large one. It consists of a steam cylinder (*a*, Fig. 486) driving one end of the link, *b*, and a second cylinder, *c*, whose piston-rod opens and closes the valve cylinder, *a*, by tappets, *d d*, attached to the valve stalk. The speed of both cylinders *a* and *b* can be regulated by the water cataracts *c* and *f* to any desired rate. The outer end of the link, *b*, is attached by a rod, *g*, to a rocking shaft connected to the pump quadrant, and consequently receives a motion proportionate to the speed at which the engine travels. The valves are operated by a rocking shaft controlled by a rod, *h*, attached to the centre of the link, *b*, and as both the ends of this link move, it follows that the central point to which the rod, *h*, is attached has a differential motion. The arrangement is such, that the valves of the main engine are opened when the link *b* travels in the direction in which the subsidiary engine tends to move it, and closed when the link is moved in the direction in which the main engine tends to move it. As the speed of the subsidiary engine, *a*, can be regulated by the cataract, *f*, it can be set to give the necessary valve opening at any required speed, but when such speed is exceeded, either by a decreased load or increased steam pressure, the main engine gains on the subsidiary engine, and accelerates the closing of the main valves. The second small engine, *c*, is employed solely to drive the valve of the subsidiary engine, *a*; its valve is opened and closed by the main engine, through the rod, *g*, tappets, *i i*, and link, *k*, connected to the valve spindle, *l*. The speed of this engine is regulated by the cataract, *e*, and as its piston-rod on its travel opens the valve of the driving engine, *a*, it necessarily follows that both the main engine and the driving engine have to stop until the second small engine has made its stroke. The cataract regulation enables this pause to be adjusted to a nicety.

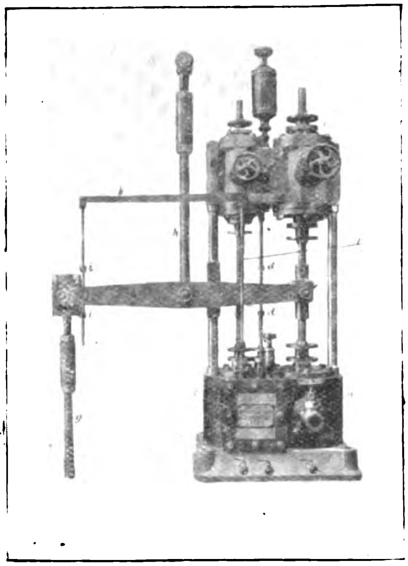


Fig. 486.

It is now many years since this gear was brought out, and long experience has proved its perfect reliability. Opinions differ as to the relative economies of the compound engine, with which this arrangement is connected, and that of the Cornish engine; but every one is agreed on the merits of the valve-gear, and it is becoming quite common to find it applied to the Cornish engine. Mr. Davey mentions an instance during sinking operations where the bottom clack failed, and 90 yards of 18-inch column was riding on the bucket, and the engine continued working without any injury whatever. The total weight on the engine in the outward stroke was 7 or 8 tons, and in order to save the cylinder covers from being carried away, steam had to be admitted on the opposite side of the piston, reversing the ordinary working of the engine, and forming a cushion in front of the piston. This was accomplished by the automatic action of the differential valve gear, but as the engine when used during sinking is generally out of balance, a special "shutter" valve is recommended. The arrangement consists in substituting a ported valve for a plain D slide valve in the low-pressure steam chest, and providing an adjustable cut-off plate with which either port can at pleasure be wholly or partially blanked. The adjustment is made from the outside without stopping the engine, and both shuts off steam from the low-pressure cylinder and cushions it against the high-pressure piston on the side on which it is applied while leaving the other side entirely unaffected.

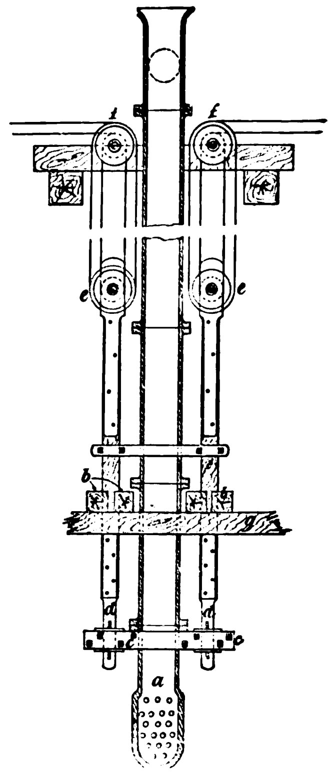


Fig. 487.

Suspended Lifts.—When water is met with in sinkings, even in small quantities, pumping has to be resorted to. Owing to the limited space, this is not only a difficult but a very expensive operation. With the ordinary spear-rods and engine at the surface, there are several methods for dealing with pumps during sinking, which may be divided into two distinct types —(*a*) the trees may be permanently fixed in the shaft as sinking proceeds and pipes added above the working barrel; such system requires a telescopic suction, or a telescopic pipe above the working barrel, and owing to the difficulty of securing the lower part of the pipes, is not to be preferred to (*b*) where the lift is slung by ground spears, and pipes added at the top of the lift.

With this suspended lift the first thing to do is to make one part of the shaft into which the suction pipe is dipped lower than the other. An ordinary snore-piece is employed (*a*, Fig. 487), above which the clack-piece is attached, followed by the working barrel and rising main until the surface is reached. Sometimes projecting pieces are cast on each side of either the suction or clack pipe, but a commoner plan is to fix two wrought-iron glands, *c*, underneath a flange. These glands receive the wrought-iron ends of the ground spears, *d*, which are secured in their place by cotters. These ground spears consist of two pieces of timber, passing down each side of the pump, and they carry at their upper ends pulley blocks, *e*, which are connected to similar pulleys, *f*, at the surface, and with the aid of ropes, the whole set can be lowered or raised as necessity requires. For additional security, other wrought-iron glands are added, which not only steady the lift, but strengthen the spears. A front bearer, or collar ring, *g*, is also fixed to steady the pump, and prevent any movement, which would be likely to take place through the up-and-down motion of the pump-rods. Other cross-pieces, *b*, are placed to serve as guides for the spear-rods. The ropes from the pulleys on the ground spears are wound on small crab engines at the surface. Pipes are added at the top as required.

In order to make the entire column more rigid and less likely to swing about as it sometimes does when suspended on ropes, it seems

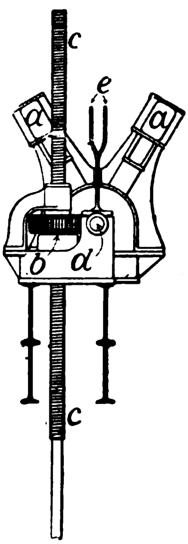


Fig. 488.

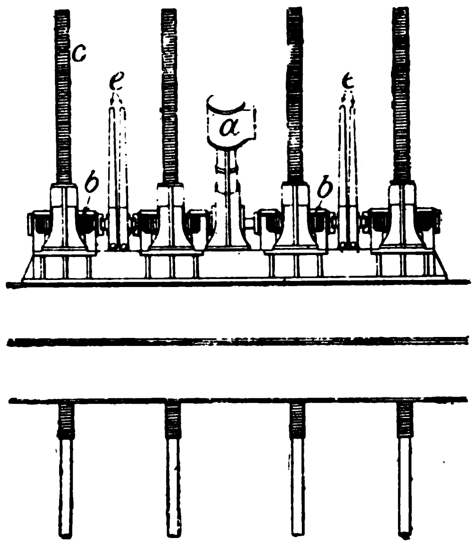
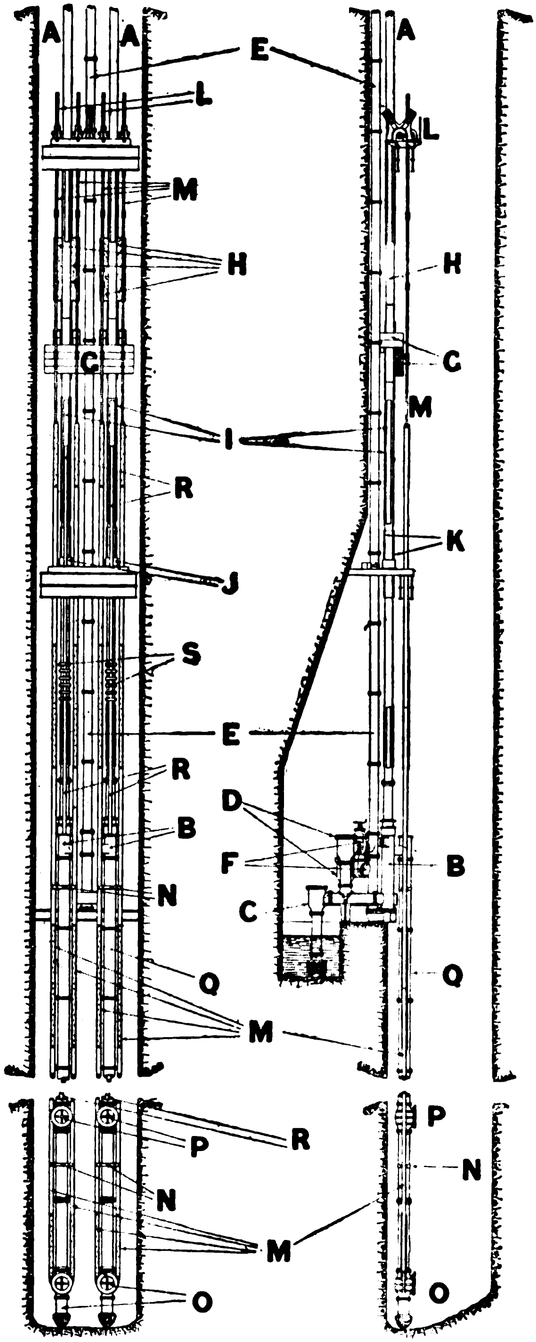


Fig. 489.

advisable to use part iron and part wood rods from one end of the lift to the other. When steam winches are employed to lower sinking pumps, as two ropes are generally attached to each set, there is often a difficulty in lowering both equally. To remedy this, Hathorn, Davey & Co. have designed a lowering tackle, consisting of a pair of small vertical engines (*a*, Figs. 488 and 489) with cranks at right angles, which can be mounted on girders placed at any desired portion of the shaft. The crank shaft of the engines extends outwards on either side, and has four endless screws on it gearing into four cog-wheels, *b*. These cog-wheels have long screws, *c*, working through nuts through their centre, and consequently when the engines work they revolve the shaft, *d*, and the endless screws on it, which in their turn work the cog-wheels and, consequently, either raise or lower the long screws. Clutches worked by handles, *e*, are provided so that either set can be used independently of the other. This is a compact and useful appliance, which allows pipes to be changed or added to with a minimum loss of time.

A complete arrangement for dealing with large quantities of water by an engine placed at the surface is illustrated in Figs. 490 and 491, when operations have reached the stage where the water met with in the upper portions of the shaft has been caught in a lodge or pound room, and is being dealt with by two plunger sets while sinking is proceeding lower down under two suspended bucket lifts. Two main pump-rods, A, are attached to two plungers, B, which draw water through the suction pipes and valve box, C, and force it through the delivery valves, D, into a rising main, E, common to both rams. The drawing shows how this is done, and also the sluice valves, F, for isolating either set of valve boxes for repairs or attention. The banging beams, G, the catches, H, on the rods, the



Figs. 490 and 491.

strapping plates, I, the guides, J, and the rubbing boards, K, are also indicated. The bucket-sinking set is lowered by the tackle, L, attached first to iron rods and afterwards to wooden ones, M, two of which proceed to the bottom, one on each side of the pipes, Q, forming the bucket lift. To stiffen the arrangement wrought-iron binding plates, N, shaped to fit the pipes, pass across from one suspension-rod, M, to the other, and each pair is held in position by bolts. O is the snore-piece and clack-door, P the bucket-door piece, and R the rods passing down the pipes, Q. These rods are connected to the bucket at the lower end, and are attached to the main rods of the plunger set at some convenient point, S, above the plungers by a similar coupling to that illustrated in Fig. 457. The remaining portion of the bucket-set rod projects upwards past the coupling. Such fastening is the only one permissible, because each time the set is lowered the secondary rods have to go with it, and consequently the main plunger-rods grip the bucket-rods at a different point.

The height at which the working barrel can be fixed above the water depends on several circumstances. Theoretically, the distance is 34 feet, because the pressure of the atmosphere will balance a column of water at that height. There are, however, several disturbing causes. The joints are never perfectly air-tight. There is also a certain amount of friction between the water and the sides of the pipe, which increases if bends are present. In actual practice from 27 to 30 feet is the limit.

Such lifts are expensive both in first cost and in maintenance. To a certain extent they have been superseded by direct-acting steam pumps slung in the shaft. The chief recommendation in favour of such apparatus is its comparative lightness and flexibility. Only those who have had experience with both systems appréciate the difference between having the huge, heavy inelastic range of cast-iron pipes and bucket lifts in the bottom of a sinking pit, and the relatively light and supple range of wrought-iron tubes and suspended pump. Indeed, it is scarcely going too far to say that some of the heavily-watered modern sinkings could not have been carried on with cast-iron bucket lifts, but neither system should be adopted in its entirety. It seems better to use suspended direct-acting pumps to sink with until sufficient depth is obtained for the first lodge-room, and then to put in a plunger set worked by an engine on the surface, while the lighter pumps are still retained for the actual sinking beneath the lodge-room. The types of pumps employed are described a little further on. Three ranges of pipes are required—steam, exhaust, and rising main, all of which are of wrought iron. Although differing in diameter, they should all be of equal length, so that when pipes have to be added those nearest to hand can be put in. It is in attention to such small details that success primarily depends. At a sinking, pipes are usually wanted in a hurry and there is rarely time to sort over a heap to find an odd length. The steam pipe is supplied with a sliding joint, and a sliding suction has also to be employed, as the whole arrangement is only moved bodily about every 15 to 18 feet of sinking. These telescopic wind-bores consist of a length of pipe terminating in a stuffing-box and sliding on an internal pipe which has been turned in a lathe (Fig. 492). The external pipe carrying the snore-piece is suspended by an ordinary pair of blocks attached to the holes (*b b*, Fig. 492), while the internal pipe is bolted to the rising main of the pump. As the sinkers clear away the ground, the snore-end can be lowered as desired, and may easily be raised by the blocks for a short distance when shots are to be fired. The amount of elongation allowed is in excess of the length of the change pipe, and consequently the level at which water is discharged, and that of the pump, remains constant until the sinking has proceeded so far that a new pipe has to be added.

At Denaby Main Colliery, Yorkshire,* the pumps were suspended by two ropes worked by a steam crab, and the steam, exhaust, and delivery pipes were all clamped together and fastened to the ropes. The clamps were formed of two pieces of iron about 4 inches by 1 inch (Fig. 493), bent and curved to fit the pipes and ropes, and bolted together between each pipe. With this arrangement nearly 100 yards were sunk in one lift, but as this was not sufficient to get through the water, a tank was placed about 60 yards from the top.

At Canklow Sinking, Yorkshire,† a large quantity of water was successfully dealt with by pulsometers, which were all of No. 10 size and capable of pumping 50,000 gallons of water per hour. They were suspended on one side of the shaft by heavy chains, to which the steam and delivery pipes were clamped as at Denaby Main Colliery. At a depth at something under 30 yards, which is the limit of the pulsometer's power, a tank was fixed in the shaft, and a man stood on a platform adjoining, to regulate the flow of water and see that the two lifts kept pace with each other. At the worst period, 150,000 gallons per hour were pumped with two lifts of three pulsometers each, arranged one above the other.

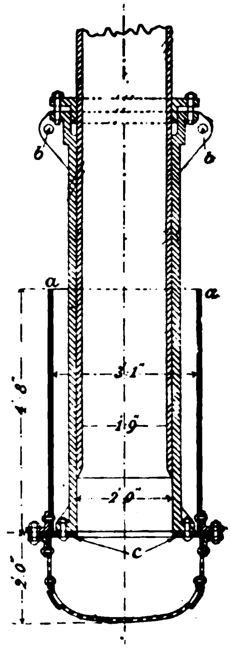


Fig. 492.

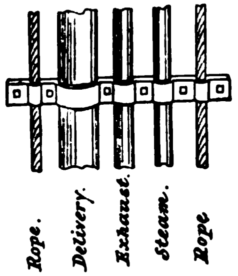


Fig. 493.

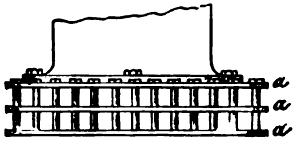
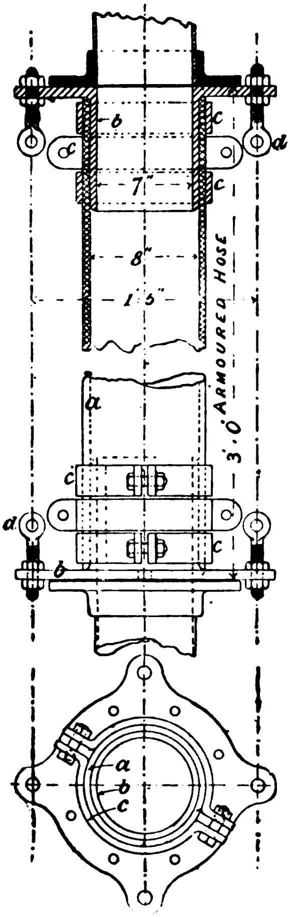


Fig. 494.

With an ordinary cast-iron snore-piece, breakages through shot firing are common. At Canklow an excellent form of wind-bore was

* *Brit. Soc. Min. Stud.*, xiv., 56. † *Ibid.*, xiv., 52.

employed. It consisted of three wrought-iron plates (*a a a*, Fig. 494), the bottom one blank, the other two with a hole the size of the suction pipe through them. The lower flange of the cast-iron pipe was bolted to the top plate, and the three flanges were fastened together by a large number of small bolts, covered with iron ferrules, which being loose, withstood the shots, the whole forming a grating or cage. The ferrules served the double purpose of protecting the bolts and of keeping the horizontal plates in their proper position.



Figs. 495 and 496

Even with wrought-iron snore-pieces, considerable damage is often done to the pipes of the rising main by shots, more especially to the sliding wind-bore which sometimes gets dented so that the inner tube cannot slide properly. Such damage may be prevented to a large extent by enclosing the sliding suction in an annular shield (*a a*, Fig. 492) made out of strong boiler plate. The method of connecting this up to the sliding tube and the snore-piece by angle-iron rings bolted to a horizontal plate, *c*, is clearly shown in the illustration.

Although such a shield prevents a considerable portion of the damage, it does not relieve the pipe flanges above from the serious shocks they often receive when the sinkers carelessly neglect to raise the wind-bore before blasting, nor indeed from the blows of pieces of debris which are often thrown violently against the lower pipes by overcharged shots, even when the snore-piece has been lifted as far as possible. The difficulty has been overcome by Mr. James Keen who, at the Maypole Sinking, Wigan, employed a flexible coupling between the shielded wind-bore and the pump. This consisted of a length of armoured hose (*a*, Figs. 495 and 496) slipped over ⅂ shaped ferrules, *b*, and secured there by three ordinary glands, *c*. As this hose would not be capable of supporting the weight of pipes hanging below it, four pieces of chain were connected between the two ferrules by eye bolts, *d d*, having screwed ends and two nuts, one below and the other above the flange, to permit of ready adjustment. The lower pipes are consequently free to swing about to a moderate extent, and all shock to the working parts of the pump is avoided.

DIRECT-ACTING STEAM PUMPS.—With any type of engine fixed at the surface the first cost is great, both for the engine itself and for its pit work. As considerable power is required to lift the great weight of rods hanging in the shaft, the engine has to be made larger than if such were absent. It has consequently become common, instead of employing such type of engine, to fix the pumps at the bottom of the shaft and force the water to the surface. The disadvantages here are—conveying steam underground, the difficulty of dealing with the exhaust-steam, and the liability for the pump itself to be "drowned," if the lodge- or sump-room is not large.

The objections to introducing steam are counterbalanced by the convenience of using the pumps, for their portability and the ease with which they may be worked is considerable. The exhaust steam, except with the larger pumps, can be got rid of by several devices. The liability to drowning can, to a certain extent, be avoided by fixing the pump in a special chamber, and only allowing as much water to pass into it as the pump can raise. This is usually done by a self-acting tap and ball arrangement.

Such pumps can be applied to lifts of a thousand feet, as the water is always flowing in the same direction, the movement during the reversal of the stroke being kept up by an air reservoir. The cost is low, breakages are rare, and the space occupied by them in the shaft is small To lessen the difficulty of working the engine and keeping the room for it open, they are constructed long, narrow, and low. With the single cylinder engines, the resistance of the pump plunger is practically constant, and steam has to be admitted nearly throughout the stroke. The economies resulting from expansive working have consequently to be sacrificed unless compound engines are adopted. Even then, the number of expansions which can be obtained are very limited, while the cost of the pump is considerably increased. While the surface engine is probably worked at a smaller expense than even the very highest type of underground pump, yet its first cost is so much larger that in some cases the extra interest on capital invested may amount to as much as the saving resulting from its working economy. When, however, underground pumps are placed in such risky situations that they have to be duplicated to prevent the possibility of their being lost by flooding this advantage disappears.

As with the other type, they are capable of being divided into two classes—bucket and plunger—and in addition, may be single- and double-acting. For clean water, the bucket pump with cup leathers is the best up to 400 to 500 feet head, as the packing is easily replaced —any ordinary mechanic can do it—and its cost is less to commence with. For gritty water and high lifts the plunger types are preferable, as they are outside-packed, and any leakage is easily detected. Double-acting pumps are certainly preferable to single-acting ones. The latter only deliver water at each alternate stroke; their capacity is half that of a double-acting one, and the column of water is brought to rest after each stroke, and has to be started again. In all cases, the stroke should be made as long as possible, as to obtain a given piston speed fewer strokes are required; the direction of motion is not changed so often, there is less wear and tear on the valves, and less shock to the different parts.

Among the many excellent pumps before the mining public, those of Jos. Evans & Sons are in great favour. They are strong, well-designed machines, perform the work they are stated to do, and are easily managed by any ordinary attendant. They will restart themselves if stopped by want of steam, and require little supervision. It may appear invidious to single out one particular firm, but this is done because it is impossible to give descriptions of even a portion of the many good pumps which are at work, to which the remarks made above may apply equally well.

The steam end of Evans's Cornish pump consists of an ordinary piston fitted with Tonkin's valve, which is a steam-moved one, consisting of a smaller plunger inside a larger one, the latter carrying a common slide valve. The steam chest is placed on the side of the cylinder, and the bottom of the steam port on the same level as the bottom of the cylinder; the whole of the condensed steam is carried out at every stroke of the piston, and the necessity for drain cocks avoided. There is no extraneous gear whatever; the pumps will start at any point of the stroke, there being no dead centre, and they can be worked by compressed air. The double-acting plunger pump, with the pump end half in section, is shown in Fig. 497.

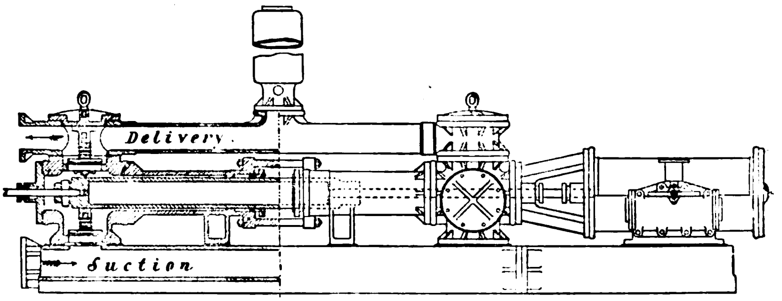


Fig. 497.

All the pump parts are of cylindrical form, and the various portions are so arranged that they may be renewed without necessitating an entirely new pump. The valve boxes are constructed to work against very heavy pressure, every valve is easy of access, and may be readily got at and renewed when required.

With the ordinary form of direct-acting steam pumps, the motion is a purely reciprocating one. To make them work more smoothly and regularly, and also, perhaps, with more economy, flywheels are added; such type lose the advantage of compactness, which is so valuable for underground use.

Worthington Pumps.—In this type, two pumps are placed side by side, the valve of each cylinder deriving its motion through levers, &c., coupled to the piston-rod of the opposite cylinder. When the one piston has nearly completed its stroke, the piston of the second cylinder is put into motion, and in turn gives effect to the slide valve and piston of the first cylinder. The great advantage is that, as the second piston starts to move just at the moment when the first piston is completing its stroke, a steady and uniform flow is obtained in the delivery main. The column of water is never entirely stopped, and any recoil or shock is prevented. As one or other of the steam valves is always open, the pump will start at any point in the stroke. At the present time every one is manufacturing the duplex pump, and they are rapidly replacing the single cylinder form. For heavy pressures, they are, undoubtedly, superior to all others. They are open to the objection that if one pump meets with an accident, both become useless, that the length of the stroke is very short, and that the pistons seldom travel their full stroke.

Evans Duplex.—To obtain a longer and complete stroke, Messrs. Evans have patented a duplex arrangement of their Cornish steam pump, each of which has Tonkin's valves, and can be worked independently of the other in case of breakdown. The valves of each cylinder are actuated by steam taken from the opposite cylinder through cross-over pipes, while the position of these pipe connections with the cylinders is such that the pistons are never at the ends of their stroke at the same time. Fig. 498 shows in plan the steam distribution

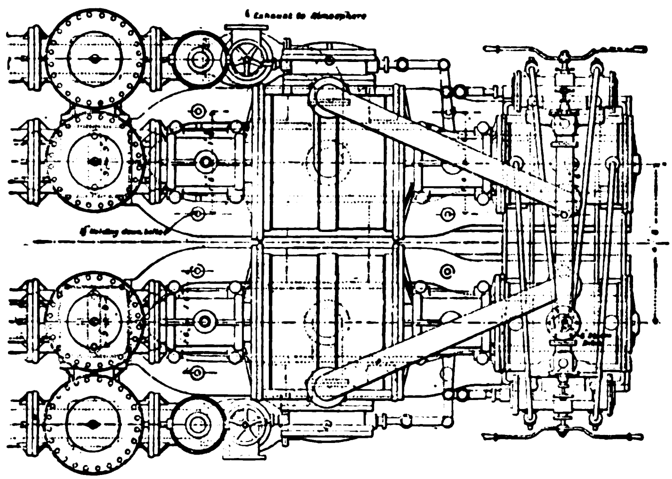


Fig. 498.

gear of two complete compound tandem engines, with high-pressure cylinders, 24 inches diameter, low-pressure cylinders, 44 inches diameter, by 36 inches stroke, made for the Miike Coal Mines, Japan, to raise 2000 gallons of water per minute 600 feet high. Under ordinary conditions the two engines work together on the duplex principle, but either may be kept working while the other is at rest. The disconnection of the two sets of gear is effected by the manipulation of certain stop valves, and can be done very quickly.

The cross-over pipes are clearly shown, and as these communicate with small port holes, which have to be uncovered by the pistons before the valves are reversed, and as the pistons cannot reverse until the valves have done so, the full stroke of the piston is ensured. They are claimed to be more economical in steam than the ordinary duplex, because cushioning the piston is not so necessary, and consequently clearance spaces are cut down to the finest limits, while they are more simple, because in place of the levers, rocking shafts, &c., employed to move the valves of the ordinary duplex, the proper distribution of steam is secured by the steam itself through the medium of the small cross-over pipes. Where capital cost is an important consideration they are a decided convenience, as one pump can be bought first, and duplicated when circumstances are favourable. These engines, too, need not be so large as ordinary duplex ones to deal with the same quantities of water, because they can be run at a higher piston speed with safety.

Tipton Compound.—To obtain the advantages of compounding without sacrificing any of the conveniences attendant on the use of a single-cylinder engine in confined situations, Messrs. Howl and Attwood designed a pump, whose steam cylinder, shown in Figs. 499 to 501, is divided into two parts in the centre of its length by the

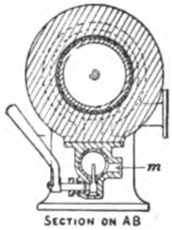


Fig. 499.

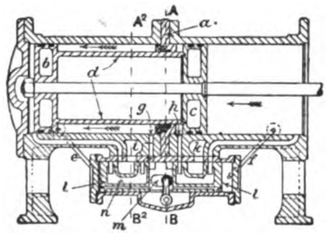


Fig. 500.

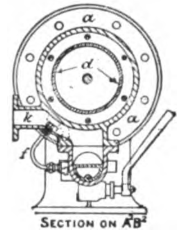


Fig. 501.

annular ring, *a*. The two pistons, *b* and *c*, are connected by the trunk, *d*, leaving an annular space between it and the cylinder walls. Such space forms the high-pressure cylinders, in which steam acts on the annular ring formed by the difference in diameter between the outside cylinder and inner trunk. The same steam is then conveyed to the outer end of piston *b* or *c*, and acts on the low-pressure areas, which are here the full diameter of the cylinder, and are consequently larger, so that expansion must take place. There is only one valve, *l l*, which is moved to and fro by steam conveyed alternately from the high-pressure areas by the pipes *e* and *f*. Steam admission takes place through the centre, *m*, of this valve alternately by the passages *g* and *h* to the high-pressure annuli, thence to the low-pressure side of the pistons, and finally to the exhausts, *i* and *k*.

The illustration shows the engine terminating its stroke from right to left, with the steam pressing on the pistons in the direction indicated by the arrows, the exhaust, *i*, being in direct communication with the outer end or low-pressure side of *b*. When the piston, *b*, has travelled far enough to uncover the port-hole connected to the pipe, *e*, the high-pressure steam passes from the annulus to the back of the piston-valve, *l l*, and drives it to the right hand, closing the passage, *m* to *g*, but opening it to *h*, while the low-pressure side of piston *c* is opened to communication with *k*. At the same time the high-pressure steam, which during the last stroke acted on the annulus of piston *b*, is conveyed through *g* (which has been opened to *n* by the travel of the valve) to the low-pressure side of the same piston.

Apart from the conveniences of the arrangement, the pump is necessarily more economical than an ordinary direct-acting one, while, as the heat is contained in one cylinder, there is less radiation than when compounding with two cylinders. The rate of expansion may be varied, if desired, by replacing the trunk and division ring by one of smaller or larger diameter, without interfering with the outer cylinder and valve gear. Owing to the placing of the valve at the bottom of the cylinder, an unusual position, all condensation water drains into the lowest point of the valve chest, from whence it can readily be removed by a pipe connection to any ordinary steam trap; steam economy is thus increased by keeping the cylinder dry.

Riedler Pump.—The principal feature of this pump is the mechanically operated valve, which is circular in form and has a lift of from 1 to 2 inches, and an area of such an amount as to reduce the speed of the water flowing through the valve to a few feet per second. At the beginning of the stroke the valve opens automatically but under the control of a simple device, and remains open practically the entire stroke until near the end when it is positively closed at the proper moment by the controller. There is only one valve for suction and one for the discharge, consequently the pump end is of the simplest kind.

The valve itself is shown in detail in Fig. 502. The valve seat with its face, A, has a centre spindle terminating in the cap, H. The

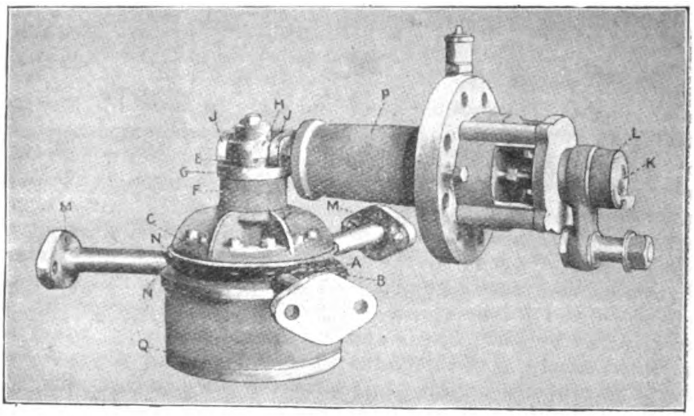


Fig. 502.

valve C faced at B is threaded over this spindle. F is a rubber buffer fitting over the shank of the washer, G, which in its turn fits over the shank or collar of the valve, and is prevented from coming off by the cap nut, E. J J are two forks keyed on the one end of the spindle, K, which passes out of the valve chamber to the outside of the pump through the bonnet or gland, P, which contains the packing for preventing the egress of water. Keyed to the other end of the spindle, K, is a lever, L, through which the spindle receives its motion from the pump wrist plate. M M are pins forced in from the outside having taper ends, N N, which bear on the edges of the valve seat and keep it in position. They allow of the valve and seat being easily removed for repairs without doing any work inside of the pump body. The groove, Q, is used for hydraulic packing.

The pump itself is of differential construction, delivering a portion of the water at each stroke, but there is only one suction and one delivery valve. Water enters the suction pipe, A (Fig. 503) into the suction air chamber, and thence into the suction funnel, B. It should be noted that the large chamber into which A leads not only forms the base on which the pump rests, but also, in its upper part, an air chamber ensuring efficient action of the suction valve, E. When the main plunger, J, moves towards the right it draws in a quantity of water equal to its displacement through the valve, E, and on the return stroke to the left, as E has then been closed by mechanical means, it forces a volume of water equal to its displacement through the discharge valve, F, half of which passes away to the rising main, D, while the other half passes down and follows the differential plunger, H. When the discharge valve has been closed, the main and differential plungers, which are connected by means of slide bars, move again to the right; the main plunger draws water into the pump through the suction valve, E, while the differential plunger

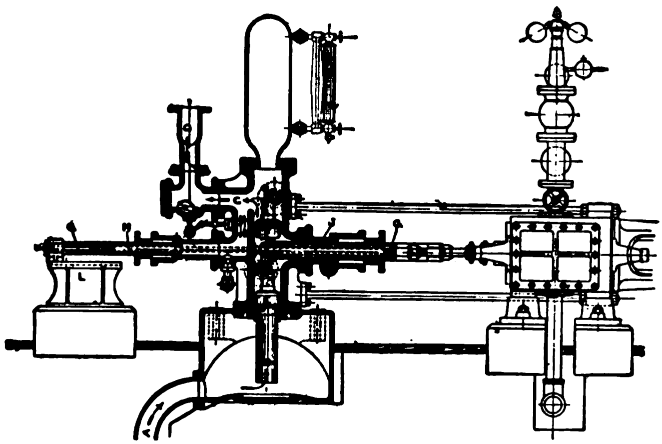


Fig. 503.

drives the water in front of it through the discharge pipe, C, into the rising main, D. The sectional areas of the main and differential plungers are generally made in the ratio of 2 to 1 in order to equalise the work done at each revolution of the engine. The rods, G, which are always in tension, are the side rods connecting the cross heads of the main and differential plungers. The differential plunger cross head is generally provided with a shoe which works on a cast-iron guide, L, to prevent wear of the stuffing-box and cylinder. At the bottom of pipe D will be noticed a clack valve shown open. This can be closed at any time from the outside, when any of the internal parts of the pump need inspection or renewal and is particularly valuable, when two pumps are run side by side, as when it is closed, it enables one pump to continue working while the other is stopped for repairs. It opens automatically as soon as the pressure inside the pump exceeds the pressure in the rising main, and further allows the additional advantage to be secured of continually having the pump primed, because the water in the rising main and the differential plunger, H, are always in connection. Consequently shocks and strains are reduced, because so long as there is water in the column the pumping engine has a resistance to overcome, even should the suction be lost.

The valves are closed by forks which are operated through levers connected to a wrist plate, which is a circular plate of iron rocked to and fro on a centre by a link passing from it to an eccentric on the main engine shaft. Their action will be understood by an examination of Fig. 504, where the numerals 1, 2, and 3 represent the beginning, middle, and end of a stroke.

Owing to its large and mechanically-operated valves, this pump can safely be worked at a higher piston speed than those of ordinary construction with a consequently greater efficiency of steam consumption.

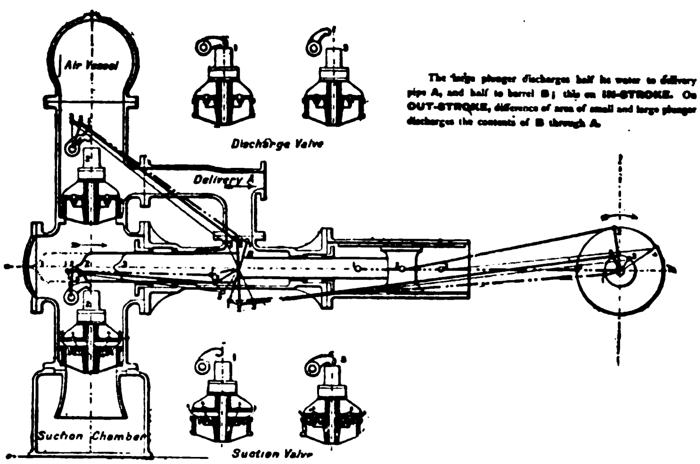


Fig. 504.

Holst Pump.—In order to avoid the loss from inertia due to the stopping and starting of the water column, which is the most serious factor in pumping operations and increases with the speed, Mr. C. P. Holst, of Amsterdam,* has designed a new system where when the engine is once started the water flows through the pump in a stream of which the velocity in all parts and at all times is constant. Four pumps are so combined that there is but one passage for the water through the entire four, these being in series with one another and not in parallel and in separate water passages as usual. The pump buckets are single-acting, and have valves which open outwardly in the lower pair and inwardly in the upper pair. Any bucket whose motion at any instant is opposite to that of the water, simply allows the water to pass through it with the valves open, while of those which move in the same direction as the water, the one moving the faster will do all the work, the water simply passing through the one moving at the lower speed. Suitable connecting mechanism is introduced between the steam and water cylinders, with the object of taking up the uneven motion of the steam piston-rod and so modi-

* *Coll. Guard*, 1898, lxxvi., 201.

fying it that the resulting motion of the pump-rods during the working part of the stroke will be almost uniform. The water piston-rods are made of such a diameter that the annular passages round them have the same area as the water pipes, so that there is no lost work due to the acceleration and retardation of the water.

Pumps for Sinking.—Any well constructed pump can be used during sinking, but special types are manufactured for this purpose. Messrs. Evans construct one in which two rams are placed in the same straight line as the steam cylinder, which is of the ordinary pattern. The lower pump ram is twice the diameter of the upper one, and only one suction valve is used. All the water first passes under the lower ram, which on its downward stroke delivers half the water into the rising main, and half into the upper end of the top plunger. When the rams rise, the lower one sucks in water, and the upper one delivers that water which has passed into it during the downward stroke. An air vessel is placed in the vertical delivery pipe similar in construction to Fig. 508. The Griff pattern pump, the Deane straight-line pump, and others are representatives of a type which has been especially designed for sinking purposes.

At Denaby Main sinking a special type of pump was designed by Bailey & Co., which consisted of three hollow plungers. The upper pair (*a* and *b*, Fig. 505) are stationary, and over them slide barrels, which are connected to the steam piston. From the lower end of these barrels projects the bottom plunger, *c*, which works into the third barrel, together with the two stationary plungers, and is secured by means of connecting-rods to the steam cylinder; thus, there are two smaller barrels in connection with the larger ram, moving between the larger barrel connected with the smaller rams. A series of valves, *d*, constituting the delivery valves, are placed in the junction between the smaller barrels and the large ram, while the suction valves, *e*, are placed at the bottom of the large barrel.

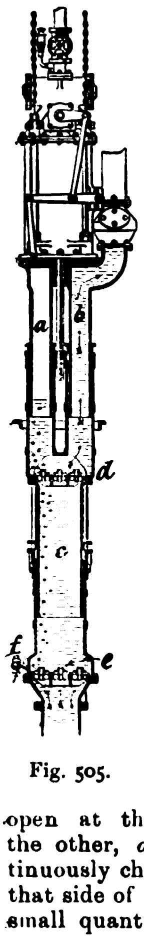


Fig. 505.

As the bottom plunger rises, the water follows it into the lower barrel, while at the same time the water in the upper hollow plunger is forced into the rising main. On the down stroke, the water in the lower barrel is forced through the lower plunger and valve into the upper barrels and plunger, and thence into the rising main; the discharge of water is therefore continuous. One of the upper plungers, *b*, is open at the top, and forms the discharge orifice for the water; the other, *a*, is closed, forming an air vessel which is kept continuously charged with air, as a suitable snifting valve, *f*, is fitted to that side of the pump and below the discharge valves. It permits a small quantity of air to be taken in with every up stroke of the pump.

Arrangement of Supply Pipes, &c.—For successful working, a great deal depends on the arrangement of the suction and delivery pipes. The bends should be made as large as possible, and suitable air vessels are a necessity. Perhaps the best arrangement is that shown in Fig. 506. The suction pipe is attached to the end of the pump, and its lower length is provided with a foot valve, *b*, which always keeps the pipes and cylinder charged with water, and prevents the pump, on being started, from having to free both itself and the suction pipes from air. For gritty water, a strainer, *c*, is introduced in the suct on pipes, and serves to prevent any coarse matter passing into the pump. A retaining valve should be placed between the end of the pump and the commencement of the delivery main, so that when any repairs are necessary, the pressure of water is kept off the pump. For charging the suction if at any time it loses water, a short length of pipe, *a*, with a suitable valve is inserted between the suction and the delivery pipes, of course, beyond the retaining valve. Where the suction pipe is long, it is just as necessary that an air vessel should be placed on it as on the delivery side. This is best done by carrying the suction pipe upwards and introducing a tee-pipe, *d*. This chamber can easily be extended by adding ordinary pipes and putting a blank flange at the top.

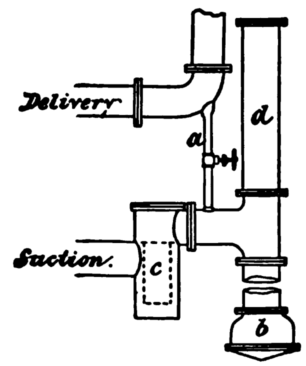


Fig. 506.

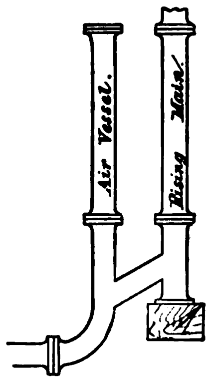


Fig. 507.

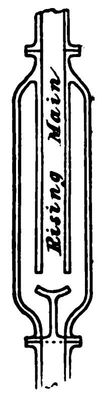


Fig. 508.

Air Vessels.—Direct acting steam pumps always work better with air vessels, although their utility is much questioned. Water being an incompressible fluid, some elastic medium has to be introduced to resist the shocks due to stopping and starting the column. Sometimes a pump works just as well (or rather as badly) with an air vessel as it did without one, but this is not the fault of the air vessel; it is more probably due to its improper position, insufficient size, and lack of attention. In the first place, the air vessel should be so situated that the air in the water tends to come back into it and not to flow past it. A very good rough arrangement is shown in Fig. 507, but, perhaps, the best is Fig. 508, where all the water has actually to flow right through the air vessel.

Then as to its size. What may appear to be a large chamber is fitted on to a pump, but it must be remembered that it is only charged with air at atmospheric pressure. With a lift, say, 300 feet, the pressure per square inch would be roughly 150 lbs., and immediately the pump starts to work, the water will compress the air in the air chamber with this pressure, and necessarily reduce its bulk; therefore instead of having, say, 10 cubic feet of air in the chamber, the volume under the above load is reduced to 1 cubic foot. It is also suggested that the air enters into mechanical combination with the water under this heavy pressure, just in the same way as it does in mineral waters, and that, sooner or later, unless it is attended to, the air chamber gets completely filled with water.

Neglect has in many cases made air vessels quite useless, and has given them a bad name, but with proper attention they will do everything that is claimed for them. They never work well, unless means are adopted to keep them properly char ed with air, and the air so introduced should be above atmospheric pressure. Mr. H. F. Bulman* states that at Byer Moor Colliery a small ½-inch tap was fixed in the suction pipe at a point before the suction valve, and that when this tap was opened slightly and the engines were working, a small quantity of air was drawn in at each stroke, and found its way through the pumps into the air vessel, and remained there at a pressure due to the head of water in the rising main. The more satisfactory plan, although it entails a little expense, is to employ a small force pump, worked by the piston-rod of the pump, which delivers a small quantity of air into the air vessel with each stroke.

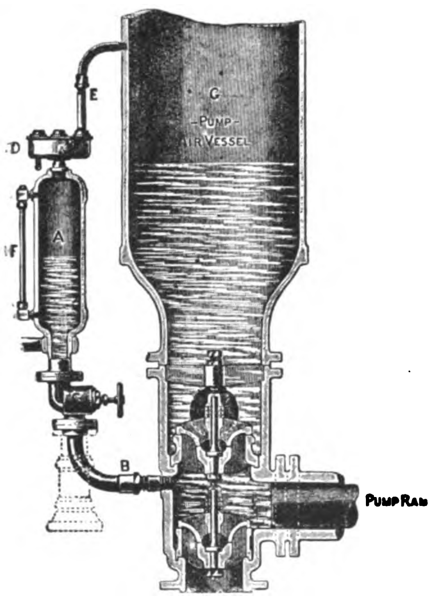


Fig. 509.

Wipperman and Lewis's Apparatus.—This instrument has been designed for supplying air to pumping engines, and consists of a cylindrical vessel (A, Fig. 509) which has no working parts, the air itself forming a piston; at the bottom of the chamber is fixed a regulating cock, C, which must be connected to the pump valve box between the suction and delivery valves as illustrated. At the top of the vessel, A, is fixed a small gun-metal valve box, D, fitted with inlet and outlet air valves, and from this a delivery pipe, E, communicates directly to the air vessel, preferably at the top.

The action of the apparatus is as follows:—When the pump draws its water it will partly empty the vessel, A, the amount being indicated by the gauge, F, and regulated to a nicety by the cock, C. On the return stroke of the pump plunger, the whole of the air drawn into the chamber, A, through the inlet valve in the box, D, is sure to be delivered into the pump air vessel, G, because the pressure in the main

* *Brit. Soc. Min. Stud.*, xvii., 90.

pump, when delivering, is in all cases greater than on the suction side.

The advantages of this simple apparatus are many. The supply can be regulated; there is no friction as there are no working parts; it is noiseless in action; and it can be applied to any engine at a less cost than an ordinary charging pump.

Condensing Arrangements.—Where the diameter of the steam end is not double that of the water end, the exhaust steam can be easily got rid of in several ways. If the steam end is large, and the pump end small, the volume of exhaust steam is so great that the water is heated too much. Often the exhaust is turned into the suction pipes simply with ordinary pipe connections; but a far more successful arrangement is Holman's condenser, as applied by Messrs. Tangye to their steam pumps (Fig. 510). A vacuum of from 8 to 10 lbs. is easily obtained, and back pressure removed. The apparatus consists of one or more double-beat valves, and the steam is introduced in annular streams to meet the suction water passing to the pump.

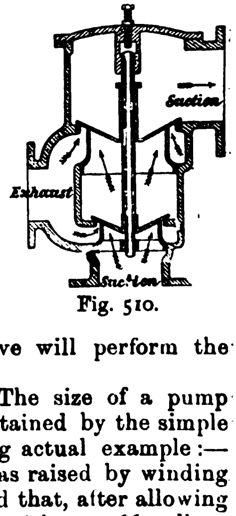


Fig. 510.

A condenser, acting in a very similar manner, is made by Messrs. Hayward, Tyler & Co. The aim of this appliance is to distribute the steam as much as possible in order that a large surface may be operated upon, and the condensation be correspondingly rapid. Where such appliances are used some valve has to be introduced, to allow the exhaust steam to be turned into the atmosphere whenever required. When the pump is first started, before the pipes are thoroughly filled with water, some such device is absolutely necessary. Any ordinary two-way valve will perform the operation.

Calculations as to the Size of Pumps.—The size of a pump to perform a certain amount of work is easily obtained by the simple method of reasoning indicated by the following actual example:—At a colliery under the author's charge, water was raised by winding it in a tank; and by measurement it was found that, after allowing for slip, 10,000 gallons an hour had to be dealt with, or 166 gallons per minute. The first point to decide is the piston speed; many authorities say that this may be from 200 to 300 feet per minute. There is no doubt that such velocity can be used, but no pump makers, who, after all, are the best judges of the capacities of the machines, would recommend such speed for regular working. By common consent, a good and safe velocity may be taken at 100 feet per minute. If 166 gallons have to be delivered every minute, and the piston speed be 100 feet, 1·66, or, say, 1·7 gallons will be delivered for each foot the pump works, if it is a double-acting one.

One gallon of water contains 277·25 cubic inches, therefore, 1·7 gallons × 277·25 = 471·325 cubic inches of water have to be delivered for each foot the pump works.

$$\therefore \frac{471 \cdot 325}{12} = 39 \cdot 277$$

is the area in square inches of the required water column.

If the piston-rod of the pump is put at 3 inches diameter, its area will be 7·068 inches, and this added to the area of the water column makes the area of the required plunger to be:—

$$39{\cdot}277 + 7{\cdot}068 = 46{\cdot}345 \text{ square inches.}$$

$$\therefore \text{ diameter of required plunger } \sqrt{\frac{46{\cdot}345}{{\cdot}7854}} = 7{\cdot}68 \text{ inches.}$$

The height to which water had to be lifted was 400 feet; the pressure per square inch will, therefore, be:—

$$400 \times {\cdot}433 = 173{\cdot}2 \text{ lbs.} \therefore \text{ total pressure} = 39{\cdot}277^{*} \times 173{\cdot}2 = 6802{\cdot}6 \text{ lbs.}$$

The steam pressure available was 60 lbs. per square inch. The area of the steam cylinder, therefore, should be:—

$$\frac{6802{\cdot}6}{60} = 113{\cdot}38 \text{ square inches.}$$

One half of this area should be added for frictional resistance, &c., making the area 170·07 square inches.

$$\therefore \text{ diameter of steam cylinder} = \sqrt{\frac{170{\cdot}07}{{\cdot}7854}} = 14{\cdot}743 \text{ inches.}$$

or practically 15 inches.

From these results a pump was put to work, having a steam cylinder 16 inches in diameter, and 7½-inch rams, which has dealt with the quantity of water it was intended for.

In determining the quantity of water a pump of a given size will deliver, the converse of the preceding calculations can easily be made. When the piston speed is known, all that has to be done is to find the area of the rams, remembering that the area of the piston-rods must be taken out, as the water cannot occupy the space that they take up in the pump chamber.

The quantity so found is the theoretical one, but is never reached in practice, owing to the occurrence of what is known as "slip." Neither the suction nor delivery valves can be instantaneously opened or closed, and, as a result, the piston does not discharge its theoretical volume at each stroke; a certain quantity is forced back into the suction during the delivery stroke, and another quantity escapes back into the pump-chamber on the return stroke. The amount depends entirely on whether the pump is in efficient working order or not. With the best constructed varieties in good order, the loss or slip will not amount to more than 2 per cent., but it may increase from that to anything if the valves are worn, or if an obstruction gets beneath them and prevents their closing.

Effect of Acid Water.—Water containing sulphates and chlorides has a most injurious effect on the working parts of pumps. Even when present in small quantities their influence soon roughens the working parts, and this roughness either cuts away the bucket leathers or grooves the plungers. Free sulphuric and hydrochloric acids occur in many mine waters, and are specially objectionable. To prevent this action the working parts are generally lined with gun-metal with satisfactory results. The experiment of neutralising the

* The pressure only acts on that part of the plunger surrounding the piston-rod, not on the rod itself.

acid with lime has also been tried, while the Goodyear Hard Rubber Co., of New York, manufacture a pump of special design for use in chemical works in which all the parts that come into contact with corrosive liquids are lined with hard rubber. The Scranton Steam Pump Co. line the water cylinders with lead.* The cylinders are designed to permit the internal contour being readily fitted with metal cores, and after these have been accurately placed in position in the barrel, which has been properly prepared, the space left is filled up with a suitable lead alloy. A suitable counterbore at either end of the cylinder, with a joint which is watertight when the head is in place, protects the iron from corrosion.

Unfortunately, the corrosive action is not confined to the pump, as the rising main suffers also. At Butte, Montana, the water contained so much free sulphuric acid that the rising main had to be made of drawn copper tubes. The cost of a copper main is almost prohibitive. For low pressures, pipes formed of wooden staves about 2 inches thick, asphalted heavily, and hooped with iron bands have been employed, but the water softens wood fibres. For higher pressures, iron pipes lined with pine staves ¾ of an inch thick and soaked in asphalt have given good results.

Mr. E. Le Neve Foster found that, in Nevada, the action of corrosive mine waters is greater on wrought iron than on cast iron, and that the lower pipes were eaten away more rapidly than the upper ones. He thinks that the rising main should be formed of cast-iron pipes of extra thickness, and observes that the action of the corrosive water dripping on iron is much more severe than when iron is immersed in it.†

DRAINING DEEP WORKINGS.—If the shaft is at the lowest point the water may easily be conveyed from the working places to it and raised to the surface, but if the shaft is on a higher level than the workings the problem becomes a far more difficult one. With small quantities, the common way is to load the water into special tubs and convey them to the shaft in the same manner as the mineral, or handpumps can be employed. Both of these operations are very costly.

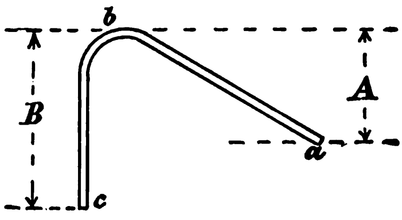


Fig. 511.

If the height to which the water has to be lifted is not very great, large quantities can be removed from deep workings by the use of a syphon, the principle of which is shown in Fig. 511. If the tube, *a b c*, is filled with water and open at both ends, the water naturally falls out of the end, *c*, which is the lowest, and creates a vacuum at the point *b*. Now if the end *a* be connected with a reservoir of water the pressure of the atmosphere at that point will force the water along *a b* to fill the vacuum, and a constant flow will pass from *a* to *c* under certain conditions. One condition is that the vertical height from *a* to *b*, or the height, A, must not be more than that which the pressure of the atmosphere will supply. This theoretical height is never reached, owing to the friction of the water in the pipes and the

* *Eng. and Min. Journ.*, 1902, lxxiii., 183. † *Ibid.*, 1897, lxiv., 368.

resistance caused by the introduction of certain valves which are necessary for the successful working of the syphon. Practice proves that it cannot with safety be more than 27 feet. The other condition is that the discharge orifice must be lower than the inlet; it is also advisable that the gradient should be as uniform as possible, or air will collect in the bend and the syphon cease to work. Indeed, where the pipes are undulating, as they sometimes have to be, discharge cocks must be placed at each bend in order that the pipes can be always freed from air. The discharge orifice should be as far below the inlet as is possible, for the velocity of efflux is represented by the pressure, B—A.

Where pumps are used, a small pipe should be led from the rising main into the syphon to allow water to be taken out and the syphon filled, if any leakage has taken place. If such means are not available for charging the pipes small pumps, made by several manufacturers for the purpose, have to be employed. These consist of a ⊥-pipe casting having two light flap valves in the horizontal passage, one on each side of the vertical pipe which contains a small plunger. Both these valves open in the direction in which the water flows, and when the pump is being worked to charge the pipes, act as suction and delivery valves; but when the syphon commences to draw water, the steady flow readily opens both valves. A clack of a very light construction should be fixed at the inlet end to prevent the water flowing out when not at work, and a tap should also be introduced in the drop-leg to regulate the flow.

If the height exceeds 27 feet other means have to be adopted, the commonest of which, where horses are used, is that of a throw-pump worked by bevel gearing. This is, perhaps, the most arduous work to which horses can be put, and they are unable to remain at it for any length of time; it is also slow and costly. The horses are soon worn out, and something else must be employed. If power transmitted by wire ropes passes the place where the pumps are situated, or any point near, it becomes a very simple matter to carry an off-shoot to a pulley, which then takes the place of a horse. The endless rope system is particularly suitable for such arrangement. A clutch can be fixed to the pump, which can be set to work whenever required.

Hydraulic Power.—Where pumping appliances are fixed in the shaft, hydraulic engines are often employed to pump from deep workings into the sump, the power to drive them being obtained from the rising main of the pumps. Their action depends on the principle that a small quantity under heavy pressure is equal to a large quantity at a small pressure, or having a head of water of 600 or 700 feet in the rising main, a small quantity of this can be conveyed to the deep, and will lift a larger quantity of water into the sump for a considerably less height. Hydraulic motors are particularly suitable for pumping, because, as the resistance to a pump is nearly constant, they can be always worked at full load, while variations in the speed can readily be obtained by merely throttling the driving water at the admission stop-valve, which action does not in any way interfere with the efficiency of the pump.

A common construction of such engine is employed at Tees Hetton Colliery, Durham,* and is shown in Fig. 512. It consists

* *Brit. Soc. Min. Stud.*, xi., 132.

of a motor cylinder of special design, provided with controlling valves, and connected through a strong base plate to the pump, which is of the ordinary type. The piston of the motor cylinder, *a*, is connected direct to the piston of the pump, *c*, and the latter is provided with a cross-head, *d*, which serves to actuate the tappets on the tappet-rod, *e*. The small auxiliary valve, *f*, is operated by the tappet-rod, *e*, through the lever and valve-rod, *g*, thus admitting the drive water to either end of the piston, *h*, which, in its turn, engages the main slide valve, *j*, and admits drive water to the motor piston, *k*. The latter accordingly makes its stroke until arriving at the opposite tappet, when the motion is reversed. The exhaust water from the motor cylinder is discharged on the upper side of the delivery valves in the pump, and passes away to the main pumping engine. The con-

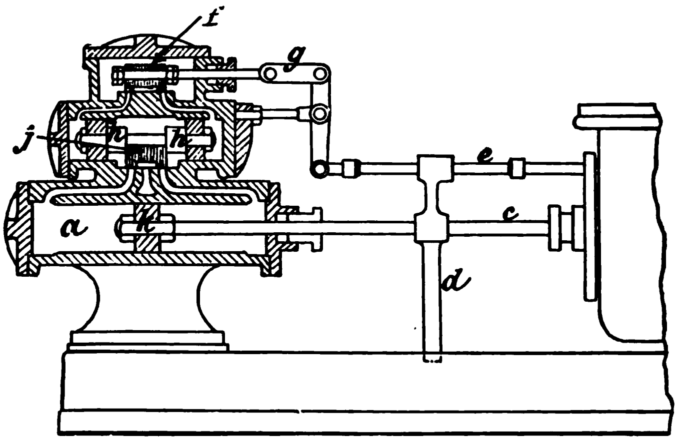


Fig. 512.

trolling valves of the motor cylinder are composed of lignum-vitæ, as this wood requires no further lubrication than is afforded by the water. The pressure on the motor piston of the pump was roughly 230 lbs. per square inch, and by means of this pressure, 7000 gallons per hour were forced to a height of 156 feet.

*Moore's Arrangement.**—A hydraulic engine of a totally different class is that designed by Mr. Joseph Moore, where two columns of water are substituted for the ordinary solid rods connecting the steam engine to the pump. The action will best be seen from the diagrammatic representation (Fig. 513). A cylinder, *a b*, at the surface, having a piston, *p*, is driven in the ordinary way by a steam engine, and each end of this piston is connected to each end of a smaller cylinder, *c d*, situated underground, having a piston, *q*, and connected through a piston-rod to an ordinary double-acting pump. The pipes and the cylinders are all full of water. When the surface piston, *p*, moves from *a* towards *b*, water is forced down the pipe, *e*, and moves over the piston, *q*, towards *d*; when the piston, *p*, reverses its motion, the piston, *q*, is also reversed.

The success of the appliance is due to an arrangement whereby the

* *Min. Inst. Scot.*, xii., 168.

stroke of the rams is adjusted, as without some such appliance, should there be any leakage in one of the power pipes, the plunger at the bottom would make a shorter stroke in one direction than in the other, and would work towards the end, and, unless there were some regulator, knock off the cylinder cover. It will be noticed that the pipe, *g h*, connects the two power pipes, *e* and *f*. In this pipe are two valves, *j* and *k*, opening in opposite directions, the former closing against pressure from pipe *e*, and the latter against pressure from *f*. These valves are opened by tappets, *m* and *l*, set apart a few inches more than the length of the stroke. If the pipe, *e*, leaks, the piston, *q*, will not make as long a stroke as it should do, and stops short of *d*. In the return stroke, when the piston, *q*, has travelled as far as it safely should do, and before the piston, *p*, on the surface has completed its stroke, the projection, *s*, catches the tappet, *l*, and opens the valve, *k*. The pressure of water in *f* is now free to lift the valve, *j*, and to run into *e*, immediately equalising the pressure on both sides of the piston, *q*, and stopping it. The water displaced by the remaining part of the stroke of the piston, *p*, passes through the valves from one power pipe to the other.

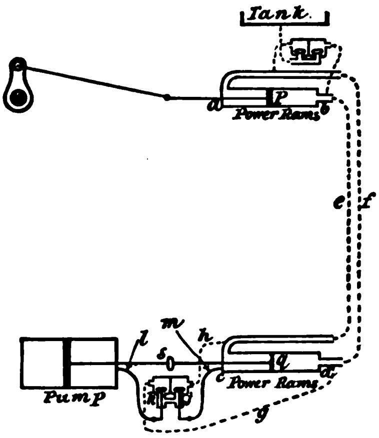


Fig. 513.

The power pipes are kept charged from a tank placed above the level of the highest point. There is a valve opening inwards on each of them, and when the piston, *p*, makes the return stroke, enough water is sucked in to make up any leakage. A considerable number of these engines are at work, and it is stated that diagrams taken from one working at the Shotts Iron Co.'s Collieries, near Edinburgh, show that 66·26 per cent. of the work shown in the indicator diagram of the steam engine is got out of the pump.

Hathorn-Davey Arrangement. — Both when the power is obtained from the rising main, and when special power engines are fitted on the surface, Messrs. Hathorn, Davey & Co. favour the employment of duplex pumps underground, as these give a fairly constant speed and uniformity of flow, both in the power as well as in the pump column, with a consequent avoidance of shock, which is so necessary when dealing with such an incompressible fluid as water. Each half of the pump consists of two pairs of rams of the *same* diameter, each pair joined by a rod, which itself for convenience of taking apart is connected with a coupling in the centre. From these couplings the valves of the power cylinders are worked by a similar arrangement of levers to those on an ordinary duplex pump. The hydraulic power is applied to the inner ends of the rams (which are all single-acting), while the outer ends form the plungers of the pump. The arrangement is clearly indicated in the diagrammatic sketch (Fig. 514), where *e e* are the hydraulic valves, each pair joined by the rod *r*, *c c* the power ram cases, *d d* the pump ram cases, and *b b* the pump rams joined by the rods *a* having a coupling-box in the middle of their length. The power-water acts on the difference between the area of *b* and the area of *a*, so that in proportioning a hydraulic pump of this type, after ascertaining the size of the rams, *b*, which depend solely on the amount of water to be dealt with, the diameter of *a* is determined by the effective pressure of the power-water and by the height to which the pump has to lift the water. It will be seen that each half of the pump, A and B, is a complete thing in itself, with the exception that it does not work its own power valves, which are moved by its neighbour. In this case, one pump must be a little past the centre of its stroke before the other pump commences to move, and as the latter approaches the centre of its stroke it first closes and then reverses the valves of the former; the duration of the pause between the closing and reversing of the valves can be readily varied by hand adjustment, enabling the pump valves to settle quietly on their seats, and avoiding the jar to which pumps driven by so inelastic a fluid as water are specially liable, if too suddenly reversed.

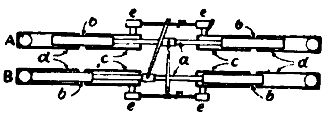


Fig. 514.

The valves for the admission and exhaust of the driving water are made to close on mitred seats, instead of sliding over ports, and are therefore particularly suitable for dealing with gritty water. They are also so arranged that the passage for the exhaust water of any of the power plungers can only be opened *after* the admission passage to that plunger has closed, thus preventing all risk of the drive water escaping to exhaust, without doing its proper work in the pump. Fig. 515 is a longitudinal section of the valve designed by Mr. J. A. Towler for one end of the cylinder, an equal and similar valve being arranged for the other end, the same rod working both; *a* is the inlet for the working fluid, *b* is the outlet or exhaust, and *c* is the passage to one end of the cylinder. *d* is a lining provided with a cup leather, and having through it lateral openings, *e*, to an annular space communicating with *b*.

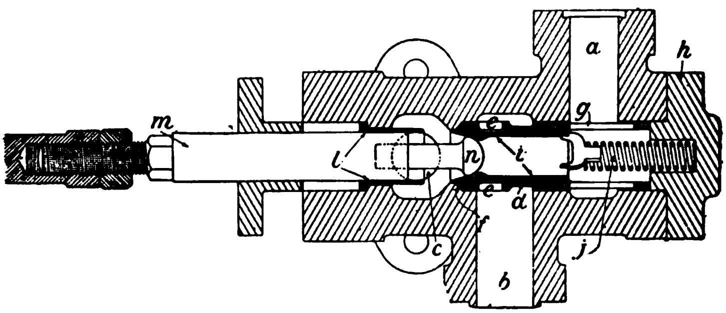


Fig. 515.

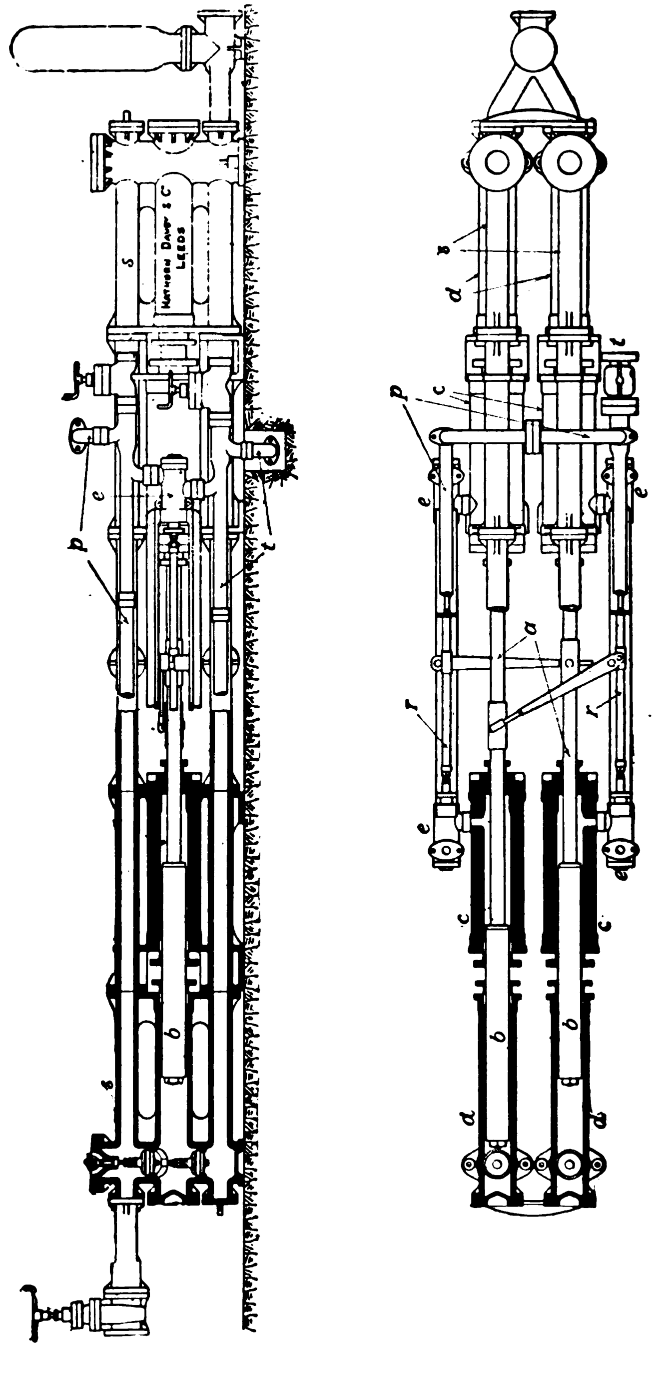
This lining fits against a shoulder, *f*, where the joint is made tight by suitable packing, and it is held in place by another lining, *g*, having lateral openings communicating with *a*, and held in position by the valve-box cover, *h*. Within the lining, *d*, is fitted the slide valve, *i*, which is pressed by a spring, *j*, against a seat formed in the lining, *d*. Within another lining, *l*, works the valve-rod, *m*, which terminates in a spherical end, *n*, bearing against the inner edge of the slide valve, *i*. When the parts are in the position shown in the drawing, there is no communication with the cylinder; when *n* advances to the right it pushes *i* off the seating, *k*, and then farther advancing puts *c* in free communication with *b*, allowing fluid to escape from the cylinder. When *a* retreats to the left the spring, *j*, causes *i* to move until it meets the seating, *k*, thus closing passage to *b*, and as *n* continues to move to the left there is free passage for fluid from *a* through *i* and *c* to the cylinder.

As the rod, *m*, moves to and fro it works also the similar valve for the other end of the cylinder, so that fluid is admitted to the one end of the cylinder while it is allowed to escape from the other, and conversely, and both valves, having equal sectional areas, are under equilibrium in respect of pressure. By removing the cover, *h*, all the parts of the valve can be taken out, thus allowing of easy inspection. There is only one U-shaped leather (shown by a thick line) to each valve-box—*i.e.*, only four leathers to the complete pump itself. All the rest of the running joints are externally packed glands. Should the power valves, through faulty workmanship or wear, get out of line, the faces of the valves are made spherical, enabling them to keep tight, and as the inlet and outlet valves are perfectly balanced there is only friction to overcome in moving them, while as the inlet valve must necessarily be closed to open the outlet valve, it follows that there can never be a straight blow through.

A complete pump for raising mine water 1000 feet high, with a hydraulic pressure on the surface of 800 lbs. per square inch, is shown in Figs. 516 and 517. The arrangement and combination of the several parts will be clearly understood from a comparison of this illustration with Fig. 514, as similar reference lettering is employed in both instances. The drive water is brought by the pipes, *p*, to the valves, *e*, and after doing its work in the power cylinders, *c*, passes away through the exhaust pipes, *r*, either through a connection to the delivery main, *s*, or to waste.

In such a design the water is never arrested, either in the pressure supply and return or in the pump suction and delivery, because one side of the hydraulic is always working, and when the other stops the side working increases its speed, thus causing a very uniform flow; as these hydraulics are fitted with plungers both on the power and on the pump side, leakages are immediately detected and can be stopped. They are fitted with flanges at both ends, so that the suction or delivery pipes can be connected to either as desired.

Electricity.—The use of electricity in mines was first called into requisition for pumping, and by far the larger number of installations are still applied to such a purpose. An electric motor can be readily connected to a pump, either by gearing or belts. The convenience of electricity is such that in all installations of the last few years, scarcely anything else has been employed in pumping from deep workings. Innumerable instances could be quoted of its success, but for our purpose reference may best be made to the first pumping plant and its



Figs. 516 and 517.

additions, which were put down by Mr. F. Brain, at Trafalgar Colliery, Gloucestershire.* This commenced working in December, 1882, and attained such success that three additional plants were erected in May, 1887, and are doing the larger part of the underground pumping.

A later installation consists of a double throw 9-inch plunger, by 10 inches stroke, situated 2200 yards from the generator, and 1650 yards from the bottom of the shaft; the pipe main is 7 inches in diameter, and at a maximum speed of 25 strokes, the pump lifts 120 gallons per minute 300 feet high. The current is conveyed to the motor by a copper conductor consisting of $\frac{19}{16}$ wire, insulated and carried on earthenware cups. The E. M. F. is 320 volts, and the current required is 43 ampères. The cost of the engine and the electrical plant was £644; the weekly cost for maintenance, including 15 per cent. for depreciation and interest on capital, is £7 17s. or ·002d. per horse-power per hour. The efficiency attained throughout was only 35 per cent., but the engine, which is an old one, loses 6·49 horse-power, or 22 per cent. alone; excluding loss in the engine the efficiency is 45 per cent.

With the aid of accumulators, or secondary batteries, in which the current of electricity can be stored and carried about, small quantities of water at inaccessible points can be, and have been, dealt with in mines. These accumulators can be placed on a carriage and taken anywhere required. A small motor and pump on a second carriage are also arranged, and accompany the accumulators.

Unfortunately, electric motors as generally constructed run at high speeds, and considerable losses result in the gearing down from the armature shaft to the slow moving pump rams. Messrs. Scott & Mountain have employed an endless screw gearing into a cog wheel, while specially wound low speed motors can be manufactured to revolve at such a comparatively low velocity as to need only one reduction—*i.e*, the pinion on the armature shaft gears direct into a larger wheel on the pump shaft, but the increased cost has prevented their general application. By direct connection, however, all the attendant evils of gearing are avoided, and the increased durability and economy will in a short time save the difference in first cost. Pumps of such high piston speed as the Riedler type are undoubtedly preferable to those of ordinary construction. On account of the high number of revolutions less work is done per stroke, and the total work being more evenly distributed, the strains on the motor are comparatively light and uniform. Owing to the increasing demand for a pump that can be coupled direct to an electric motor running at a comparatively high speed, a further development of the ordinary Riedler pump, called the "Express," has resulted. The general features are retained, but the suction valve is closed by means of a buffer or controller fastened on the end of the plunger. The ordinary Riedler is externally, and the "Express" internally, controlled, while the delivery valve is spring-loaded in the latter, which dispenses with the valve gear necessary in the ordinary Riedler pump. The stroke is considerably shortened, and the pump can run 350 revolutions per minute. Messrs. Merryweather & Sons have designed their "Hatfield" pump, which has three reciprocating pistons, and may be driven

* *Brit. Soc. Min. Stud.*, xi., 48.

up to any speed not exceeding 200 revolutions per minute; the valves are on the same principle as those of their well-known fire engines. Messrs. Mather & Platt construct a variable throw pump where the quantity delivered is varied by altering the length of the stroke instead of reducing the speed, and claim a much increased efficiency.

The ordinary centrifugal pumps cannot work against even a moderate head of water, or they would have been largely employed for connection to electric motors, owing to the speed at which they may be run. Working independently of each other at first, but afterwards in conjunction, Reynolds in England and Sülzer in Germany have so modified the construction that even in single-chamber pumps up to 200 feet head can be dealt with, and, under favourable conditions, 60 to 70 per cent. efficiency can be obtained.* Single-chamber pumps are not, however, recommended for high lifts, compound or multiple-chamber pumps being advised. In principle, these consist of a number of centrifugal pumps coupled together in series and mounted on the same shaft. In reality, a series of pump blades mounted on one shaft operate in a corresponding series of chambers formed in one enclosing casing, and the water passes through this series rising step by step in pressure. The water enters the pump axially, passes outwards through the revolving blades which give it high velocity, and discharges it tangentially through peripheral evasée guide passages into what is termed a whirlpool chamber, where most of the kinetic energy of discharge velocity is converted into pressure energy, with only such velocity as is necessary to discharge the desired bulk of water through the given size of delivery pipe.

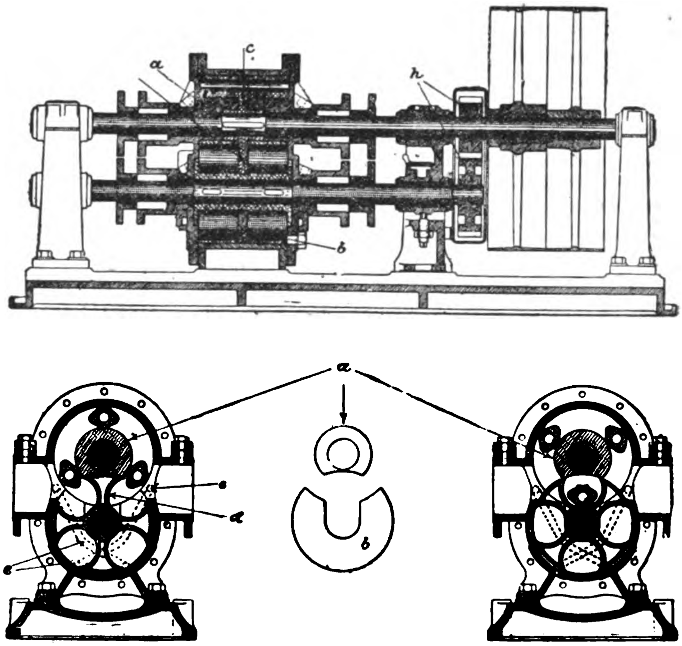
A set of these pumps have been erected at the Horcajo Mine, Spain, powerful enough to deal with 1,505,000 gallons per day from a depth of 1640 feet.† The water is not pumped the whole height in one lift, each pump with its motor being placed in chambers off the shaft at vertical distances apart of about 450 feet. The electric motors mounted on the same base plate as the pumps, to which they are connected by an elastic coupling, are six-pole three-phase type, and run about 900 revolutions per minute. The armature is short-circuited, and the starting is effected by an autotransformer, the current required at starting being 200 amperes.

Rotary pumps would be valuable for use with electric motors owing to their greater capacity, due to steadier flow, and absence from shocks, if the difficulty of making the working bodies fluid tight could be overcome and the excessive wear and tear prevented. Such pumps usually consist of two star-shaped bodies revolving in a casing, and where the contact of the revolving bodies is relied upon as a cut-off between suction and delivery, as such contact consists only of a line along the length of the revolving portions, and as the bodies have to work with large surfaces exposed to pressure, and are consequently forced against the casing and work heavily and unevenly in their bearings, a little wear soon destroys the close fit so necessary to prevent the water leaking back from the delivery side to the suction, with a consequent loss of efficiency.

Such defects are claimed to be remedied in the Piftin rotary

* *The Engineer*, 1901, xcii., 215.
† *Inst. C.E.*, cxlviii., 396.

pump, which can be applied for lifts up to a maximum of 250 feet. It consists of two bodies revolving in a casing (Figs. 518, 519, and 520) of which only one does work—viz., the upper body consisting of



Figs. 518, 519, and 520.

three revolving pistons. This body is built in such a way that the whole of it, except the working faces of the pistons is shielded from pressure. The pulley shaft inside the casing is enveloped by the crescent-shaped sleeves, *a* and *b*, extending inwards from the cylinder ends, and the pistons are connected to the shaft by a disc, *c*, midway in the cylinder, and working close between the sleeve ends. As there are always two pistons at a time in the pressure cylinder, each having broad surfaces working close against the casing and the sleeve, they work fluid-tight; *c* rotates with the top shaft, while *b* remains stationary and fills the gap in *d* caused by *c* cutting through it.

The lower body is a sluice body allowing the pistons to return while preventing any communication between the pressure and suction sides. The sluices continually carry fluid round with them, and result in no loss of volume. The piston body and the sluice body are never in touch, there being a clearance of from $\frac{3}{8}$ to $\frac{3}{4}$ of an inch according to the size of pump. It will be observed that the vanes of the sluice body work close against the crescent-shaped sleeve-bearing which envelopes the piston shaft, and this forms a fluid-tight cut-off, and prevents the fluid working back between the bodies. This arrangement constitutes the principal difference between the pump and those of ordinary construction, because at this point in former designs, the two bodies worked on one another and left a gap when they parted.

The cut-off is made complete by the hoof-shaped plate, *b*, cutting the sluice body midway and fitting close under the disc which carries the pistons, so that, at all points, broad surfaces in contact prevent any backward escapement, and each body works fluid-tight independently of the other. Fluid pressure is conducted by channels, *e*, in the cylinder ends to spaces opposite the thrusts on the sluice body, thus releasing the surfaces of this body from frictional contact with the casing, and releasing the shaft in its bearings from friction due to those thrusts, so that the body works absolutely freely and is not thrust in any direction. Consequently, the gearing, *h*, connecting the two shafts does not work under pressure, but merely keeps time between the pistons and the sluices, and there is so little wear in the gearing that it need not be taken into account, and what there is is perfectly even.

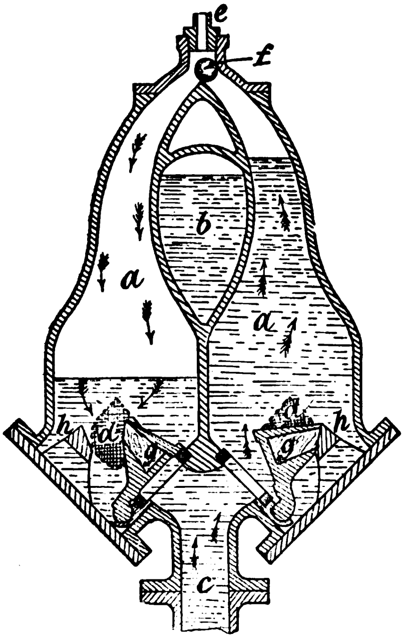


Fig. 521.

The wear in the pump is confined to the bearings, and is very slight and even. The bearings can, however, be adjusted when, by continued work, they require it. It will be seen, moreover, that this construction admits of an excellent disposition of the bearings, as the sleeve enveloping the piston shaft forms a valuable full-length bearing for it.

Pulsometer.—When describing the methods of dealing with water during sinking, reference was made to the pulsometer, which is also largely employed for draining deep workings. It consumes a great deal of steam, but its advantage is that it will pump nearly everything that will go through the valves. No matter how gritty or dirty the water is, it works nearly as well as if it were quite clean. Its peculiarity consists in there not being any steam cylinder, piston, piston-rods, or bucket, as is usual in the ordinary form of pump. Its construction is shown in Fig. 521. It consists* of two pear-shaped water chambers, *a a*, the air chamber, *b*, the suction passage, *c*, and the delivery passages, *d d*, which communicate with the discharge pipe. Steam is admitted to either of the chambers, *a*, through the pipe, *e*, but the direction is controlled by a ball valve, *f*, which is capable of oscillating, and closes each passage alternately; *g g* are the suction valves, which are of the ordinary flap form, and are prevented going too far by the stops, *h h*. It should be especially noticed that the delivery passages, *d d*, commence in each of the water chambers just above the suction valves.

* *So. Wales Inst.*, xi., 85.

The action of the apparatus is as follows:—When the two chambers, *a a*, are full of water, if steam be admitted through the opening, *e*, it will pass into that chamber which is not closed by the ball valve, *f*, and rapidly depressing the water *without causing any agitation*, will force it through the delivery chamber, *d*, into the rising main. This action continues until the water is depressed to the top of the passage, *d*, when the steam attempts to rush through this opening, and in doing so violently agitates the surface of the water. Immediately this takes place, instant condensation follows, and a vacuum is produced in the chamber. This sucks over the ball valve, and diverts the live steam into the other chamber, depressing in turn the water there. While this is going on the vacuum in the first chamber sucks up the water through the pipe, *c*, and lifts the suction valve, *g*. When condensation takes place in the second chamber, as it will do as soon as the water is lowered to the top of the discharge orifice, *d*, the ball valve is again sucked over, and live steam diverted into the first chamber. The suction valve then closes, and the water is discharged as before; first one chamber and then the other is filled and emptied.

There are several modifications of the original type on the market, all designed to economise the consumption of steam. For sinking purposes, where steam economy is a minor consideration, so long as the water in the pit bottom can be got away, these pumps are particularly useful and are being more largely employed year by year. As the height to which they can force water is limited, they have to be arranged in series one above another, the lower pulsometer delivering into a tank (some 70 to 90 feet above the pit bottom) into which the suction pipe of the second pulsometer dips. This forces water up to a second tank, where a third pulsometer is placed, and so on until sufficient depth is obtained for the lift of the permanent pump to be extended.

They are liable to one serious failing—at times, for no apparent reason, they miss their stroke—that is to say, the steam fails to condense, with the consequent result that the chamber into which it is entering gets so hot, that the whole apparatus is rendered useless, and cannot be got to pump again until it is quite cold. As such an event would mean the entire suspension of sinking operations, it is usual to station an attendant at each pulsometer, who with his hand on the steam admission valve, listens to the click, click, of the ball valve in the pulsometer, as it charges over and falls into its seat at each stroke. Should the valve fail to act, steam is at once shut off, and a bucket of cold water poured over the pump. In all probability, as soon as steam is turned on again, the pulsometer will commence to work, but if it does not, the above process is repeated. As an additional precaution, two pumps should be employed, each of which is capable of dealing with the maximum quantity of water, in order that one may be kept in reserve should the other break down.

Compressed Air.—When this agent is available, pumps can be driven by it readily and cheaply; several are designed which work very satisfactorily with such power, and are capable of dealing with large quantities of water.

The principle of the air-lift pump, in which compressed air is applied direct to raise water, has been known for a long time, but its first successful employment is due to Dr. Pohlé. In its ordinary form it consists of a larger open-ended pipe with an expanded mouthpiece, into which is led a smaller pipe through which compressed air is forced. These two pipes are lowered to the bottom of the water, and until air is introduced, the water stands at the same level inside the larger pipe, which forms the delivery main, as it does outside, but as soon as compressed air is forced down the smaller pipe into the expanded end of the water discharge pipe, it escapes in bubbles which form layers in the water and reduce the pressure inside the discharge pipe. More bubbles are formed, and the outer water flows continually into the bottom of the larger pipes, and a discharge commences at the upper end. The pressure of the air determines the height to which water may be lifted, but by the introduction of compound or stage-lifting it is now possible to raise water to considerable heights.

An important development was made by the introduction of the so-called direct pressure pumps, in which water is first sucked into a closed vessel and afterwards expelled by the direct application of

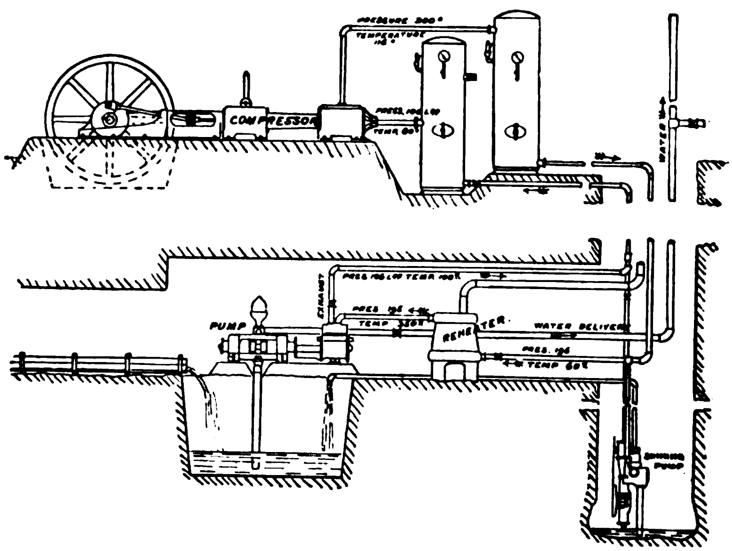


Fig. 521*a*.

compressed air to the surface of the liquid. The action is similar to a pulsometer, except that the pressure air is not condensed, the only original difficulty being the great loss of power which resulted from the escape of the compressed air into the atmosphere after it had driven the water out of the closed vessel. This defect has been remedied in a number of ingenious ways, the majority of which consist of an automatic switch which reverses the connections between the compressor and the chambers constituting the pump. Some of the switches are controlled by floats, and others by differential air valves, but the object of all is the same—viz., to direct compressed air to and from the closed vessels constituting the pump chambers, and from which water is alternately discharged.

A system has been employed in California for a considerable number of years, similar in principle to Moore's hydraulic arrangement with air substituted for water in the pressure pipes. An ordinary compressor is employed, and air at considerable pressure, after passing through a receiver at the surface and a reheater underground, performs work in an ordinary direct-acting pump. The exhaust is delivered by a line of pipes into a second low-pressure receiver at the surface. The chief compressor draws its air from this receiver, and consequently the exhaust is again compressed to the higher pressure, and returned to the pump to perform another round in this cycle of air work. In practice, the low-pressure air is sufficiently above atmospheric pressure and sufficiently cool to allow of an economic line of compression in reaching the high pressure. A small compressor is connected to the low-pressure return line to replace the leakages through bad joints in the pipes and the stuffing-boxes in the pumps, and keep the quantity of air in the system constant. The application of this system to the pumping arrangements at the Bisbee Mine, California,* is illustrated in Fig. 521*a*. The compressor is of the standard straight-line type with the inlet enclosed in a bracket fitted for pipe connection to the receiver of the return system. Two lines of pipe are carried to the 700-feet level, where an ordinary standard pattern steam pump, having an air cylinder 16 inches diameter and a centre packed plunger 6½ inches diameter, is erected. The high-pressure pipe-line is 2½ inches diameter, and the low-pressure one 3 inches diameter. The reheater raises the temperature of the air to 350° F. There is a second pump suspended in the sump lifting water into the lodge-room, from which the principal pump draws its supply.

Dams.—It is often necessary to put in stoppings, called "dams," to prevent water passing from one part of the mine to another. On the Continent of Europe wooden dams are most in favour, while in Britain masonry is generally employed. The advantages of the former are that if the wood is perfectly dry when put in, the moisture expands it and makes the structure more water-tight, and any movement in the surrounding strata is not so liable to dislodge or crack the wooden dam, as it is a masonry one. Owing, however, to the convenience and ease with which bricks can be obtained and put in position, their use is becoming common, even in districts where wood was formerly employed.

In putting in permanent dams the first thing is to select some spot where the strata is of an impervious character and quite free from cracks. Dams are invariably wedge-shaped, with the broader end towards the pressure. If this be heavy, two or three wedges are built, one against the other. In preparing the ground, nothing but the pick and chisel should be employed; the sides, floor, and roof are carefully dressed to the required shape, and covered with Portland or other cement, to obtain a hard and proper surface to receive the masonry. Good hard burnt bricks should be employed, and the lime should be of an hydraulic character.

To pass the water from one side to the other while building is going on, a pipe is invariably built through the lower part of the dam, this being fitted with a valve at one end, which can be closed when

* *Eng. and Min. Journ.*, 1902, lxxiv., 855.

the work is finished. A second pipe of smaller dimensions is also built through the dam near the top, and its inlet end carried into a cavity in the roof the object of this being to ensure the removal of the last trace of air from behind the dam, which is a point of the greatest importance. The water side of the dam is often covered with either tarred sheets or well puddled clay, either of which will preserve it, and prevent leakage should it become much cracked.

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CHES. INST.: *Draining and Ventilating, &c., at Staveley Collieries*, Jos. Humble, ix., 31.

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CHAPTER X.

VENTILATION.

Importance.—It is most important that mines should be properly ventilated. All coals give off, to a more or less greater extent, a quantity of deleterious gases, which have an injurious effect on the human life, even if they are not explosive. In addition the breathing of men and of other animals, and the burning of illuminants, render air impure. It, therefore, becomes necessary that a vigorous current of cool, fresh air should be circulated through the galleries and working-places; indeed, General Rule I. of the British Mines' Regulation Act, 1887, makes such a current compulsory, but even if such were not so, it really pays to have good ventilation, as men are not only capable of doing a greater quantity of work, but they do it with greater comfort and are far more contented.

The quantity of air required in a given mine depends principally on the volume of gases produced by the coal. The quantity of gas given off does not always increase as the workings become more extensive, as it principally depends on the area of freshly exposed coal surface. If bord and pillar working be adopted, a quantity of gas will be given off while the exploring work is being done, but as the pillars are large blocks of coal, up to 50 yards square or more, the comparatively narrow (2 to 5 yards) places driven to form the pillars, cannot liberate the whole of the gas. When the second or broken workings are proceeding wider places are driven and the coal is got more easily, so that more coal is being worked per man per shift, and more gas is liberated. With long wall working, as the workings get more extensive, a greater area of face is opened out, and consequently more gas will be given off. The best plan is, therefore, to make the amount of air proportionate to the output and to increase the current, if exploratory work is proceeding. It is often stated that the amount of air passing should be regulated by the number of men employed. Of course, if the output increases, the number of men generally increases also, but the better plan is to be guided by the output; this is the practice of the Borinage district of Belgium, which is, probably, the most fiery in the world.

Gases met with in Mines.—Atmospheric air in its pure state is a mixture of two gases, nitrogen and oxygen, but, as generally found in Nature, it contains small quantities of another gas, carbonic acid, and of aqueous vapour. The oxygen is the life-supporting element, the nitrogen acting simply as a diluting agent. Dry air is composed of 79 per cent. by volume of nitrogen gas and 21 per cent. of oxygen. The following table shows the specific gravities, molecular weights, &c., of the gases met with in mines:—

	Symbol.	Specific Gravity.	Weight of 1000 cubic feet at 0° C. and barometer 760 mm.	Molecular Weight.
Air, ...	...	1·000	80·712 lbs.	
Nitrogen, ...	N	0·9713	78·395 ,,	
Oxygen, ...	O	1·1056	89·235 ,,	
Carbonic oxide, . .	CO	0·9678	78·113 ,,	12 + 16 = 28
Carbonic acid, . .	CO_2	1·52901	123·409 ,,	12 + 32 = 44
Marsh gas, ...	CH_4	0·559	45·118 ,,	12 + 4 = 16
Sulphuretted hydrogen, .	SH_2	1·1749	94·828 ,,	32 + 2 = 34

In breathing, men and other animals take air into their lungs, and part of the oxygen combines with carbon, forming carbonic acid, whilst the nitrogen is unaltered; the same result follows the burning of lights.

Our knowledge of the composition of the gases met with in mines and of their action on flame and on life has been greatly increased by the researches of Prof. F. Clowes and Dr. J. Haldane. Indeed, the latter's experiments possess an increased value due to the fact that they have in some measure been carried out on human beings. Prof. V. B. Lewes has pointed out that rabbits and other rodents resist the action of gaseous poisoning from carbon monoxide better than carnivorous animals, such as dogs, and it is impossible to argue from the action of the gas upon the one what the action will be upon the other, whilst it has not been made clear that the action upon either is a very safe index as to the action of the gas upon man.

Carbonic Acid is known to the miner as black- or choke-damp, or stythe, but black-damp invariably contains both marsh gas and an excess of nitrogen over the quantity contained in pure air. Its presence is common, and is due to the combustion of illuminants, respiration of men and horses, combustion of blasting explosives, decomposition of pit timber, and often exudation from the coal. In the chapter on working, an opinion has already been expressed that oxidation of the coal is one of the chief agents tending to spontaneous combustion, and although matters may not proceed so far as to cause absolute ignition, the action probably goes on in all seams, the oxygen in the air combines with the carbon in the coal and sets free the nitrogen and carbonic acid gas. The latter is chemically composed of carbon and oxygen; its symbol is CO_2, and it has a specific gravity of 1·53. As it is considerably heavier than air, it tends to occupy the lowest part of the mine. In its pure state it has no colour, but has a peculiar sharp, but not sour, odour and taste. Its presence is manifested by its influence on the flame of a candle, as it will not support combustion.

When carbonic acid is mixed in increasing proportions with air, a man breathing the mixture begins to pant long before the point at which a light burning in the same atmosphere is extinguished, as so little as 3·5 per cent. will affect respiration. This is proved by the experiments conducted by Prof. Clowes* to determine the least proportion of carbonic acid gas in air which is sufficient to extinguish flame. The following table gives the results obtained with naked flame:—

* *Fed. Inst.*, vii., 420.

Combustible substance burnt in the Mixture.	Extinctive proportion of CO_2 added to the air.		
	Percentage of CO_2 added.	Percentage composition of the Mixture.	
		Oxygen.	Nitrogen and Carbonic Acid.
I. Candle, ...	14	18·1	81·9
Colza and petroleum, . .	16	17·6	82·4
Ordinary paraffin lamp, . .	15	17·9	82·1
Alcohol (pure), . . .	14	18·1	81·9
Alcohol (methylated), . .	13	18·3	81·7
II. Hydrogen, ...	58	8·8	91·2
Coal gas, ...	33	14·1	85·9
Methane (fire-damp), . .	10	18·9	81·1
Carbonic oxide (white-damp),	24	16·0	84·0
Ethylene, ...	26	15·5	84·5

The flames in division I. were burnt from wicks, and show a nearly uniform extinctive proportion of carbonic acid gas, while those in division II., which were burnt from jets, vary to a considerable amount. With an ordinary safety lamp the admixture of 16 per cent. of carbonic acid *with air* marks the lower limit of rapidly extinctive atmospheres. As experiments have proved that animals can breathe with impunity in an atmosphere containing 25 per cent. of CO_2, it appears that respiration may be maintained in a mixture containing 10 per cent. more carbonic acid gas than is sufficient to extinguish the flame of a safety lamp. A knowledge of this fact should not, however, tempt any one to remain in an atmosphere which will not support combustion, because there are seldom means available underground to readily determine whether 16 per cent. or 60 per cent. of carbonic acid is present.

The above results were obtained by adding carbonic acid gas to air, but black-damp as found in mines contains other gases than carbonic acid, and Dr. Haldane states* that 26 to 27 per cent. is requisite to just affect the breathing, while with about 50 to 55 per cent. the panting is very violent and accompanied with marked distress. Imminent risk of loss of power over the limbs or loss of sensation is reached with about 60 per cent. of black-damp. To produce a mixture which will extinguish a light before it affects the respiration of a man, it is necessary to add to air, along with each volume of carbonic acid, more than three times as much nitrogen. The latter condition of affairs exists underground, as part of the oxygen in the air combines with carbon forming carbonic acid gas, thus decreasing the quantity of oxygen and increasing the nitrogen. Indeed, it is the decrease of oxygen which produces the serious symptoms on breathing black-damp; confusion of mind, loss of power, and the appearance of a leaden blue colour are undoubtedly due to an insufficient percentage of oxygen to saturate the red corpuscles of blood as they pass through the lungs. On breathing fresh air again recovery is almost instan-

* *Loc. cit.*, viii., 849.

taneous, and no after effects were experienced from breathing black-damp, even after the experimenters had been for a considerable time in an atmosphere which instantly extinguished a lamp.

In some European mines, outbursts of carbonic acid are frequent, and are in every respect similar to those of fire-damp. The blowers are generally found in the vicinity of faults. At Toulane Pit, Rochebelle, one blower filled 500,000 cubic feet of workings in less than ten minutes, and disengaged over 400 tons of coal.

Carbonic Oxide is variously known as carbon monoxide and white-damp. Its chemical symbol is CO and specific gravity 0·97. Luckily its presence is much less frequent in mines than black-damp, as it is far more poisonous than that gas. As little as a ½ per cent. produces giddiness and faintness, while over 1 per cent. may cause death. Indeed, $\frac{1}{10}$ per cent. breathed for any length of time is fatal. Dr. Haldane* states that the smallest percentage of carbonic oxide which visibly affects such small animals as a mouse was 0·06 per cent., or roughly speaking one part in 2000. Its presence in the blood could be detected long before it produced any outward symptoms, and it gradually accumulated until a point is reached where the blood was so saturated with carbonic oxide that it would no longer convey sufficient oxygen. Carbonic oxide is known by its sweet and delicate odour and deadly results. Candles burn well in this gas, if anything, a little brighter, although their flame is not elongated until 12½ per cent. is present. It is produced by imperfect combustion, and especially by spontaneous ignition and by explosions. From Dr. Haldane's experiments it appears that the first distinct symptoms of poisoning by carbon monoxide, an unusual tendency to giddiness, palpitation, and shortness of breath on exertion, occur when the blood is 30 per cent. saturated. At about 50 per cent. saturation the power over the limbs becomes less and less, and any exertion causes the legs to give way, so that it is hardly possible for a man to make his escape. Finally, death occurs when saturation reaches 80 per cent., consciousness is gradually lost with no pain and little or no mental distress, the action being almost that of a gentle anæsthetic. With about 0·06 per cent. of carbon monoxide in the air, the blood of a man becomes about 30 per cent. saturated after 1½ hours; 0·10 per cent. would cause helplessness after about an hour; with more than 0·20 per cent. life would be endangered.†

Sulphuretted Hydrogen is not found in large quantities. Its chemical symbol is SH_2, and specific gravity 1·17. It arises from the decomposition of timber in water containing sulphates in solution, or, to a smaller extent, from blasting, especially if inferior cheap gunpowder is employed. It has an injurious effect on life, does not support combustion, and burns with a blue flame. Its presence is immediately detected by a characteristic and offensive smell.

Light Carburetted Hydrogen.—This gas, known as fire-damp, is the one commonly found in mines, and to which explosions are principally due. It consists, in the pure state, of carbon and hydrogen, its symbol being CH_4 and specific gravity 0·559. The fire-damp of the miner is, more correctly speaking, a mixture of several gases, the largest proportion being carburetted hydrogen; other hydrocarbons, with hydrogen, carbonic oxide, oxygen, and nitrogen, are generally

* *Fed. Inst.*, ix., 381. † *Loc. cit.*, xi., 506.

present, the quantities of such gases varying considerably in almost every colliery, and often in different districts of the same pit, while its average density is nearly 0·70.

The coal itself is the principal reservoir of the gas, where it is held in the pores or cells in a state of more or less high tension. Different gases exuded from the coal have been described in Chapter i., where the phenomenon of "blowers" was also referred to. Blowers are a more or less steady discharge of gases from the coal, continuing for a long time. Where this discharge is a violent and sudden one of large quantity, only continuing a short time, it is known as an "outburst."

Carburetted hydrogen is colourless, and when pure is odourless, while fire-damp is often detected by its smell. This gas, if breathed in a pure state, would soon cause death; it quickly extinguishes flame or lamps if undiluted by air. When 3 to 4 per cent. is present in air, the gas can easily be detected by the elongation of the flame in a safety lamp. If 6 per cent. be present the flame is not only elongated, but a blue halo or cap, appears above it. This halo is often of a brown colour, produced by the presence of carbonic acid gas with the fire-damp. With 7 to 8 per cent. the mixture becomes explosive, and flame is propagated through the contents of the lamp; with 10 to 12 per cent. the propagation is instantaneous and the explosion attains its maximum amount; with 20 per cent. the mixture no longer explodes, but instantly puts out any flame that may be brought into it.

Messrs. Haldane and Atkinson's experiments* have proved that (1) a mixture of black-damp and fire-damp may, when largely diluted with air, be extinctive to lamps and not explosive, but may become explosive when less diluted; (2) a mixture containing air and 6 per cent. of marsh gas is still explosive, in spite of the presence in it of even a third of its volume of black-damp.

The presence of black damp in a mixture of fire-damp and air, has thus little or no influence on the explosibility of the mixture, provided that sufficient oxygen is present for the complete combustion of the fire-damp.

After-damp.—Under this head is included all the products resulting from the ignition of an explosive mixture. When fire-damp is exploded, the carbon combines with the oxygen in the air, and forms carbonic acid, while hydrogen also combines with oxygen and forms aqueous vapour, leaving a large amount of free nitrogen without the corresponding amount of oxygen. Carbonic oxide is generally present in after-damp, and is always formed during the combustion of every explosive mixture containing carburetted hydrogen in which the proportion of air is less than 9·5 parts. Messrs. Atkinson† give an analysis of the after-damp gases of the Usworth explosion in 1885. The sample was taken from between two stoppings erected on the fifth and seventh days after the explosion, and contained 2·48 per cent. of carbonic oxide, and 4·54 per cent. of carbonic acid gas; it is probable, however, that the presence of a fire beyond may have had some influence on the production of these gases, the proportions being unusually high.

The combustion of 1 cubic foot of fire-damp renders about 40 cubic

* *Loc. cit*, viii., 559. † *Explosions in Coal Mines*, London, 1886, 113.

feet of air unfit for respiration. If an excess of air or fire-damp were present before explosion, such excess would remain mixed with the after-damp after the explosion, but in no case can the after-damp gases contain more than one-third of their volume of unchanged air, or the explosion would not have happened. After-damp is sometimes responsible for more deaths than an actual explosion, as often all that escape the latter are suffocated by the former, indeed, Dr. Haldane's investigations on the bodies of those who had been killed in three serious explosions led him to strongly assert that in almost every case the actual cause of death was poisoning by carbon monoxide.* It seemed probable that many men must be killed by absence of oxygen in the after-damp, and many others by burns or violence, but analysis of the blood showed that this was not the case. It would seem that the after-damp is so largely diluted with air, that more than enough of oxygen is left to support life. From 60 to 70 per cent. of the bodies were neither burnt nor injured, and taking the average of the three explosions it seems probable that about 77 per cent. might have escaped but for the after-damp. From the analysis of blood from the bodies found along the course of the explosion at Tylorstown, it may safely be concluded that there was less than 3 per cent. and more than 0·50 per cent. of carbon monoxide, about 1 or 1·5 per cent. would be a fair percentage.

A man who has been rendered unconscious from carbon monoxide poisoning suffers severely from the after-effects. If the exposure has been long he may die a considerable time after the blood has quite freed itself from the poison. The best remedy is the administration of pure oxygen, although it is of no avail against the after symptoms. Artificial respiration should be at once applied if the breathing ceases, and if the pulse be weak stimulants should be given.

Unfortunately, this deadly constituent of after-damp cannot be detected by the safety lamp, as its action on flame is inappreciable, except perhaps to cause it to burn a little brighter. Its presence can easily be detected by its action on the colour of diluted blood, but this examination cannot be made by artificial light, and is consequently inapplicable underground. Dr. Haldane suggests that the effect of the action of the impure air current on a small warm-blooded animal, such as a mouse, should be carefully noted, as immediately it shows weakness of the legs there is danger to a man, though probably not for twenty minutes or half an hour. A mouse is not more sensitive to carbon monoxide than a man, but it shows the symptoms of poisoning in about one-twentieth of the time. If the mouse becomes quite helpless and unable to stand, there is danger within a few minutes to the man. It should be clearly understood that this test cannot do more than indicate the presence of dangerous proportions of carbon monoxide, and only a practised observer could detect the outward signs of slight symptoms in a mouse, while correspondingly slight symptoms in a man might be distinctly felt by the subject of them. As the specific gravity of after-damp must be, if anything, lighter than air, it is desirable to add a caution as to the desirability of keeping the animal as high as the head of the man carrying it.

Mr. A. Mermet † suggests the use of a prepared solution containing small quantities of permanganate of potash, silver nitrate, and *pure*

* *Fed. Inst.*, xi., 502. † *Coll. Guard.*, 1897, lxiii., 771.

nitric acid as a preservative. This is exposed to the action of air from the mine, and a similar quantity also exposed to ordinary air at the same time, the two flasks containing the solution being put side by side on a sheet of white paper. The impure air decolorises the solution, 1 part of carbon monoxide per 500 to 5000 parts of air acting in from one to twenty-four hours. Such a test is too slow to be of any value to a rescuing party.

Coal-Dust.—The roadways of some mines contain accumulations of very fine coal-dust scattered over the timber and resting on the floor, this being more particularly true of the main haulage roads. Several hundreds of tons of coal pass down these in trams or tubs day by day, and the lumps are ground and shaken against each other, more so when the speed of hauling is high, while the speed of the air current is also greater than in branch roads. Deep mines should theoretically be dustier than shallow ones; the temperature of the strata is higher, and consequently the intake air is heated more than it would be in a shallow mine, and is really drier, because it is able to absorb a larger quantity of moisture before becoming saturated. The air current thus dries the dust and blows it about, the lighter and more dangerous particles being carried on to the roof timbers and the remainder to the sides and floor, the latter being the least dangerous. These accumulations can be prevented to a great extent by exercising ordinary care in using tubs with close sides, and seeing that they are properly emptied at the surface, and not sent back into the mine with quantities of small coal in them, and by watering the broken coal in the tubs, as described later on. That such deposits may be prevented from accumulating, is established by the fact that they exist in minimum quantities at or near the working face, and increase in thickness towards the shaft. From observations made at Cinder Hill Colliery, a perfectly dry mine, which has been opened fifty years, Mr. G. Fowler* states that the film of dust is insignificant for 900 feet back from the face, which represents the distance worked out in three years, and shows that for that length of time the accumulation of dust is scarcely noticeable.

Messrs. Faraday and Lyell, in a report on the Haswell Colliery explosion in 1844, were the first to demonstrate the effect these accumulations of dust may have in extending fire-damp explosions. Although several persons investigated the matter. it was not until 1876, when Mr. Wm. Galloway read his first paper before the Royal Society,† that general attention was directed to the important part that coal-dust plays in aggravating fire-damp explosions. Subsequent experiments by Mr. Galloway,‡ by several members of the North of England Institute,§ a committee of the Chesterfield Institute,|| Sir F. A. Abel,¶ and particularly by the Prussian Fire-Damp Commission,** demonstrated that, under certain conditions, the presence of coal-dust

* *Fed. Inst.*, xi., 129.
† *Proc. Royal Society*, March 2, 1876, xxiv., 239.
‡ *Ibid.*, xxviii., 437 and 490, and xxxvii., 42.
§ *N. E. I.*, xxv., 239, and xxviii., 85.
|| Vol. x., with Appendices.
¶ Blue-Book, *Seaham Colliery Explosion*, and *Proc. Royal Institution*, x., Part I., 1882.
** Translation by T. W. Bunning, *N. E. I.*, xxxiv., 199 and 297.

in a fine state of division is a source of danger in dry mines in which blasting is carried on without special precautions.*

Upwards of 300 experiments were made by the Prussian Fire-Damp Commission at Neunkirchen, near Saarbrücken, and it was considered that the following conclusions were warranted by the results obtained: †

1. The presence of coal-dust in more or less abundance in the immediate vicinity of the working face, gives rise to more or less elongation of the flame projected by a blown-out shot, *whether small quantities of fire-damp be present in the surrounding air or not.*

2. (*a*) In the complete absence of fire-damp, the elongation or propagation of flame is generally of limited extent, however far the deposits of dust may extend in the mine ways.

(*b*) There are, however, certain descriptions of coal-dust which, if ignited by a blown-out shot, will not only continue to carry on the flame even to distances extending considerably beyond the confines of the dust deposits, but will also give rise to explosive phenomena or results, *in the complete absence of any trace of fire-damp,* which in character and effects are similar to those produced by some other dusts in air containing 7 per cent. of fire-damp.

3. (*a*) All the phenomena produced by the burning of and propagation of flame by coal-dust are intensified by the presence in the air of small proportions of fire-damp.

(*b*) Certain dusts which, under favourable conditions, appear to have the power of propagating flame to an indefinite extent in a dust-laden area, the air being free from fire-damp, will, if only sparsely suspended in air containing fire-damp in some proportion below 3 per cent., render such a gas mixture susceptible of explosion by a blown-out shot.

4. Special experiments in which the branch gallery, described as opening into the main gallery near its extremity, was charged with a fire-damp mixture (retained by brattice cloth), demonstrated that a coal-dust ignition or explosion, developed in the complete absence of fire-damp, can communicate ignition to an explosive gas mixture existing at a very considerable distance from the point of first ignition.

Special stress was, however, laid on the fact that the occurrence of a blown-out shot is indispensable to the production of any and all of the effects (of ignition, propagation of flame, or explosion) to which coal-dust can give rise; and Mr. Hilt emphasises the fact that the part played by coal-dust is not nearly so dangerous as it might appear from a superficial examination of the Saarbrücken experiments.

Messrs. Mallard and Le Chatelier, in a review of the work of the Prussian Commission,‡ consider the phenomenon of the ignition of coal-dust by a blown-out shot to be as follows:—In that part of the gallery reached by the powder gases travelling at a high velocity and endowed with a high temperature, the dust is violently thrown into suspension and ignites. The gaseous mass thus ignited (considerably expanded by heat and increased by the partial distillation of dust that has been thrown into suspension by the mechanical effects of the powder shot) expands into the gallery, and extends to a distance proportional to the mechanical effects of the powder gases and to the ease with which the dust in suspension is distilled. The mechanical effect of this jet of flame on the dust in the gallery, situated at such

* A complete review of the literature of the subject with extracts of the opinions held by English authors, is given by Mr. E. S. Hutchinson in a paper entitled "Notes on Coal-Dust in Colliery Explosions," *Amer. Inst. M. E.*, xiii., 253.

† *English Commission on Accidents in Mines. Final Report*, 1886, 43.

‡ *Ann. des Mines* (8e Série), ix., 638.

a distance as to escape the initial action of the powder gases is small, and rapidly decreases until it is destroyed at a very short distance from the shot. They consider that the experiments of the Prussian Commission confirm these opinions, and also their previously expressed ones,* that the combustions of dusts are not, to speak exactly, explosions; that combustions only produce mechanical effects entirely insignificant for most dusts, and always much less than fire-damp explosions, even for most exceptional dusts; and that the combustion produced at any point does not extend indefinitely over the whole area covered with dust.

On the other hand, the English Commission on Accidents in Mines† considered that the most emphatic refutation of Messrs. Mallard and Le Chatelier's conclusion, "that the influence of fire-damp upon the combustibility of dusts, if not altogether *nil*, is at least much slighter than was at first believed," and confirmation of the established facts which it combated, was furnished by the Saarbrücken experiments, and, after a review of the whole subject, considered that the following facts relating to the part played by dust in coal-mine explosions may be regarded as conclusively established:—

1. The occurrence of a blown-out shot in working places *where very highly inflammable coal-dust exists in great abundance* may, *even in the total absence of fire-damp*, possibly give rise to violent explosions, or may at any rate be followed by the propagation of flame through very considerable areas, and even by the communication of flame to distant parts of the workings where explosive gas-mixtures, or dust-deposits in association with non-explosive gas-mixtures exist.

2. The occurrence of a blown-out shot in localities *where only small proportions of fire-damp* exist in the air, *in the presence of even comparatively slightly inflammable, or actually non-inflammable but very fine, dry and porous dusts*, may give rise to explosions, the flame from which may reach to distant localities, where either gas accumulations or deposits of inflammable coal-dust may be inflamed, and may extend the disastrous results to other regions.

That the above conclusions are true is now generally admitted, and the importance of adopting some effectual means for dealing with dust-deposits becomes self-evident when it is remembered that the most practised observer cannot detect gas in the air currents with safety lamps when the proportion present does not exceed 2 per cent.

It is, however, contended, more prominently by Mr. Galloway and Messrs. Atkinson,‡ that coal-dust plays the principal part in colliery explosions, and that fire-damp must be relegated to a secondary position. The chief argument in favour of this view is that explosions are so often confined to the intake air-ways and not to return air-ways. The intakes are where dust collects owing to the haulage of coal, while the returns are those along which gas is carried off. It is also contended that gas explodes equally in all directions, while many explosions in mines do not seem to pass into all the routes equally open to them, but follow certain definite paths, such as intake airways where gas is absent but coal-dust present. An explosion that took place in a coal-hopper at Brancepeth Colliery, Durham, where no gas could be present, is also quoted as an argument in favour of this theory. This hopper was used to store coal in for the use of the coke ovens. It was being cleaned out, when the fine dust took fire at an open torch lamp. Several men were severely burnt and three lost

* *Ann. des Mines* (8e Série), iv., 274. † *Final Report*, 47.
‡ *Explosions in Coal Mines*, London, 1886.

their lives. It may, however, be taken more as an instance of ignition than of explosion, as, although several windows existed in the hopper, none of the panes of glass were blown out, although they were much cracked by the intense heat. Only one sheet of corrugated iron was burst off the box, and this was not blown away, but was simply dislodged and fell to the ground.*

The theory is supported by the fact that explosions happen in flour mills, and in the drying chambers used for the preparation of brown coal for the market. It has also been proved by large explosions which have taken place in flour mills at Annapolis, U.S.A., that in the entire absence of inflammable gas, the explosion beginning in a distant portion of the works may be carried through the entire building. It is also possible, experimentally, to obtain explosions with air and lycopodium, simply with the lycopodium lying on the floor and not forming a thick cloud.

The great argument against coal-dust being the principal agent in coal mine explosions, as pointed out by the English Commission on Accidents in Mines,† is the fact that, if it were so, *every* blown-out shot occurring in a *very* dusty and dry mine should actually be attended by a more or less disastrous explosion or conflagration; and that, looking therefore to the enormous amount of powder expended in shot-firing in this and other countries, and to the not inconsiderable proportion which blown-out shots must constitute in many localities, of the total number of shots fired, disastrous coal mine explosions should be of more than daily occurrence, if this view were correct.

Messrs. Mallard and Le Chateller maintain that all explosions of magnitude which have been solely attributed to coal-dust have occurred in mines in which fire-damp occurs; that the possibility of coal-dust, *per se*, giving rise to an important explosion could only be established by the occurrence of an explosion in a mine in which the total absence of fire-damp can be absolutely demonstrated; and by the fact that lignite mines, which are generally very dusty, the dust being extremely inflammable, but which are at the same time almost free from fire-damp, have never yet been visited by accidents of this class.

In Chapter i. reference was made to the experiments of Mr. J. W. Thomas on the gases enclosed in coal. Dr. P. P. Bedson has conducted similar investigations on coal-dust,‡ and has established the point that some dusts give off considerable volumes of explosive gas at a comparatively low temperature. The enclosed gases in coal-dust resemble in many respects those which have been obtained from coal. The main points of difference to be noted are—first, the large proportion of carbon dioxide (CO_2) as compared with the amounts found by Mr. Thomas, and, second, the presence of olefines and higher members of the paraffin series of hydrocarbons. Further experiments by Dr. Bedson and Mr. McConnel§ showed that not only is the greater portion of the occluded gases given off at the temperature of boiling water, but that this is more emphatically true of the combustible gases, while it is evident that mechanical subdivision of the coal favours the release of these gases to a marked extent. They also established the fact, that the denser hydrocarbons are more firmly held than the

* *Royal Commission on Coal Dust, First Report*, 108. † *Final Report*, 47.
‡ "A Contribution to our Knowledge of Coal-dust," *N.E.I.*, xxxvii., 245.
§ *Fed. Inst.*, vii., 27 and 32.

lighter marsh gas. These hydrocarbons differ from marsh gas not only in the proportion required to form an explosive mixture with air, but also in the temperature required for ignition. While about 9 per cent. of marsh gas is required to form the most explosive mixture with air, only about 4 per cent. of the denser hydrocarbons would be necessary. It has also been clearly demonstrated that explosive mixtures of oxygen and ethane ignite at lower temperatures than similar mixtures of oxygen and marsh gas (methane). Some coal dusts have been ignited by heating in a current of air at 140° C.

In the final Report of the Austrian Fire-damp Commission * it is stated that the experiments made confirm those of Neunkirchen with regard to the danger of coal-dust, but also show that the dangers are greater than have hitherto been admitted. First of all the Commission tested the different kinds of coal-dust so as to classify them according to their sensitiveness to ignition and their danger. As they considered that black powder and similar explosives are dangerous in fiery mines and that their use should be entirely prohibited, they confined their experiments to high explosives, especially dynamite No. 1. The experiments were made in levels, like the one at Neunkirchen. Each kind of dust that was used was also tested in order to determine the following facts concerning it :—

1. Percentage of volatile matter.
2. Hygroscopic moisture.
3. Percentage of ash.
4. Quantity of marsh gas in 100 grammes of dust.
5. Quantity of gas given out by 100 grammes of dust at 100° C.
6. Composition of gas given out by 100 grammes of dust at 100° C.

Instead of imitating blown-out shots, the experiments were mostly made with cartridges of dynamite lying loose, or with a slight covering of coal-dust. The coal-dust experiments were almost exclusively made without any admixture of gas. In one of the levels, 353 experiments were carried out and showed that many notoriously dangerous dusts were less inflammable than other less dangerous dusts. Coal-dusts were therefore classified into sensitive and dangerous kinds. To judge of their sensitiveness, the coal-dusts were all tested with the same charge of dynamite—viz., 100 grammes (3½ ounces). The experiments showed that without any admixture of fire-damp, nearly all kinds of coal-dust were ignited by a cartridge of 100 grammes of dynamite lying loose. The following points were considered established :—

1. The degree of inflammability can scarcely be deduced from the chemical composition.

2. The texture of the coal is important. Hard compact coal will give less dust than crumbling friable coal. The fineness of coal-dust depends upon its texture.

3. The sensitiveness of a coal-dust, and, as a rule, its danger, increase with its dryness.

4. The danger of a coal-dust appears to depend more upon its physical qualities than upon its chemical composition.

5. A blown-out shot with coal-dust as tamping, or a charge of dynamite lying free, will ignite every kind of coal-dust. Most kinds of coal-dust were

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* *Schlussbericht des Centralcomités der österreichischen Commission zur Ermittelung der zweckmässigsten Sicherheitmassregeln gegen die Explosion schlagender Wetter in Bergwerken.* Vienna, 1891.

ignited with a charge of 100 grms. (3½ ozs.), and all without exception were ignited with a charge of 300 grms. (10⅝ ozs.).

6. A coal-dust which otherwise is not dangerous and takes fire with difficulty, may give rise to a disastrous explosion if there is a little fire-damp present.

The question continuing to be a very debatable one, Mr. Henry Hall was appointed by the British Home Secretary, in 1890, to carry on a further series of experiments.* The results of these experiments being still non-conclusive, a Royal Commission was appointed in Britain in 1891, to inquire into the effect of coal-dust in originating or extending explosions in mines, whether by itself or in conjunction with fire-damp, and presented a preliminary report† giving the evidence of witnesses examined.

Sir F. A. Abel ‡ considered that, under extremely favourable conditions as regards the nature of dust, its physical condition and its composition, and the quantity of dust existing and suspended in the air at the time of the explosion, in the entire absence of fire-damp, coal-dust undoubtedly has the power of carrying on explosions almost to an indefinite extent in mines. He questioned whether there is practically any limit, as, looking to the great commotion set up by the rush of gas produced as the explosion originates and as it progresses, the motion of the air is such that particles of coal-dust must be whirled up into it, and must continue to produce a mixture of sufficient intimacy and sufficiently highly charged with inflammable particles to develop afresh the conditions which existed originally when the explosion was started, and in that way the explosion may be considered to be a continuous one.

On the other side, Mr. A. H. Stokes § considered that the Prussian experiments proved that coal-dust, without a trace of gas, in a pure atmosphere, is not dangerous. Coal-dust in mines promotes, extends, and aggravates explosions due to fire-damp, by reason of the rapid inflammability of its finely divided particles. The sensitiveness to ignition of coal-dust and air appears to be in proportion to the intensity of heat at the point of ignition, and the size and impact of the initial flame has a very important influence in controlling the propagation of flame. The condition necessary to ignite a mixture of coal-dust and air appears to depend on the temperature, volume, and the way in which the initial flame strikes the current; also that each atom of dust be surrounded by air so that it can get oxygen instantly, and that each atom be near enough to its neighbour to be able to communicate flame. In most experimental cases where coal-dust was fired, the atmosphere was thickly charged with coal-dust—in fact, so thick that no living being could exist in it; and this was a state of affairs which could scarcely be found in any mine unless as the result of a serious explosion of fire-damp, nor one that a blown-out shot could create and fire with its own flame unless it were pointed directly into, and in close proximity to, an accumulation of dust. A mixture of air and fire-damp which cannot be detected by a safety-lamp, and which may be harmless in the absence of dust, may, if dust be present in sufficient quantities,

* *Coll. Guard.*, 1890, lx., 875.

† Blue-Book: *First Report of the Royal Commission on Explosions from Coal-dust in Mines*, July, 1891.

‡ *Ibid.*, 82.

§ *Ibid.*, 103 and 104.

become an inflammable mixture, and be the means of carrying flame as far as such mixture extends. The current of ventilation in a dry and dusty mine may be charged with such a low percentage of fire-damp that the most careful observer would fail to detect the blue cap indicative of fire-damp in the ordinary safety lamp, yet it might be so charged with fire-damp that any unusual circumstances, such as a heavily charged blown-out shot or other violent concussion, might raise a cloud of dust and render the current at once an inflammable mixture. A comparatively small explosion in a dry and dusty mine giving off fire-damp, may be developed link by link into a most extensive disaster.

Mr. Hall's further experiments in 1893 undoubtedly proved that under certain conditions some coal-dusts were capable of producing an explosion in the complete absence of fire-damp. Such dusts were obtained from collieries in districts where terrible disasters had occurred, while in the cases of districts like the Forest of Dean, Somersetshire, and South Staffordshire, where explosions are practically unknown, the dusts experimented with produced little more than the charring of the particles, and gave nothing resembling an explosion. Before the Commission presented their report, considerable light was thrown on the controversy by the explosion at Camerton Colliery in 1893, which occurred in a pit supposed to enjoy an immunity from such accidents, and where the presence of fire-damp had not been detected for nearly a century. After carefully considering the facts of this explosion, it is not surprising to find that the Commission said—*

We have no hesitation in expressing our opinion that a blown-out shot may, under certain conditions, set up a most dangerous explosion in a mine even when fire-damp is not present at all, or only in infinitesimal qualities; and while we are prepared to admit that the danger of a coal-dust explosion varies greatly according to the composition of the dust, we are unable to say that any mine is absolutely safe in this respect, or that its owners can properly be absolved from taking reasonable precautions against a possible explosion from this cause. But even if we had been able to come to a different conclusion, we should still have to call attention to the serious danger which results from the action of coal-dust in carrying on and extending an explosion, which may have originally been set up by the ignition of fire-damp.

The conclusions to which the British Commissioners arrived at are summarised as follows:—†

1. The danger of explosion in a mine in which gas exists, even in very small quantities, is greatly increased by the presence of coal-dust.

2. A gas explosion in a fiery mine may be intensified, and carried on indefinitely, by coal-dust raised by the explosion itself.

3. Coal-dust alone, without the presence of any gas at all, may cause a dangerous explosion, if ignited by a blown-out shot or other violent inflammation. To produce such a result, however, the conditions must be exceptional, and are only likely to be produced on rare occasions.

4. Different dusts are inflammable, and consequently dangerous in varying degrees; but it cannot be said with absolute certainty that any dust is entirely free from risk.

5. There appears to be no probability that a dangerous explosion of coal-dust alone could ever be produced in a mine by a naked light or ordinary flame.

These opinions are generally accepted by all moderate men, and after their publication, modified rules were set up regulating the use

* *Second Report*, 17. † *Loc. cit.*, 24.

of explosives in mines, as has been previously referred to in Chapter III.

Action of Moisture.—It is now established that the presence of moisture effectively prevents the possibility of coal-dust being ignited, and that, fortunately, only the very smallest amounts are needed. It has, consequently, become the practice at many collieries, where the coal is dry and dusty, to water the main roadways regularly. In order to be efficient the water should be applied in such quantities as will simply damp the dust and prevent clouds of it being raised by any means. If the floor be properly watered it is sufficient to prevent any deposit of dust on the sides or the roof. As a large quantity of dust is formed in the tubs during the progress of hauling them along the roads, a quantity of water is often thrown over the contents of each tub immediately before it leaves the working face.

Attempts have been made to render dust harmless by applying along the roadways some deliquescent body such as salt, but although the result in some cases has been satisfactory,* yet the method has not received many applications, the use of water being preferable. The most effective plan would be to damp the coal *in situ* before working takes place, and this has been carried out in the Saar district to a limited extent. Boreholes are put into the coal for a depth of from 3 to 4 feet, and plugged so as to be watertight. Water under pressure is forced into the holes, and left to soak into the coal for six or eight hours. It is obvious that such a system can only be employed under exceptional conditions. The difficulties of maintaining pipe lines along the principal roadways are great, and the introduction of such lines into working places would probably increase the cost to such an extent as to be prohibitive.

In some cases ordinary tubs are provided with a perforated pipe at the back, and the water applied in the same way as in streets of towns. If such a watering appliance is to be used, a good arrangement is that suggested by Messrs. Archer and Robson.† A circular brush is affixed to the rear of a tub, and is suitably connected by bevel gearing to the axle of the tub, so that when this moves along the brush is rotated. The spindle of the brush is hollow, and water is passed along it and through holes on the rim of the boss, and is thrown by centrifugal force from the tips of the bristle brush in the form of fine rain or spray.

The watering of the fallen coal in the working places can be carried out by means of a hose and rose jet. The promiscuous throwing about of water from buckets is not to be recommended. Owing to the cost and the hindrance resulting from applying either of these methods they are not much in favour, preference being given to watering the coal in each tub at the point where they are gathered together at the end of the haulage roads before they start on their journey towards the shaft. Messrs. Bell, Stevenson, and Harle have designed a method in which a tank is placed at sufficient elevation to supply overhead perforated pipes which extend across the rails on which the tubs run. Each tub in passing strikes against a lever connected with a valve in the tank, and a stream of water is rained down on the coal. The extent and duration of the shower can be easily regulated.

* *N. E. I.*, xxxi., 145. † *Ibid.*, xxxvi., 99.

Many collieries in South Wales are fitted with watering appliances, and the methods used have been described by Mr. A. Hood.* At Llwynypia Colliery, water pipes are carried along the roads, and a fine jet allowed to issue at intervals, the spray being carried along by the air current. Round outlet holes can be used when a deflecting plate is placed at a small inclination to the jet to drive it into spray. Flat jets, however, give a better spray, but round ones are less likely to be choked up with dirt. In some cases, even with the finest spray, the action of the water causes the roads to heave to a considerable extent, but at Ynishir Colliery, where two miles of piping are laid with outlet pipes at intervals of from 40 to 60 yards, little difficulty has been experienced from heaving. Of course this objection depends entirely on the nature of the roof and floor. The best procedure is to load up and remove the dust as much as possible before watering, as not so much water is necessary, and mud is not formed. Watering certainly makes the conditions more pleasant. At Pochin Colliery the intake air had been warmed and a jet of steam injected into it with satisfactory results. The warming of the intake air-current is, however, objectionable.

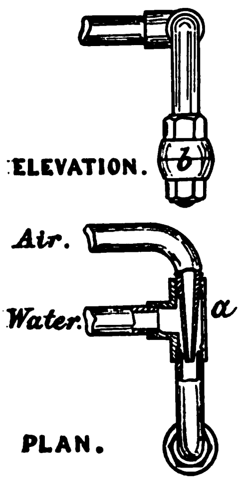


Fig. 522.

Mr. H. W. Martin has described the method in use at Dowlais, where a very elaborate system is applied.† Two mains are laid, one for water, and the other for compressed air. Out of these at intervals small branch pipes of half-inch internal diameter are carried to the roof, and then across, when they join together, by a conical nozzle (*a*, Fig. 522) in the interior of an ordinary T couple. The water is forced out by the air through an adjustable spray producer, *b*. The aperture in this is made adjustable, so that in the event of its being clogged by any sediment it can be "flushed" for an instant. The adjustment is made by a nut and screw. A regulating tap is placed in both the air and water branches, and to prevent entry of water into the air-pipe, and *vice versâ*, a small ball-valve on a leather seating is introduced into each pipe. The spray producer hangs vertically from the roof. An exceedingly fine spray is obtained, which is carried along with the air, and effectually damps the finest dust lurking behind timbers. It also cools the air-current, the experience at Harris Navigation Colliery being that the temperature of the intake has been reduced 4° to 5°. The pressure of water should exceed that of the air, but it is only necessary that it should be a few pounds above. The spray producer is made of brass, and is globular in form. It can be opened in a second by unscrewing a nut at the bottom, when dirt is readily blown out.

The mixture of air and water not only produces a very fine spray, but it seems to act further owing to the intimate mixture, and hence the discharge jets can be placed at greater distances apart. There can, however, be little doubt that the velocity of the air-current

* *So. Wales Inst.*, xiv., 257. † *Ibid.*, xv., 267.

influences in a great measure the distance to which the spray is carried.

Laws of Friction, &c.—Before describing how a ventilating current is produced and circulated through the workings, a short description should be given of the laws of friction and of the general rules relating to ventilation. The subject is such a complicated and extensive one that only the briefest summary is possible here. The finest series of papers in the English language are those by the late Mr. J. J. Atkinson,* which, although written so long ago, still remain the standard authority. To these, and others written at the same time by several of his contemporaries, the student is referred for detail of information and reasoning. The principal points dealt with, and brought out by the above series of papers, have been summarised and elucidated by Mr. W. Fairley.†

Currents of air, either on the surface or in a mine, are produced by a difference of pressure, and would flow at a great speed if no resistance were encountered. If v = the velocity in feet per second, g = gravity, or 32·2, and h = the height from which a body must fall in order to generate this velocity, such height being the motive column,

$$v = \sqrt{2gh} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The water gauge (W.G.), which is the measurement of the pressure required to generate this velocity at which the air travels, *if resistance were absent*, would be a small one, and may be determined by the formula—

$$\text{W.G.} = \frac{w \times h}{5{\cdot}196} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where w = the weight of a cubic foot of air at the temperature of the upcast, and h = the motive power.

Now

$$w = \frac{1{\cdot}3253 \times \text{height of barometer (H)}}{459 + \text{temperature } (t)} \quad . \quad . \quad . \quad . \quad (3)$$

and

$$h = \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\therefore \text{W.G. (in inches)} = \frac{\dfrac{1{\cdot}3253 \times \text{H}}{459 + t} \times \dfrac{v^2}{2g}}{5{\cdot}196} \quad . \quad . \quad . \quad (5)$$

From this formula it will be found, that if the air has a final velocity of, say, 50 feet a second, the theoretical water gauge required to produce it is only 0·6 inch. Fifty feet per second is a velocity scarcely attained in mines, and it is equally rare that the water gauge only shows 0·6 inch. The difference between the water gauge due to velocity, and the actual water gauge of any mine, is the measurement of the friction which the air meets with in passing through the airways.

The three main laws which govern the friction of gases flowing through pipes are as follows:—

* See list at end of chapter.

† *The Theory and Practice of Ventilating Coal Mines.*

(1) The frictional resistance varies directly as the rubbing surface; this rubbing surface is found by multiplying the length of the gallery by its perimeter, or, in other words, its circumference.

(2) The pressure required to overcome the friction varies inversely as the area, if the rubbing surface and velocity remain the same—that is to say, if two air-ways be taken, one of which is double the area of the other, only half the pressure has to be applied to each square foot of the large one as would have to be applied to the small one, to overcome the same amount of friction in the two ways, provided the velocity of the air and the extent of rubbing surface were the same in each.

(3) The frictional resistance varies directly as the square of the velocity; consequently, if the velocity be doubled, the resistance increases four times. The explanation of this law is a simple one, if it be remembered that if the velocity be doubled, double the quantity of air passes through the air-way in a given time, and meets every resistance with double velocity.

From these laws the following formula is deduced :—

$$pa = ksv^2 \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where p = the pressure in lbs. per square foot, a = the area of the air-way in square feet, s = the area in square feet of rubbing surface, v = the velocity of air in feet per minute, and k is a constant called a coefficient of friction, and is equal to the ventilating pressure required to overcome the resistance that a unit of air with unit velocity would meet with in circulating round a mine of unit area and having unit rubbing surface. The value of this coefficient has never been satisfactorily determined for the irregular passages of mines. Although it is generally admitted that Mr. Atkinson's figures are not strictly correct, yet they are freely adopted. He states that it seems probable that for every foot of rubbing surface, and for a velocity in the air of 1000 feet a minute, the friction is equal to 0·26881 foot of air column of the same density as the flowing air, which is equal to a pressure, with air at 32° F., of 0·0217 lb. per square foot of area of section.

The difference between pressure and power must be clearly understood; pressure is the force per square foot producing the ventilation, and power is the quantity passing multiplied by the pressure. The quantity is found by multiplying the area by the velocity.

By transposing and substituting values of the different symbols in (6) nearly every formula can be deduced to work out the problems met with in ventilating mines. Several of the more prominent results obtained may be summarised as follows :—

(1) The quantity of air circulating in a mine is according to the square root of the pressure.

(2) In air-ways of the same sectional area, but which only vary in length, the volume and velocity of air currents are inversely proportionate to the square root of the lengths.

(3) The quantity of air passing in air-ways of different areas, other things being equal, is according to the square root of the area multiplied by the area.

(4) The resistance varies directly as the length.

(5) The pressure required to propel air through passages is inversely proportional to the area, other conditions remaining the same.

(6) If any two machines are employed to ventilate a mine, each of which when working separately will produce certain quantities which may be denoted by a and b, the quantity of air that will pass when the two are working together will be $\sqrt{a^2 + b^2}$.

(7) The quantity of air passing is according to the cube root of the power applied.*

(8) Since the quantity of air circulating varies as the cube root of the power employed, and as the number of revolutions of a fan also varies as the cube root of the power employed, it follows that the quantity of air circulating depends directly on the speed of the fan.

PRODUCTION OF AIR CURRENTS.—The problem of producing sufficient air, and of so carrying it into every part of the mine that the noxious gases are effectually removed, is one of great importance. By the law in Great Britain and in many other countries, every mine has to be provided with two shafts, or outlets; one of these serves for the introduction of the fresh air, and is called the "down-cast"; the other, for the egress of the current after it has passed round the workings, and is called the "up-cast."

Natural Ventilation.—No matter what the respective sizes of the two shafts may be, provided that they are connected by a passage and that the density of the air in the two columns is equal, no current is produced. If, however, the densities are different, the pressure of the one column of air will overbalance that of the other. The equilibrium in the two shafts is destroyed by the natural heat of the strata altering the density of the air. As a descent is made towards the centre of the earth, a proportionate rise of temperature is found—that is, after a certain limit is passed. This limit is found at a depth of about 50 feet, where the temperature of the rocks is on an average 50½° F., this temperature remaining constant all the year round. From the mean of numerous observations, it may be taken that the underground temperature increases 1° for every 60 feet of depth below the invariable stratum. Therefore, the deeper the mine, the greater the difference of temperature of the air in the two shafts, consequently, the greater the ventilation.

From this cause ventilation is produced without any artificial assistance, and is called natural ventilation. It is, however, so inconstant as to be wholly unreliable, depending to a considerable extent on the temperature of the outside air, and the difference in the levels of the tops of the two shafts. Natural ventilation is due to exactly the same cause as furnace or fan ventilation, only in the latter cases the density of the air is altered artificially. It is present more or less in all mines, because of the heat given off from the strata and from the men and animals working below ground, which rarefies the air

* A most interesting paper has been contributed to the Federated Institution of Mining Engineers (vol. ii., 483) by Mr. W. Cochrane on a Duplex Arrangement of Ventilators, the results obtained agreeing remarkably well with the theoretical deductions given in (6) and (7).

and causes it to rise to the surface. The amount of air put into circulation is readily affected by changes of temperature in the external atmosphere. In winter, when the air above ground is cold, it is of much greater density in the downcast shaft than it would be on a hot day in summer, and consequently the natural pressure producing ventilation is greater in winter than it is in summer. In shallow mines, the temperature of the air at the surface in summer may rise as high as that of the air underground, or even on a very hot day may exceed it. In the former case, if the mine relied entirely on natural ventilation, the air current would be stagnant, while in the latter case, the direction of the flow would be reversed from that which went on during the cold weather. While a difference in the level of the two shafts, especially in shallow mines, greatly assists natural ventilation, it is not absolutely necessary.

In deep mines there is always more or less natural ventilation, and as the temperature of the rocks in such cases is more than that of the air at the surface, even on a summer day, the current, when once started to flow by any means in a certain direction, always maintains that direction and only varies in amount, more in winter, less in summer.

For the reasons given, natural ventilation is never to be relied upon, although it does in many cases materially assist the other means which are used to produce the air current.

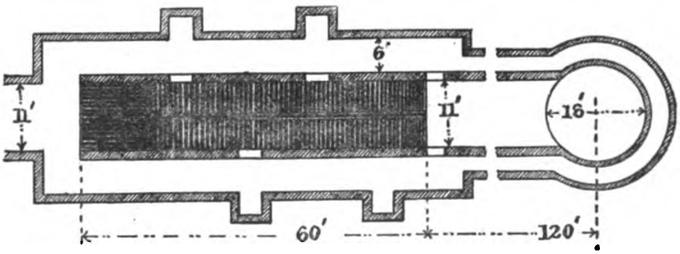


Fig. 523.

Furnace Ventilation.—The oldest means of producing ventilation was to artificially alter the density of one of the columns of air by heating it. At first, this was done by merely hanging fire-lamps in the up-cast shaft, to be soon superseded by placing a furnace at the bottom, as by the latter means the greatest effect is obtained. Furnaces may be constructed on two main principles, (*a*) either an open fire-place with all the air passing over the fire; or (*b*) contracting the area above the fire, and forcing the greater part of the current through the bars. Neither of these methods, separately, gives the best result. In the former, where a strong current is passed over the fire, its cooling action is so great that the combustion is feeble and a high temperature is not attained; while in the latter, if all the air passes through the bars, not only is carbonic oxide formed in large quantities, but the resistance or drag of the mine is much increased. A combination of the two gives the best results, and is almost invariably employed.

No better illustration of a well constructed and efficient furnace can be given than that at Eppleton Colliery (Fig. 523). The length of the grate is 60 feet, and its breadth 11 feet; the end of the fire bars are 120 feet away from the shaft. An air passage and firing-hole is provided on each side of the furnace, and also an air passage along each side of the drift going to the shaft. This drift rises 1 in 2, and is lined throughout with fire bricks. With this large grate area, all the air passing over the fire is thoroughly heated, and, in addition, doors are provided at the front, so that the quantity forced through the bars can be regulated. Doors on furnaces are, to a certain extent, necessary, especially on re-starting after cleaning. The current, which is then small, can be forced through the fire, and as it increases, owing to the temperature getting high, the doors are gradually opened, and more air allowed to pass over the fire. The advantage of the side passages is, that not only may firing be entirely done at the side, but the risk of setting the adjoining strata on fire is reduced. A good casing of sand is placed all round these arches as an additional precaution.

At Eppleton Colliery, 24 tons of coal are burnt in the twenty-four hours. During two shifts a number of boilers are at work underground, so that the furnace does not produce all the air circulated. While these boilers are at work one man per shift is employed for firing, but at night two men are necessary; this means four men per twenty-four hours. The quantity of air circulated is 303,000 cubic feet per minute, with 2 inches of water gauge, but only 120,000 cubic feet passes over the furnace.

In fiery mines it would not be safe to pass the return air-current over a furnace, and it has to be fed with fresh air. As the temperature at the bottom of the up-cast shaft is sufficient to ignite gas, the return air-current has furthermore to be brought through a passage called a "dumb-drift" into the shaft at some point above the furnace where the temperature has fallen below the igniting point. Neither feeding the furnace with fresh air nor carrying the return air-current through a dumb-drift increases the efficiency of furnace ventilation, but on the contrary, diminishes it, as not only is the temperature of the air-current reduced, but a shorter column of air is heated.

The amount of ventilation produced by a furnace varies as the square root of the difference of temperature in the two shafts—that is to say, if the mean temperature of the down-cast be 50° F. and the up-cast 75° F., if the temperature of the up-cast be increased to 150° the ventilation will be doubled, as the difference in the first instance was 25° and in the second 100°; therefore,

$$\frac{\sqrt{100}}{\sqrt{25}} = 2.$$

The objections to furnaces are the danger of introducing fire into mines yielding fire-damp, the risk of setting adjacent coal on fire, the corrosive effect on all shaft fittings and tubbing, and to the fact that no more than a certain quantity of air can be got out of a given furnace, no matter how much coal is used.

Furnaces are most objectionable where tubbing is employed, as the wood sheeting between the segments is continually being burnt out. Lining with brick-work offers little protection, as when the fires are damped down (for repairs to furnace or drift) the tubbing contracts so much that a large escape of water takes place, which, in some instances, so cools the shaft that the air-current is reversed. Where tubbing is employed, it is practically impossible to stop firing. In some cases in the north of England, which is the home of furnace ventilation, a second furnace is often built, and when the first is slacked for repairs the second one is started.

Steam Jet.—In the early part of last century, Sir Goldsworthy Gurney proposed that furnace ventilation should be superseded by the use of a steam jet. Steam at high pressure was to be carried in pipes down the shaft, and allowed to escape at the bottom through a series of jets arranged gridiron-fashion across the pit. As it was soon found that this method was neither so economical, nor so capable of producing large volumes of air, as a furnace, its use was abandoned, and except in cases of emergency it is never employed.

Mechanical Ventilators.—From the earliest times attempts were made to produce currents of air by mechanical means. The first forms consisted of a species of pump, which, in its improved form, represents the modern displacement machine. Other attempts were made to circulate air by the rotation of fans, which was not attended with much success until about forty years ago.

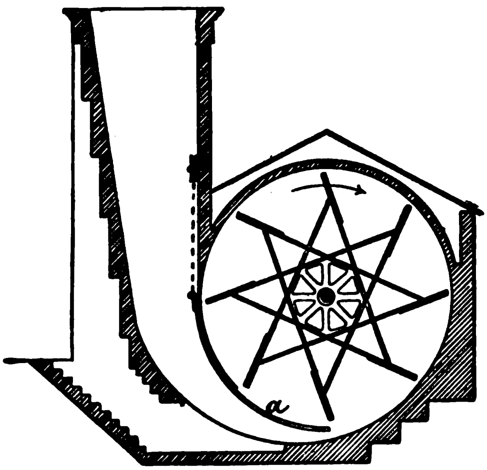


Fig. 524.

The comparative efficiencies of displacement machines and centrifugal ventilators have been exhaustively dealt with by Mr. W. Cochrane.* The chief disadvantages of the former are the heavy and cumbrous machine which has to be employed to produce large quantities of air, and the defect that, if there are sources of leakage in the apparatus, the volume of external air thus let in would *increase* as the depression increases, and, therefore, the air drawn from the mine will *diminish*. The re-entry of air must always be considerable, as a shutter is employed, which is neither rigid, nor even in contact with the casing.

The theoretical objections have been fully sustained in practice, and at the present time displacement machines have been entirely superseded by fans, of which numerous and varied types exist. It would be quite impossible to describe the steps which have led up to the latest designs, or even the whole of these designs. Reference can only be made to those largely in use, and which give good results.

Guibal.—This fan usually consists of eight or ten rectangular vanes, which are not, however, arranged radially, but are set backwards, as will be seen from Fig. 524. Each vane is secured to a pair

* *N. E. I.*, xxvi., 161.

of bars and angle irons, which, in their turn, are bolted to cast-iron bosses, keyed on the main shaft. As these bars are carried past the bosses and interlaced, a very firm, simple, and inexpensive structure is obtained. The fan is enclosed in a casing, giving about ½ inch to 1 inch clearance on each side. Over the fan an arch is provided, giving about 2 inches clearance to the vanes, such arch being continued round as an invert, but towards the bottom the clearance is increased, and gradually expands until it ends in the sloping side of a chimney.

In its original form this fan differed from all others in one point: it was provided with a sliding shutter, *a*, which is really a continuation of the circle of the top arch of the casing. This shutter allowed the area of the discharge opening to be regulated and fixed at such an amount that the best results could be obtained. In many fans only one inlet orifice was left in the casing. On the other side a blank wall was provided, through which the shaft of the fan passed, and was connected to an engine. For machines of small capacity such arrangement acted very well, but in the larger fans it was not only found that the ventilator did not get sufficient air, but that all this air, entering on one side, and doing so diagonally, threw a severe thrust on the shaft and its bearings. For such reasons it was found preferable to give such fans a double inlet—that is to say, leave a circular orifice through the casing on both sides.

The use of the shutter is to regulate the outlet to suit the special requirements of the mine, and its proper position can only be determined by experiment, as no theoretical calculations will determine the quantity of air that any fan will produce from any particular mine. If the discharge orifice be too large, air will re-enter the fan, while if it be too small, the air will not get away fast enough. The use of the expanding chimney is to reduce the velocity of the air as it leaves the fan. When the air leaves the vanes, it is travelling at a very high velocity, but as it passes up the chimney, whose area increases as it expands, it gradually travels slower and slower, until at the top it is discharged quietly into the atmosphere.

From its simplicity, freedom from repairs, and high efficiency, the Guibal fan has been in marked favour ever since its introduction in 1862, and probably more of its type have been erected than of all the other fans put together. The objection to the Guibal is its very large size, the expensive foundations required, and that it cannot be run above a certain velocity with safety. The latter difficulty has been removed by Messrs. Walker Bros.' shutter, which is described a little further on, but even with this the tendency at the present time is to put down some of the smaller type of fans which run at very much higher velocities.

Waddle.—This is of an entirely different type to the Guibal, being what is known as an open running fan—that is to say, it is not enclosed in a casing, and air is discharged all the way round the circumference instead of only at one point. As constructed until recently, it consisted of an arrangement of long and short curved blades arranged alternately between two iron discs; one of these discs is provided with a central opening through which the air passes into the fan, and is inclined towards the other disc at such an amount that the products of the angular velocity, multiplied by the sectional area at any point, are constant throughout the fan. Mr. M. Walton

Brown* has described several modifications, which have been recently introduced. In the old type the air was discharged into the atmosphere at a somewhat high velocity, but in the new fan its velocity is considerably reduced by the addition of a trumpet-shaped outlet which extends beyond the external ends of the blades. Fig. 525 shows the fan as constructed at the present time; *a* and *b* are the curved blades, the former running down to the centre. The area of this outlet is more than double the area described by the external tips of the blades, consequently the velocity of the air is gradually reduced as it passes through this divergent outlet, and as the resistance varies with the square of the velocity, less power is required to discharge

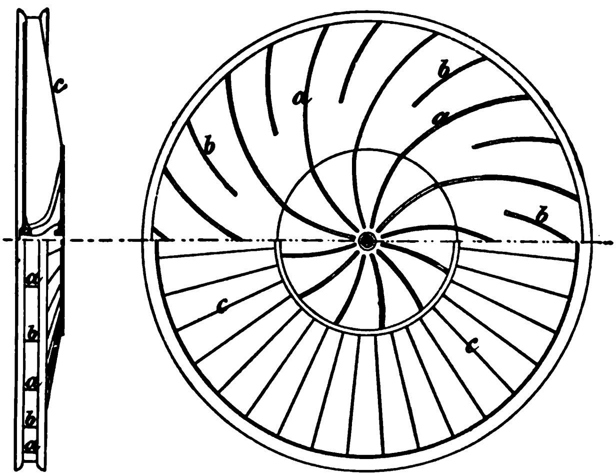


Fig. 525.

the air, and therefore less power is required to drive the fan, the result of which is to increase its efficiency. In addition, the blades are brought in towards the centre, and the air strikes all parts of them equally, but to give the maximum area for the entrance of the air, the long blades, *a*, are reduced in width as they near the centre. The disadvantage of open-running fans is their liability to be affected by high winds.

Schiele.—This is an enclosed fan, but is not placed centrally within the casing (Fig. 526). The moving part is small in diameter, and the blades of the fan taper from the tip widening towards the centre. The air enters at each side in equal proportions, and the vanes revolve between a casing of such form that its sides follow the taper of the blades, while the circumference is arranged as a gradually increasing volute chamber surrounding the periphery of the blades, culminating in the exit, which forms the widest part of the air chamber.

Cockson.—The objections to the Guibal, as before mentioned, are its great weight, size, and the vibration resulting from its unbalanced nature. To remedy the latter defect, Mr. Cockson has modified the ordinary construction. The close-fitting casing, expanding chimney, and adjustable shutter are retained, but the blades taper from the centre to the circumference in such proportion that an equal area of air passage is obtained throughout the fan (Fig. 527). The expanding chimney is not so wide in one direction owing to the blades tapering,

* *Fed. Inst.*, ii., 173.

and its width is, therefore, increased in the other direction so as to obtain the proper area of discharge. This alteration has removed the objectionable vibration, such fans being practically noiseless, and as they are more balanced, can be run at a higher speed, thereby allowing a smaller one to be used.

Capell.—This fan is a departure from all others in its arrangement and construction. All sizes above eight feet diameter are constructed with a double inlet. In its original form the fan was divided both

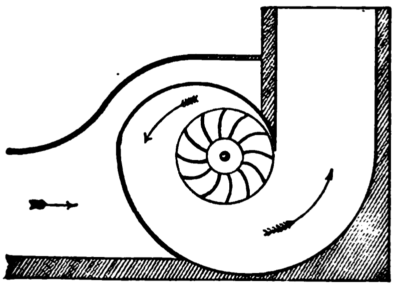


Fig. 526.

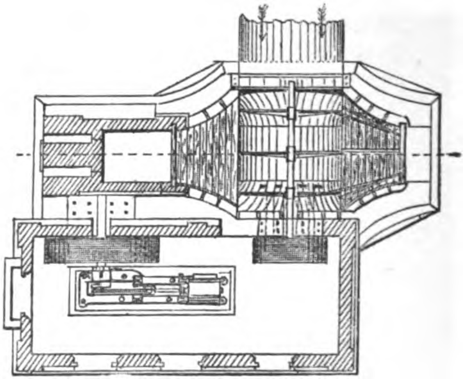


Fig. 527.

vertically and horizontally, into chambers. The vertical division consisted of a stiff steel diaphragm (*a*, Fig. 528) which entirely separated the air received on one side from that of the other. The horizontal division consisted of a cylinder, *b*, having a series of port-holes through it whose combined area was made 10 per cent. larger than the inlet opening to prevent throttling, and usually six blades, *c*, projecting inwards, curved with the convex side in the direction of rotation. The air entered into this cylindrical chamber, and was

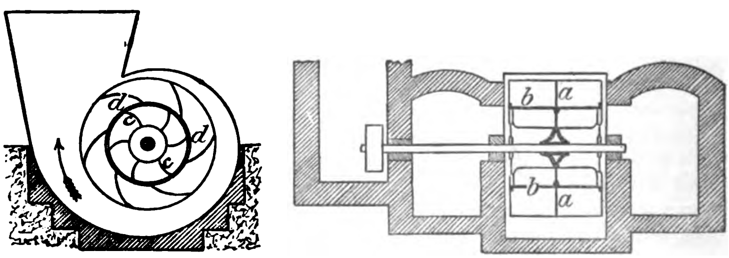


Fig. 528.

discharged through the port-holes, *d*, at a very high velocity against the inner and concave side of the outer wings. Claims were made that to some extent the *vis viva* in the air was given up to the outer wings and assisted in driving the fan. When the air leaves the tips of the blades its velocity is further reduced as it is discharged into a spiral volute chamber, and finally passes, by means of an expanding chimney, into the open air. In more recent patents, the original construction has been materially modified. The horizontal division with its port-holes has been abandoned, the outer wings have been compounded, and the inner wings have had their edges extended and turned in, forming a sort of scoop. The modifications will be followed from an examination of Fig. 529 which gives an outline of the blades, both in former (full lines) and recent constructions (dotted lines); *a b c* was the outer wing, *d e* the inner wing, and *d c'* the port-hole. Part of the original wing *a b* has been retained and part, *b c d*, abandoned, while a second wing, *f b d*, has been added. The inner wing, *d e*, practically remains as before, but is lengthened and has its inlet edge bent to form a scoop. The complete fan is illustrated in Fig. 530.

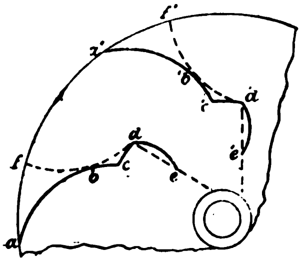


Fig. 529.

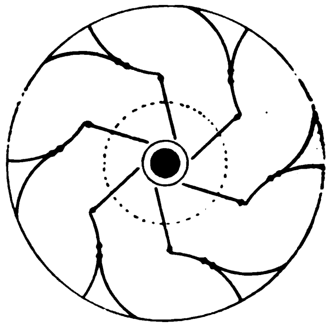


Fig. 530.

The novelty lies in the combination of the concave and convex blades. It has been known for some time that a fan blade running with its concave surface in the direction of rotation gave high water gauges and low useful effects, due probably to the fact that the vacuum created at the back of a blade of this form caused a portion of the air discharged to re-enter between the wings. In the case of blades running with their convex surface in the direction of rotation, this re-entry was obviated but the water gauge was lowered. By combining the two systems in one compound wing, the inventor claims to have overcome the difficulty, and to be able to produce both a high manometrical and useful effect.

Walker.—This is one of the more recently designed fans, and is more or less a combination of several types. It has Guibal blades, chimney, and shutter, but it is placed eccentrically in the casing like a Schiele. Its construction is of the strongest type, and it is claimed by the makers to be indestructible. It is built up somewhat as follows:—In the centre is a mild steel disc (G, Fig. 531), which does not, however, reach the circumference as in the Capell. On each side of this are angle irons, C, to which the vanes, A, eight or ten in number, are attached. Rivets pass through the two angle-irons and disc, and through each angle-iron and blade. The disc is supported between two iron bosses, D, turned where they come in contact with the disc plate, and secured thereto by turned bolts driven into rimered holes. The bosses are bored out and secured to the fan shaft by keys. The blades in the larger fans are also braced together by struts, H, and strengthened by a gusset-stay, B, and instead of being full width from the top to the boss, they are cut away, as shown at A, in the cross section, and, if necessary, removable pieces are attached by bolts to partially fill up the opening. By doing so, it is claimed that the minimum amount of central obstruction with the largest amount of fan power could be secured in each case.

Ser.—The vanes are curved with their convex surface towards the direction of rotation. They are also diminished in width outwards in order to preserve an air channel of constant resistance throughout. The inlet orifices are of peculiar construction, and the air on entering is guided up into the vanes (*e e*, Figs. 532 and 533) by

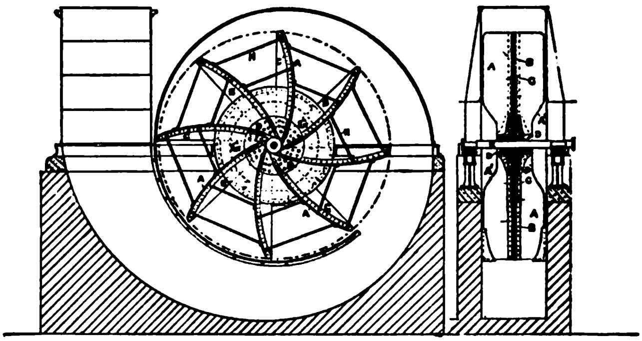
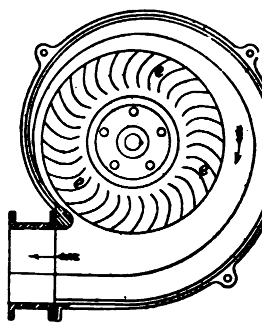


Fig. 531.

curved plates, *a b*, extending from the fan shaft to the central division plate, *c*, which cuts the fan into two halves. The fan is enclosed in a casing formed by two castings, connected together at the centre by a strip of wrought iron, *d*, and such casing can be bodily swung round to allow the air outlet to be pointed into any desired position, or if needs be, the width of the fan can be increased by sliding the two sides further apart and replacing *d* with a broader strip. The casing



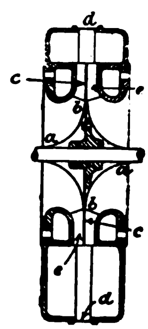


Fig. 532. Fig. 533.

constitutes a spiral channel like the Schiele, and terminates in an expanding chimney. It has not been made of a greater diameter than 8 feet, and runs about 8400 revolutions per minute.

Rateau.—The principal parts of this fan are the vanes and the diffuser which serves to transform the active force of the current into useful statical pressure. The fan wheel, or turbine as it is called by the inventor, is constructed of a body, A, of the shape shown in Figs. 534 and 535, the surface of which forms the arc of a circle, *a b*, provided with a boss, B, whereby it is mounted on the shaft, C, by which it is rotated. On the body, A, are fixed vanes, D, to the number of about thirty* of special form. Each vane has four edges; one of these edges, *a b*, is fixed on the body, A, of the wheel; a second, *b c*, is a generatrix of the imaginary periphery of the wheel; a third, *c d*, during rotation of the fan moves in close proximity to a part, E, of the casing, forming a continuation of the bell or trumpet mouth inlet, *d e*; finally, the fourth edge, *d a*, extends across the inlet opening.

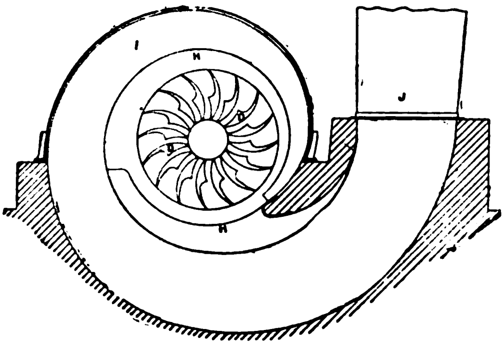


Fig. 534.

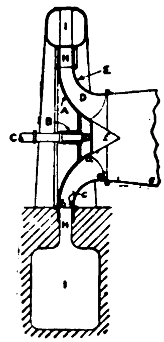


Fig. 535.

The shape of the space between A and E is calculated so that the relative speed of the air between the vanes, D, remains nearly constant. A conical cap, *f*, covers the end of both the shaft, C, and casing, A, and guides the air before it passes on to the edge, *a b*, of the vanes.

The diffuser is composed of three distinct parts: firstly, of a flat spiral, H H, formed of two parallel plates limited to the peripheral circumference of the body, A, and to an Archimedean spiral, the height of which increases progressively from the inlet mouth of the diffuser to the outlet; secondly, of a diffusing collector, I I, or volute of circular or square section, increasing in diameter in proportion as the spiral increases in height; thirdly, the conical or pyramidal outlet pipe, J. The principal feature of the diffuser is the combination of the flat spiral portion with the enlarged part; this is done with the object of allowing an almost complete transformation of the active force in the air into pressure before it enters the outlet chimney, J.

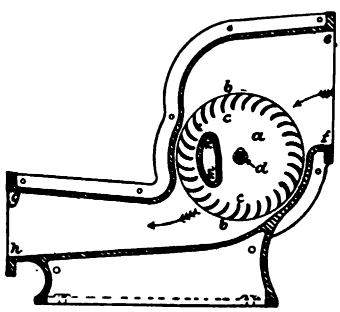


Fig. 536.

Mortier.—This apparatus differs in principle from all the centrifugal ventilating machines described, inasmuch as the air enters the casing not through lateral apertures in the direction of the axis, as is the case with fans ordinarily employed, but through a wide portion of *periphery*. It is caught by the forwardly curved vanes of a sort of

* For the sake of clearness, half the number have been omitted in the drawing showing the side elevation.

paddle wheel and caused to traverse the casing diametrically at a high velocity, where it again encounters the opposite revolving vanes of the paddle wheel, and is forced with a still higher velocity into an expanding outlet or chimney.

The apparatus comprises a wheel or disc (*a*, Fig. 536) having curved vanes, *b c*, arranged symmetrically around the periphery and on both sides of the disc, *a*, which is keyed upon the driving shaft, *d*, of the machine. The disc is enclosed in a casing of the shape shown, having an inlet orifice, *e f*, and outlet orifice, *g h*, and apertures through its two flat sides for the passage of the driving shaft, *d*. Two fixed cores or projecting pieces, *m n′*, proceed from the flat sides of the casing, and extend within the central part of the crown of vanes so as to nearly touch the central disc, *a*. These projecting pieces are intended to augment the capacity of the apparatus, and are fixed for the object of guiding the stream of air passing through the wheel, and to prevent it being driven in the opposite direction, which might be caused by that portion of the wheel situated on the left.

Walker's Shutter.—The object of this invention is to reduce the objectionable noise and vibration caused by rotary fans. In the ordinary Guibal, the edge of the shutter forms a horizontal line parallel with the shaft of the fan, and faces the blades. A little consideration will show that during the revolution, as each blade nears the discharge orifice, it has on it a large pressure, but as soon as the tip of the blade and bottom of the shutter coincide the delivery of air is abruptly terminated, the fan enters the fan casing, the load is removed, and a rebound necessarily takes place. The jerk thus caused, is transmitted to the fan shaft, and as each arm acts in a similar manner, the result is that the whole structure is in a constant state of vibration, and injury to it must necessarily follow.

Messrs. Walker replace the horizontal edge of the shutter with an inverted V, thus, Λ. Each blade commences to discharge at the broad part of the Λ, and as it proceeds on its journey meets with a gradually decreasing area of discharge orifice, until at the top of the Λ all egress of air is stopped. As a result, the pressure of air is gradually taken off each vane. The length of the Λ is somewhat greater than the distance between two blades, so that the following vane may be opposite the commencement of the shutter before the blade next in advance has entirely left it. Without doubt, this is one of the greatest improvements which has been added to enclosed fans of late years.

Driving by Straps and Ropes.—High speed fans, except in rare instances, are not driven direct by engines, but through belts, or better still, by a number of ropes working in grooved pulleys. With a steady running fan engine high degrees of expansion can be used, as the work is uniform, but such procedure causes a certain amount of shock to the fan, as the piston receives full pressure of steam at beginning of stroke. Then steam is cut off, and the rest of the revolution is due to the momentum obtained and the expansion of steam already in the cylinder. The fan is thus practically driven by a series of kicks.

Belts or ropes take up this shock. Ropes, although more expensive than belts in first cost, are, perhaps, the best in the long run. If a belt breaks, all the machinery is stopped, but all the ropes will never break at the same time. The only mistake that can be made is to put too great a strain on each rope, by which wear becomes very rapid. These ropes are constructed of hemp, and to obtain sufficient grip are generally made to run in grooves, whose sides are inclined towards each other at an angle of 45°. The ordinary method of application is to have each rope in separate grooves. They are pulled very taut at first, but get less tight as the rope lengthens. Another method is to wind a single rope round the two pulleys as many times as required for the necessary horse-power, and to put on a tension pulley to get the required grip and to take up slack.

The wear of a rope is due to two causes—internally, by the movement of the fibres on each other due to the bending on the pulleys, and, externally, through the wedging and slipping on the grooves of the pulley, both of which may be said to be directly proportional to the speed. Rope drives have been employed for about the past twenty years; their wearing capacity appears to be unlimited.

Speed Indicators.—Counters attached to the fan shaft are generally employed for indicating the number of revolutions made by the fan, but they do not indicate at a glance the speed at which the machine is running. Indicators for such purpose are more necessary with the higher speed fans than with the slower larger types. One form made by Harding & Co., consists of two small fans side by side in a case, but not attached to the same axle. One fan is driven by a small pulley and belt, worked from the main fan shaft, and produces a certain current of air, which acts on the vanes of the second fan, and would drive it round, if it was not prevented from doing so by a spring. The action, however, coils up this spring to a more or less extent dependent on the speed, and the spring works a pointer indicating the number of revolutions at which the main fan shaft is revolving.

A similar result is obtained by Napier & Son, who use a small centrifugal pump, driven by a strap from the fan shaft, to elevate a column of mercury up a tube. The height to which this column is lifted varies with the speed of the engine.

A similar appliance, which has the additional advantage of recording the speed, has been invented by Mr. J. Karlik, of Kladno, in Bohemia, and is called a tachograph. Like similar appliances of its kind, it consists essentially of a governor and recording device. The governor is of novel design, and consists of three communicating tubes; a wide central one and two narrow side tubes, the latter having a peculiar shape based on mathematical calculations. When these tubes are filled to a certain height with mercury, and rotated, the mercury sinks in the central tube, and simultaneously rises in the side tubes in such a way that the amount of the depression in the central tube is directly proportional to the number of revolutions. A float on the surface of the mercury is suitably connected with a recording device, consisting of two pens filled with red and blue ink, one being movable and recording the curve, while the other is fixed and records a base line. The drum carrying the paper strip is driven by clockwork, and is so arranged that the diagrams are written in a spiral form above one another, and consequently a great number of consecutive diagrams may be drawn on a strip of paper of moderate length.

Arrangement of Engines, &c.—To minimise the result of a breakdown in the engine, it is usual to apply two to a fan, each working alternately for certain lengths of time, generally about three months at a stretch.

This arrangement only provides relief in case of accident to the engine, and if the fan breaks down everything is stopped. Of late years it has become common to duplicate the whole of the ventilating machinery, and work each fan alternately. A very good arrangement for two ventilators, as applied at Celynen Colliery, South Wales, is shown in Fig. 537. Two Waddle fans, each 45 feet diameter, are situated as illustrated. The air drifts are 18 feet wide by 19 feet 6 inches high, and in each one, at points *a* and *b*, are eight wooden doors, working in iron frames (see cross section). These doors open *towards* the fans.

To change fans, the one that has been standing is started, and speed gradually got up to about 40 revolutions. The other fan is slowed down to 50 revolutions, while the speed of the second fan is increased; immediately the revolutions of the second fan exceed those

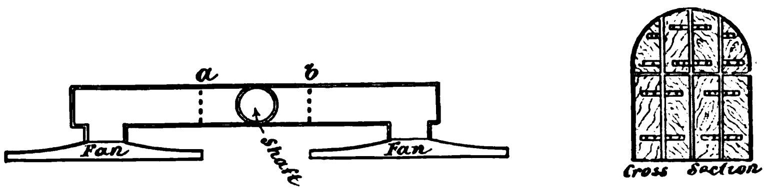


Fig. 537.

of the first, the air doors in its drift open, and at the same time, those going to the first machine shut. The first fan is then stopped, and the speed of the second one increased to the ordinary amount.

Secondary Ventilation.—Of later years, and more particularly in Europe, it has become a common practice to erect small subsidiary pressure fans at points some considerable distance from the shaft, either for the purpose of assisting the main ventilating current, or for the sole ventilation of winning headways. These fans are arranged to force air down a range of sheet-iron pipes, some 18 to 24 inches diameter, and are often driven by electric motors, coupled direct. They are an efficient and convenient adjunct to the main fan, when this is working anywhere near its maximum capacity.

Determination of the Useful Effect.—The amount of useful effect produced by a fan is found by carefully determining the quantity of air put into circulation by it, and by measuring the water gauge. Each inch of water gauge is equal to a pressure of 5·2 lbs. per square foot. The horse-power in the air

$$= \frac{q \times \text{W.G.} \times 5{\cdot}2}{33{,}000}$$

where q = the quantity of air in cubic feet per minute and W.G. = water gauge in inches.

While the air measurements are being taken, the speed of the engine is carefully noted, and indicator diagrams taken, from which the mean steam pressure in the cylinder is determined. The H.P. of the engine

$$= \frac{p \times d^2 \times {\cdot}7854 \times 2 \times \text{S} \times \text{R}}{33{,}000}$$

where p = the average steam pressure, d = the diameter of the cylinder, S = the length of the stroke in feet, and R = the number of revolutions per minute. The ratio between the horse-power in the air and the horse-power exerted by the engine gives the useful effect of the fan. The manometrical efficiency is the ratio between the observed and the theoretical water gauge for any determined velocity.

It must be admitted that, in comparing fans, it is scarcely fair to do so, without deducting the power required to drive the engine when it is not connected to the fan. The higher type of engine in perfect condition necessarily absorbs less power to drive it than a badly designed machine in an indifferent condition; it may, therefore, happen that a good fan driven by a bad engine will not show such a high efficiency as a less perfect fan driven by a good engine, indeed, a badly constructed engine may take more power to drive it than a good fan.

Efficiency of Fans.—No matter whether the fan is a large one, running slowly, or small one travelling at high velocity, the work done depends on the speed of the periphery, or tangential velocity. The theoretical depression which a perfect fan would produce is determined by the formula—

$$H = \frac{u^2}{g}$$

where H is expressed in feet of air column required to overcome the resistance of the mine, and u = tangential velocity in feet per second. This depression is never realised in practice, owing to several causes, the chief of which is the resistance of the machine itself to the passage of the air through it. The theory of ventilators now generally accepted is that of Mr. Murgue,* the third part of which has been translated into English by Mr. A. L. Steavenson,† to which the student is referred for the reasoning by which the following formulæ are deduced.

Mr. Murgue assimilates every mine to an orifice in a thin plate, which he calls the "*equivalent orifice*"—that is to say, all mines requiring a certain water gauge for the production of a certain volume of air are exactly equivalent to an orifice in a thin plate which requires the same water gauge to pass the same volume. By this means all existing mines can be compared by the sizes of their orifices.

The equivalent orifice depends upon the well-known laws relating to the flow of fluids, being chiefly affected by what is known as the *vena contracta*, or the quantity which passes through an orifice in a thin plate is 0·65 that of the quantity due to the area of the full orifice. If it is assumed that the normal densities of air and water are respectively 1·2 and 1000 and expressing V, the volume, in thousands of cubic feet per minute and h in inches of water gauge, the equivalent orifice a will be found from the formula—

$$a = 0{\cdot}403 \frac{V}{\sqrt{h}}$$

The second point of Mr. Murgue is that the ventilator even while exhausting the air from the mine, forms at the same time an obstacle

* *Soc. Ind. Min.* (2e Série), 1st part, ii., 445; 2nd part, iv., 747; 3rd part, ix., 5.

† *The Theory and Practice of Centrifugal Ventilating Machines.* London, 1883.

to the passage of the air, causing a sensible loss of duty. This he calls the "*orifice of passage.*"

In order to compare two machines, they are regulated to the same speed of periphery, or their results may be easily reduced to equal speeds, since the volumes vary as the revolutions, and the depressions as the square of the speeds.

The mine is altered to, say, five different conditions, first, by obstructing the passages; then in a normal state; and afterwards by opening some of the doors.

With the equivalent orifices of these five different mines, or conditions of mine, plotted as abscissæ, and the volumes as ordinates, a curve is obtained, which clearly shows the effectiveness of each fan, and is called its "*characteristic curve.*"

A perfect fan moving without friction and giving the theoretical water gauges, produces volumes of air proportional to its equivalent orifice, and its curve is represented by a straight line, O B (Fig. 538), commencing from the origin, because when the mine is closed the volume of air is necessarily *nil.* Owing to the resistances of the fan itself which vary with the volume produced, the straight line is never obtained in practice, but a curved one takes its place. The nearer this curved line approaches the straight one the more perfect is the fan.

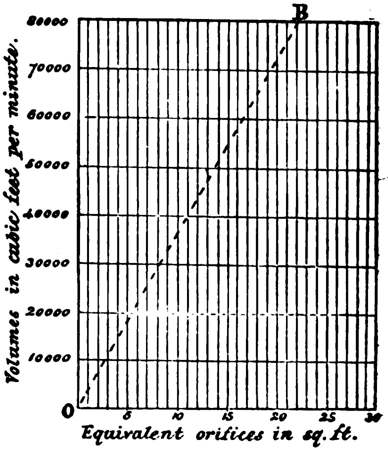


Fig. 538.

In calculating the efficiency of fans the chief error which is likely to arise is neglecting the amount of natural ventilation, as, if this is large, it has to be passed through the fan, and in doing so little or no water gauge is produced.

Under favourable conditions, and with a machine designed for the work it has to perform, the efficiencies of the Guibal and improved Waddle fans may reach 65 to 70 per cent., while that of the Schiele fan is smaller. The efficiency of the Capell and Walker fans is probably higher than the above figure. Any fan dealing with the maximum quantity of air that it was designed to pass, gives better results than if the quantity of air put into circulation is either more or less than the amount for which it was designed.

It is very difficult to arrive at the relative merits of the different types of fans, as comparisons are apt to be misleading. In order to arrive at a trustworthy conclusion, the fans should be of equal capacities and be working under the same conditions. The latter condition can scarcely be fulfilled unless the fans have been designed for, and are applied to the same mine. In many instances when fans are being erected they are put down of much larger size than is theoretically necessary in order that larger volumes of air may be circulated should circumstances require it. It is, therefore, misleading to compare such a fan with another working to the full capacity for which it was designed. In order to determine the relative merits of several types of fans, the North of England, the South Wales, and the Midland Institutes of Mining Engineers appointed a committee, and their report was issued in May, 1899.* The report confirms the opinion generally held that the enclosed type of fan is superior in efficiency to the open running type. The enclosed Guibal fan had a manometric efficiency, which is also the measure of the resistance of the fan to the passage of air, of 0·636, the enclosed Schiele fan 0·502, and the open-running fan only 0·464. It is also pointed out that the mechanical efficiency of a fan was not a constant quantity and varied with the orifice of the mine, from *zero* upwards. The mechanical efficiency of the Guibal fan varied from 0 when the orifice was closed to 24·5 per cent. on an orifice of 10 square feet, 43·4 per cent. at 20 square feet, 52·7 per cent. at 30 square feet, 54·8 per cent. at 40 square feet, and fell to 53·2 per cent. for 50 square feet; and for larger orifices there was a continuing decrease in the mechanical efficiency. The committee direct particular attention to the question of the choice of a driving engine which so materially affects the mechanical efficiency of the fan, an efficient fan being practically valueless when driven by an inefficient engine. The report is most interesting and valuable, but it is to be regretted that the experiments were confined to the Guibal, Schiele, and Waddle fans.

The practice of recent years has been to employ smaller high speed fans in place of the older designs of slow moving ventilators, and while the former are cheaper in first cost and in foundations, &c., experience has demonstrated that their efficiency is equal if not superior to the latter, and that their wearing capacity is satisfactory. In Great Britain the Walker and Capell are probably most in favour; in Europe the Mortier, Ser, and Rateau are generally employed, although numbers of Capell are in operation, while in America the last named fan is making considerable headway.

Messrs. Mativa, Desvachez, Isaac, and Evrard † have made experiments on four different types of fans—viz., Guibal, Capell, Ser, and Rateau. Four tests were made on each at different mines and the results are detailed in an elaborate table. They give the approximate cost of the different fans, including steam engine for driving, foundations, and buildings for covering, as follows:—Guibal, £1120; Ser, £1280; Capell, £1380; Rateau, £1200; and they summarise the four different fans thus—They are all efficient from many points of view and possess good qualities, but the Rateau appears to possess advantages which place it first, as it produces a higher pressure, has a higher mechanical efficiency, and works regularly and silently.

As has been already pointed out, fan tests are apt to be misleading. The only fair comparison is to test them under similar conditions, and each fan should be doing the work for which it was designed. It is obviously unfair to compare a fan doing the duty for which it was constructed, with one working under or over its capacity. For the comparisons to be of any value they must be made on fans travelling at equal circumferential velocities, and experiments conducted with varied resistances of the mine to the passage of air. Natural venti-

* *Fed. Inst.*, vii., 482. † *Ibid.*, vi., 601.

lation should theoretically also be taken into consideration; it is an uncertain factor sometimes aiding and at others reducing the work of the mechanical ventilator.

Comparison of Furnaces and Fans.—Mr. J. J. Atkinson appears to have been the only person to theoretically compare the relative efficiencies of furnace and mechanical ventilation.* After considering the varying circumstances of different mines and the conditions under which furnaces and fans produce a ventilating current, he gives a formula from which it appears that the depth at which furnace action becomes as economical in fuel as a ventilating machine, increases directly as the volume assumed by a given weight of air as due to the average upcast temperature required for the production of ventilation by furnace action—that is to say, inversely as the average density of the heated air in the upcast. This depth, of course, must decrease in the same proportion that the fuel per horse-power per hour, required to drive the engine of a ventilating machine increases.

By this formula the following table was calculated, showing the depths at which furnaces become equal to ventilating machines in point of economy of fuel, on the assumption that the fuel due to the temperature lost between the furnace and the point in the upcast column, where the average temperature prevails, is the same percentage of the whole fuel as that which arises from the application of ventilating machines, driven by engine power, to produce the same ventilation :—

Consumption of Coal by Engine in lbs. per hour per horse-power expended.	Average Temperature of Upcast Columns.		
	100° F.	150° F.	200° F.
	Depth in Yards.	Depth in Yards.	Depth in Yards.
8	958	1044	1130
10	766	834	904
12	638	696	752

A table is also given showing that the average loss in eleven cases of furnace action was 40 per cent. If therefore ventilating machines lose 40 and utilise 60 per cent. of the engine power, the depths that are necessary to render furnace ventilation as economical as such ventilating machines in the consumption of fuel are as stated above. It should, however, be noted that many engines at the present day do not consume 4 lbs. of coal per horse-power per hour, and hence the economy of fan ventilation is more than that shown by the table.

Mr. C. Cockson after giving a description of a fan at Dairy Pit, Wigan,† stated that the plant was erected to take the place of two underground furnaces, having a fire-bar area of 129 square feet on which 12 tons 17 cwts. of Arley mine mixture were burnt per 24 hours, producing, with the furnace very hard fired, 142,570 cubic feet of air per minute, the cost for wages being 19s. 3d. and for fuel

* *N. E. I.*, vi., 135. † *Man. Geo. Soc.*, xvii., 231.

£4 3s. 7d., or a total cost of £5 2s. 10d. per 24 hours, which, multiplied by 365, will be £1876 per annum. The fan gave the same quantity of air as the furnaces when running at 52 revolutions per minute, burning 4 tons 2 cwts. of rough buzzard slack per 24 hours, and costing for wages 10s. 6d., and for fuel, 15s. 4d.; or a total per day of £1 5s. 10d., which, multiplied by 365, gives a cost of £471 per annum, or a saving by the use of the fan on the two items of fuel and labour of £1405 per annum. Of course, from this an allowance has to be made for interest, depreciation, stores, &c.

Many similar instances could be quoted if it were necessary, but it is now generally admitted that mechanical ventilation is superior to furnace ventilation, as it is more under control, cheaper, more efficient, and capable of being easily varied in quantity whenever desired.

DISTRIBUTION OF THE AIR CURRENT.—Having described the means of producing the air current, and the laws which regulate its flow, its distribution underground should be readily understood. It has been mentioned that two paths are provided for the current, one for the fresh air to enter and the other for its return. The distribution into the workings is a far more difficult point than simply leading it along two roads. To reduce resistance and allow large volumes to be readily passed, it is necessary that the air-ways should have as large a section as possible. As the resistance varies with the square of the velocity, the only practicable way to pass large quantities is to reduce the velocity, which may be done by diminishing the rubbing surface, increasing the area of the air-way, or better still, by what is known as splitting—that is to say, dividing the current into several parts, and providing a separate air-way for each.

The rubbing surface can only be reduced by shortening the length of the air-ways which is generally impracticable. Considerable saving in this respect may be effected by the careful laying out and design of the roadways in the first instance, by making them as straight as possible, and by keeping the timbering regular, or by making the sides smooth; indeed, by lining the sides with masonry for some considerable distance from the shaft.

The velocity is more readily reduced by increasing the area of the air-ways, limited, however, by considerations of safety and cost in maintaining large air-ways dependent on the nature and structure of the strata. Roadways of double the area may more easily be maintained in some seams than those of half the size in adjoining ones. It is often cheaper to provide and maintain two air-ways than one of double the size, and in extensive collieries, two intakes and two returns are commonly provided. The area of the air-ways should be kept as large as possible, and friction can often be reduced by increasing the size of the existing roads, either by ripping the roof or widening the sides. This increases the amount of rubbing surface and friction, but not to such an extent as the friction is reduced by the smaller velocity of the air current, because friction varies directly as the extent of the rubbing surface, but in proportion to the square of the velocity.

The most effective method is by splitting the air. Supposing one current of 100,000 cubic feet exists in the mine, and passes down an air-way having an area of 100 square feet, its velocity would be 1000 feet a minute. If this current be divided into five, each of which contains 20,000 cubic feet, the same total quantity will be passed through the mine, and if each of these currents be provided with an air-way 100 square feet in area the velocity will be 200 feet per minute, or only one-fifth of what it was before, consequently the resistance is reduced to one twenty-fifth part.

The enormous gain resulting from splitting the air is at once apparent, but it must be remarked that there is a limit to the number of splits that can be used at any mine. All the splits, however separate they may be kept in the workings, have to unite at the bottom of the upcast shaft, and pass through it; therefore, when the resistance of the shaft is equal to the sum of the resistances of the air-ways, the limit of advantageous splitting is reached.

A further advantage arises from the fact that the air throughout the mine is purer, because the gases, &c., from each district are kept separate in their respective air-ways, and each face is supplied with a current of fresh air. The reduction in velocity also minimises the probability of the flame of a safety lamp being passed through the gauze to an explosive mixture.

To obtain the best results from splitting the air current it is necessary that every split should commence as near as possible to the shaft bottom, and have a separate intake and return, and that the splits should approximately be of equal lengths, to avoid the necessity for regulating doors.

Stoppings.—When the two main roads are being driven, one for the in-take, and the other for the return, they are connected at intervals by cross-drivages, and those nearest the shaft are stopped up again immediately another one nearer the face is driven. These stoppings are usually built of dirt or rubbish, and a brick wall put on the side nearest the intake current. Every care should be taken that this is air-tight, or a small quantity will escape through and pass away to the upcast shaft without doing any good. The practice is sometimes followed of leaving a small hole through the stopping to ventilate the cross-road, but it is difficult to see how this can do any good, as the quantity of air which escapes through is so small that it cannot effectively ventilate the road; while the total loss occasioned by a number of such outlets seriously reduces the quantity passing into the workings.

Doors.—Where tubs, men, or animals have to pass through these cross-roads, doors replace the stoppings previously referred to. Generally two and often three sets of doors are employed, the object of which is to prevent the possibility of all being open at the same time. The main doors which are of a permanent character, should be built in a masonry abutment, carefully made and fitted, and provided with a latch. If tubs travel through the road a guard should be fixed to each door to prevent the tub striking the wood-work; this usually consists of a curved strip of flat iron, bent as shown in plan by Fig. 539. Unless this precaution is taken, sooner or later the door will be damaged, and leakage of air follows.

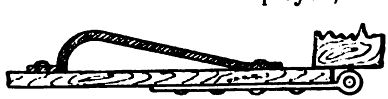
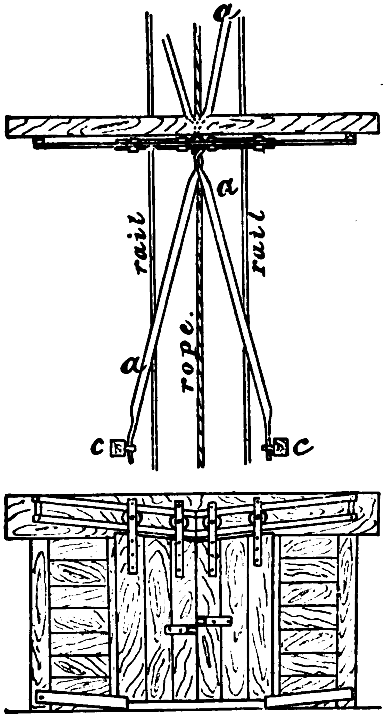
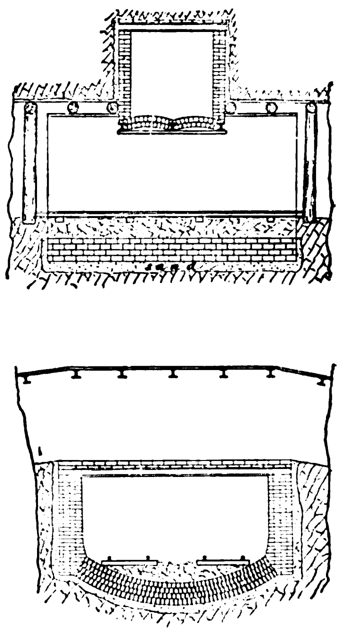


Fig. 539.

Several arrangements have been made for interlocking air doors, so that both cannot be opened at the same time, but are objected to on the ground that some mechanical arrangement has to be set in action before the first door can be passed through. A design adopted at Firminy Colliery* is free from such objection, the doors opening in exactly the same manner as two ordinary doors a small distance apart, except that they cannot both be opened at the same instant. The arrangement is based on the principle of making the opening of one door in the pair, dependent on the penetration of a rod fixed to it, into the recess of a disc moved by the other door, and interlocked with it. This disc is connected by a wire cord with the other door in such a manner that when the latter is opened the disc turns on its



Figs. 540 and 541.



Figs. 542 and 543.

axis, and the curved bolt cannot then pass into the recess normally provided for it. The second door cannot therefore open until the first is shut again. The cost of the complete apparatus is about 28s.

It sometimes happens that doors have to be placed in roads where haulage is carried out by mechanical means, although such practice is by no means to be recommended. Either special boys have to be kept to open and shut these doors at the proper time, or, what is still better, a self-closing door, illustrated in plan and elevation (Figs. 540 and 541), which is adopted at Hetton Colliery, can be used. The door is in two divisions, hung by pulleys travelling on rails, these being arranged at such an inclination that the two halves run together

* *Comp. Rend. Soc. Ind. Min.*, 1897, 33.

by their own weight, and shut close. Hinged to the edge of each half where it meets the other, and about 2 feet from the bottom of the door, is a stout piece of angle steel, *a a*, about 8 feet long, the outer end of which passes through an eye bolt fastened to a tree, *c*, this being placed as near the rails as will only just allow the tub to pass. When a set reaches the door, the first tub encounters the bars, *a*, presses them outwards, and in doing so opens the door, which closes again when the last tub has gone by. As this arrangement is similar on both sides of the door, it is opened equally easily whichever way the set is travelling, and the motion being gradual there is a complete absence of shock, so noticeable when the tubs strike against ordinary doors.

Regulating Doors.—If all the splits are of equal length and the airways of equal area, the same resistance is encountered by each, but as such condition scarcely ever exists, artificial resistance has to be added to regulate the quantity passing in each split to the desired amount. If it were not, the shortest splits would take the largest quantity. This regulation is effected by an opening in a door, such being covered by a sliding shutter, which can be set at any point to give the desired result.

Air Crossings.—In splitting air, one current has to pass over, or under, the other, but it must do so in a separate conduit. This is

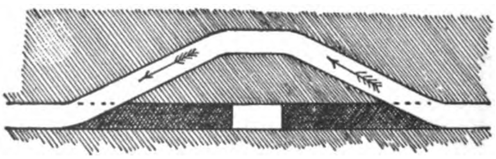


Fig. 544.

effected by what are known as air crossings. A temporary form is to build, where two roads cross each other, a brick wall on each side of the intake current, place two timber bearers on the top, and connect the two walls by planks laid across. The incoming current passes between the walls underneath the planks, while the return air passes over the walls and planks.

This construction results in great loss by leakage, especially if there is any movement in the ground. At Lye Cross pit, crossings are used as illustrated in Figs. 542 and 543. In the intake road an invert of masonry and two side walls are built, girders put across from one to the other and bricked in between with small arches. The return air-way is formed by carrying two walls up to the roof, this being also capped by girders which run at right angles to those previously mentioned. The construction is very solid, but is required on account of the movements in the strata, which, if not prevented, would result in serious leakage.

In fiery mines, should an explosion happen, all stoppings constructed in the ordinary way would be blown down, the two currents intermingled and ventilation entirely suspended. To provide against such contingency, it is often the practice to drive the return air-way some considerable distance above the intake (Fig. 544).

Loss in Circulation.—By the aid of stoppings, doors, and air crossings the currents are regulated and made to follow certain paths at will, in order that ventilation shall be carried into the workings and perform its mission. The greatest care must be taken to reduce leakage through cross-roads, but in spite of all precautions only a portion of the air that passes through the down-cast shaft reaches the working face. It is difficult to believe how small this portion is, but the following example given by Mr. Henry Palmer* may be quoted, showing the great loss. A ventilating current was measured at several places during its passage from the down-cast shaft to the workings. It is stated that the doors in the seam in question were well fitting and double, and that the stoppings were made as solid as possible, and well stowed. The first measurement was taken 140 yards from the shaft, and the quantity found to be 16,650 cubic feet per minute. At 805 yards from the shaft the quantity was 12,550 cubic feet; about this point a split of 3140 cubic feet passed away to ventilate an engine and travelling road. At 1470 yards from the shaft the quantity was 7700 cubic feet, and immediately after this point a second split of 3510 cubic feet passed away to ventilate another district. At the face of the workings, 2200 yards from the shaft, the quantity was 1560 cubic feet.

It will, therefore, be seen that while 16,650 cubic feet left the shaft, only 1560 cubic feet reached the face. From the initial quantity, however, the two splits alluded to, must be deducted—viz., 3140 and 3510, making a total of 6650 cubic feet. Deducting this from 16,650 leaves 10,000 cubic feet, and a very simple calculation will show, that no less than 84·4 per cent. of the air current was lost in its passage from the shaft to the working face.

MEASUREMENT OF AIR CURRENTS.—In order to determine the quantity of air passing, the velocity has to be ascertained. This, multiplied by the area in square feet at the point of observation, gives the quantity of cubic feet of air. The velocity may be determined by several methods, only two of which need, however, be considered.

In the first, some light body, such as smoke, is employed, and the time it takes to travel a measured distance noted. Even when exercising the greatest care, the results obtained are not exact, although near approximations are given. If the road is of uniform area, some definite quantity, such as 1 cubic inch of gunpowder, should be always employed.

Anemometers.—At the present time the invariable practice is to employ what are called anemometers for measuring the velocity of the air current. The common form is known as Biram's (Fig. 545), which consists of a series of vanes, *a*, placed obliquely to the axis like the sails of a windmill. An indicator, or counter, is placed in the centre. The axis of the vanes carries an endless screw, which gears into a wheel, to which a pointer is connected. Another form much used is Casartelli's, which is very similar to Biram's, but is usually made with five dials, registering units, hundreds, thousands, &c., and, in addition, a small lever or stop is provided, by means of which the counting mechanism can be thrown in and out of gear.

With the two anemometers just described the velocity is measured by holding them in the air current for a certain length of time, and noting the number of revolutions. This means that two persons are required, as one man cannot hold a watch, anemometer, and lamp

* *Brit. Soc. Min. Stud.*, xi., 46.

with two hands. Davis's self-timing anemometer dispenses with the use of a watch altogether, and registers at once the velocity in feet per second, and not the number of revolutions of the vanes. In taking observations the instrument (Fig. 546), is held out at arm's length for a short time until the vanes are travelling at full speed due to the air current, a small button, *a*, is pressed, and the pointer turns to the speed, and is kept there by a locking arrangement. Each instrument being graduated by experiment, no allowances have to be made. To return the pointer to zero, the small milled head, *b*, is screwed down until *a* is released, when as soon as *b* is unscrewed, the pointer turns to zero, and the instrument is ready to take another observation. Two graduated circles are provided, and a pointer, *c*, travelling in a small dial, informs the observer which one to read.

Messrs. Davis & Son have also introduced a new form of anemometer for measuring currents of high velocity (over 20 feet per second). It is called the "Capell-Davis," as the vanes are shaped like those of the Capell fan. It differs from anemometers on the

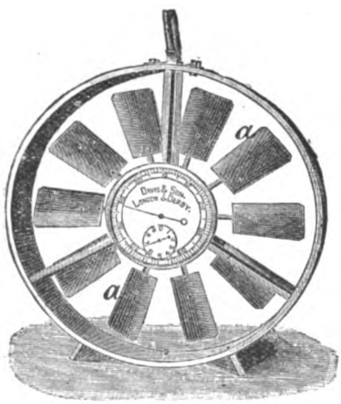


Fig. 545.

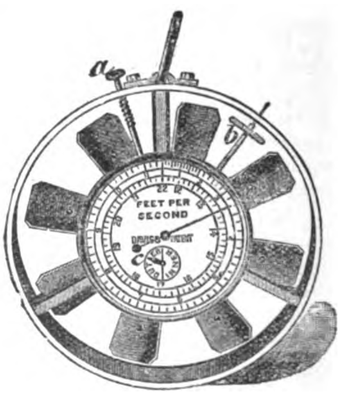


Fig. 546.

Biram principle in having the vanes rigidly attached to a blank disc. As a result, the wind pressure bears equally on the whole surface, whereas in the old construction it might impinge on one vane more than another and distort one of the delicate arms.

Messrs. Atkinson and Daglish* conducted a series of experiments with anemometers, and determined that they all required correction, to bring the velocity they recorded to the true velocity at which the air is travelling. The true velocity may be determined by the formula,

$$v = a\text{R} \times b$$

where *a* is a constant proportional to the number of linear feet travelled by the air per revolution, R is the number of revolutions registered by the anemometer, and *b* the losses of velocity due to friction of machine, this loss being determined experimentally by a whirling machine.

Instead of this formula, the correction is usually made by adding numbers, which are supplied by the makers, and vary for every

* *N. E. I.*, x., 207.

instrument and for different velocities. Anemometers are necessarily of very light and fragile construction, and easily get out of order. It, therefore, becomes necessary if accuracy is desired, that they should be tested from time to time.

In order to obtain trustworthy results, the places of measurement must be of uniform section and preferably divided, by a series of horizontal and vertical strings, into a number of equal parts (Fig. 547), and the anemometer placed in each for a certain length of time. If a disengaging gear is applied to the instrument, it should be placed in the current, and allowed to attain the full velocity before throwing the mechanism into gear. For very accurate results the observations should be taken in each division. Mr. Murgue, however, states that the ratio between the mean velocity and the velocity at any given point in the same section remains constant, whatever variations there are in the mean velocity. It is only necessary, therefore, to find the ratio between the mean velocity, and the velocity of air at any one convenient point, and in future merely measure the velocity at that point.

For all ordinary purposes, the velocity can be determined by holding the anemometer out at arm's length and moving it slowly over the section of the gallery, following the course indicated by the dotted line in Fig. 548.

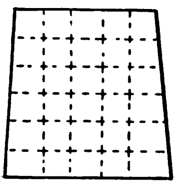


Fig. 547.

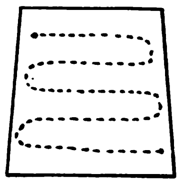


Fig. 548.

Barometer and Thermometer.—At every mine a barometer and thermometer have to be placed. The former indicates the pressure of the atmosphere, and as the volume of air varies inversely as the pressure, the rise or fall in the barometer influences the volume of air in the mine. It is also contended that if the barometer falls, a certain amount of pressure is taken off the face of the strata, and that the gases contained in the coal are more freely liberated, or, that any accumulations contained in old goaves may be liberated. There does not appear to be much ground for this assertion, as the gas in coal exists under such a pressure that the small variations occasioned by difference in height of the barometer are unappreciable. In addition, a barometer is by no means delicate enough to act as a forewarning instrument; since such a light substance as air or gas would be affected long before any indication of change is given by a mercury column.

The indications of the thermometer are valuable, as they point out the expansion in the air current; for, as the volume varies directly as the temperature, a rise means that a smaller weight or quantity of air will enter into the mine in a given time.

Water Gauges.—For measuring the pressure producing ventilation, water gauges are employed. A cubic foot of water at 62° F. under 30 inches barometrical pressure, weighs 62·355 lbs., so that the pressure per square foot due to each inch in height is consequently $\frac{62 \cdot 355}{12} = 5 \cdot 196$ lbs., but in ordinary calculations it is usual to take one inch of water gauge as being equal to a pressure of 5·2 lbs. The ordinary form consists of an open-ended U-shaped tube, containing a small quantity of water; one end remains open to the atmosphere, and the other is placed in communication with the return air-way of the mine. As the pressure of air inside the mine is smaller than that outside, the weight of the atmosphere depresses the column in one leg of the tube and raises it in the other. The difference in height is measured by a movable scale, graduated in inches, and indicates the pressure producing ventilation. The shape of the legs of the tube or any irregularity of section is immaterial, because the pressure of a column of water is dependent only on the vertical height.

The variations in the pressure which are constantly going on with centrifugal ventilators cause considerable oscillation of the liquid in the tubes, and, in addition, capillary attraction causes the surface of the water to take a curved line. It is, therefore, difficult to take accurate observations with the ordinary water gauge. The author has adopted a form (Fig. 549), the design of which is due to Messrs. Atkinson and Daglish. In it the two tubes are replaced by two large compartments, *a* and *b*, having sheet glass in front. These are connected by a very small copper tube, *c*, in the centre of which is a three-way cock. One compartment is closely sealed, and connected by means of a pipe, *d*, with the fan drift, while the other is open to the atmosphere. Owing to each compartment being of large area while the connection between the two is very small, the column of the water remains quite steady and capillary attraction is not noticeable. A movable scale serves to determine the difference in level.

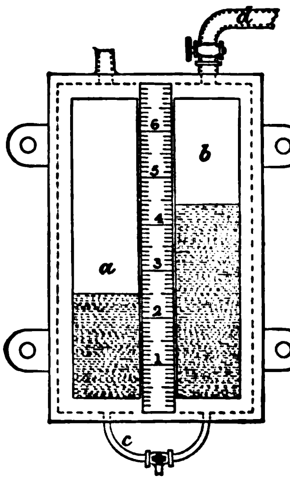


Fig. 549.

Considerable difference of opinion exists as to the proper position to take the water gauge at, and in which direction the end of the tube should be placed respecting the current. The English Fan Commission take the gauge 6 feet from the entrance to the fan inlet. This appears to be open to the objection, where small high-speed fans are used, that the eddies produced by rapid revolution are likely to give false results so near the machine. The general opinion is that the end of the pipe going to the water gauge should be placed at right angles to the air current and preferably covered loosely with a roll of felt plugged at the top with wood, to cause the air to pass through the cloth (Fig. 550).

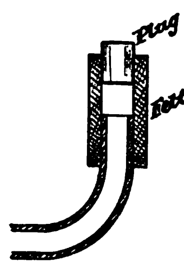


Fig. 550.

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CHAPTER XI.

LIGHTING.

Naked Lights.—The original and most successful method of lighting the miner at his work was to employ the ordinary tallow candle, or small oil-lamp. The illumination given is far better than that of any enclosed lamps; indeed, naked lights are so superior in this respect, that the inducement to use them sometimes oversteps discretion. In some mines, fire-damp is found in small quantities, and through using naked lights accidents happen at rare intervals. To secure the maximum safety the enclosed type of lamp should be adopted, but it is an open question whether, owing to the smaller amount of light yielded, the increase of the number of accidents from falls of the roof and sides will not more than counterbalance those due to explosions, because even with safety lamps absolute security is not obtainable. Miners much prefer working at collieries where naked lights are used.

Ordinary tallow candles of 16 or 18 to the lb., of the proper hardness to withstand the heat of the mine, are the common illuminant in non-fiery seams. They are usually stuck in a ball of clay, which allows them to be attached to timber or coal in any required position. In Scotland a small oil-lamp is very largely employed. It gives a good light and can be carried about easily, but cannot be attached to the timber or sides in the same ready way that a candle can.

SAFETY LAMPS.—At the beginning of this century so many accidents took place through the employment of naked lights, that an attempt was made to devise some arrangement for insulating the flame of a lamp, and for preventing it from producing an explosion in the surrounding atmosphere.

Davy's Invention.—Perhaps what might be called the first safety lamp was that invented by Dr. Clanny, in which a current of air was passed into a lamp through a stratum of water below, while the products of combustion escaped through a similar layer of water at the top; but to Sir Humphry Davy belongs the credit of not only designing the first safety lamp in a practical form, but also of discovering the principle which is still retained, and which forms the main element of security in every modern safety lamp. He found that an explosion would not pass through small apertures and tubes, and before the close of the year 1815 gave to the world a wire-gauze lamp. The Davy lamp (Fig. 551 *), as originally and still constructed, consists of a cylindrical gauze, *a*, screwed to a brass ring, which, in its turn, is attached to the oil vessel, *b*. The gauze is protected from accidental blows by three iron pillars, *c*, passing upwards from the brass base

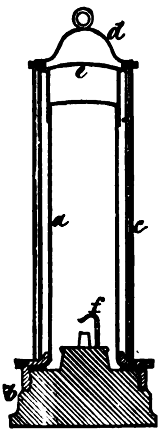
* **In all the lamp illustrations, the various parts are shown thus:—**

Glass ▨ *Brass* ▨ *Thin Sheet Metal* —— *Gauze* ——

to an annular ring at the top, to which is further attached a metal cap or hood, *d*, above which a loop is placed to enable the lamp to be carried about. As an additional security a second cylinder of gauze is attached at the top of the first one forming a cap, *e*. To trim the wick and to regulate its height without opening the lamp, a thin piece of wire, *f*, called a "pricker," passes up a closely fitting tube through the oil vessel. The gauze should not contain less than 784 apertures to the square inch.

Clanny.—In this lamp a portion of the gauze of the Davy is replaced by a glass cylinder, *a*, protected by metal bars, *b* (Fig. 552). The other arrangements are similar to the Davy. The feed-air which supplies the flame has to enter the lamp above the glass, and hence gets mixed with the products of combustion, the result being that the light afforded is very little superior to the Davy.

Stephenson.—The celebrated engineer, George Stephenson, then at Killingworth Colliery, was experimenting upon safety lamps simultaneously with Sir Humphry Davy, and indeed constructed



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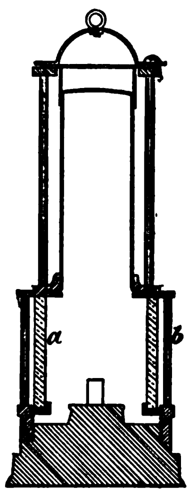

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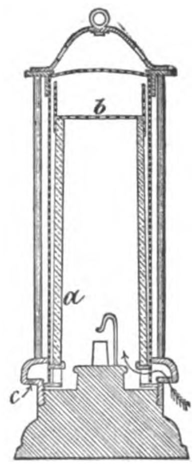

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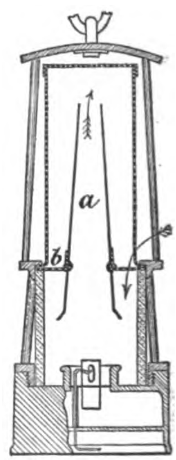


Fig. 554.

one where the ingoing current was passed through small tubes. As soon as the wire gauze was proposed, he adopted it in his lamp, which then took the form shown in Fig. 553. A cylinder of glass, *a*, is placed inside the wire gauze, and is covered over by a perforated copper cap, *b*. The feed-air is admitted through a number of small perforations, *c*, below the bottom of the wire gauze and glass cylinder. If the lamp is to burn well, it is very necessary that these small perforations should be kept free from dust, which is rather a difficult matter.

Mueseler.—This lamp resembles the Clanny, as it consists of a glass cylinder at the bottom and a wire gauze one above, but its main feature is the introduction of a central metal chimney, *a*, supported by a horizontal gauze diaphragm, *b*, placed at the top of the glass (Fig. 554). The products of combustion pass up the chimney and induce a strong draught so that the feed-air is drawn smartly down on to the flame, and produces good combustion. This lamp, by a Royal Edict in 1876, is alone permitted to be used in the fiery collieries of Belgium, and only three modifications of a typical form are allowed. The total height of the chimney must be 4·6 inches, it has to have 3·55 inches of its height above the gauze diaphragm, and its base must be 0·85 inch above the top of the wick tube.

Design of Lamps.—The modifications introduced into safety lamps have all been with a view of rendering them safer in currents travelling at high velocities. Davy himself pointed out that his lamp should be guarded by a shield when exposed to a rapid current of explosive air, as if not, the flame would be forced through the gauze. The safety is due also to the fact that the small holes offer such a large extent of cooling surface, that when the flame impinges on the gauze, the heat is conveyed away so rapidly and the temperature so reduced, that flame cannot pass from one side to the other. If the gauze becomes hot, it loses its power of isolating flame, and hence it is most important that the gases should not be allowed to continue burning in the lamp, or they will inevitably ignite the external atmosphere.

Experiments made in Great Britain and abroad, determined that the Davy lamp would pass flame if exposed to a current having a velocity of 8 feet a second, and that none of the other lamps just described were safe if the velocity exceeded 12 feet a second, with the exception perhaps of the Mueseler, which has a slightly higher limit, if the current meets the lamp horizontally, but it passes flame far more readily than the others, if the current strikes it obliquely. Although this danger was often pointed out, no official action was taken in the matter until the British Royal Commission on Accidents in Mines reported that such was the case, and the result of which is that the Coal Mines Regulation Act, 1887, contains a clause (General Rule 9) which practically prohibits the use of the lamps just described in the form illustrated. At the same time, such lamps form the basis of all the modern ones, but the latter are safeguarded by the addition of shields.

It should, however, be pointed out that something more is needed in a safety lamp than the fact that it is safe in explosive currents of high velocity. Experiments at the surface are carried out with lamps perfectly clean; the experimenter's hands are in the same condition, the currents to which they are exposed are of high velocity, and are composed of fresh air mixed with gas, while coal-dust is conspicuous by its absence. Underground, the conditions are essentially different; no matter how high the velocity is in the gate-roads, it is considerably reduced when it passes into the working place; powder smoke hangs about, and small quantities of carbonic acid gas are mixed with the air current. From the nature of his avocation, the miner's hands are by no means clean, he handles lamps in a rather rough-and-ready style, with the result that dirt and grease are transferred to them. Coal-dust also clogs the inlet holes and gauze. It therefore follows that the behaviour of some of the modern types of safety lamps after they have been some hours underground, and in the return air current, is not what one would desire. This, however, is exactly what might be expected from the nature of the conditions which the lamps are constructed to withstand. In order to be safe in the highest velocity of air current, they must be enclosed in one or two shields, and the inlet area for feed-air must be reduced to the smallest dimensions. So long as they are clean, and remain in a strong current, the requisite amount of air for proper combustion is delivered to the flame, but when the velocity is small and the lamp gets dirty, or is used in impure currents, the light given is of a very inferior character.

Another point of considerable importance is that demonstrated by Mr. Marsaut,* and confirmed by several other observers, that every type of lamp facilitates more or less easily the passage of flame resulting from an internal explosion. It is necessary that a certain relation should exist between the volume contained in a lamp and the surface open for the escape of the products of combustion resulting from the internal explosion, as experiments proved that exterior explosions or the ignition of the mixture outside the lamp were more rare as the open surface of the gauze was enlarged.

Mr. Marsaut proved that—(1) A small diameter lamp (such as a Davy) does not readily pass an explosion, as the volume susceptible to explosion is insignificant. (2) A lamp without a glass is more secure against the effects of internal explosions than a lamp with a glass cylinder, as the glass in the lamp confines the gases there at the time of an explosion and acts like a cannon; it is therefore both advisable to reduce the height and diameter of the glass. (3) A wire gauze of conical shape of the same capacity is more secure against the transmission of internal explosion than is one of cylindrical shape. (4) Gases resulting from combustion play a certain part in preventing external explosions, and it might therefore not be advisable to guide them by a chimney. (5) A descending current of feed-air prevents the filling up of glass lamps with an explosive mixture, and occasions the formation of an unexplosive and elastic cushion at the bottom of the lamp.

MODERN LAMPS.—In describing some typical forms of lamps, the remarks concerning them must be taken as applying to their behaviour in practical working underground. Only such lamps are referred to as have been proved by numerous experiments to be safe in all velocities which ordinarily occur in coal mines. As previously stated, this is not the only point required in a lamp. Knowing them to be safe, the great thing is to select some form which will keep burning all through the length of a shift, and which will also detect gas in small quantities quickly and distinctly.

Hepplewhite-Gray.—The Report of the British Royal Commission on Accidents in Mines first drew attention to the original form of this type. The lamp then reported on so favourably is so different in construction to its modern representative that the drawing of it is reproduced in Fig. 555, with a view of clearly showing the successive developments which have taken place. Its chief peculiarity (and in which it differs from other modern safety lamps) is the admission of free air from the top down four tubes, and through an annular chamber, *b*, situated immediately over the oil vessel. It is impossible for a current to rush directly down the inlet tubes, as they are protected by the projecting top of the lamp. The only gauze employed is that covering the outlet, *c*, and the annular inlet chamber. The first improvement consisted in introducing a gauze cylinder above the glass, which now took a conical form, and adding a cone to the discharge orifice. The importance of the latter cannot

* *Soc. Ind. Min.* (2ᵉ Série), xii., 321; translation in *Ches. Inst.*, xii., 179.

be over-estimated. The outlet arrangements of most lamps are haphazard, and bear no relative proportion to the area of inlet. With the discharge regulated in such a manner the top of the gauze is kept in a bath of carbonic acid gas, and should internal explosions occur, gas will not continue burning in the lamp. Sliding shutters were also placed at the lower ends of two tubes, by which means the feed-air could either be taken from the top or the base of the tubes, an improvement properly appreciated by any one regularly testing for gas.

In the form now generally adopted, three inlet tubes instead of four are used (Fig. 556). The third tube is considerably broader than

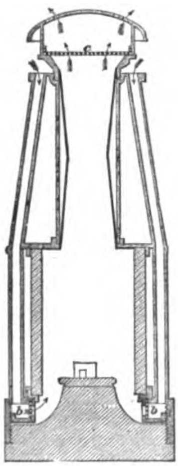


Fig. 555.

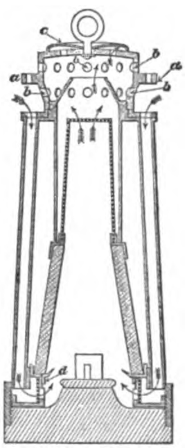


Fig. 556.

the others, and acts as a reflector. The shield-plate, *a*, in the hood is made of such a size as to completely cover the inlet holes. This is an important point, as it was found that if such was not done the lamps were often extinguished in an unaccountable manner. The height of the outlet cone must be such as to just reach the level of the shield-plate, when it then occupies a position intermediate between the two horizontal rings of holes, *b b*, which are placed in the hood for the products of combustion to escape by. A row of circular holes is put in the top crown of the lamp, and is covered by a thin sheet brass plate $1\frac{5}{8}$ inches diameter. To stiffen the covering plate it is crimped in three places, the crimped parts touching the crown, as shown at *c*. These improvements remove the defect of the light being suddenly extinguished from no apparent cause.

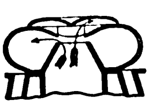


Fig. 557.

The same result is obtained with the form of hood shown in Fig. 557; here the outlet cone and inlet tubes are covered by a piece of brass bent into the shape illustrated. One hole, $\frac{1}{2}$ inch in diameter, serves for the escape of the products of combustion, this being protected from direct currents by a piece of sheet brass crimped as before mentioned. This shape of hood scarcely appears of such a safe character as the former one, but a large number of lamps have been constructed to this design. Another improvement which facilitates cleaning is that the ring securing the glass in position is screwed on to the vertical plate forming the air inlet chamber, *d* (Fig. 556), instead of the frame of the lamp.

It follows from this that when the lower gauze ring is unscrewed all the inside parts of the lamp at once fall out.

In the lamp of latest design the portion of oil vessel supporting the wick tube has been lowered, but the wick tube itself has been lengthened, so that the flame is only slightly lower than in the old types. The breadth of the wick has been increased, and now stands at $\frac{9}{16}$ inches full.

The numerous small improvements, which may not separately seem of much importance, but which in conjunction materially affect the practical working, certainly make the present design superior to the earlier ones. Taking first its lighting capacity; under ordinary conditions it gives more useful illumination than any other lamp. Photometric tests conducted at the surface are misleading, for the same reasons as were referred to when dealing with velocity trials. In addition, one other fact must be pointed out. With the photometer, either when testing against another lamp or against a standard candle, the two articles are placed on the same level, and it is the horizontal rays, or those that are nearly so, which reach the screen and decide the result. Collieries require light to be thrown in all directions, especially upwards, and hence naked lights are often used under conditions which may at any time become dangerous. They are not actually unsafe, but no one can say whether they may become so. All ordinary shielded lamps suffer from the great disadvantage of giving practically no illumination on the roof. Their shields are necessarily of larger diameter than the glass, and really act like a shade, preventing any light striking upwards. The conical glass of the Hepplewhite-Gray performs just the contrary action, as it deflects the light towards the roof, and as the shield above is of smaller diameter than the lower part of the glass, nothing prevents the rays reaching the place where they are specially useful and desirable. The examination of the roof can be rapidly and satisfactorily carried out with this lamp, as the illumination given is far superior in that direction to any other design. Ordinary lamps must be tilted, and when in that position the light obtained is of a very inferior character.

With respect to its power to detect small quantities of gas it ranks superior to all others.* All ordinary forms, with the inlet above the glass, will miss, say, 4 inches of gas lying immediately against the roof, except when they are tilted very much, and then there is great danger of their going out. Many lamps are now constructed to take air if desirable from the top, like the Gray, and then they will detect thin layers also; but even then they will not do so *rapidly*. It is possible to put some modern lamps into gas, and take them out again without any indication being given—that is to say, if it is done hurriedly. This is quite impossible with the Gray, as the flame immediately "spires" up. In comparison with the unbonneted Davy or Clanny it readily shows a cap on the flame where those lamps fail to show the slighest indication.

Numerous experiments have proved the safety of this type in currents

* As the Pieler lamp cannot be used in ordinary every-day working it is not taken into consideration.

of high velocity. The risk of internal explosions passing outwards is practically absent, owing to the small quantity contained in the lamp, the regulation of the outlet of the products of combustion, and the conditions under which feed air is introduced. Theoretically an internal explosion is impossible, as owing to the admission being below the flame, any fire-damp is burnt as it arrives, and the inside of the lamp is filled entirely with the products of combustion; but this, however, is not absolutely the case.

A statement was once made to the author that this lamp went out so soon when introduced into gas that it was impossible to clearly ascertain whether such gas was fire-damp or black-damp, if only small quantities were present. On the other hand, he has been assured by an ovreman, who has specially been working and examining places with this lamp for over twelve months, that not the slightest difficulty has been experienced in this respect. With black-damp the flame drops and fades away, but if any gas is present, a slight "spiring" of the flame is immediately noticed, and this takes place once or twice before the light is lost. Of course it is possible to abuse anything. If the lamp be pushed bodily and suddenly into gas it certainly goes out before any definite indication is obtained; but if it be introduced slowly and steadily, and withdrawn as soon as gas is indicated, the light is not often lost.

Bonneted Mueseler.—This type of lamp has deservedly been held in good repute for many years, and the report of the Mines Accidents Commission on the shielded variety was very favourable. As a detector of gas it ranks a very good second to the Gray; it shows gas in a clear delicate manner, the cap produced being very distinct.

Owing to the presence of a chimney in this lamp, when it is tilted the products of combustion pass outside the chimney and foul the inlet air, with the consequent result that the light is extinguished. This, in combination with the shield acting as a shade, make the examination of the roof a matter of difficulty. This disadvantage of the Mueseler lamp appears to have been rather exaggerated, as it stands a fair amount of tilting, especially if the time during which this is done be not of long duration.

Ashworth's Mueseler, shown in Fig. 558, is one of the safest of all lamps, as it has been tested in explosive currents of 100 feet per second without failure. It differs from the ordinary forms of Mueseler type in having a gauze chimney instead of a metal one, and the diaphragm is conical instead of horizontal, *b*. Its safety is due to the double shield employed, the inner one of which is provided with a conical outlet; the exit of the products of combustion is retarded; the upper part of the gauzes is kept in a bath of carbonic acid gas, and in case of any internal explosion, the light is immediately extinguished and the inlet air fouled. The arrows in the figure show the direction taken by the supply air and the products of combustion, and that the gauzes are protected from all violent currents. There are ten holes in the inside shield and seven in the outer one, the latter being placed near the top. A gas-testing shutter, *a*, is placed above the horizontal inlet holes near the top of the glass, and when this is closed, the feed-air is compelled to enter through the holes in the outer shield near the top and pass downwards, thin layers of gas near the roof being thereby easily detected.

This lamp does not burn well in "dampy" or slow currents, and great difficulty is experienced in lighting it, as from the winding path pursued by the feed-air, proper circulation does not take place until the lamp gets hot.

Morgan.—Prominent attention was drawn to this lamp immediately after the report of the Accidents in Mines Commission was published. Experiments showed that it would not pass flame in explosive currents of the highest velocities.

An inner and outer shield are provided (Fig. 559), the latter having a series of five horizontal rows of circular holes punched through it, while the former is similarly supplied with six horizontal rows of slits. The openings in one shield are opposite the solid portions of the other. Three gauzes are used; an outer cylindrical one without a top, a middle one of the Clanny type, and an inner one, really built up of two gauzes and a chimney.

This lamp detects gas readily, burns well in a good current of air, but badly in a "dampy" one, does not get hot (probably owing to its large internal volume), and stands a fair amount of tilting without the light being extinguished. After being in use several hours underground, the light gets very defective. This type has not been used extensively at any colliery. It is composed of six parts, neglecting washers, and is of complicated construction. As there are so many lamps of simpler design which are perfectly safe under ordinary conditions it is unlikely that this form will come into general use.

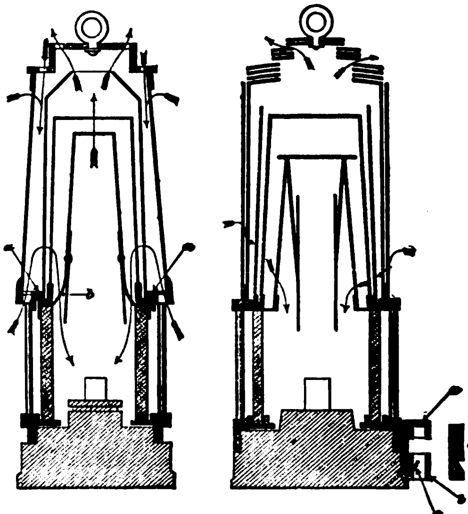


Fig. 558. Fig. 559.

Marsaut.—The report of the Committee of the Ellis Lever Prize, and of the Accidents in Mines Commission brought this, then new, lamp very prominently before the mining public, and results obtained in practical use increased the favourable opinion. It has, however, received a few small modifications from the form in which it was experimented upon by the two Commissions referred to above. As originally constructed, *two* rows of inlet holes were supplied, one at the bottom of the bonnet, *a* (Fig. 560), and the other in the horizontal flange, *b*, forming the base of this part. The Accidents in Mines Commission recommended doing away with the holes in the base of the bonnet,* and in most of the lamps now constructed in this country this is carried out. In the form illustrated, three slightly conical

* *Final Report*, p. 84.

gauzes are employed, but often two only are used. They are protected by a sheet-iron shield. After considerable experience with this lamp, the author expressed an opinion that it appeared to be the most suitable for the working miner; its construction was simple and strong, and it gave a reliable indication of gas, and a good light.

Further experience has not materially altered that opinion, as, although the lamp finding most favour does not go by Mr. Marsaut's name, yet it is practically a lamp of his type, with an addition which increases its efficiency and lighting power in the impure currents of return air-ways.

Deflector.— During an excursion in Lancashire, the author's attention was called to this lamp, and as complaints had been made of the difficulty in getting some of the other forms to burn brightly, a few lamps of this type were obtained and placed in the hands of the miners at one of the collieries under his charge.

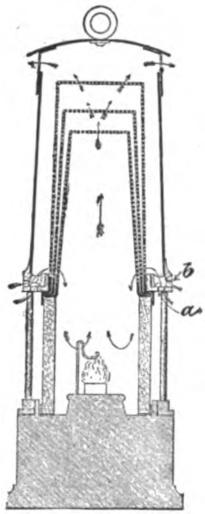


Fig. 560.

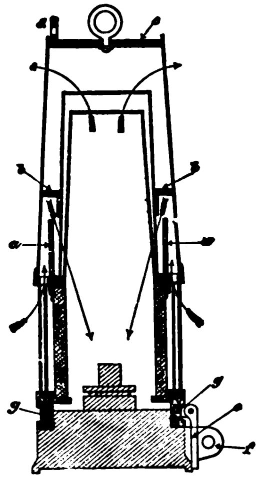


Fig. 561.

Fig. 561 illustrates the lamp, and it will be seen that the Marsaut is followed, so far as the arrangement of gauzes, shield, oil vessel, and glass are concerned. The distinctive difference, however, consists in the guiding of the inlet air; this is admitted through a row of holes in the horizontal flange, supporting the shield, and is prevented from impinging on the gauze by a vertical cylinder of brass, *a*, 1¼ inches high, which acts as a guide, and directs the in-going current vertically upwards. At a point about 1½ inches above the horizontal flange supporting the shield, an angle-ring, *b*, is introduced, the horizontal part of which completely fills up the space between the outside gauze and the inside of the shield. The other flange projects downwards close against the gauze, terminating just before reaching the vertical cylinder which proceeds from the horizontal flange forming the base of the shield. It will be noticed that the vertical cylinder, *a*, is not placed close to the gauze, but occupies an intermediate position between that part and the shield.

The inlet air after being directed upwards meets this "deflector," and is thus thrown on to the flame. As the lamp gets hot, more air is sucked in, and passed on to support combustion. This forms the explanation why such good illumination is obtained. At the end of a shift the light given is nearly as good as it was at the beginning. After burning a short time and getting hot, the illuminating power sensibly increases, and no difficulty is experienced in lighting the lamp when all the parts are cold.

In all ordinary lamps a rapid circulation is obtained as soon as the parts get hot, but no appliances are introduced to properly direct the inlet current, and, as a result, the greater part passes away at once with the products of combustion, only a portion going downwards to supply the flame. In the "Deflector," all the air which enters reaches the flame, and before doing so is heated by contact with the warm deflecting ring and gauzes. To this heating of inlet air and proper directing of current is due the fact that this lamp will burn in an air containing such a quantity of carbonic acid gas that all ordinary forms, even unbonneted ones, are extinguished.

The lamp is supplied with a solid top, *c*, and the shield is secured by a lead rivet, *d*. This is an advantage, as the locking of the bonnet can be left to the last minute, and until the miner has satisfied himself that all the parts are in their proper position.

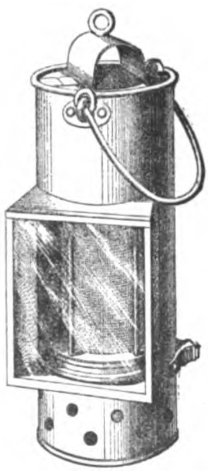


Fig. 562.

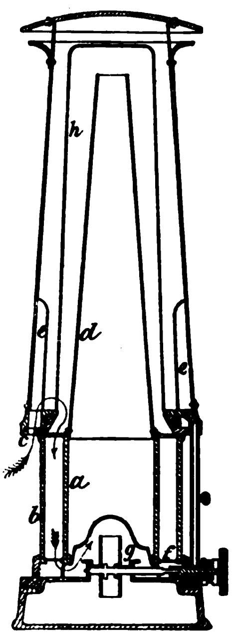


Fig. 563.

Tin Can Davy.—In the North of England the ordinary Davy is enclosed in a tin case, provided with a window (Fig. 562). If this case extends the entire height of the lamp, the security afforded is greatly increased. Indeed, the British Royal Commission on Accidents in Mines* stated that the addition caused the lamp to become one of the safest tested, but they also point out that at high velocities a very small difference in the form of the case, or in the position of the lamp with respect to the current, greatly affects the behaviour of the lamp.

Thorneburry.—A lamp which attracted considerable attention was that invented by Dr. Thorne, in which a heavy petroleum oil, having a flashing point of 250°, is burnt in a cone similar to those employed in paraffin lamps (Fig. 563). Two concentric glasses, *a* and *b*, are employed, which are not disturbed when the lamp is taken to

* *Final Report*, p. 75.

pieces for cleaning. A metal chimney, *d*, which carries away the products of combustion, leads directly from the inner glass, while the gauze, *h*, leads from the outer glass, and as a further protection in currents in high velocity, a second piece of short gauze, *e*, is attached. The whole is enclosed in a metal shield. The feed-air enters at the point, *c*, passes down between the two glasses, and through the gauze, *f*, into the combustion chamber, *g*.

So far as safety is concerned this lamp gave excellent results, but it had a tendency to get very hot. The fact that it was very complicated, and weighed more than any other lamp, and required more delicate handling than an ordinary miner will give it, led to its disuse.

Sight Lamp.—An improvement of considerable importance has been introduced by the Sight Lamp Company, who employ a shield, having a great number of perforated holes through it, but which has a glass lining especially made for the purpose. In this way the shield does not obstruct the light to anything like the same amount as a solid one does. Breakages are not of frequent occurrence, as the glass is well protected by the perforated shield; there is no space between the metal and glass shield.

Conclusions.—Owing to the large amount of useful light given by the Hepplewhite-Gray, the way this is directed on to the roof, and the delicate indication of gas given by this lamp, it is preferred to all others for use by deputies, firemen, and timberers. It requires however, very careful handling; and the light is easily extinguished even when gas is absent. Men are apt to get careless, and carry it about with the lower slide holes open, and when in that state, if the current impinges suddenly on the lamp, the light is lost. The distribution of light on the roof is due to the truncated cone form of glass, which is claimed to be stronger than a cylindrical one, and to automatically accommodate itself to sudden changes of temperature. The rapidity with which gas is detected is a great point in its favour. With this lamp it is scarcely possible to miss the smallest quantity, even when passing hurriedly from one place to another, which can easily be done with any other form, as, unless there is an appreciable quantity of gas present, they require to be held a definite time in it before any indication is given.

For the ordinary miner who requires something a little less delicate than the Gray, the Deflector lamp gives excellent results. The light given in impure air is superior to that obtained from any other form, and it will continue to burn even when the unbonneted varieties will not. It gives as good an indication of gas as any other lamp, with the exception of the Gray and Mueseler. The author obtained a number of different types of lamps for use at one of the collieries under his charge, and after an experience of two years there was not a miner at the pit who, if he had his choice, would not select a Deflector lamp in preference to any other, his reasons for this being that it burns brightly in slow and impure currents, gives a good light for a long time, and will endure a great deal of rough usage.

Oil.—The report of the British Accidents in Mines Commission first drew attention to the fact that a mixture of one-third petroleum and two-thirds rape or seal oil was more suitable for safety lamps than best refined colza. It is necessary that the petroleum should be of the best quality, and that no more than the quantity given above should be used. The mixture is considerably cheaper than best colza, and gives equal illuminating power, and the wick has not such a tendency to form a hard cake on the top.

Mineral oils are but rarely employed for safety lamps, although attempts have been made from time to time to utilise them for this purpose. Benzoline is used in some of the lamps made by the Protector Company, and by Wolff, of Zwickau, Saxony. It is a volatile substance and requires the greatest care in its application. No free oil is allowed to remain in the oil vessel, which is filled with a sponge, and as the wick itself does not burn an asbestos one is provided. In filling the lamp a small quantity of benzoline is poured into the vessel and the sponge saturated, all excess is then emptied back again into the tanks. It certainly gives a nice clear light and produces no smoke, but requires so many precautions in the filling-room that it has never been largely employed in this country. A special charging apparatus has to be provided, and no naked lights can be introduced into the room where the lamps are replenished. The employment of mineral oil is not allowed in the fiery mines of Belgium.

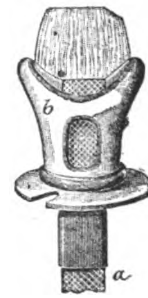


Fig. 564.

Wick.—In the lamps of recent introduction, flat wicks are invariably employed. The illuminating power of the old forms of safety lamps, when the wick was round, varied from 0·3 to 0·5 of a standard candle, but where a flat wick is employed it may rise as high as 0·7. With a view of further improvement Mr. A. H. Stokes has introduced a wick tube which is guttered along one side and the wick is supplied rather wider than the tube, so that it takes a corrugated form. A longer surface of flame is obtained and the supply of the oil to the wick is better. Mr. J. Ashworth obtains a similar result by making the wick wider than the wick tube, and the tube broader than the wick.

The Barton burner (Fig. 564) undoubtedly increases the illuminating power of a lamp. The wick, *a*, is carried up inside a flat porcelain holder with an expanding top shaped to a semi-circle along its upper edges, *b*. This porcelain holder gets hot and vaporises the oil, with the result that the breadth of the flame extends across the whole width of the holder, and is consequently nearly twice the extent of that of the wick.

A point to which little attention has been drawn is the material of which the oil vessel is constructed. In England it is invariably made of brass, while on the Continent of Europe it is just as regularly made of iron. Mr. Marsaut's experiments proved that the lighting power is influenced by the material of which the lamps are constructed, and that a brass lamp only gave 70 per cent. of the luminous intensity of the same lamp in iron. The explanation of this seems to be found in the superior heat conductivity of the former, as the lamp bottom gets very hot and the oil becomes viscous. Brass oil vessels seem to be cheaper than if made of iron, owing to the ease with which they can be cast. To remove the objection Mr. Ashworth coats the top of his oil vessels with a bad conductor of heat (tin).

Glasses.—Glasses having their edges polished are now more extensively used than any other form. It is very important that all gaps should be closed, and therefore the edges must be ground approximately parallel, for if they are chipped, or not parallel, no matter what washers are used, some opening is left. Asbestos millboard washers should always be introduced between the parts where metal and glass meet. Rubber and leather are liable to perish.

Locking Lamps.—The original device employed was that of a screw bolt turned by a key till its head was concealed below the surface of the metal into which it was inserted. This can scarcely be called a lock at all, as it may readily be opened by any one with an old nail.

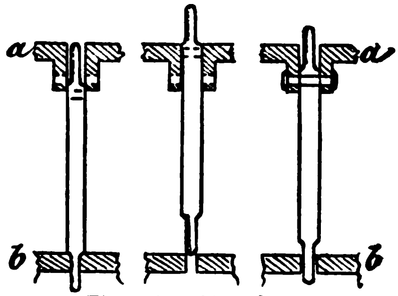
Magnetic Locks.—In several types of lamps a lock has been designed which requires the application of a powerful magnet to open it. The general arrangement consists in employing a bolt which fits into notches in a circular plate and is kept there by a spring. When a magnet is placed in a certain position it attracts the bolt, withdrawing it from the notch, compresses the spring, and allows the oil vessel to be unscrewed. The shape of the spring and notches is such that the magnet is not necessary to enable the bottom to be screwed on.

Lead Rivets.—Magnetic locks possess one advantage, that the lamp cannot be opened without suitable appliances, but they are apt to get out of order and are cumbersome. By far the commonest, and indeed the simplest, method of securing safety lamps is that of employing a pin of lead, which is riveted into place and has a device punched upon it. It is impossible to open the lamp without breaking this pin, and although, of course, any one so desiring can open the lamp, it cannot be done without detection. The common locking arrangement is illustrated in Fig. 561, and is performed by a hasp, *e*, dropping over a projecting boss, *f*, through which a hole is bored for the reception of a lead rivet. The hasp, *e*, is fitted to a loose collar, *g*, surrounding the oil vessel, which can easily be turned round, giving compensation for the wear on the screw and the oil vessel, and enabling the projection, *f*, and the hasp, *e*, to be always brought exactly together.

The locking arrangement of the Morgan lamp possesses several points of novelty. Two projections, one on the oil vessel, the other on the upper part of the lamp, with vertical holes, are provided, *a* and *b* (Fig. 559), but the passage in the upper projection does not go completely through it. A small spring catch, *c*, is situated in the lower projection and will allow a cylinder of equal diameter to the hole to pass by if the direction of motion be vertically upwards. The lead plug employed, *d*, consists of a cylinder with a >-shaped piece cut out. To lock the lamp the cylinder of lead is pushed in through the lower hole; it cannot go out at the top, as the covering prevents it, and it cannot be drawn back again, as the small spring catches under the >. This arrangement seems to be an improvement on the ordinary lead rivet, as time is saved.

Ryder's Lock.—In order to allow the shield to be removed after the internal parts have been fitted together, a sliding pillar is employed, which, when the oil vessel is screwed up, projects into the base of the shield and prevents its being removed, but, on the other hand, when the oil vessel is taken off, the pillar can be pulled down a short distance, thus releasing the shield.

This has recently been improved; it now locks both shield and oil vessel. In Figs. 565 to 567, *a* is the upper horizontal ring of the cage of a lamp on to which the shield is screwed, and *b* is the bottom one that receives the oil vessel. The sliding-bar, *c*, occupies the position shown in Fig. 565 while the shield is being screwed on, and as soon as this is done, the bar is pushed upwards and takes the position illustrated in Fig. 566, locking the shield. The oil vessel is now screwed on and then the sliding bar is *lowered* a little, its bottom end going into a recess in the oil vessel. This motion is not sufficient to take the pin entirely out of the shield, and, as a result, both shield and oil vessel are locked, and the sliding-bar is then secured in this position by a lead rivet (Fig. 567).



Figs. 565, 566, and 567.

Casting Rivets.—A machine largely employed for casting lead rivets, is that of Howat's, which consists of a series of recesses (*c c*, Figs. 568 and 569) of the exact size of the rivet, arranged in a circular manner around central spindles, *d d*, which have a mushroom-shaped head. These spindles can be moved vertically upwards by means of the cross-bar, *e*, and lever, *f*. The top is covered by a lid, *g g*, having holes through it at *h h*. Molten lead is poured in through these holes, and fills up the recesses, *c c*, the lid is lifted off by the handle, *j*, and by depressing the handle, *f*, the bunches of rivets are raised out of their bed. To remove them from the central core to which they are attached, they are placed over a special die, and with one blow of a punch the

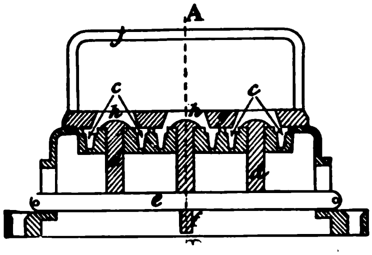


Fig. 568.

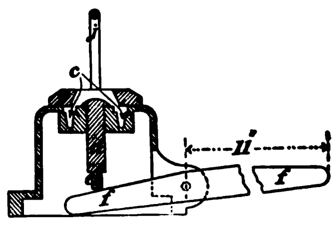


Fig. 569.

central block of lead is detached, and the rivets are left ready for use. Each machine casts three sets of twelve rivets at a time.

Relighting Lamps.—An arrangement is sometimes provided to put out the flame if the lamp be unscrewed, but this affords no security, as it tempts the miner to carry matches about with him to relight the lamp, which may be done without detection. With the Protector lamp, however, by means of a locking bolt, after being once unscrewed the lamp cannot be relighted without unlocking. If the oil vessel (Fig. 570) is withdrawn, the wick passes down the sides of the tube, *a*, and the flame is put out and cannot again be lighted and replaced in position until the tube, *a*, is taken from the lamp and put in its proper position in the oil vessel. The tube, *a*, is locked by the bolt, *b*, which, when pushed home, is kept in position by a small spring.

The number of lamps which become extinguished from different causes in the workings is very great, and amounts, according to statistics, at many collieries to as much as 20 per cent., which have to be either relighted, or other ones served out to the men. The general practice is to provide special lighting stations, and to insist on men taking their lamps to these places when they become extinguished. Such a station must be situated at some point where a naked light is allowable, and as this is often only at or near the pit-bottom, men have to travel a considerable distance when their lights become extinguished, which acts in a very salutary way in causing them to take every precaution to prevent losing their lights. As in some mines naked lights are not allowed at all, a certain number of extra lamps are taken down, which replace those that become extinguished.

Where a volatile illuminant like benzoline is employed, a relighting arrangement can be applied. In the Wolff lamp* a strip of paper is employed, provided with fulminating spots, each of which can be brought opposite the wick by a step movement, and at the same time be struck by a trigger released by a spring; the fulminating compound explodes and ignites the benzoline vapour. The process can be repeated until the whole of the caps are exhausted, when the paper containing them is removed and a fresh piece put in its place.

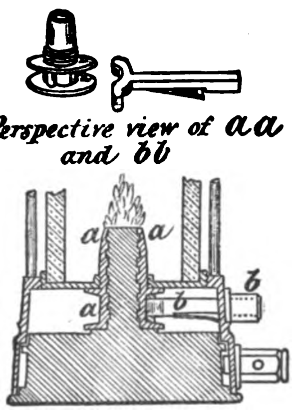


Fig. 570.

A similar device is that of Mr. H. Elsom,† but is applicable to vegetable oil lamps. A small wire rod is fixed in the lamp on the opposite side of the wick trimmer, and carries one or more ordinary matches which can be lighted by friction. When the light is extinguished, one of these matches is rubbed on a roughened plate and ignites, the lamp being tilted so as to bring the wick over the match. A guard plate, or shield, is fixed against the adjacent match to prevent the flame of one accidentally igniting the other.

The objection to any such appliance is that supposing any lamp has been extinguished through the presence of an explosive mixture, when one of the matches was struck, an internal explosion would be produced which might result in the passage of flame to the external atmosphere.

In several lamps which are constructed to burn paraffin oil, relighting can be effected by an electric spark which passes between two terminals carried through the oil vessel. When used underground, the electric current is produced by secondary batteries which are kept at the lamp stations.

* *Man. Geo. Soc.*, xvii., 280. † *Fed. Inst.*, ii., 53.

Cleaning Lamps.—Where a large number of safety lamps are employed they are now generally cleaned by machines, consisting of a series of revolving brushes fitting the several parts. Of this class, Ackroyd and Best's, and Wolstenholme's may be taken as the types. To remove the oil adhering to the gauze, powdered magnesian limestone is generally sprinkled on the brushes. In some cases to obtain a similar result the gauzes are steeped at intervals in a solution of caustic potash.

For removing the internal fittings of lamps, a simple arrangement (Fig. 571) can be employed. It consists of a nut, *a*, which fits into the projecting lugs on the lamp-glass ring, and on turning the handle this ring is unscrewed.

A more elaborate machine is that of Howat's (Fig. 572), which both rivets the lead plugs and unscrews the various parts of the lamps. It consists of a cup, A, containing a number of slots, which can be rotated by turning the handle, B. The lamp bottom can be unscrewed by placing it in the cup, with the projecting boss in one of the slots, and then turning the handle. In order to remove the internal fittings, the cup, A, is taken off, and the lamp placed on a square nut thus ex-

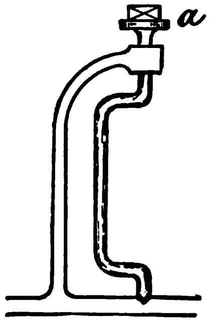


Fig. 571.

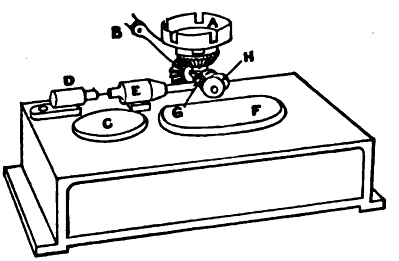


Fig. 572.

posed, which fits into the projecting lugs on the ring securing the lamp glass, &c., in their proper position. A few turns of the handle removes everything, and after cleaning, a reversal of the above operations soon puts the parts together. To rivet, the lamp is placed on the platform, C, with one head of the rivet againt the stop, D, when half a turn of the handle brings the movable bar, E, forward, and locks the lamp. To unlock the lamp, it is placed on the platform, F, with the head of the rivet under the cutter, G, which on being pressed cuts off the rivet. The lamp is then removed, placed at the other end of the platform, F, and the handle, B, reversed when the eccentric block, H, pushes the rivet out.

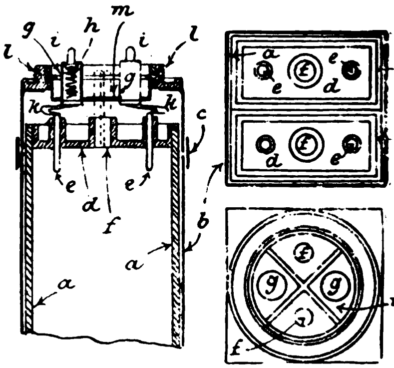
Electric Light Underground.—Many collieries are now provided with the electric light underground, but the system extends only a short distance from the shaft. The ordinary incandescent light, if worked direct from the dynamo, requires two conducting wires to convey the current, and as illumination is specially required in the working places, it seems improbable that the direct system of lighting as is employed on the surface will ever be used underground, except to a limited extent. The working places are naturally moving day by day, falls of roof are common, and as the space is confined, conducting wires would be quite out of place there. There are, however, numerous cases where cables are led along the main roads to electric power plants situated far in-bye, and it is an easy matter to tap these cables at all important haulage junctions, and fit up such places with incandescent electric lights. The author has carried out this procedure at several collieries, and cannot speak too highly of the increased facilities which the extra light affords, for the ready and convenient attachment of the tubs, and the consequent smooth working of such busy places as haulage crossings and junctions.

Secondary Batteries.—By employing what are known as secondary batteries, or accumulators, a charge of electricity can be stored up to be given out as required. These secondary batteries consist of a series of lead plates covered with spongy lead, arranged in cells and surrounded by a solution of dilute sulphuric acid. Various elements are employed, and the cells are arranged differently by several makers, all with a view of reducing weight and increasing efficiency and luminosity. With a lamp weighing about 4 lbs., a light equal to 1 or 1½ standard candles can be produced for about twelve hours. The lamps are charged by connecting them to a dynamo, and passing in a current for from eight to ten hours, or for such a length of time as is necessary. It generally takes as long to charge as to uncharge. The lamp itself is a small incandescent one, and the light can be turned on and off by a switch.

Accumulators require constant care, even when made of large size, and still more is this the case when they are of small dimensions. During the progress of discharging and re-charging, gas is given off by the cells, and it is, therefore, impossible to hermetically seal them. A small hole has to be left for the escape of this gas, and as the cells contain a liquid, this liquid also escapes, and being an acid, attacks the connections and eats them away; sooner or later short-circuiting results. There is also considerable difficulty in determining when the cells are charged; they often appear to be so, and yet after taking the lamp underground, the light goes out in a few hours.

Sussman Lamp.—This construction is regarded with considerable favour for its nearly dry accumulator suppresses some drawbacks with which its predecessors were reproached. Its electrolyte consists of paper paste impregnated with sulphuric acid, into which extend the lead plates of the elements, which possess a high degree of porosity and at the same time considerable adhesive property, consequently allowing from a given superficial area a discharge said to be equal to double that obtainable from an ordinary battery. Each accumulator comprises two elements connected in tension, formed of three lead plates, one positive and two negative, enclosed in a case divided into two compartments. The whole is covered with a thick layer of insulating material, only allowing the projection of the two terminals and two small holes closed by plugs, the latter permitting of the introduction of the dilute acid in quantity sufficient only for the moistening of the electrolyte, and for the disengagement of the vapours due to the reaction.

Nearly 2000 of an improved construction of this lamp are in use at the Bracquegnies Colliery, Belgium,* where flexible couplings have been substituted for rigid ones as far as practicable. The two cells of the accumulator are contained in indiarubber receptacles (*a a*, Figs. 573, 574, and 575) enclosed in a tin case, *b*, cut in two towards the top, the two parts being joined together after the accumulator is put in place by the strip of tinplate, *c*, soldered over the joint. The receptacles, *a a*, are closed by flexible indiarubber covers, *d d*, with raised cups for receiving the connections, *e e*, and also tubes, *f f*, for allowing gas to escape. The incandescent light is separate from the accumulator cells and screws on to them by the thread, *e e*. The current is conveyed from the cells to the lamp by the spiral spring, *h*, soldered, on the one hand, to one of the nipples, *i i*, and on the other to the flexible conducting wires, *k k*, which connect them with the accumulator poles, *e e*. The springs are enclosed in two small brass tubes, *g g*, which guide them and keep them in the fixed support, *m*. When the accumulator portion is screwed into the glass carrier containing the incandescent light, the nipples, *i i*, rub against segments connected with the carbon filament inside the lamp and so switch on the light.



Figs. 573, 574, and 575.

Primary Batteries. — If some form of battery can be designed at a low working cost, which will provide in itself electricity of sufficient power to work an incandescent lamp, it will, no doubt, meet with considerable favour. The disadvantage of primary batteries, by which is meant a battery which is replenished by putting fresh plates and fresh chemicals into it, is that they are expensive to keep in action, as they consume a lot of material and involve considerable trouble in emptying and charging them.

Probably the most successful up to the present is that of Mr. A. Schanschieff,† which has for its elements carbon and zinc, the exciting fluid being a solution of basic sulphate of mercury in the acid sulphate, one part of the salt being dissolved in three parts of water. In one form, the elements occupy a little less than one half of the cell (the top part) and the solution a little less than the other half. The top and bottom of the lamp being hermetically sealed, on turning the battery upside down the solution flows on to the elements and the lamp begins to work. The great advantage is that no gas is given off. A second form is so arranged that the plates are electrically disconnected by lifting them out of the liquid. Lord Kelvin reports that the battery has a high E. M. F. (1·39 volts) and a very low resistance (0·15 ohm for 10 square inches of zinc surface). Its disadvantages are, the cost of the exciting fluid (4s. a gallon, although it is stated that 3s. 7d. a gallon would be allowed for the spent liquid

* *Coll. Guard.*, 1899, lxxviii., 879 † *So. Wales Inst.*, xv., 373.

with its solid residue and free mercury, but the loss at collieries would be considerable), and that the liquid is also exceedingly corrosive and attacks everything. The consumption of zinc is about ½ lb. in forty-eight hours.

As constructed, both forms of portable electric lights seem to be far too delicate to be employed by the ordinary every-day miner. They will scarcely give good results even in the hands of the officials.

Delicate Indicators.—The ordinary safety lamp will not detect a smaller amount of gas than 2½ per cent., and in dry and dusty mines it is desirable that a smaller amount than this should be discovered if present. To do this, what are known as delicate indicators are employed. Several forms are very complicated, but others exist which give good results in the hands of miners.

*Pieler Lamp.**—This consists of an ordinary oil vessel, but the illuminant is pure alcohol. The wick, composed of silk, can be raised or lowered in the wick tube in the ordinary manner. To prevent the observer seeing the flame of the burning alcohol, a conical shield is provided, covering the flame. When an observation has to be made, the flame is drawn down until it is hidden inside the shield, and then the increased height due to the presence of gas is readily observed. The wire gauze is of the Davy type, but much larger, to allow for the increased height of the flame produced. In the later lamps a shield, having a door on one side, has been added as a protection, as in its original form the lamp was very unsafe even in currents of the most ordinary velocity. When moving about, the door in the shield is shut, but when an observation is being taken it is opened. With this lamp ¼ per cent. of fire-damp produces a cap 1⅛ inches long, with ½ per cent. the cap reaches 2 inches, and when 1¼ per cent. is present the cap reaches the top of the lamp, and is of a deep blue colour. This lamp is only useful for detecting low percentages of gas, and must not be taken where gas might be present until a previous examination has been made with an ordinary safety lamp. The Pieler lamp should only be used by persons of experience and discretion.

Chesneau Lamp.—The ordinary Pieler lamp has a tendency to become dangerous by the volatilisation of the alcohol, and has been modified by Mr. G. Chesneau, who forms a circular chamber above the vessel containing the alcohol, the top of which consists of sheet iron and protects the vessel from radiation. He also suggests the addition of a small quantity of chloride of copper in an acid solution to the alcohol, which gives the flame a green tinge and renders it more visible, but as the copper chloride solution has a tendency to form an insoluble sub-chloride, through an action between it and the brass walls of the reservoir, which clogs the wick and prevents the ascension of alcohol, he advises the use of cotton wadding in the spirit reservoir as this absorbs the sub-chloride. Further experiments proved that the cotton wadding was unnecessary, if methylic alcohol with the addition of a thousandth part per volume of crystallised nitrate of copper was employed, as this did not produce any appreciable deposit or clog the wick.

Stokes's Lamp.—To avoid the incovenience of carrying about two lamps, Mr. A. H. Stokes † designed an arrangement which is per-

* *N. E. I.*, xxiv., 285, and *Soc. Ind. Min.* (3ᵉ série), i., 299. † *Fed. Inst.*, v., 462.

fectly fitted to a Hepplewhite-Gray, allowing both oil and alcohol flames to be employed. The ordinary oil vessel, *d* (Fig. 576), with its wick, *a*, is retained, but an additional small tube, *b*, is provided passing through the oil vessel. This is covered at the top by a spring cap, *g*, and is similar to a pricker tube, but slightly larger in diameter, and, except when a test is being made with the alcohol flame, is closed by the brass plug, *c*, which is screwed into the recess, *m*, in the base of the oil vessel. The alcohol tester consists of a small cylindrical brass vessel, *e*, with a long wick tube, *i*, which can be inserted through the passage, *b*, and screwed into the position, *m*, of the oil vessel normally occupied by the plug, *c*. This tester is charged with pure alcohol before it is taken into the mine, and allows 120 tests of two minutes each to be made before becoming exhausted. The alcohol flame is only intended to be used when an examination in the ordinary way with the oil flame has failed to detect gas.

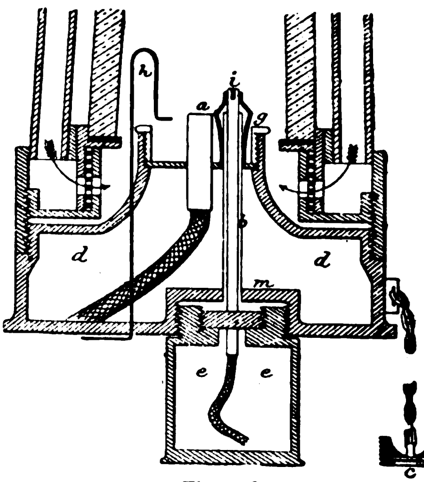


Fig. 576.

The method of testing is to first see that the wick of the alcohol vessel is cut perfectly clean and straight, and then to insert it into the tube, *b*, and screw the vessel, *e*, into position. The upper end of the tube, *i*, should have opened the spring cap, *g*, and have appeared above the same. The heat of the oil flame, *a*, causes alcohol to ascend the wick, *i*, and to ignite, when the oil wick will be drawn down and extinguished, leaving only the small blue alcohol flame burning in the lamp. After the test has been made, the oil wick is pushed up again by the pricker, *h*, and relighted at the alcohol flame, the latter being then disconnected.

*Ashworth's Lamp.**—In this form, which is a modification of the Hepplewhite-Gray lamp, benzoline is used as the illuminant, which not only gives an excellent light, but when reduced and a special burner employed produces a very hot flame, which aids the detection of fire-damp. The glass of the lamp is ground dead for over two-thirds of its inner surface, and completely deadens all reflection. This materially assists the detection of the cap. It is said to give an indication of ½ per cent., and to detect gas better than any other lamp, with the exception of the Pieler. Its advantage consists in the fact that it gives a good light when not used for testing purposes. The Pieler lamp is simply a gas-tester, and another lamp has to be carried about to light the miner on his way.

Coloured Glass.—Mr. A. L. Stevenson † proposes to apply the law of the absorption of light, and employs a piece of coloured glass,

* *Fed. Inst.*, ii., 352. † *N. E. I.*, xxvi., 133.

which shuts off the flame of the safety lamp, and renders evident the pale blue cap in a more distinct manner than is possible with the unassisted eye. Either a slip of blue pot opal is adjusted on a lamp whenever it is desired to make an examination, or a pair of spectacles may be fitted with glass of this colour. He states that such addition is most beneficial, enabling an observer to detect the presence of gas when quite invisible to the unaided eye.

*Liveing's Indicator.**—When a coil of platinum is heated in contact with marsh gas, the combustion of the gas adds some heat to the platinum, which consequently glows more brightly than if it were in air. This is the principle which Mr. E. H. Liveing has utilised in his indicator. It consists of two coils of platinum wire through which an electric current is passed by turning the handle of a small magneto machine. One of these spirals is enclosed in a tube made air-tight and filled with pure air, the other is surrounded by a cylinder of wire gauze. One end of each spiral is provided with a glass cover, the two facing each other, while in between, a small screen, such as is used in photometric experiments, is placed. When the air of the mine is quite free from fire-damp, both spirals glow equally, and the screen would be midway between them, but when fire-damp is present, one spiral glows more than the other, and the screen has to be moved farther from it to equalise the amount of light on the two faces. A graduated scale is provided which points out the percentage of gas present due to any position of the screen.

After one spiral has been heated more than the other on several occasions, its electrical conductivity becomes altered and the two will not glow to an equal extent, even when a trial is made in pure air. To allow the instrument to accommodate itself to this change, it is possible to move the zero point of the scale. After using the instrument several times, before taking it into the mine the sliding screen is moved until its two sides appear equally bright on turning the handle. The screen should then stand opposite zero on the scale of percentages, but if it does not the scale should be moved slightly until it is right, which is done by loosening a small thumb-screw that holds it. This instrument readily detects a ¼ per cent. of gas, but is far too delicate for practical use.

Shaw Gas Tester.—This apparatus consists of two cylinders, one containing air from the mine and the other pure gas. Measured quantities can be obtained from either cylinder by a simple mechanical device, and the mixture so obtained is passed into an igniting chamber and exploded, provided sufficient gas is present. It is first necessary to determine how much pure gas is needed to form an explosive mixture with atmospheric air, and having done this, it necessarily follows that if the air from the mine explodes with a smaller percentage of added gas than the air from the surface, the difference must be caused by the presence of gas in the air sample from the mine.

When the apparatus was first introduced, it was proposed that air from the mine should be conveyed direct to the apparatus through small suction pipes laid from it into each working place, a suggestion so impracticable as to be scarcely worth consideration. Recent procedure is to collect the air in 6-gallon bags by the aid of a small

* *N. E. I.*, xxvii., 287, and xxviii., 167.

pump, and to label each sample and forward it to the surface. The inconvenience and delay are great, the sample only represents the state of the air at the immediate point where it was collected from, and in addition is liable to undergo change in composition before testing can take place. Such apparatus is of service only in a laboratory.

Hydrogen Flame.—Messrs. Mallard and Le Chatelier pointed out in 1881 the delicate indication of gas given by a hydrogen flame, as little as ¼ per cent. being clearly shown, but the difficulty of producing an apparatus sufficiently portable to be workable has been overcome by Prof. F. Clowes,* from whose paper the following remarks are abstracted :—

At first the hydrogen was introduced into the lamp from a small cylinder slung by a strap from the shoulder, connection with the lamp being made by a flexible tube. The maximum degree of portability is now secured by making the cylinder of small dimensions and arranging that it may be quickly attached directly to the lamp so as to form a convenient handle for supporting it. The cylinder weighs a little over a pound, and when charged with hydrogen under a pressure of 100 atmospheres it furnishes a standard flame (10 mm., = 0·4 inch, high) burning continuously for forty minutes. The cylinder is attached to and detached from an ordinary safety lamp instantaneously by a quarter turn. The new hydrogen-oil lamp presents the advantage of enabling any ordinary efficient illuminating safety lamp to be converted in the simplest way into a delicate gas detector, this being effected without permanently adding to its weight, the hydrogen supply being attached only at the spot where delicate tests are to be made. The whole proceeding of passing from the bright oil flame to the hydrogen flame, making a test and passing back to the luminous flame, can be effected in 30 seconds.

The lamp will probably be used as follows :—If the percentage of gas is unknown, the oil flame will first be reduced, and a cap looked for over it. If the gas amounts to 3 per cent., or more, it may be detected and estimated by this flame. If no cap is seen and low percentages of gas have to be looked for, the hydrogen cylinder is attached, the standard hydrogen flame obtained in the lamp, and the percentage of gas can be seen and estimated if it is between 0·2 and 3 per cent.

The hydrogen-oil lamp fulfils the primary conditions of an efficient testing apparatus ; it is convenient, safe, a good illuminant, and combines delicacy with accuracy and with a wide range of indications.

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CHAPTER XII.

WORKS AT SURFACE.

Boilers.—The generation of steam at a colliery is a point of considerable importance. Not so long ago the argument was often put forth that coal at a colliery cost nothing. Certainly, a quantity of unsaleable mineral is produced, but this bears a small proportion to the total output. When labour was cheap, little machinery was employed, requiring only a limited quantity of steam. The tendency, however, at the present day is to do nothing by hand that can be performed by machinery, and, as a result, greatly increased quantities of steam have to be used; the consumption of coal has correspondingly increased, and in addition to the unsaleable produce, the better quality of coal has also to be used. In consequence of this, fuel-saving appliances are becoming quite common; indeed, many of the more modern collieries are as well designed in this respect as any other branch of engineering.

Under the old régime, cylindrical externally fixed boilers were invariably applied, and a great deal may still be said in favour of them. They certainly do not raise steam economically, but to a great extent this failing is counterbalanced by their low cost of repairs, and the facility with which they may be cleaned from incrustation resulting from bad water. This is the chief recommendation of boilers of this type, and where the water is very bad they cannot be surpassed.

The tendency at the present day is to employ high-pressure steam. Its advantages are numerous, as superiority in economy is not its only recommendation. Its use from the beginning materially affects the capital outlay at any colliery. If instead of using 50 lbs. pressure, 150 lbs. is employed, which is now becoming common, not only is the size of every engine on the place less, and the cost also, but the buildings are smaller, the size of the steam-pipes is reduced, and the whole installation can be made more compact. The only disadvantages which have been found in practice are the occasional fracture of a pipe, and the difficulty of keeping tight joints. The former is of so serious a character, owing to the severe strains set up by excessive expansion and contraction due to the high temperature of the steam, that it is becoming an invariable practice to construct all steam mains of wrought iron or steel-riveted pipes, and in some instances, as an additional security, to provide duplicate mains. The joints may be kept steam-tight by increasing both the thickness of the flanges and the number and size of the bolts. Within reasonable limits as many bolts of as large diameter as possible should be employed, while, as ordinary packing materials soon burn out, it seems best to turn two concentric V grooves in each flange after it has been faced, and employ rings of round copper wire for the jointing material. These are placed in the V grooves and the flanges screwed up until they nearly meet.

The generation of high-pressure steam requires tubular boilers, of which there are numerous types. That well-known form called the Lancashire boiler, which consists of a cylindrical shell, having two longitudinal tubes running the entire length, may be taken as the type upon which other designs are based. Two fires are employed, one in the front end of each flue, and the products of combustion, after passing through the boiler, are conveyed along each side, and finally returned beneath the bottom to the chimney.

In the Galloway boiler, the two main tubes in which the fires are situated, merge into one of elliptical form, in which are placed taper vertical tubes, the circulation of water and heating surface being thereby increased. This boiler is in extensive use, and for the past fifteen years has stood in the foremost rank as an efficient and cheap steam-producer.

The final division under which boilers may be classed is that of the multitubular or locomotive type, in which a series of small tubes placed longitudinally are arranged within the shell, but such class is capable of further subdivision. In one type, the hot gases pass through the tubes, which are surrounded by water; while in the other, the tubes are full of water, and the hot gases circulate on the outside. In the latter type, the tubes are placed in an inclined position and are connected with each other and with a horizontal cylinder by vertical passages at each end. The upper cylinder is kept half full of water, and steam forms in the remaining portion. The former type of multitubular boilers has not received much favour at collieries, but water-tube boilers have been adopted somewhat extensively. They are efficient and quick generators of steam, but give a lot of trouble if the feed-water is bad.

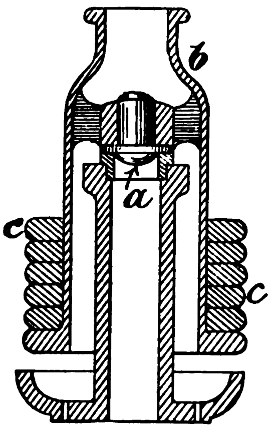
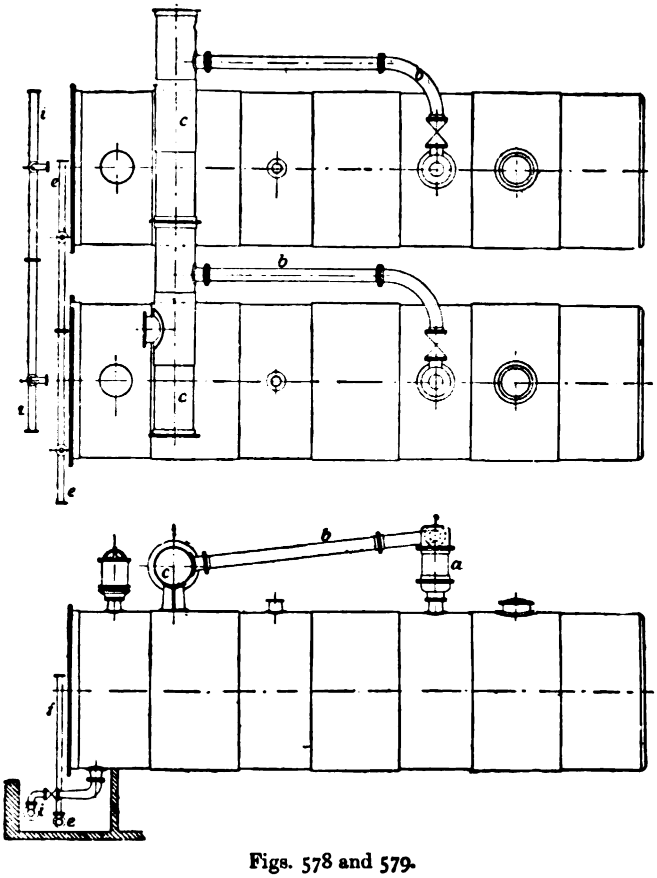


Fig. 577.

All high-pressure boilers should be provided with mountings of the best types, and only such as are supplied by makers of acknowledged repute should be employed. Increased steam pressures and modern circumstances have necessitated such improvements, both in the material used in the construction and in the general mechanical details of boiler mountings, that those made from old patterns are valueless. Two safety valves should be employed, one of which gives warning either when the steam pressure gets too high or the water level two low, while the other acts as an auxiliary valve for high steam only. Such a valve is best of the dead-weight type, a common form being shown in Fig. 577. The valve, *a*, which is ball-shaped, is attached by brackets to a cylinder, *b*, upon which a number of weights, *c*, are threaded. The advantage of this construction is, that there is no fear of any of the parts rusting and sticking. Instead of employing only one set of weights, sometimes the valves are arranged in groups, the discharge aperture of each being made exactly one square inch in area.

The British Coal Mines Regulation Act also provides that each boiler shall have attached to it a proper steam gauge and water gauge to show respectively the pressure of steam and height of water. Steam gauges are all of the Bourdon type, and generally have a red mark indicating the ordinary working pressure. They should be fitted with a tap and syphon, and to facilitate the testing of the gauge, the tap should be made to open to the atmosphere or boiler as required. The water gauge indicates the level of water in the boiler, and consists of two brass cocks fixed into the fire-grate end of the boiler, one being a few inches below and the other as much



Figs. 578 and 579.

above the proper level of water in the boiler. These cocks are connected by a glass tube, and when both cocks are open it is obvious that the water in the tube will be at the same level as in the boiler. It is very desirable that water gauges should be so constructed to automatically shut off both the escape of steam and water should the gauge glass burst, and that a safety shield should be provided to prevent the boiler attendant from being struck by the pieces of flying glass usually scattered about when such an accident happens.

A general arrangement of steam, feed, and blow-off pipes, with large bends and long arms to give as much movement in the pipes with as little strain on the flanges as possible, is illustrated in Figs. 578 and 579. Steam passes from each boiler through an anti-priming apparatus, *a*, and stop-valve through the pipe, *b*, into a central main, *c*, of large diameter common to each boiler, and running across the set as shown. Branches (*d*) are arranged at any desired point on this main. The feed water is brought along the main, *e*, and delivered to each boiler through a vertical copper pipe, *f*. The blow-off pipes and valves, *h*, are connected to the common discharge pipe, *i*, by copper bend pipes. In all cases where a battery of boilers are coupled to a common steam and blown-off main, automatic isolating valves should be used in each branch pipe in addition to the ordinary stop-valves in order to prevent the possibility of the steam passing back into an empty boiler when the stop-valve of such boiler is left open.

Economical and quick generation of steam is considerably assisted by delivering feed-water into the boiler as hot as possible. The general procedure is to employ the exhaust steam to supply the necessary heat. At East Howle Colliery, Durham, the exhaust steam is turned into an old boiler. Cold water enters at the top, and is allowed to fall on to a series of horizontal trays placed one below another in step form. The feed-water is heated to 200°, and is then forced by a donkey pump into the boiler.

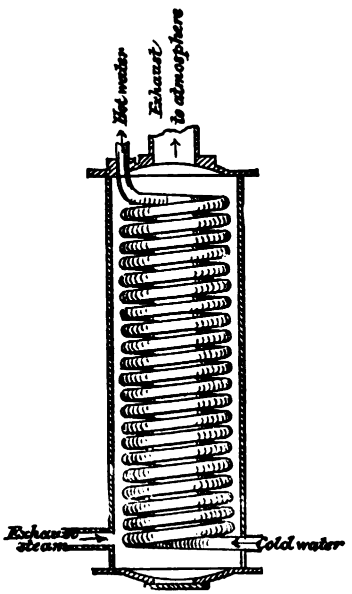


Fig. 580.

Exhaust injectors are largely employed ; these, as their name implies, use exhaust not live steam, and as they automatically commence working they can be used with intermittently running engines. The practice of bringing the exhaust steam into contact with the feed-water is open to the objection that the greater part of the oil and grease which is used in the engines is carried back into the boilers.

To overcome this, at Abram Colliery, Lancashire, the arrangement shown in Fig. 580 is employed. The exhaust steam is turned into a vertical chamber which is in free communication with the atmosphere through an opening at the top. Feed-water enters near the bottom through a pipe and is forced to circulate through a spiral tube, and on reaching the upper extremity passes by another pipe into the boilers. The exhaust steam which is in contact with the outside of the tube heats the water to nearly boiling point, and as the steam has free passage through the appliance, no back pressure is put on the engine.

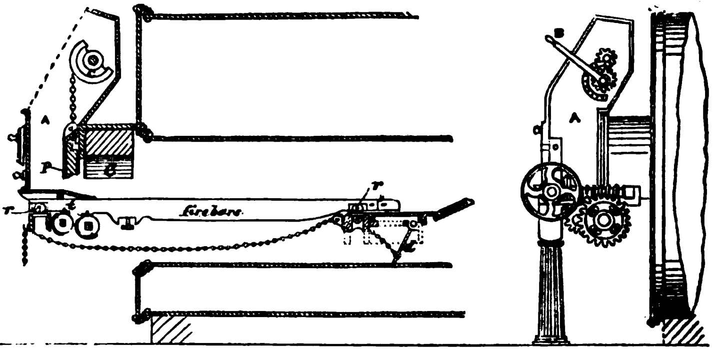
Economisers are now commonly employed for heating the feed-water. They consist of a series of vertical tubes arranged in an enlarged portion of the main flue leading from the boilers to the chimney. The cold feed-water is circulated to and fro in these tubes as it passes from the pumps to the boiler, and is heated by the waste gases on the outside of the pipes. The soot which collects on the pipes, and which, if allowed to remain, would seriously reduce the efficiency, is removed by a series of scrapers slowly moved up and down by a small auxiliary engine.

Mechanical Stoking.*—Firing by hand being a very laborious operation, numerous attempts have been made to supersede it by mechanical means, and at the present time many successful devices are in operation. They may be divided into two types—(*a*) where the fuel is fed from a hopper on to a plate, and then carried forward on to the bars; (*b*) where the coal is thrown on to the fire in small quantities at a time, by either a small revolving fan or a shovel moved by a spring.

It may now be regarded that the claim made for such machines of using an inferior class of coal and raising steam cheaper may be conceded. With them the fire is added to by the smallest quantities at a time, and the operation is perfectly regular, which can never take place with hand firing, unless one man is kept to each boiler. A saving also results from the fact that the fire doors are rarely if ever open. Not only does this prevent smoke, but it reduces the wear of the boiler, as cold air is prevented from getting on to the hot plates.

The bars in both types of stokers are movable, usually arranged to all move forward together, to carry with them the fire, and to return by ones and twos at a time, leaving the fire behind, but at the same time breaking it up. In this way the fire is gradually carried forward into the boiler, finally dropping over the bridge at the end with the coal wholly consumed.

A mechanical stoker of the coking class is shown in Figs. 581 and 582. A trough, A, runs across the front of the boiler, and the slack



Figs. 581 and 582.

for consumption is placed there. The projecting ends of the movable bars form the bottom of the trough, and as they travel forward carry with them a certain proportion of fuel at each stroke. The bars run

* Consult "Machine-stoking," J. F. Spencer, *Inst. C.E*, civ., 55.

on rollers, *r r*, and are all moved forward some 3 inches at the same time by tappets, *t*, the thickness of the layer of slack carried onward being regulated by the distance between the bottom of the trough and the plate *p* which can be either raised or lowered by revolving the wheel, *c*. The slack passes underneath a fire-brick arch, *e*, which is red hot, and is ignited; the bars return in twos, leaving the fire where it was taken to by the forward motion.

This operation is repeated twice a minute, or as often as is desired, the rate being so arranged that when the charge reaches the end of the bars complete combustion has taken place. The clinker drops off at the end of the bars, and when fit to be pulled out is removed through the door, *d*.

Forced Draught.—The air required for the combustion of the coal on the fire grates can generally be increased in quantity by raising the height of the chimney, but as the cost of such procedure is considerable the economical limit is soon reached. All substances burn more quickly when the quantity of air is increased, as the supply of oxygen is greater, and it is possible to burn some materials with the aid of an artificially-induced draught, which under ordinary conditions are incombustible.

The extra draught is usually produced by a modification of the steam jet. The lower part of the front of the flue below the firing doors is covered with a dead plate through which one or two conical nozzles are inserted. A small pipe is led from the steam range into the centre of each of these nozzles and a jet of steam allowed to escape through small orifices. This causes a strong current of air to pass through the nozzles into the space beneath the fire bars and increases the draught beyond the normal amount. Such furnaces will burn the poor carbonaceous shales associated with many coal seams and materially reduce the colliery consumption.

Superheating.—Steam generated in a boiler in contact with water contains just the amount of heat necessary for its existence as steam. It is known as saturated steam, and has a certain definite temperature for each pressure. For instance, saturated steam at 100 lbs. pressure can only have a temperature of 338° F. When heat is abstracted the pressure still remains at 100 lbs., but some of the steam is condensed, causing a great loss of economy in working steam engines. When heat is added the steam is said to be superheated, and behaves approximately like air. It expands and rises in temperature, the pressure remaining constant, when heat is added, and contracts and falls in temperature without condensing if it loses heat, until all the superheat is taken from it. The general form of superheater employed at collieries consists of a number of U-shaped tubes of small diameter which hang vertically from an iron box, provided with inlet and outlet branches, and divided by a diaphragm so that the steam is forced to pass down the leg of one set of tubes and up the other; the inlet and outlet branches connect the superheater respectively with the steam space in the boiler and the main steam pipe. This apparatus is usually placed in the ordinary down-take at the back of the boiler, and the steam in passing from the boiler to the engines is subjected to all the heat of the flue gases which play round the U-shaped tubes. There is another type of superheater employed where much higher temperatures are desired, which consists of an independent coil or coils of pipe heated by a separate furnace. In the latter case the superheat obtained is from 300° to 400°, and is sufficient, not only to prevent initial condensation in the cylinder, but also to supply the heat required for conversion into work during expansion, thus keeping the steam dry throughout the entire stroke.

It is difficult to estimate the amount of superheat which would be given by an apparatus heated by the waste gases, because there is probably no type of boiler which produces absolutely dry saturated steam. In the majority of cases a certain amount of entrained water is carried over, the whole of which cannot be removed by any known form of separator, and the useful effect of the superheater may be spent on vaporising the water and furnishing dry steam. Even then the gain is large, for under ordinary circumstances there would be a further condensation in the steam pipes varying from 1 to 5 per cent., which is prevented when the steam has only a few degrees of superheat. At a gauge pressure of 100 lbs. the condensation of 1 per cent. would be prevented by superheating about 20°, but with 5 per cent. condensation, a superheat of about 100° would be required to ensure dry steam. There is now ample experience to prove that with modern superheaters, engines, and lubricants the economy due to superheating can be obtained without incurring the difficulties which caused it to fall into disfavour many years ago. Oil of good quality must be used, and the valves freely lubricated. The loss by radiation in the pipes may be reduced by employing an efficient thick covering and a high steam velocity. When steam is first being raised, a suitable damper should be arranged for shutting off the gases from the superheater when steam is not passing through, and it is advisable, in order to obtain the best results, that the velocity of the steam through the superheater tubes should be as high as possible, that it may rapidly extract the heat from the walls of the pipes.

Coal Conveyors.—Mechanical stokers reduce labour to a certain extent. They take off cleaning and feeding the fires, but still require manual labour to fill the hoppers, and as these are usually some distance above the ground level, their feeding requires considerable labour, as the coal has to be thrown upwards to a height of at least six feet. The advantages of mechanical stoking are, therefore, not fully realised unless some automatic means are provided for conveying the coal into the hoppers, and the economy is still more marked if, at the same time, the ashes are also conveyed away automatically. The latter is of considerable importance, because the coal employed with mechanical stokers is generally of a far inferior character to that used with hand firing, and consequently makes a larger proportion of ashes, this being especially the case when very inferior qualities are burnt.

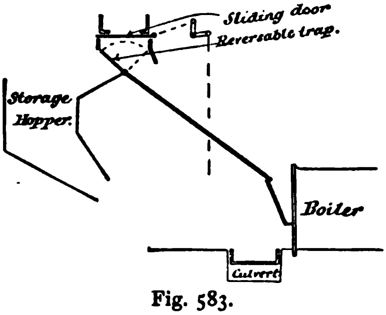


Fig. 583.

An arrangement for automatically conveying the coal and removing the ashes, as adopted at a large colliery, is shown in Fig. 583. The coal, after being freed from all large, is raised by a bucket

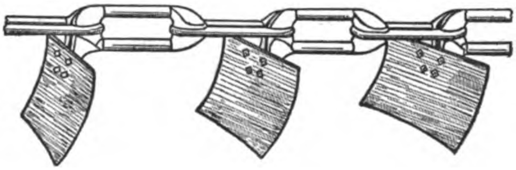


Fig. 584.

elevator, or Jacob's ladder, and delivered on to a channel formed of iron plates, in the bottom of which, opposite each hopper of the mechanical stoker, are fixed sliding doors, which are under the control of the stoker, who can open and shut them by means of suitably arranged levers. Below each hole is a reversible trap which either directs the coal into the shoot going to the hoppers, or into a storage bin. Travelling along the channel is an arrangement known as a "conveyor," which consists of a series of plates fastened at intervals to a chain (Fig. 584). As the chain moves along, the coal is carried forward in front of each scraper, and passes down through any of the openings which are not closed by the sliding doors, and thence by the shoot into the feed hoppers.

A culvert with a similar conveyor running in it is arranged along the front of the boilers. The ashes are raked into this culvert, and are carried along by the creeper to the end, where they fall into a trough and are raised by a Jacob's ladder into a truck, and then pass away to the refuse heap.

Another form of conveyor consists of a spiral revolving in a semicircular trough. If the spiral is made strong enough the appliance works very smoothly and gives good results with small particles, but unless the shaft of the spiral is well supported by bearings, it has a tendency to "sag," and soon wears out the bottom of the trough.

A conveyor of an entirely different type, largely employed in America both for carrying coal to and from storage hoppers, and for cleaning and sorting belts, is manufactured by the Robins Belt Co. It consists essentially of a flexible rubber-coated belt, which on its loaded side is forced to take a trough form by the specially shaped carrying rollers which support it at regular intervals. This belt is driven by a drum in the ordinary manner, and is provided with a stretching arrangement at the other end to take up any slack. The troughing idler rollers which support the loaded belt consist of three cast-iron pulleys, *a*, *b*, and *c* (Fig. 585), running on hollow steel shafts held in two cast-iron brackets. Lubrication is accomplished by forcing grease into the shafts with compression grease cups, and holes are drilled in the

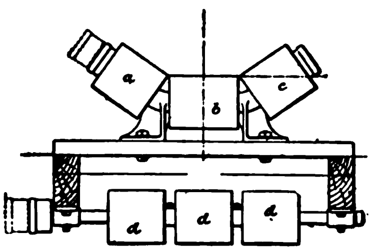


Fig. 585.

shafts through which the lubricant works under the hub of the pulley. Bottom idlers, *d d*, are employed for supporting the returning empty side of the belt, and sometimes guide idlers are used which perform no function ordinarily, but only come into use should the belt run sideways from settling of the framework or other cause.

There are only two component parts, a set of fixed pulleys and a belt, while the conveying portion is entirely separate from the running portion. The material is received directly on the troughed belt and never comes into contact with the pulleys to retard or clog their action, while the point where the load is received is the only point of abrasion or friction between the material and the belt. Experience having shown that the wear is greatest in a line along the centre of the belt, the rubber-protecting cover is made of extra thickness there, while the belt is further stiffened by running two or three plies of duck a part of the way in from the edges.

Swinging conveyors made under the Kreiss-Zimmer patents have come into considerable favour owing to their simplicity, large capacity, and small amount of driving power required. They consist of a trough, *a*, Fig. 585*a*, fixed on inclined spring legs, *b*, securely bolted to the floor or other support. The trough receives a swinging motion from a countershaft and crank through the rod, *c*, which is not rigidly fixed to the trough, but has a strong spring placed on each side of the attachment. The combination of the reciprocating motion from the

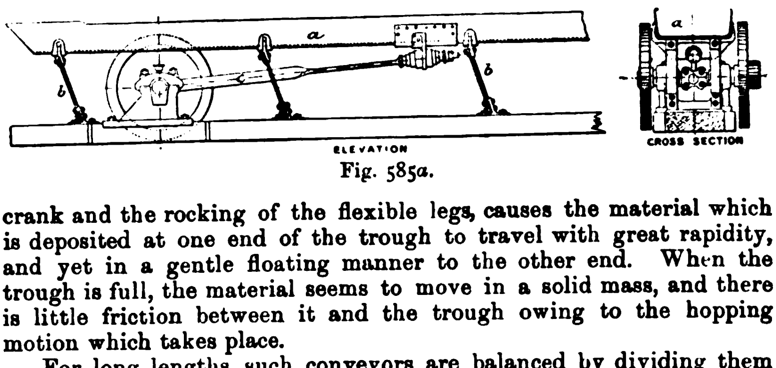


Fig. 585*a*.

crank and the rocking of the flexible legs, causes the material which is deposited at one end of the trough to travel with great rapidity, and yet in a gentle floating manner to the other end. When the trough is full, the material seems to move in a solid mass, and there is little friction between it and the trough owing to the hopping motion which takes place.

For long lengths, such conveyors are balanced by dividing them into two equal portions, and arranging one a little above the other, so that the higher trough can deliver into the lower. The driving crank is made double, one part fixed 180° in front of the other, so that one-half of the conveyor moves forwards while the other half moves backwards, but as the spring legs are fixed at the same inclination, the material travels in the same direction in both sections of the conveyor. Their chief merit is their simplicity, as there are only two bearings and two cranks to keep in order and oil whatever the length may be. Material can be withdrawn at any number of points by providing ordinary slide doors in the bottom of the trough. They can be used as picking belts in combination with any screen, and, indeed, by perforating the bottom of the trough, dust may be separated from the larger coal as the material passes along. These conveyors will carry material up an incline, but their capacity diminishes rapidly as the gradient increases.

Coating Steam Pipes.—To prevent condensation and loss of heat by radiation, boiler houses are often roofed in, not perhaps so often at collieries as they should be. The pipes conveying steam to the different engines should also be protected by some external covering, not only to minimise radiation, but to prevent the severe strains which would otherwise be set up from expansion and contraction if such were not done. Such coverings are more necessary than ever now that the steam pressures are being increased. A very good cheap kind is to bind on a series of rough wood bars all the way round the pipes. At Mariemont, the covering employed possesses the advantage of being movable. A zinc or sheet iron-tube surrounds the steam pipe, and a layer of non-conducting material is placed between (Fig. 586). These tubes are made in halves with a hinge, *a*, at one side, and a clasp, *b*, at the other.

The ordinary practice is to put a series of layers of composition along each pipe and to let the first coat dry before the next is added, and repeat the process until the material is sufficiently thick. The covering does not extend from flange to flange of each pipe, but is tapered away at each end in order that the bolts may be unscrewed and a joint remade without breaking any of the composition off. The result is that the pipe is uncovered at the flanges and for a few inches on each side, and a great deal of condensation takes place there. It is consequently advisable to use a movable covering at such places similar to that shown in Fig. 586. Not only does this save steam, but it reduces the strain on the flanges from expansion.

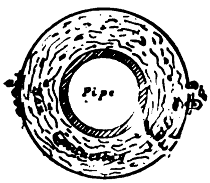


Fig. 586.

A great many different kinds of non-conducting materials for covering steam pipes are in existence. The subject has been most carefully gone into by the late Mr. W. J. Bird, who states that in an actual case the loss of steam was reduced from 12·16 per cent. when the pipes were uncovered to 1·86 per cent. with covered pipes. The saving is increased by increasing the thickness of the covering, but this thickness has an economical limit. It may broadly be stated that the great majority of compositions give very satisfactory results, and that the worst of them is better than nothing at all. They are liable to deterioration from damp and heat, and should be protected by a covering of tar; in places where the covering is liable to receive blows it is further protected by a layer of felt, followed on the outside by a sheeting of zinc.

Workshops.—As the great majority of collieries are situated away from towns, it is very necessary that they should be provided with mechanics' shops, either of a simple or elaborate character, depending on the size of the mine. At the largest collieries nearly everything is made on the ground, indeed, in many cases, new engines are built there, and the shops rival those of engineering establishments. At all mines a certain staff of mechanics have to be retained to attend to breakages, and if good men are to be kept, they must have regular employment. It is far better to do repairs on the spot than to send them away. Not only is time saved, but the cost is reduced, as urgency work has always to be paid for at increased rates. In all cases a small lathe and drilling machine should be put down; in the smith's shop, the fires should be blown by fans, and a steam hammer erected, this tool being perhaps the most useful about any colliery.

The practice of building and repairing railway waggons at the mine is now becoming common, and elaborate wood-working machinery is put down for the purpose. Boring and morticing machines and band saws are then required, but in all cases the introduction of wood-boring machines results in economy. If performed by hand, the operation is a most laborious one, while a small machine with revolving auger can be purchased very cheaply.

For sawing timber, either for sleepers or for props and bars, circular saws are invariably put down. For cross cutting, the saw is carried on an iron swing frame, suspended from beams overhead and drawn against the piece of timber placed in front. The pendulum frame is counterbalanced to move back after the cut has been made. Such an apparatus works satisfactorily with all ordinary sizes, but for the larger logs, the arrangement shown in Fig. 587 is adopted.

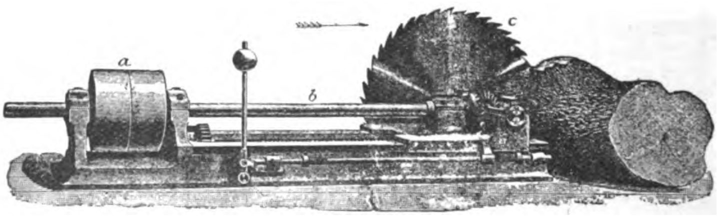


Fig. 587.

The spindle and saw are mounted on a travelling carriage which slides on the cast-iron bed of the machine. Motion is given to the belt-driven pulley, *a*, fixed on the shaft, *b*, in which a long key-way is cut, and through bevel gearing a movement of rotation is given to the circular saw, *c*. The back and forward movement of the saw can be obtained by means of a screw driven by gearing from the main shaft, or it can be moved to and fro by an arrangement of levers, and when pulled forward by the attendant in the direction shown by the arrow, cuts through the timber placed before it. The pulley, *a*, remains in its place, but the key slides in the long key-way, and the shaft, *b*, continues revolving.

Bibliography.—The following is a list of the more important memoirs dealing with the subject matter of this chapter :—

So. Wales Inst. : *Feed Water Heaters*, A. C. Elliot, xviii., 370.

Brit. Soc. Min. Stud. : *Meldrum's Patent Dust Fuel Furnace*, W. H. Mungall, xiv., 165.

Fed. Inst. : *Steam Boilers with Forced Blast*, Bryan Donkin, iv., 154 ; *Powdered Coal for Firing Steam Boilers*, Bryan Donkin, xi., 321.

CHAPTER XIII.

PREPARATION OF COAL FOR MARKET.

General Considerations.—No operation connected with mining has passed through greater changes during the past few years than that of cleaning and sorting the coal. In this country so many good coals existed that a ready sale was found for them in the state they came from the mine. Naturally the best seams were worked first, but as they became exhausted, the inferior qualities had to be mined. It, therefore, became necessary not only to adopt a more equal division into sizes, but to employ some means for removing the impurities, in order that the dirty coal in its clean state may become equal, if possible, to the good coal in its dirty condition.

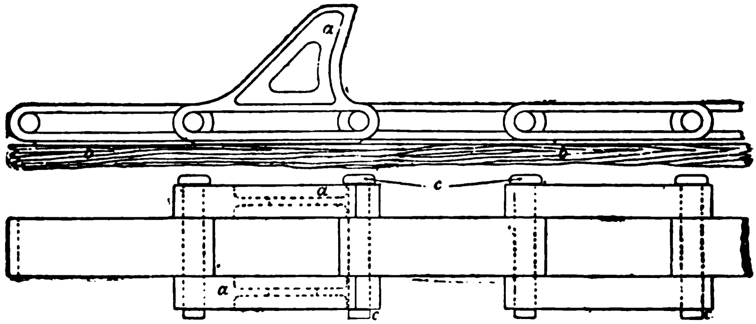
The trade of the present day requires a more careful division into sizes than it did a few years ago, and for such reason the means employed to obtain such division have become much more elaborate and made to perform their work more accurately. The coal coming out of the mine has first to be emptied on to a screen, an operation which is performed by various machines called "tipplers." After passing over and through the screen, the mineral is received on travelling bands or belts, and the dirt picked out of it by attendants. It passes from the belts into shoots and thence to waggons, in which it leaves the colliery.

So long as the coal is large, the stones and dirt mixed with it can be picked out fairly easily, but in the smaller qualities where the refuse is fine, other means have to be adopted, either dry or wet cleaning, called "washing." Both methods depend on the different specific gravities of dirt and coal. In the former, a current of air is directed on to the mixed material, and blows the lighter coal farther than the heavier refuse. In the latter, moving water is employed which has the same effect. The former has not received a very extended application, but the latter is not only largely employed, but is becoming more and more used every day.

Although it would be impossible to give here anything like a complete description of the many varied types of installations which are carried out in different countries to suit different conditions, yet the main features of the various parts of the apparatus used for coal cleaning will be considered under their respective heads, and an outline given of the way several plants are arranged.

One important point must be dwelt on at the outset—viz., that it is impossible to force the trade of any district to take a certain class of coal, and that cleaning and sorting appliances must be put down at each colliery to suit the trade of that district. What is acting very well at one place with economical results might work just as economically at another place, but if the sizes and qualities made are not suited to the trade of the second district, the result of its application would be a failure. Before, therefore, adopting anything, it is essential that the conditions under which it is working should be compared with the conditions under which it will have to work in its new situation.

Circulation of Tubs.—As soon as the tubs leave the cage at the surface, they have to be conveyed to the tipplers, and, after emptying, returned again to the pit mouth. If the screens are near the shaft, the heapstead will be covered with iron plates called "flat sheets," upon which the tubs can be turned about in any direction. A better plan is to lay lines of rails and ensure movement taking place in definite paths. The tubs can then be pushed, or the rails placed at such an inclination that the tubs gravitate towards the discharging place. As they are generally taken off the cage on one side, and put on it again from the other, if it is downhill to the tipplers, it



Figs. 588 and 589.

must be uphill going back, and consequently a more or less greater expenditure of labour is required to perform the haulage, the amount depending on the size and weight of the tubs.

No better appliance has been introduced for minimising the cost of conveying tubs about the heapstead than that known as the "finger" or "creeper" chain, which was originally designed by a Belgian engineer. It consists of an endless chain travelling in the centre of the railway under the tubs, provided at intervals with vertical projecting pieces of iron (*a a*, Fig. 588 and 589) fastened to the links. The chain is built up by arranging two narrow links alternately with a broader one. These are connected together by a pin, *c*, having a round head at the one end and a T-shaped head on the other, which is readily slipped through the three components of the chain, and allows of an easy extension or reduction in the length of the creeper. The projecting catches can be inserted at any desired interval. The entire length of the top half of the chain rests on a wooden baulk, *b*, which acts both as a support and a guide. It is driven by a sprocket or cogwheel, the teeth of which have a pitch equal to that of the chain. When a tub is conducted to the commencement of this chain, the first passing hook seizes the axle and drags on the tub, which is released at the other extremity.

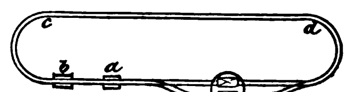


Fig. 590.

Such apparatus is generally arranged as in Fig. 590. The tubs leave the cage at the shaft, and after being weighed on the machine at *a*, gravitate to the tippler at *b*, the road being suitably inclined. The tippler is horizontal, and so placed that the tubs stop on arriving there. They are emptied, and then pushed on by the next following tub, and proceed, still by gravitation, to the point *c*; the road here is, therefore, at a lower level than the pit top. From *c* to *d* the tubs are carried along by a creeper chain, the road rising in the direction they travel, until at *d* the level of the rails is at such a height above the pit's mouth that the tubs gravitate there as soon as they are released from the chain. Any desired variation in this arrangement can be made, the common one being that instead of the tubs gravitating to the tippler they are lifted there by a creeper, and then gravitate back to the shaft. This is perhaps the preferable arrangement, as more height is obtained from the screening level to the ground.

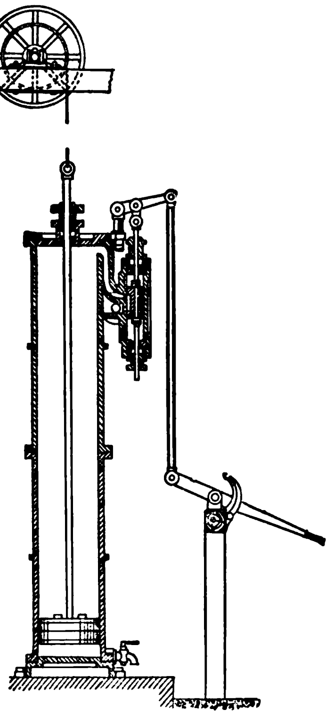


Fig. 591.

In some cases the screening establishment is not at the pit's mouth but farther away, and the banking level is at the surface of the ground. If the screens are any distance away, the tubs can be conveyed there, and lifted the required height by any of the forms of haulage which have been described, but instead of doing this, it is common to raise them direct by an ordinary steam lift.

With a steam lift for a height of, say, 20 feet, the piston would have to be equally long, and would become not only costly but expensive to work. To overcome this difficulty a shorter piston is used, but the piston-rod is connected through a rope to a small wheel keyed on a shaft, on which a larger wheel is also fixed (Fig. 591). To the latter is attached one end of a rope while the other end is connected to a cage in which the tub is placed. The piston travelling a short distance, but attached to the smaller wheel, raises the cage a much greater distance, as this is connected to the larger diameter wheel.

After the tubs have been raised this height they can gravitate back to the shaft, but if the horizontal distance is small they attain too high a velocity, unless their progress is checked by some means. Such is done by placing wooden planks between the rails, with one end fastened down to a sleeper, as shown in Fig. 592, and as the tub in passing over has to depress the end *a* its velocity is retarded. These planks may also be placed to engage the sides of the tub.

A creeper chain as ordinarily constructed cannot work round a curve. At Clifton Colliery, instead of employing flat links as is usual, a creeper is constructed of ordinary round iron chain and works in guides, which not only govern the direction but also keep the chain down. A section through the guide is given in Fig. 593. It will be seen that only enough space is left open at the top for the projecting piece to work through. It was found that something of

Fig. 592.

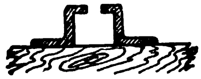
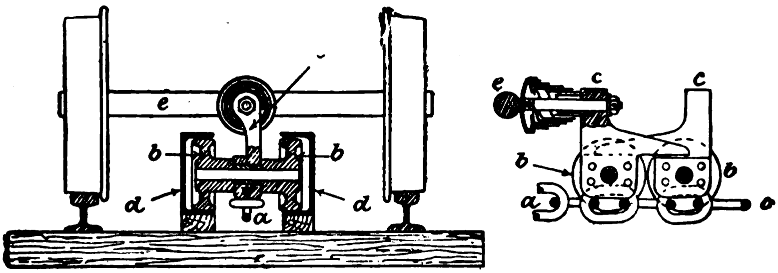


Fig. 593.

this kind was necessary, as the chain was continually going out of an ordinary guide open at the top.

An elaboration of this construction has been introduced by the Humboldt Co., who employ a common round link chain carried by rollers working in guides of channel-iron section. Such an arrangement is particularly suitable for roadways with curvilinear courses. It consists of the chain *a* (Figs. 594 and 595), rollers, *b*, for supporting



Figs. 594 and 595.

the chain, and catches, *c*, for engaging the axles of the tubs. The rollers run in channel-iron guides, *d*. By grouping two rollers and catches together, not only does one strengthen the other, as will be seen from the sectional elevation, but the chain may be used on undulating gradients as one catch is arranged to hold back and the other to push. For heavy gradients the catches, *c*, may be fitted with spring buffers to reduce the shock that takes place when the axle, *e*, is suddenly struck.

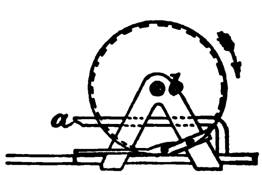


Fig. 596.

TIPPLERS.—Three classes of this machine are in vogue—(*a*) those discharging the coal forward; (*b*) where the tub is turned backwards; and (*c*) where the discharge is sideways.

Front Tipplers.—The ordinary construction is shown in Fig 596. The tub runs on and is locked in position by the hoop part, *a*, which catches over the axles. The machine is pivoted about a centre, *b*; when the tub is full, equilibrium is unstable, and the machine turns round the centre point in the direction indicated by the arrow, emptying out the coal, the rate of turning being regulated by a brake.

As soon as the coal is discharged, the centre of gravity falls below the axis, and the tippler returns to its former position.

The disadvantage of this class is the distance coals have to fall on to the screen, occasioning considerable breakage. Several devices are in use for minimising such objection. In Rigg's tippler (Fig. 597) the front is enclosed by an upright plate hinged along its upper side, and during the revolution the coal is not discharged until this plate nearly rests on the screen bars.

At Cowpen Colliery, Northumberland,* a sliding door is provided at the top of the end tipplers to prevent breakage of coal when emptying. Half the tippler is covered in with a fixed plate (*a b*, Fig. 598), the other portion, *b c*, sliding on rollers. When the tub is pushed into the tippler, the whole revolves about the axis, *d*, and no coal is discharged until the end, *c*, of the sliding door drops on to the fixed projecting stop, *e*, which pushes it open in the direction indicated by the arrow. The opening so made is small at the commencement, when the coals have to be dropped furthest, and reaches its maximum when the tub is just above the screen bars.

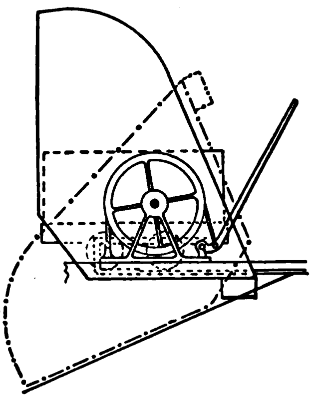


Fig. 597.

Back Tipplers.—With the object of reducing the distance through which the coals have to fall, back tipplers were designed. In these, the tubs run on in the direction of the arrow, A (Fig. 599), and are prevented going too far by the stop, B. By a movement of the lever, C, the catch keeping the tippler in position is withdrawn, and revolution takes place in the direction of the arrow, D, the speed at which this is done is controlled by a strap brake, upon which pressure

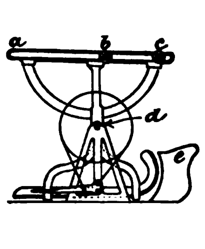


Fig. 598.

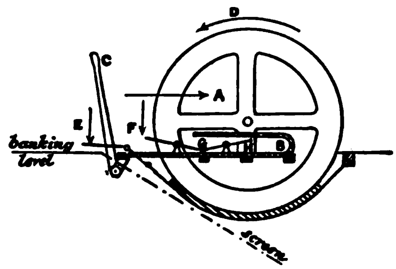


Fig. 599.

is exerted in the direction of the arrow, E, and during the revolution the tubs are kept in their proper position by the stop, F G H, consisting of two links, F G and G H, each pivoted near its centre. As soon as the contents are emptied, the tippler returns to its proper position, the catch is put on by the lever, C, and the end, F, of the second stop is depressed as indicated by the arrow, this lowering the end, H, and allowing the tub to be removed.

* *Fed. Inst.*, i., 95.

Side Tipplers.—With the tipplers just described, the coal only falls a short distance from the tub on to the screen, and breakage is small. The same result can be obtained by sliding doors, &c., applied to forward tipplers, but both have two objections, which are serious ones—(1) the tub has to leave the tippler by the same path as it went in, which occasions considerable waste of time; (2) the discharge of coal takes place from the end of the tub, which is, comparatively speaking, of small dimensions, and the tendency is to deposit the coal in heaps on the screen, such action being unfavourable to perfect removal of the small.

To remove these disadvantages, side tipplers have been designed. They consist of two circles of iron connected together, resting on grooved wheel bearings, two of which support each hoop (A A′, Fig. 600). The tubs run in from one side of the appliance, and are supported in their inverted position by two side pieces, B B, which project over the wheels. The revolution can either be completed or return in the same direction, and the tub can either be pushed through the tippler or pulled back into the place it originally came from.

The advantages are, that if the tub comes out at the opposite end to which it enters, loss of time in manœuvring is avoided, and as the tipping takes place sideways and throughout the entire length of the waggon, the coal distributes itself equally over the whole surface of the screen. Tipping is easy, because when the tippler is in its normal position, the centre of gravity is above the centre of rotation when the waggon is full; whereas it is below after the tipping. Equilibrium is unstable when the tub is full, but stable when it is empty.

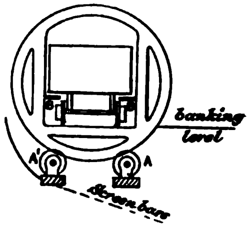


Fig. 600.

A circular plate, terminating in a movable platform resting on the bars of the screen, prevents the coal from falling during the tipping, and conducts it without shock on to the screen.

When these tipplers are revolved by hand the operation is rather slow, and, in addition, the rough unregulated movements resulting from handwork are prejudicial to the preservation of the coal. To increase the efficiency, side tipplers revolved by machinery are now used in the majority of cases. If one of the rollers supporting the tippler be made to engage with another wheel keyed on to a shaft which is constantly revolving, its motion is communicated to the tippler, which commences to revolve and discharges its contents, not with a sudden rush, but with a slow regulated movement.

The two wheels can be connected by an ordinary friction or cone clutch, which is thrown in and out of gear by an attendant. This means is used at Harton Colliery. An attendant depresses a foot treadle and throws the clutch gear into action. When the tippler has made a revolution, he moves his foot and disengages the apparatus. The disadvantage here is that the attendant has to remain at the tippler all the while it is revolving, as, if he moves his foot, the motion stops.

At Bascoup Colliery, this inconvenience has been avoided by the adoption of a friction coupling arrangement, represented in Fig. 601, which makes the tipping automatic. On the shaft, *a*, carrying the bearing rollers of the tippler, is keyed a friction wheel, *b*, and a second friction wheel, *d*, is also keyed upon the shaft, *c*, this being constantly revolving in the direction indicated by the arrow. If a third parasite roller, *e*, is put into contact with the two first by a given movement, it is clear that the movement of the shaft, *c*, will be transmitted to the hoop of the tippler, which will turn in the direction shown by the arrow. Upon the shaft, *f*, opposite to one of the hoops of the tippler, is wedged a lever, *g*, carrying a counterpoise, *h*, and a small roller, *i*, the latter being able to bind itself in a mortise cut in the hoop, and prevent the tippler from turning when in its normal position. The lever, *j*, is also keyed upon the axle, *f*. This is double, and includes the bent or elbow lever, *k*, one of whose branches carries the counterpoise, *p*. This lever can turn upon the axle, *f*, by slight friction, and

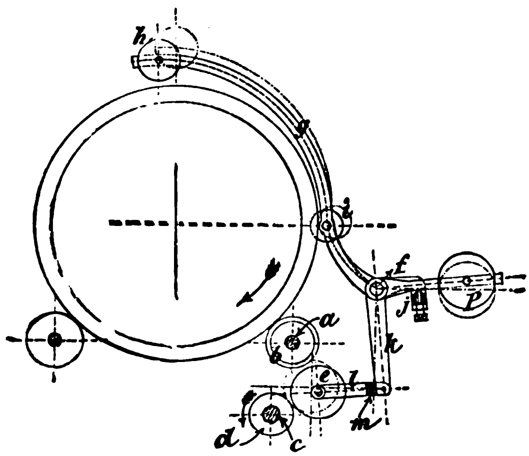


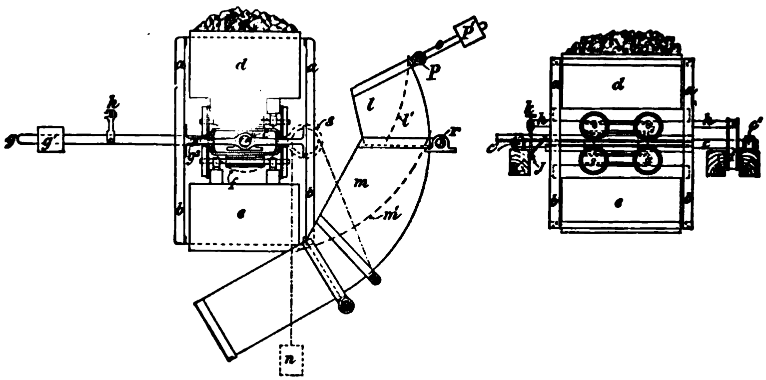
Fig. 601.

can be raised by the propping, supporting, screw of the lever, *j*. The parasite roller, *e*, is bound to the elbow, *k*, by means of the crank, *l*, which cannot fall, as it is propped at *m*. This support is necessary, as when the tippler is not turning, the roller, *e*, does not touch the wheel, *a*. The counterpoise, *h*, having a greater weight than the counterpoise, *p*, will maintain it (*p*) raised when the small wheel, *i*, is in the notch of the hoop, and, therefore, the roller, *e*, will not touch either of the wheels, *b* or *d*. But, on the contrary, if the counterpoise, *h*, is raised, the lever, *k*, becomes free, the counterpoise pushes the parasite roller upon the two friction wheels, and the tippler revolves. The counterpoise, *h*, is not held by the workman who conducts the tipping during the whole time this takes place. He merely raises it to such an extent that the little wheel comes out of the notch, and afterwards lets go. The small wheel then runs over the hoop until it again falls into the notch, the tippler having then made an entire revolution.

The levers are placed at such an angle in their normal position that the arm, *k*, is free, and at the same time sufficient friction can be obtained on the wheels without touching the regulating screw of the lever, *j*, so that wear is taken up. The friction wheels are designed so that only the smallest pressure has to be exercised against the parasite roller to cause it to grip. An equally small effort frees it, for if at any part of the V grooves of the wheel coincide, the points of contact change constantly, and separation is easily made. This advantage does not exist in other forms of disengaging apparatus.

Tipplers designed on similar lines are generally employed in all modern installations, as it has been found that the regular motion of such appliances which slowly empty the coal on to the screen is preferable to that of a tippler acting through gravity, which more or less dashes the coal out and causes considerable breakage.

Duplex Tipplers.—Mr. Henry Fisher has introduced a tippler at Clifton Colliery by means of which two tubs are emptied each revolution. It consists of two duplicate parts, *a* and *b* (Figs. 602 and 603), placed diametrically opposite each other, and both carried by



Figs. 602 and 603.

the central shaft, *c*, journalled in bearings, *c'*. The two parts, *a* and *b*, balance each other in all positions, but when a loaded tub, shown at *d*, is run on the upper part the weight turns the tippler over, empties the tub, and brings the lower part and the empty tub, shown at *e*, into the upper position, so that the latter may be removed, and be replaced by a full one.

The shaft, *c*, is provided with a brake wheel, *f*, for locking the tippler in position while the empty tubs are being replaced by full ones. The brake band is actuated by the lever, *g*, pivoted at g^2, which automatically applies the brake by the action of the weight, g^1. The outer end of the lever, *g*, is raised to release the brake by the lever, *h*, pivoted at its centre, connected at one of its ends to the lever, *g*, and at the other end to a lever, *j*. The latter turns about a centre at one end, while the other is connected to a foot treadle, *k*, which can be depressed by the attendant.

The chief advantage claimed for the appliance is that the speed of tipping is greater than with machines of ordinary construction, as one tub is emptied for each half revolution. This advantage can be obtained with any side tippler by constructing it to hold two tubs, end to end; appliances of this type are by no means uncommon, indeed, at the No. 3 pit, Lens Colliery, a side tippler is in use holding four tubs, all of which are emptied by one revolution.

A disadvantage of the machine, as at present constructed, is that the tubs have to be withdrawn by the same way as they go on to the tippler, occasioning loss of time in manœuvring. In addition, the revolution is affected by the weight of the loaded tub, and is more or less a rapid, unregulated one, tending more to *throw* the coal out of the tub than to empty it. Machine-driven tipplers are certainly preferable with tender coal.

The latter disadvantage is, to a great extent, removed by an excellent arrangement of a balance-shoot. The upper end of the shoot is formed of tranverse segments of convenient lengths, arranged so that their inner surfaces form a curve approximating to that described by the tippler. The two segments, *l* and *m*, are carried by the shafts, *p* and *r*. The segment, *l*, is counterweighted by the weight, *p*, at the end of the lever, *o*, and *m* by a weight, *n*, connected to a chain passing over the pulley, *s*. By the action of these counterweights the segments, *l* and *m*, take the position shown by dotted lines at *l'* and *m'* when they carry no load. When the tippler is overturned, the segments, *l* and *m*, break the fall of the load until this overcomes the

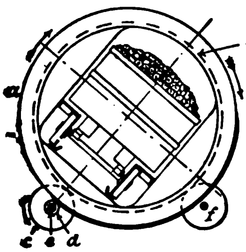


Fig. 604.

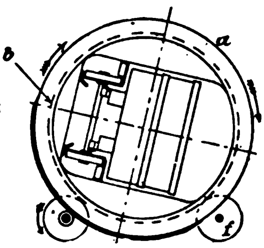


Fig. 605.

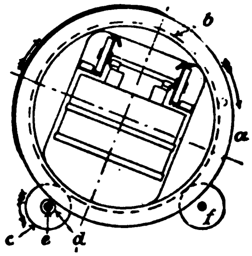


Fig. 606.

action of the counterbalancing weights, *p'* and *n*; the segments then recede from the tippler and permit the mineral to pass down the shoot.

Two Speed Tipplers.—Mechanically driven tipplers have only one disadvantage—their speed is slow and regular and they consequently do not empty the tubs so rapidly as is desirable when a large output has to be passed over one screen. This disadvantage has been removed by causing them to revolve at a variable speed. When the tippler commences to turn, and before any coal is emptied, the motion is rapid until the tub reaches such an angle that its contents commence to be deposited on the screen; the velocity of rotation is then reduced, until all the coal has been discharged, when the motion is again accelerated and the tub rapidly brought back from its upside down position.

In Turnbull's tippler, this action is secured by forming the outer ring with two peripheries of different diameters, and causing them to alternately engage with a driving roller, also having two peripheries one larger than the other. The combination is so arranged that the smaller periphery of the driving roller only engages with the larger one of the tippler when the larger circle of the roller is not in contact with the smaller ring of the tippler. The former action takes place while the coal is being emptied from the tub, and the speed is then consequently slower than at any other period of the revolution. If the two diameters of the tippler ring be respectively 6 feet and 5 feet, and those of the driving roller 6 inches and 18 inches, the ratio of fast and slow speeds will be nearly 4 to 1.

In appearance the tippler resembles an ordinary side-emptying one, but is provided with two rings, *a* and *b* (Figs. 604 to 606), which alternately engage with the rollers, *c* and *d*, keyed on the driving shaft, *e*. The outer ring, *a*, is thickened up along a portion of its circumference as shown by the broad black line. The idler rollers, *f*, only serve to carry the tippler, and run on the inner rings, *b*, which are circular. At the commencement of each revolution the larger roller, *d*, which is in contact with the smaller ring, *b*, drives the tippler at its maximum speed until the position illustrated in Fig. 604 is reached and the coal commences to fall out of the tub. At this point, the thicker portion of the outer ring, *a*, comes into frictional contact with the small roller, *c*, and as this portion is of slightly larger radius than the remainder of the ring, the tippler is raised a little on the driving side and the contact broken between the small ring, *b*, and the large roller, *d*. The speed consequently changes from fast to slow, and continues as illustrated in Fig. 605 until the end of the thickened strip is reached and all the coal has been emptied from the tub. The smaller ring then re-engages with the larger roller (Fig. 606), and the tippler finishes the remainder of its revolution at the maximum speed.

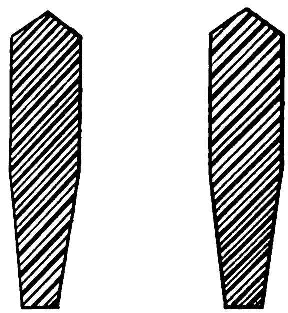


Fig. 607.

A similar result is obtained at Glyncastle Colliery,* Wales, by driving the tippler through a crank, moving with a uniform speed, coupled by a connecting link to a pin, fixed in such a relation to the centre of the tippler that it constitutes a second or following crank. The first eleven seconds are occupied in inverting the full tub until the coal commences to fall out. This continues until at the twenty-sixth second the whole is emptied. Very rapid motion then commences with the empty tub, one-half the revolution being completed in four seconds, with gradually reducing speed, the last two seconds being occupied in quietly bringing the tippler to rest.

SCREENS.—The old type of screen consisted of a number of bars placed side by side, at equal distances apart, at such an inclination that the coal, if emptied on to the top portions, slides down the bars to the lower end, and during its passage the fine is removed. The width between the bars depends on the size of the coal to be made. The form of the screen bar is of importance. They are often made of a simple rectangular section, but bars of this form possess no advantage. They soon become choked up, and do nothing to direct the coal into the apertures. After considerable experience the section shown in Fig. 607 has been adopted at Bascoup. The top of each

* *Fed. Inst.*, xii., 240.

bar is triangular-shaped; the two sides are parallel for a short distance, and then converge towards the centre. The triangular ridge on the top directs the pieces of coal into the openings, and as soon as any piece gets a short distance through it readily falls away, for the space between the bars gradually gets wider.

If large quantities are to be dealt with on ordinary fixed bar screens, the screens either have to be placed at a high inclination, or increased in number, and the slope made less. In the former case separation is not only imperfect, but the coal travels at a high velocity, especially towards the bottom of the screen, with the result that it is not only broken on the screen, thereby increasing small, but with a tender coal, a further breakage results in passing into the waggons, sometimes producing as much slack as is taken out by the screen. The velocity may be either reduced by decreasing the inclination, or by placing movable doors at certain points, an ordinary form of this being shown at Fig. 608.

The effect of reducing the velocity is to diminish the quantity passing over each screen, and to increase the cost of cleaning, because a larger amount of labour is required to assist the screening, by raking the coal over the bars. For such reasons screens worked by mechanical power have received extended application during recent years. Either the bars may be movable, or the entire screen may receive a reciprocating motion.

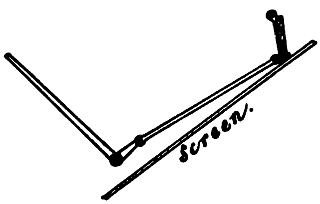


Fig. 608.

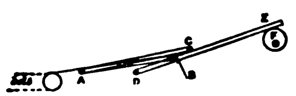
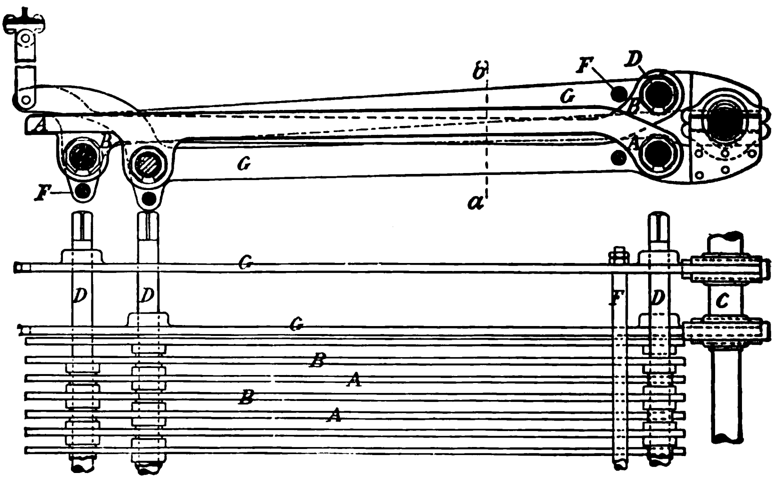


Fig. 609.

Movable Bar Screens.—A simple but effective device for increasing the sorting capacity of bar screens is that adopted at Brinsop Hall Colliery, where an up-and-down motion is obtained from two eccentrics, having a throw of about 8 inches, one being fixed on each side of the screen. The screen consists of two sets of bars arranged alternately, one being fixed, and the other movable. The movable bars are about 4 inches longer than the fixed ones, and while the top ends of the latter are bolted to the framework of the screen, the former are fastened to a cross-piece of iron, the ends of which are turned and rest on a lever. This lever turns about a centre at its lower end, but the top portion rests on the eccentric, so that during the revolution of this eccentric, the lever is alternately raised and lowered, carrying with it the movable bars. Fig. 609 shows the arrangement. All the lowered bars are threaded on the spindle, A, the fixed ones are secured at B, while the movable ones project above, and are fastened to the bar, C, which rests on the lever, D E, working about the fixed centre, D. By the motion of the eccentric, F, the movable bars are raised, but only to a proportionate extent, as the bar, C, is fixed about 15 inches from the fulcrum of the lever.

The most successful screen of this class is that employed so largely in Belgium, the design of which is due to Mr. A. Briart. In its original form it consisted of alternate rows of fixed and movable bars, which when at rest lay in the same plane. All the movable bars were fixed in a framework, carried at its lower end by two cranks, at its upper extremity by two eccentrics keyed on a shaft, to which a rotary movement is given. The arrangement was so constructed that during the first half of the revolution of the eccentric, the movable bars were carried forward *above* the fixed bars, while in the latter half of the revolution they returned *below* the fixed bars, the result being that the coal when tipped on to the screen was lifted by the movable bars and carried forward a distance equal to the throw of the eccentric, and then rested on the fixed bars while the latter half of the stroke was being made.

To increase the capacity of each screen, both sets of bars were



Figs. 610 and 611.

Section on a b

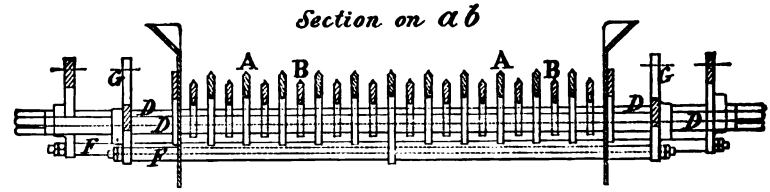


Fig. 612.

soon made movable, this being effected by driving each set by eccentrics keyed on shafts 180° apart, with the result that each set of bars not only moves backwards and forwards, but one set is above the other when moving forward, and below when moving back, while at the beginning and end of each forward motion they are level.

The screen as at present constructed is shown in Figs. 610, 611, and 612, which are respectively a side elevation, plan, and cross section on line, *a b* (Fig. 610). It consists of two sets of bars, A and B, threaded on shafts, D D. The driving shaft, C, is cranked at two points, and two links, G G, are provided, one being connected to bars, A, and the other to bars, B. These links are suspended at the far end, as shown in Fig. 610. Distance shafts, F, are provided for the purpose of keeping the driving levers, G, properly spaced, and, in addition, it is to one of these shafts that the central bar of the screen is wedged, when the construction is such that the distance between the bars is capable of variation. Fig. 613, which is a reproduction of a photograph of a model, clearly shows the two sets of bars, and the way they are connected to the driving levers.

The great advantages of the Briart screen are—that it may be placed horizontal, thus diminishing the height of the heapstead; by regulating the speed of the driving shaft the quantity passing over them can also be varied within certain limits, as the coal is moved forwards double the throw of the eccentrics for each revolution; manual labour is diminished; in addition, as the bars have an up-and-down motion, the coal is shaken throughout its mass, and perfect removal of the small is obtained.

Its only disadvantage is that common to all bar screens—viz., that the longitudinal slits between the bars allow long thin pieces

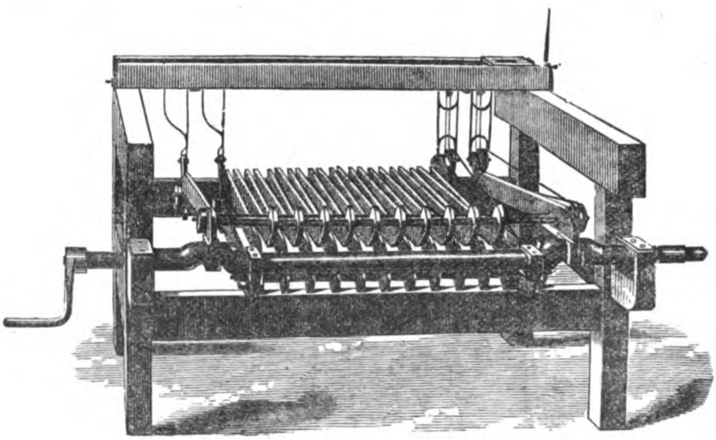
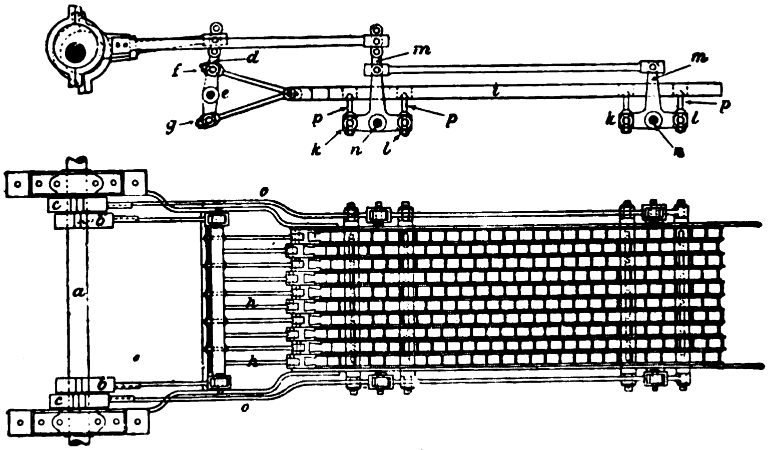


Fig. 613.

of coal to pass through, and such perfect sizing is not obtained as is given by a sieve made of wire netting. In the form constructed in Germany even this objection has been removed, as the bars, instead of being formed of strips, are made of channel iron, having perforations in the horizontal side. At Bascoup, the driving eccentrics originally employed have been replaced by elbows, which absorb less work. The two systems of bars are movable, and driven from the same axle, on which the elbows or knees are keyed diametrically opposite each other. This modification, previously employed in Germany, allow the stroke to be diminished by one-half, and to balance oue system of bars by the other.

The Chambers screen used at Denaby Main Colliery, Yorkshire, has a series of meshed bars to which a vertical and lateral movement is imparted through rods and levers from eccentrics on a revolving shaft; the bars are built up by connecting two longitudinal strips together by a series of transverse ribs, and are carried on pins rocking in inverted steps provided in the bars. The arrangement is illustrated in Figs. 614 and 615. The revolving shaft, *a*, carries four eccentrics; two, *b b*, move the bars laterally, while the others, *c c*, move them vertically. The eccentric rods from *b* are fixed to links, *d*, which turn about the centre, *e*. Two cross shafts, *f* and *g*, connect the two links, *d*, and from these rods, *h*, pass to the front end of the screen bars, *i*, the upper rods going to the even number bars, and the lower rods to the odd numbers.



Figs. 614 and 615.

If the bars were supported on fixed points, they would simply move to and fro when the shaft turned, but they rest on pins, *p*, carried by the cross shafts, *k* and *l* (the odd number bars on *k* and the even numbers on *l*), which connect the ⊥-shaped levers, *m*, turning on the centres, *n*, and connected by links, *o*, to the eccentrics, *c c*, the bars are thus lifted up and down. Therefore, in combination with the other movement, the motion of each bar is in reciprocation of the bar on either side, and rises, moves forward, falls, and recedes as the alternate one falls, recedes, rises, and moves forward; by this arrangement the coal is gradually carried forward from the head to the foot of the screen.

The coal is delivered regularly on to the picking bands, the breakage is very small, room is economised as the screen may be placed horizontally, there is no vibration to cause the heapstead to rock and the bars may be changed for different sized coal in a few minutes. It has also a relatively large capacity, four tons per minute being effectively separated.

Jigging Screens.—Reciprocating screens are easily and cheaply constructed, and size the coal very completely. They consist generally of woven iron netting carried in a frame and suspended from stays, two on each side. A rocking motion is imparted to the whole structure by means of eccentrics keyed on a shaft, which is revolved by a small steam engine (see Fig. 648). In general the direction of motion is the longway of the screen, but in others it is sideways. As the travel of the coal is assisted by the shaking, a jigging screen can be placed at a smaller inclination than a fixed bar screen, but the slope must be steeper than with the Briart screen. Instead of wire netting, plates having holes punched through them are used, and if these holes be circular instead of square the sizing is perfect.

Mr. E. B. Coxe* has designed a screen which receives a gyratory motion similar to that of an ordinary hand sieve. The chief problem was to support the screen in such a manner that it will gyrate easily and safely, and at the same time to counterbalance the centrifugal force and prevent its shaking the building. This has been done successfully by a method which consists essentially in supporting one horizontal plate upon another by means of three or more double cones (Fig. 616), while the motion of gyration is given to the upper plate by a crank, *a*, upon a shaft passing through and journalled in the lower plate. The cones roll freely in a prescribed path on the lower plate, while the upper plate moves upon the other end of the double cone.

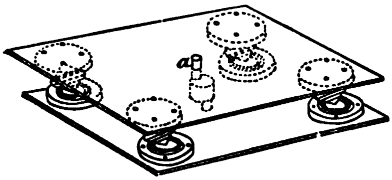


Fig. 616.

These cones are guided in various ways, but when the screens are run at high speeds there is a tendency in the double cone to fly from the centre, and the surface in such case on which the cones roll is made conical, so that the weight of the screen has a tendency to force the cone towards the centre, thus counteracting the centrifugal force to a great extent.

Fig. 617 illustrates the appearance of a single gyrating screen. The lower plate of Fig. 616 has here become a box bed-plate, and the upper plate a screen box, provided with a number of trays, one above the other and inclined as shown. The motion of gyration is imparted by the cranked vertical shaft, *a*, which has a pulley keyed on to it and is driven by a belt, while the centrifugal force is balanced by the fly-wheel, *b*, fitted with a heavy counter weight.

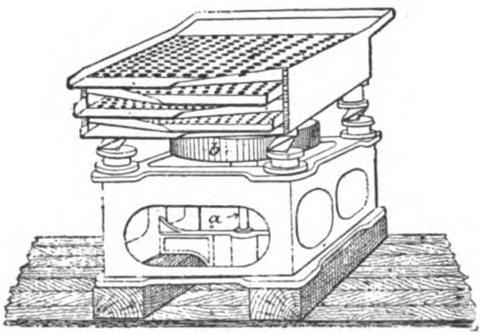


Fig. 617.

Revolving Screens.—Instead of giving the screen a reciprocating motion, cylinders revolving about an axis are often employed. If the openings between the bars, or the mesh, if the cylinder is of wire gauze, vary through different lengths of the cylinder, several sizes can be made on one of these screens. They are rarely employed for large coal as their capactity is small, only a few inches of the circumference being at one time in action. If any quantity is passed through, the screen becomes overcrowded and acts like an elevator,

* *Amer. Inst. M. E.*, xix., 398.

lifts the coal a part of the way up the sides and throws it back into the screen, producing a considerable amount of small. For separating the smallest sizes, as required for coal washing, such screens are, however, largely employed.

Spiral Screens.—In the coal districts of Germany a spiral revolving screen is used with success.* It consists of a long strip of plate perforated throughout its length with holes of different sizes. This strip is wound into a spiral, and the ends closed and mounted on a shaft. Their diameter is greater than their length, in some cases nearly double, and screening is often assisted by blows from a wooden hammer, or jerks from springs. The construction will be understood from Figs. 618 and 619.

The coal to be separated is delivered into the central part, which is a cone-shaped circle larger in diameter in its outer end, to facilitate the delivery of the larger pieces of coal which do not pass through the first series of holes. The coal passing through the first holes falls into the second division, 2, and by the revolution of the screen is separated, the pieces too large to pass through the second series of holes being retained upon the plate until they reach a point in the circumference where a channel receives them, down where they are discharged out of the side of the screen. The coals passing through the holes in division 2 are further separated, a portion passing through

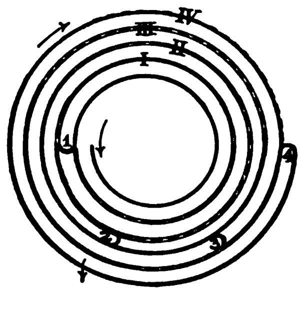


Fig. 618.

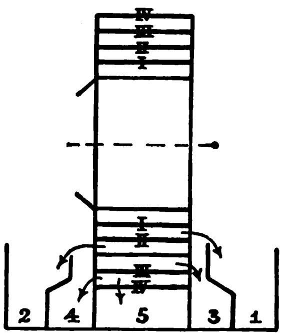


Fig. 619.

plate 3. All, however, that remains on this plate is discharged when the point 3 comes opposite the channel in the circumference. The same process goes on until finally all the remaining coal is discharged through plate 4.

It is claimed for this device that it is smaller than an ordinary revolving screen, that the space occupied is less, that the coal is not broken nearly so much, a saving of from 6 to 7 per cent. being experienced as compared with old types, and that the screening into the required sizes is most effectively done. The speed of rotation varies from 6 to 8 times a minute, and with a screen 7 feet 6 inches diameter, by 4 feet long, 50 tons an hour can be treated.

Greenwell's Screen. — This screen consists of a number of parallel endless chains which travel between bars of varying sections suitable for the size of coal to be made, and diminishing from the top of the screen (Fig. 620). The bars are fixed, but the chains are

* *N. E. I.*, xxxviii., 183.

driven by a series of sprocket-wheels fixed on a shaft at the top of the screen and travel at a speed of 70 feet per minute; they are kept taut by means of a tightening screw at the other end. As the chains are parallel and the bars diminish in section, it follows that the openings between each chain and the bars on either side of it get larger towards the lower end as will be seen from the cross-sections, and consequently as the coal is carried forward it falls between the chains and fixed bars. The dirt is picked out as the coal travels along. The advantages claimed are (1) small first cost and the small cost of repairs; (2) the small height taken up; and (3) as the chains are level there is little breakage.

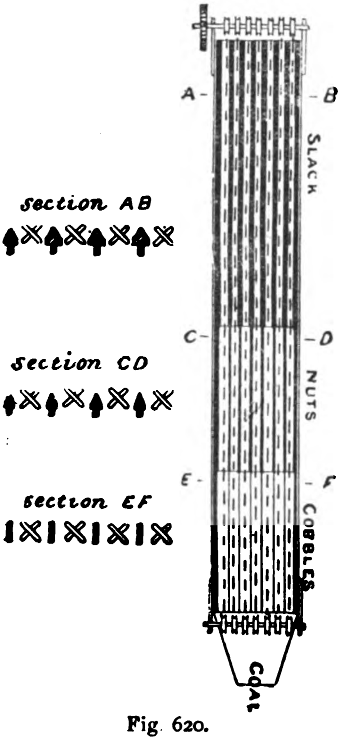
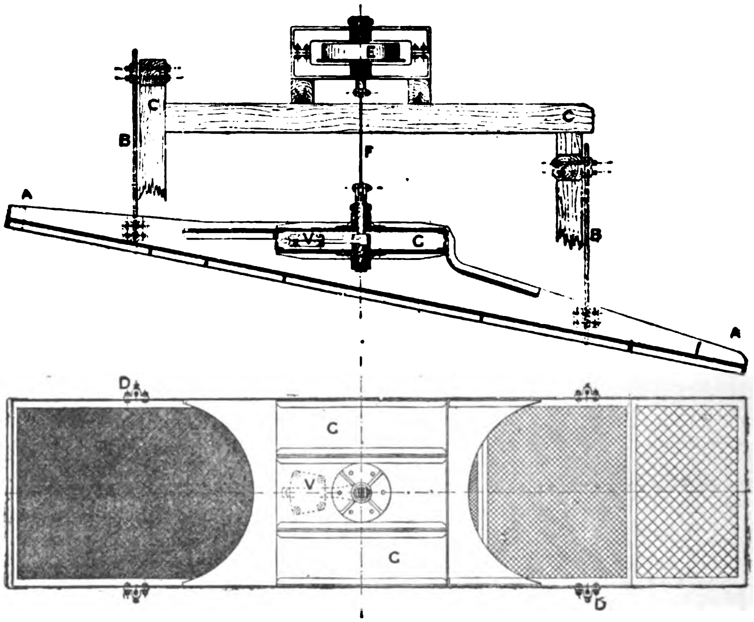


Fig. 620.

Vibromotor.—Mr. W. Worby Beaumont has designed a screen of decidedly novel principle which he calls the vibromotor. It is operated entirely by mechanical reaction, so that none of the vibration transmitted to the framing for carrying ordinary screens, has any origin with the vibromotor. Jigging screens are usually driven by cranks or eccentrics which run in bearings attached to the fixed framing by which the screen is carried, and every push and pull or reversal of direction of motion of such a screen is equally but oppositely transmitted to that framing. With the vibromotor (Figs. 621 and 622) no such bearings are attached to that framing; an unbalanced weight, V, is attached to a spindle carried in bearings fixed on the screen and rotated by a freely suspended jointed rod, F, driven by a spindle to which a driving pulley, E, is fixed. The screen, A, is suspended by wire ropes, B, adjustably held in clips, D, similar clips being attached to the framework, C. The vibromotor weight, V, in the example illustrated, revolves in the box, G; the weight, V, being unbalanced causes the spindle when set in motion to attempt to rotate round the centre of gravity of the whole mass, including the spindle arm and weight; to do this it must impart motion to that which carries the spindle, or, in other words, that which tends to restrict its gyratory action—namely, the screen. The result is that the inertia of motion of the vibromotor weight acting at a large radius is balanced by the inertia of the screen and its load acting through a small radius of gyratory motion; hence, the whole of the work transmitted through the spindle E is, with the exception of that absorbed in friction of one spindle, converted into automatically balanced motion of the coal screen under its load.

The radius of gyration of the screen is proportional to the relative weights and radii of the screen and vibromotor weights, and may therefore be varied by varying the position of the weight, V, upon the arm which carries it.

Owing to the automatic balancing, screens run on this system may be driven at a high speed, and the screen need only be moved



Figs. 621 and 622.

sufficiently to permit each and every piece of coal to drop through the nearest hole. The surging of quantities of coal of various sizes over distances of from 4 to 6 inches, and the consequent rubbing and breaking is thus avoided. It is mainly at the reversal of direction of motion of any screen that material being sifted gets the opportunity of passing through the holes, and a long range of reciprocation is only required to put the material to be sifted into motion at a sufficient velocity to cause relative motion between it and the screen at the low velocities of rotation which have to be adopted for the crank and eccentric methods of operation.

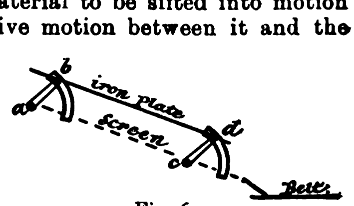


Fig. 623.

Varying the Sizes made by Screens.—In consequence of the exigencies of trade, different sizes of coal are often required, and such change cannot be made exact by varying the spaces between the bars or altering the size of the mesh. With wire netting screens, the only way to make the change is to stop the screen, take out the one riddle and replace it by another.

Plating.—It sometimes happens that unscreened coal is required —that is to say, in the state it comes from the mine, with none of the fine removed. In such cases a method of "plating" the screen is employed. At Hilda Colliery this is done by an arrangement of cranks, *a b*, *c d* (Fig. 623), turning about centres, *a* and *c*. These cranks support a plate which, when not in use, stands 6 or 7 inches above the screen grating. If these cranks are turned, the plate is lowered on to the screen and closes up all the openings. The guides for the plate are curved, as the cranks in rising or falling necessarily describe the arc of a circle.

Combs.—With the ordinary bar screen, if one size is being made and another required, the screen has to be stopped, and the bars pulled out and replaced by others. To render this operation easy, the bars are usually threaded in a kind of comb which, in its turn is dropped into and held in position by a shoe on each end. To alter the size of coal being made, the bars are lifted out of the comb, which is then replaced by another one having openings of a different width, into which the bars are replaced.

A better plan than this is that of employing a square bar, on each side of which is attached a comb having different sized slots. Here to make an alteration, the screen bars are lifted out, and

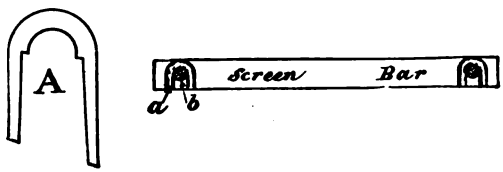


Fig. 624.

the comb bars turned over until the proper-sized openings are upwards.

In other places a circular piece is cut out of the end of each bar which rests on a circular shaft, *b* (Fig. 624). The spaces between the bars are kept by horseshoe washers, *a*, which can be added to or removed quite easily. One of these washers is shown enlarged at A.

Variable Cross-Bars. — All the preceding arrangements possess some objectionable points. Not only is there a considerable loss of time, but in putting up or pulling down, the bars often become altered and get bent and strained. To avoid these inconveniences, Messrs. Guinotte and Briart have designed the arrangement represented in Figs. 625 to 627, by means of which the spaces between the bars can be instantaneously varied without stopping work.

The screen bars, *a a* (Figs. 625 and 626), are carried by spindles, *b b*, threaded with right- and left-hand screws, which carry the sleeves or nuts, *c c*, having threads cut in the opposite direction. The direction is the same for all the screws and nuts, and all the sleeves are threaded on the shaft, *d*, common to the whole system (see Figs. 609 to 611), the two being connected together by the key, *e*, fitted into a key-way running along the whole length of the shaft. The sleeves, *c c*, are otherwise free; they turn with the shaft, but can glide longitudinally upon it. If the shaft, *d*, is turned, the sleeves and spindles rotate, and consequently the separation of two consecutive bars will augment and diminish according to the direction of rotation.

If one of these nuts is bolted upon the shaft, the bars would be displaced on either side of it, in amounts proportional to their distance from the fixed point, or the same thing may be done by fixing one bar.

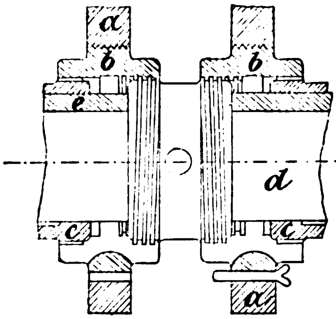


Fig. 625.

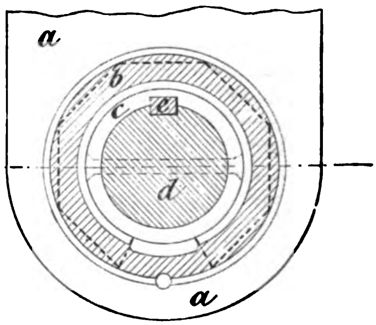


Fig. 626.

Fig. 627 shows how the bars are connected amongst themselves, and renders clear how the same relative distance is retained after varying the original opening. To prevent confusion, the two sets of bars are drawn one above the other. Taking the upper set first—the middle bar, A, is *wedged* in the centre of the screen as it is keyed to the shaft, E ; consequently, when the shaft, *d* (Fig. 625), is rotated, this bar does not move, and the nut, *b* (Fig. 625), remains at rest, but as the shaft turns, it necessarily follows that the screw, *c*, enters the nut, while at the same time, the other end of the screw, *c*, enters the

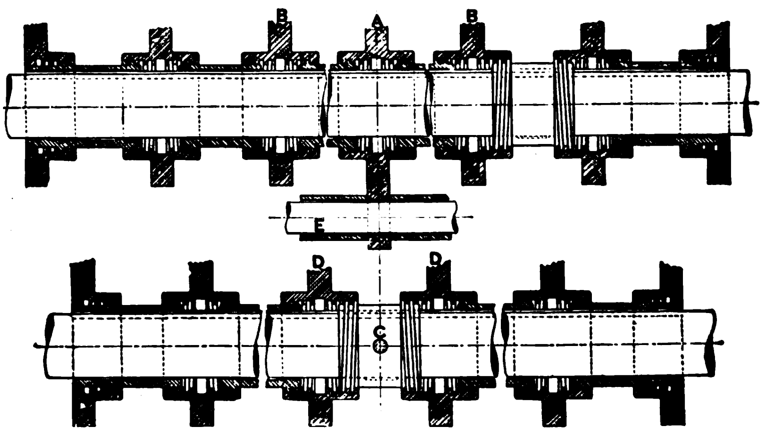


Fig. 627.

nut, *b* (Fig. 625), of screen bars, B (Fig. 627). As a result, bars B move towards A, a distance *double* that due to the pitch of the screw. That is to say, if the pitch is 1 inch, and the shaft, *d* (Fig. 625), make one-fourth of a revolution, the bars B (Fig. 627) will move a total distance of ½ inch.

These bars, however, are not the ones nearest to the central bar, A, as those of the lower set, D D, adjoin A. If this set be now considered, it will be noticed that, instead of a bar being fixed, the screw, *c* (Fig. 625), is wedged on the shaft by a bolt, C (Fig. 627), passing through it. Consequently, when the shaft is rotated, the screw turns with it and travels into the nuts on bars, D D, dragging them towards the centre. Here the shaft makes one-fourth of a revolution as with the first set, and as the screw only works into the nuts on each side, these will move ¼ inch, and bars, D, are only displaced ¼ inch.

Assuming, therefore, that the original distance between the bars was 3 inches, the result of turning the shaft is that the centre bar of the screen, A, does not move, but that the bars, D, immediately adjoining close in ¼ inch each, reducing the space between the bars to 2¾ inches. The bars, B, which are the next adjoining ones to D, were originally 6 inches from A, but as they move ½ inch, are now 5½ inches away. D is 2¾ inches away from A, and, consequently, 2¾ inches away from B. Thus the distance between the bars has been altered from 3 to 2¾ inches.

The other bars of each set move towards the centre in amounts proportional to their distance from it. The further they are away, the greater is their motion, as they are dragged a distance equal to the sum of the motion of all the right- and left-hand screws.

The distance between the bars is indicated at the extremity of the shafts by a graduated dial. With the aid of these cross-bars, without stopping the working, any variation in size required for trade purposes can be readily obtained, within the limits allowed for in construction, this being determined beforehand, and as the movement is performed by simply pulling a lever and noting a finger on a dial, any workman can do it.

The cost is high, owing to careful construction and fitting required, but there is little wear, and the results obtained compensate for the additional outlay.

Mulholland's Patent.—At East Howle Colliery, where this arrangement has been in use some time, the invention was adapted to suit the existing jigging screen, which may best be described as two screens placed end on to each other, and forming one continuous screen about 18 feet long by 5 feet wide. By this means two sizes of coal can be passed through the screens, while the best coal passes over the top. To apply the invention in this instance it was only necessary to remove the gauze and substitute perforated steel plates, the plates being riveted to the angle-iron frame, thus forming a vibrating tray, with hangers, spindles, and the necessary vibrating gear as formerly. As already said, the plant consists of two screens. The upper length of perforated plate was punched with holes 2¾ inches square, and the bottom length with holes 5 inches square, the web between the holes being 1 inch wide in each case, these sizes being the maximum required to meet the trade at this colliery. Now, by fixing on the upper length of screen another perforated plate with holes 2¾ inches square, and placing the holes so that they coincide with those in the lower plate, it is obvious that all the coal 2¾ inches square and under will pass through the screen (Fig. 628), but if the loose plate is moved down, say, a quarter of an inch, we will then get holes 2½ inches square (Fig. 629); and if we continue to slide the plate down until a point is reached where there are four holes of equal size instead of one, then the minimum size is reached—viz., $\frac{7}{8}$ inch square (Fig. 630). Similarly with the lower length of screen, if a second plate be fixed on with 5-inch square holes, changes can be made on this length from 5 inches down to 2 inches. Thus, on the two lengths of screens any fraction of an inch can be got between $\frac{7}{8}$ and 5 inches. It must also be noticed that whatever sized holes are made they are always square. This is due to the holes being placed diagonally or cornerwise to the travel of the plate. A suitable gear is attached to work the sliding plates. It is scarcely necessary to add that a greater range of sizes can be obtained by introducing extra sliding plates, and that by using three sliding plates the holes can be made dumb altogether. This adjustable screen can readily be applied to any of the jigging, and fixed screens now in use.

Belts.—After separation by the screen, the various sizes of large coal are received upon belts, by the side of which attendants are stationed to pick out dirt and stones with which the coal is associated. The length of these belts is dependent to a great extent on the nature of the coal and trade of the district, but in all cases is greater, the dirtier the coal. In the Midlands, where several qualities of

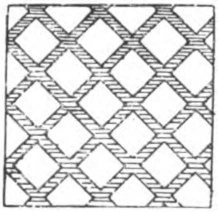


Fig. 628.

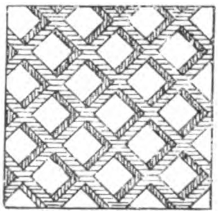


Fig. 629.

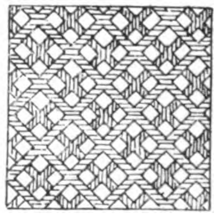


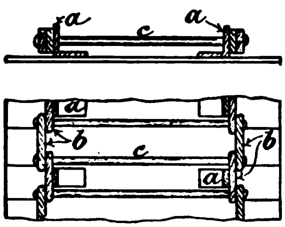
Fig. 630.

large coal are made, all of which are loaded together down the mine, it was at one time the common practice to wheel each tub from railway waggon to waggon, picking out the various qualities. This practice has been superseded by the employment of travelling belts. All the coal from the mine is tipped on to one end and gradually passes in front of a row of attendants, who pick out the qualities required for the trucks they are loading, and let the remainder pass by to be taken off further on by other attendants loading different qualities. To enable many waggons to be loaded at one time, the belts are made proportionately long, frequently from 200 to 300 feet.

These belts, however, are more for sorting the coal than for cleaning it. For the latter purpose, even with the dirtiest seams, they rarely exceed 60 or 70 feet. The width of the belt is governed by the length the attendants can easily reach. If they are stationed on both sides, 4 feet 6 inches is a common width, but better results are perhaps obtained with only 4 feet.

Belts may be constructed in several different ways. The form most generally in use consists of steel plates attached to an endless chain. These chains are usually made of alternate single and double links, which are preferably connected to the plates forming the belt by being bolted to angle-irons which are riveted to the plates. This construction allows a plate to be taken out and replaced without cutting any rivets, as would have to be done if the links of the chain were riveted direct to the plates.

A construction largely employed in Lancashire is to rivet pieces of angle-iron (*a*, Figs. 631 and 632) to each plate and to bolt the link, *b*, to them. The links of one plate overlap those of the other, and a bolt, *c*, is passed from the links on one side of the plate to those on the other, thereby forming the hinge around which the plates turn,



Figs. 631 and 632.

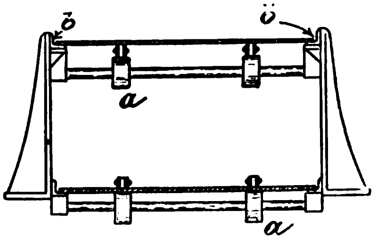


Fig. 633.

when they arrive at the driving tumbler or sprocket-wheel. Some times the plates are secured to the driving chain by a hooked bolt, which passes through a hole in the links and is secured on the top of the plate by a nut.

These belts are driven by tumblers which have their arms shaped to engage with the links. This system of driving, with any average load, has been found to give better results than an octagonal drum, which is sometimes employed. Belts may either be driven from the "leading," or "following" end, both of which are equally efficient, unless the load carried is a very heavy one; as the "following" end is more conveniently situated to the motive power they are usually driven from it. They are supported at intervals by rollers (*a*, Fig. 633), which serve the double purpose of lessening the power required to move them and of preventing any sag, and, as an additional support, the edges travel in an angle-iron slide, *b*. To reduce friction, rollers are sometimes provided at the sides of the plates (Fig. 634), these running in the angle-iron guide already referred to.

Fig. 634.

To readily remove the dirt picked out of the coal, many belts are provided with a partition in the middle, consisting of two angle-irons riveted to the plate. The attendants pick out the dirt and deposit it in this trough. The dirt is then carried along with the coal, but separate from it, and discharged down a shoot at the end. Where this is employed, the shoot leading from the screen is provided with a V-guard, which prevents the coal passing into the central trough, and directs it to the two sides of the belt.

For delivering coal from belts at points along their length the arrangement shown in Fig. 635 is applied at Aldwarke Main Colliery. A roller, *a*, is placed diagonally across the belt at any point where delivery is required and sweeps off the coal into the shoot. This roller travels in guides, and can be raised and lowered to give intermittent delivery.

Many materials, such as hemp, wire ropes, &c., have been used in the construction of picking belts, but have not received much favour. In Lancashire, belts constructed of woven wire netting are largely employed and possess one marked advantage, as they rid the coal from any fine which has not been removed during the passage over the screen. Some coals have small pieces of dirt adhering to them, and these have to be chipped off by the attendants. A quantity of small is produced which, if solid belts are employed, is carried away with the large coal, but if wire gauze ones are in use, the small pieces fall through and a more efficient separation results. These belts are

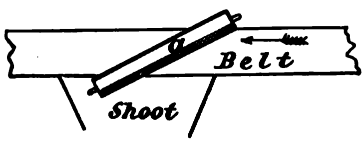


Fig. 635.

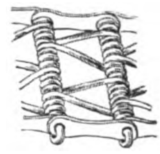
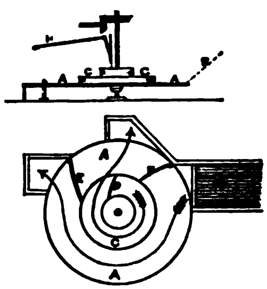


Fig. 636.

built up in several ways; a common form is shown in Fig. 636. They are obviously unsuitable for carrying the smaller qualities, for which plate-belts can only be used.

Revolving Tables.—To economise the large amount of space occupied by cleaning belts, circular picking-tables are often employed. They generally consist of a horizontal circular plate revolving about a vertical axis. The centre part of the plate is made higher than the circumference where the coal is delivered. All the dirt picked out is thrown on to this shelf near the centre and removed from time to time, while the coal is discharged at any convenient point by a scraper.



Figs. 637 and 638.

An improved arrangement, designed by Mr. Wm. Haydock, is in use at Abram Colliery, where a mixture of coal and cannel has to be very carefully sorted. A circular table (A, Figs. 637 and 638), is keyed on a vertical shaft driven by bevelled gearing, and in the centre is a raised platform, or boss, C, upon which the picked material is placed by hand. Curved scrapers (E and F, Fig. 638), working on hinges at the circumference, are provided, and these direct the qualities made into their respective shoots; D is a scraper (which can be moved up and down by an overhead lever, H) on the raised portion, and is used to turn the material off this part on to the table. The mixed coal and cannel is delivered on to the edge of the table by the screen, B, and the material which occurs in the smallest quantity is picked and deposited on the raised platform, C—that is to say, if coal and cannel are being sorted and coal predominates, then the cannel will be picked out. The table revolves and brings the material up against the scraper, E, which sweeps it off into the shoot, as shown by the arrow. The cannel on the raised platform is swept off by the scraper, D, and directed into its proper shoot by the hinge, F. The tables are 12 feet to 15 feet in diameter, and make about 1½ revolutions per minute. If a cannel truck is not in position under the shoot, this mineral can be allowed to accumulate on the platform, C, by raising the scraper, D.

Loading Shoots.—When the coal reaches the end of the belt, it is directed down a shoot into a waggon. These shoots, if fixed, have to be placed at such an inclination that the coal readily slides down them, and towards the end it attains considerable velocity, dashing violently into the bottom of the truck and causing considerable breakage. With a tender coal this becomes a serious matter, and numerous attempts have been made to minimise the damage.

A common procedure in France is to make the shoot a series of plates, which travel along as a belt; indeed, it may be considered a belt, but instead of the plates being flat, each one is of angle form. The vertical ridges effectually prevent the coal slipping (Fig. 639). Each lump is gradually taken down the slope and deposited in the truck. The leading end is carried by a movable jib, and can be raised or lowered to suit the height of coal in the waggon

An ingenious coal-lowering apparatus has been introduced by Mr. C. Soar.* It consists of a series of hinged shelves (*a*, Fig. 640), bolted to pitch chains, which are driven in the direction shown

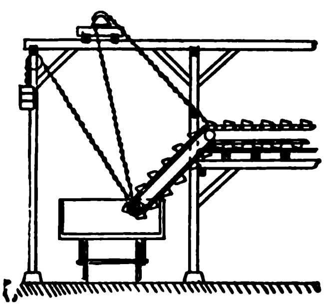


Fig. 639.

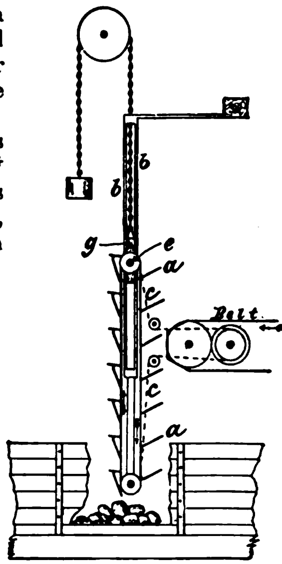


Fig. 640.

by the arrows by an endless driving chain, shown by the dotted line, *c*, actuated from the drum-shaft of the picking band, at such a speed that, as the belt delivers the coal from its end, a shelf is always in a proper position to receive it. The top shaft, *e*, works in two travel blocks, *g*, which travel up and down between the fixed guide bars, *b*. The whole apparatus can be raised or lowered, and held in any position, by a rope attached to a winch. The coal has no greater distance to fall when the truck is empty than when full, and is put down as if by hand.

An excellent loading shoot is employed at Bascoup. It can be turned about its point of support and lengthened or shortened at will by means of a suitable arrangement. The part, *a* (Fig. 641), can slide in the part, *b*. A counterpoise, *c*, whose chain is fixed to

* *Fed. Inst.*, i., 183.

the part, *a*, balances the entire shoot when at its minimum length. The variation of the length is made by a small windlass, *d*, mounted at the extremity of the part *a*, and whose chain is fastened to the end of the part *b*. A second windlass fixed to it allows the hopper to be raised or lowered at will; the chain of the windlass, which causes the part *a* to enter the part *b*, stretches the chain of the windlass *d*, thus making the whole perfectly rigid. A movable nose, *f*, also allows a discharge at two points of the axis of the hopper without displacing

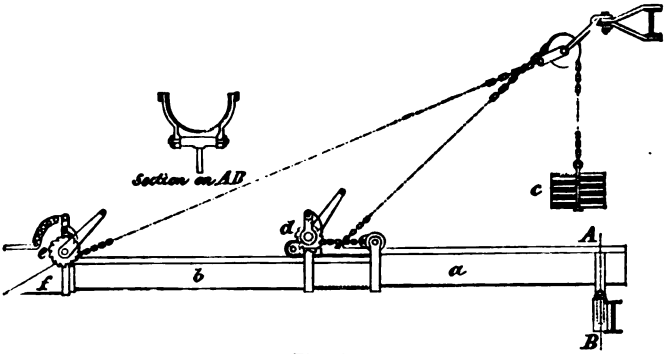


Fig. 641.

it; this nose has another *rôle*, playing the part of a stopper and regulating the discharge.

With the aid of this telescopic shoot, the coal can be directed on to any part of a waggon's surface, practically without any drop. Not only does this save expense, one man doing the work, but the most tender coal can be loaded without breakage. It is necessary that the shoot should be kept full of material.

TYPICAL ILLUSTRATIONS.—Having described the different parts of a screening establishment, a description of several arrangements as applied at collieries is given to illustrate the way they are combined amongst themselves. To a certain extent, any desired arrangement can be made, the one adopted depending, as has been before remarked, upon the conditions locally existing at the colliery, the amount to be treated, and the quantity and nature of the refuse.

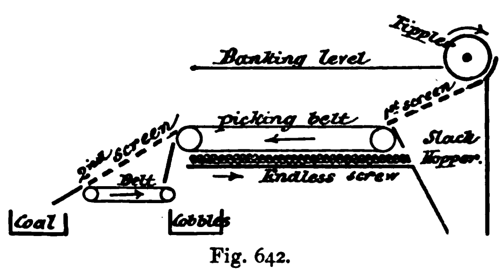


Fig. 642.

Pemberton Colliery.—The screens here have fixed bars. All the tubs are tipped on to the first one, which removes the slack, this falling into a hopper. All that passes over this screen is conveyed by a shoot on to a travelling wire picking belt. During the passage of the coal along the belt, any dirt is removed by hand-picking and any fine particles which have escaped falling through the first screen pass through the opening in this wire belt, and fall into a trough with sloping sides, in the bottom of which is an endless screw, which by its revolutions carries the slack into its proper hopper (Fig. 642). The round coal, on reaching the end of the picking belt, falls on to a second screen, which separates it into two qualities; the larger size passing over the screen drops at once into a railway waggon, while the cobbles which pass through this screen fall on to a travelling belt made of iron plates, and are conveyed to another truck. The arrows indicate the direction which the coal takes.

Brinsop Hall Colliery.—At the Arley Mine Pit, the coal, after passing over a screen, is carried along by a steel-wire picking belt,

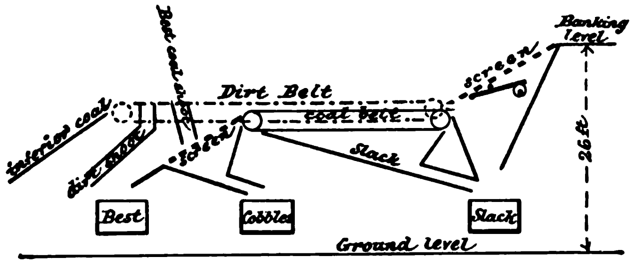


Fig. 643.

16 feet long by 4 feet wide, and having a mesh 1½ inches by 1¼ inches. To do away with the disadvantage of fixed screens, the lower portion of the bars are made movable by the arrangement already described. The screen is divided into two portions by a movable plate, about 14 inches broad, working on a hinge at its upper end. By means of the hinged plate, the coal can be steadied on to the bars, and, in addition, a vertical rake-stop is provided for the same purpose. The bars above this plate have an inclination of 14½ inches to the yard, while that of the lower ones is 19½ inches to the yard.

Running the entire length of the picking belt and on both sides, are fixed two planks on which the chipping is done; all the slack produced by this operation falls through the wire meshes and passes down a shoot into the slack waggon. At the end of the belt a second screen is fixed with bars about 4 inches apart, which takes out the cobbles, the remainder passing into the coal trucks.

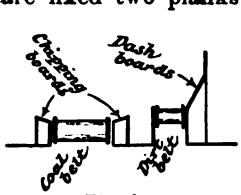


Fig. 644.

All the dirt and inferior coal is picked off the wire belt and thrown on to another travelling belt running by the side of the first one, about 20 feet away, but placed at a slightly higher inclination. Fig. 643 shows an elevation of the entire installation, while Fig. 644 gives a cross-section of the arrangement of the belts. These dirt belts are formed of old flat steel-wire ropes lying side by side, and are about 15 inches broad and 37 feet long. Any good coal is chipped off and thrown down a shoot on to the second main screen, while the dirt and inferior coal pass on to the end where they are divided, the former being directed down a side shoot into tubs, while the latter passes over the end into land sale carts.

Hilda Colliery.—This colliery is situated in the centre of a town, and the arrangement of the heapstead affords a typical illustration of what can be done in a confined space if required. On leaving the cage the tubs gravitate to a turntable (*a*, Fig. 645), and can either be passed to two tipplers used for land sale; to a third road, if dirt or refuse; or to a fourth road, if for the screens, where they are caught by a creeper and lifted up to such a height that when released they run by gravity on to the weighing machine, where they are automatically arrested by an arrangement shown in Fig. 646. A rod, *a b c*, is slung from a convenient place, *a*, the end *c* being kept in position by its own weight and prevented falling to the ground by the collar, *d*, on the vertical rod. A tub is shown held in position on the weighing machine. The next tub coming in the direction indicated by the arrow, strikes the rod near the point *b*, and as it proceeds down the rails lifts up the end *c* and releases the first tub. As soon, however, as the back end of the tub passes the point *b* the link drops down and locks the tub, keeping it on the machine until the succeeding tub releases it.

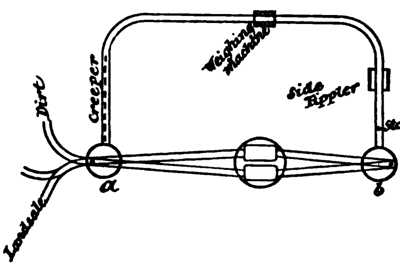


Fig. 645.

After the tubs are weighed they run on to a machine-driven side tippler and are discharged, thence proceeding to a second turntable (*b*, Fig. 645), and being turned through a right angle; thence to the shaft. The whole area of the flat sheets is about 60 feet by 45 feet, *a* being about 18 feet away from the pit, and *b* about 15 feet.

After being tipped, the coal is received into a regulating hopper, and thence passes on to a wire-gauze jigging-screen, in which three gauzes are superimposed one above the other (Fig. 647). The first

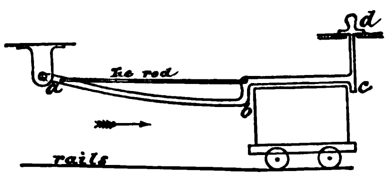


Fig. 646.

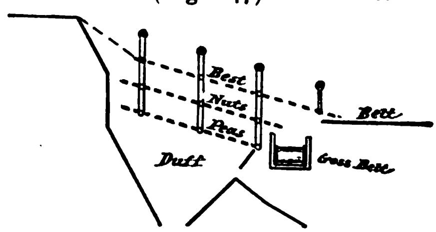


Fig. 647.

takes out large coal and delivers it on to a picking belt; the second, which has a mesh $\frac{5}{8}$ inch square, separates nuts, which are delivered on to a small cross-belt, and from thence to a picking belt running parallel with the main belt; while the third gauze separates the remainder into peas and duff, or fine. By an arrangement of traps, the nuts and peas can be remixed and loaded as one class of coal, and the peas and duff as another, or, if required all three can be combined; in addition, the top screen can be plated and unscreened coal made and loaded at the far end of the main belt, a reversible trap being provided there for such purpose.

Placing the screens one below the other, without any shoots to conduct the material passing through one screen on to the head of the screen immediately below, saves an amount of vertical space; but the sorting cannot be so accurate as is desirable, as the coal which falls through near the base of the top screen scarcely passes over the next screen at all, but at once goes to its shoot. If all the coal has to be delivered to the top of each screen, the banking level must be a considerable height above the ground, but to overcome this disadvantage a common practice in the Yorkshire coalfield is to convey the coal from the base of one screen to the top of the next one by means of conveyors similar to those already described.

Hewlett Pit.—At the No. 2 shaft two separate shaking screens are fixed. The general arrangement will be seen from Fig. 648. The coal is tipped on to the first screen, to which a rocking motion is imparted by means of an eccentric and rod, *e*, the screen being suspended by four arms, two of which are shown at *a b* and *a′ b′*. This first screen is fixed at an inclination of 14 inches to the yard,

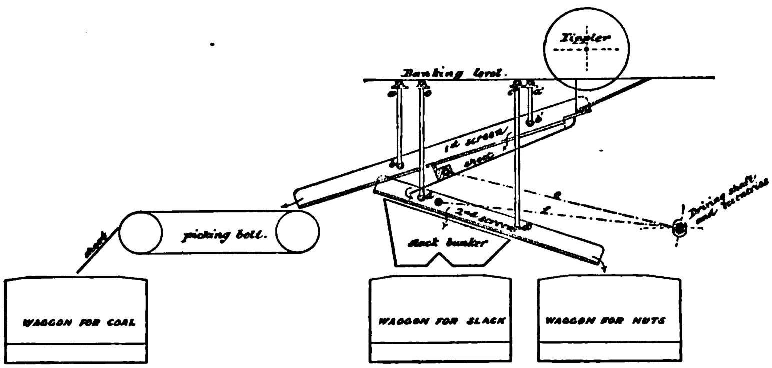


Fig. 648.

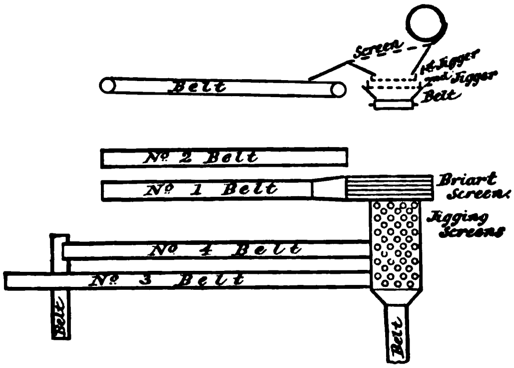
and the meshes are 1 inch square. The round coal passing over it falls on to a wire picking belt fixed in the same line as the screen where the best (merchants') coal is picked off, the cobbles passing over the end into a truck. All the material passing through the first screen is conveyed by a shoot to the head of a second screen, suspended by the arms *c d*, *c′ d′* which also receive a reciprocating motion by an arm, *f*, and eccentric keyed on the same shaft as the first one. The meshes here are ½ inch square, and the mineral is divided into nuts and slack.

Aniche Colliery, France.—Only one tippler is used, this being a machine-driven side-tip one, and all the coal is turned on to a Briart screen, placed on a small inclination. The large coal passing over this screen is conveyed down a shoot on to a travelling hempen picking belt, No. 1, which carries it to a railway truck. During its passage there the coal is sorted by hand into two sizes, part being placed on the No. 2 belt (Figs. 649 and 650).

All the coal passing through the screen with oscillating bars falls on to a jigging-screen (No. 1), worked from an eccentric in the ordinary manner; this screen is fixed at right angles to the first one, and the motion is sideways. All the coal passing over is carried on to belt No. 3; all that falls through drops on to a second jigger fixed immediately below the first, and exactly similar to it, except that the holes are smaller. The small coal passes through, falls on to a belt, and is at once conveyed to the trucks; the larger coal passes over the screen and drops on to a travelling belt, No. 4, which runs parallel to No. 3, and at right angles to the screen.

The coal from the first shaker-screen is taken by the belt directly to a waggon, but that from the second screen after being carried along on its picking belt, falls on to another belt at right angles, and is conveyed to its proper waggon.

A noticeable feature of all the jigging-screens which the author has seen on the Continent, is the fact that they are made of perforated sheet iron with circular holes, no wire netting, either with square or circular holes, having been met with. The advantage of circular holes seems to be that only the proper sized particles can pass through; with square holes, the diagonal line is longer than the sides, and larger pieces than the square of the mesh can fall through.



Figs. 649 and 650.

No. 5 Pit, Bascoup.—The collieries of Mariemont and Bascoup possess very complete screening-plants, which allow the different kinds of coal to be easily separated and classified. That at No. 5 Pit, Bascoup, is the most recent and complete one. It is shown in plan in Fig. 651. The screens, picking belts, &c., are situated in a building 142 feet in length, and 92 feet in width, placed in the axis of the pit frame. The building comprises three levels or stages. (1st) The upper floor is used entirely for the haulage of full and empty tubs, and inclines towards the winding shaft, so as to allow the waggons to return there by gravity. (2nd) The intermediate stage is horizontal; it is at this level that the handling (sorting of the coal, &c.) is done and where the principal supervision is required. (3rd) The railway level or charging floor. The freight roads are not horizontal, being inclined in various ways in order to facilitate the handling of the waggons.

Circulation of Tubs on the Upper Floor.—As soon as the tubs come off the cage they are pushed on to one of the four ways (*a*, Fig. 651), and conducted by a creeper chain to the top of an inclined plane whose summit is at the commencement of the curve leading to the tippler. At this point the tubs disengage themselves from the chain and continue running, partly by the acquired velocity, which is very feeble, however, and partly by the action of their own weight. The height of the incline is determined experimentally, so that the waggon stops on arriving at the tippler, *b*. Each succeeding tub pushes away the one that has just been emptied. The empty tubs gravitate down the roads, *c*, to the rear of the shaft at *d*. The direction of motion is shown by the arrows.

Screens making Two Sizes.—The two groups of apparatus, Nos. 3 and 4, make two sizes, large and "*tout-venant.*" From the tippler, *b*, the coal falls upon the Briart screens, *e* (Fig. 652), inclined at 10°; the large coal remaining upon the sieve passes into the hopper, *f*, inclined at 22°, from which it is conducted to the loading place. The coal passing through the screen is received upon a shaking shoot, *g*, which throws it upon two revolving picking tables, *h*, where the dirt is removed; the coal falls into a loading hopper.

Screens making Five Classifications.—The two groups of apparatus, Nos. 1 and 2 are much more complete than those just described. They make five sizes—large, "*gailleteries, gailletins, têtes de moineaux,*" *

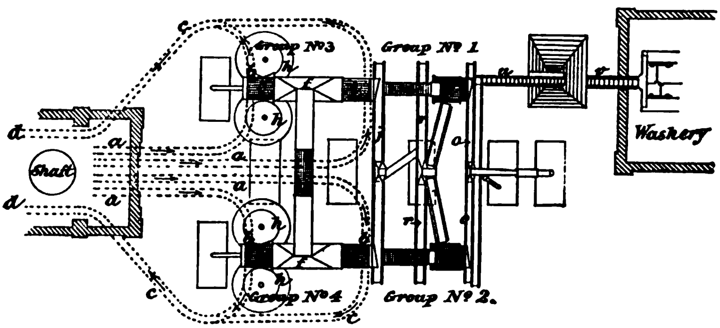


Fig. 651.

and fine. From the tippler, *b′* (Fig. 652), the coal is emptied on to the first Briart screen, *i*, inclined at 10°; this retains the large coal, which passes into the hopper, *f*, where it unites with that furnished by Nos. 3 and 4. That which passes through the screens is received upon a shaking shoot, *k*, inclined at 15°, which leads the coal to the commencement of a second Briart horizontal screen, *l*. The "*gailleteries*" which pass over the screen are pushed on to the cleaning belt, *j*, and carried into the loading hoppers, from which they are put into trucks. All the coal passing through the second sieve, *l*, falls down a shoot and is lifted by a bucket elevator, *m*, and delivered on to the third screen, *n*. This is horizontal, and retains the "*gailletins*," which then go to the belt, *o*, by means of which they are conducted into a loading hopper in the same way as "*gailleteries.*" The same hopper also receives the *gailletins* furnished by the other screen of this group. Finally, a fourth screen, *p*, receives that which falls through the third, by the aid of a shaking table, *q*. The "*têtes de moineaux*," which pass over screen, *p*, are received on a cleaning belt, *r*, and conducted to the centre of the work-shed, where they can either be loaded in a

* As it is impossible to give these sizes in their English equivalents, the technical names applied to them at the colliery are retained.

truck or sent back again by a second belt towards the screen, and mixed with the fine after it has been washed, the course adopted depending on the demands of the trade.

The fine, which passes the four screens, falls into the hopper, *s*, from which it can either be loaded directly into trucks by a shoot, or sent to the washer by means of the conveyor and bucket elevators, *u* and *v*, which deliver it on to a reciprocating table, where a further sizing takes place, to be described later on. The fine, instead of being transported by belts, and loaded at a central spot, like the *gailleteries*, *gailletins*, and *têtes de moineaux*, is either loaded into a waggon at the place where it is separated, or if destined for the washers, is sent there direct by belts, &c., from group No. 1. No. 2 group can also send its fine to the washers, but as it is rather removed from them, the small coal is taken by a belt to the bucket-elevator of the first group.

Washery.—All the coal destined for the washery, after being lifted by the bucket-elevator, is delivered upon a reciprocating table, formed of a series of perforated iron plates, arranged one below the other, which subdivide it into the following sizes:—dust, from 0 to 5 mm., and grains, from 5 to 11, from 11 to 16, and from 16 to 25 mm. Each of these four sizes is washed separately in a manner

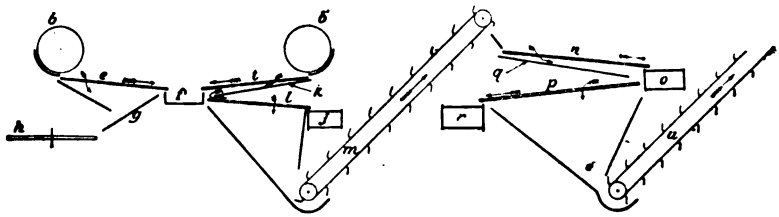


Fig. 652.

similar to that described subsequently; the two former in felspar washers of the Coppée system, and the two latter in the nut-washers of the same firm. The three sizes, 5 to 11, 11 to 16, and 16 to 25 mm., are mixed together again after washing, and sold. About 40 tons per hour can be treated.

Cross Creek Collieries, Pennsylvania.—Anthracite coal cannot be sold in the state that it comes from the mine. Owing to its compact nature, and the practical absence of volatile matters in its composition, it will not burn well unless the lumps are nearly of a uniform size, and are free from dust. The method of preparing anthracite coal for the market is therefore entirely different from that adopted with bituminous varieties. Uniform and varied sizing is essential, in order that when the lumps are burnt the air may have a free passage between them. In addition, large amounts of slaty or argillaceous coal and carbonaceous shale are intimately mixed with the pure coal, and cannot be separated by hand-picking; it is also generally impossible to sell all the large coal as it comes from the mine. For these reasons, machinery has to be employed to break up the larger pieces.

The more recent and elaborate machinery employed in Pennsylvania, has been admirably described by Mr. E. B. Coxe,* but as

* *Amer. Inst. M. E.*, xix., 398.

his memoir covers 77 pages of printed matter and is illustrated by 43 plates, it is impossible to give anything but the briefest summary here.

The coal is first tipped on to a fixed bar screen, which allows most of the small coal to pass through. The large coal passes by shoots on to a movable bar screen, and all the small that falls through is joined to that obtained from the fixed bar screen. Up to this stage, practically only two sorts are made, each of which is treated separately. The lump coal is then divided into three sorts, the first being the shale and slate, which goes to the dirt heap; the second is pure coal, which is sold as lump coal, if there is any market for it; the third product consists of pieces of coal and shale adhering to each other, and is too impure to go to market in its existing condition. Sometimes the shale can be chipped off with a pick, but more generally the mixture cannot be cleaned in this way, and has to be put through a set of crushing rolls, and then treated in gyrating screens, and the dirt picked out. The pure coal also passes through rolls, and is afterwards separated on gyrating screens, into several sizes or qualities, similar to those mentioned below.

All the coal that has passed through the fixed and movable bar screens is conveyed to two screens, each of which make three sizes, called "steamboat," "broken," and "egg." The smaller coal passes to another pair of screens, known as the stove or wet screens (A), which are situated a little lower down. The steamboat coal from both screens passes into a picking-shoot, and from thence to a loading-shoot, provided all the steamboat coal can be sold. If it cannot, a portion is passed through a set of rolls, and separated by screens into "broken," "egg," "stove," "chestnut," "pea," buckwheat No. 1, No. 2, and No. 3, and dust.

All the coal which goes to the stove or wet screens (A) is divided there into stove, chestnut, pea, and No. 1, 2, and 3 buckwheat and slime. These screens are worked wet—*i.e.*, a large amount of water is put on them, as the coal they treat contains mud and other impurities, and in order to make a good separation it is necessary to wash it. In addition, all the wet coal from this screen is cleaned in jigging coal-washers.

The movable bar screens are a modification of the Briart screen, arranged so that the bars only move up and down half as much as they move forward. With this construction the coal, although fed forward with rapidity, is not thrown up and down so much. The gyrating screens were designed by Mr. Coxe, and have been previously described.

The rolls employed for breaking the coal differ in one point from those generally adopted. The difference is in the form of the teeth. The rolls used are known as corrugated rolls, and the teeth are continuous from one end to the other. There are no points. The end of the tooth is slightly rounded, and the part doing the work is cast in chills, so as to give greater endurance. It is claimed that this type of roll breaks a lump of coal into two pieces of nearly the same size, while with rolls of ordinary construction the pointed teeth break the coal in much the same way as the stroke of a pick would do; that is, the lines of fracture radiate approximately from the point where the tooth strikes the lump of coal. Experience has also shown that separate rolls should be employed to break the coal into different sizes, as although all sizes below the size which is being broken are always made, yet the most economical method is to break any size as nearly as possible into the size immediately below it. In other words, it is more economical to break "lump" into "steamer," then break "steamer" as far as possible into "broken," the "broken" into "egg," and so on; of course, at each time eliminating all the coal below the size that you wish to break, before passing that size through the rolls.

Automatic shale-pickers are used in some parts of the establishment. They depend for their action on the fact that while the coal generally breaks into cubical masses, the pieces of shale of the same length and width are of much less thickness. Hence, if a quantity of shale and coal which has been passed through a screen and properly sized, the shale, if placed edgewise, would drop through a slit over which the coal would pass.

COAL WASHING.—Below a certain size it is impossible to pick out the dirt mixed with coal, and recourse has to be made to washing, for which a large variety of machines have been designed. Their principle and action are similar in every respect to those employed for ore dressing, but here it is the lighter material that is valuable. The theory of the subject is that bodies of different specific gravities fall through water at different velocities, the heavier more quickly than the lighter—that is to say, if both pieces are of approximately the same size; because it is obvious that a larger piece of a lighter material meets with as much resistance in passing through water as a small piece of a heavier material. For such reason a preliminary sizing should always take place before washing.

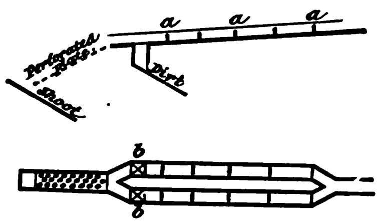
Sizing Apparatus.—The small coal which passes through the last screen is generally further subdivided, either by means of revolving sieves or trommels or reciprocating tables. The latter, perhaps, do the work better, but are not so convenient, as water cannot be employed; with trommels a stream of water is introduced and materially assists the operation. The disadvantage of a trommel having a mesh of varying size is that all the material has to pass over that part of the screen which has the finest mesh, and consequently the wear is considerable, but with such a soft substance as coal this objection is not very serious. It has been found that revolving screens require patching in the small (*fine*) portions about every year; their general life is somewhere from five to seven years, except when there is much sulphur present.

Revolving screens are unsuited for separating sizes below $\frac{1}{4}$ inch; and an apparatus which retains its German name, "*Spitzkasten*," is employed. It consists of a series of pyramidal boxes, upon whose sloping sides no material can settle. Each box is larger than the previous one. On entering the first trough, the speed of the water containing the material in suspension is checked, the particles of larger size settle down a little, and escape the velocity of the current, so that they soon reach the bottom of the trough.

The number of boxes determines the number of sizes made. A stop-cock is provided at the bottom of each box, through which the deposit can be swept out at any time by opening the tap; this device avoids any necessity for interrupting the main flow.

Trough Washers.—The first type of washer consisted of a trough, provided with a series of vertical stops, which prevent the coal and dirt passing on (Figs. 653 and 653*a*). At the point where the coal is washed the supplying channel is divided into two; into each of these divisions the stream of unwashed coal can be directed at pleasure. As soon as one trough is full, the dirty coal and water is directed into the other, and a current of *clean* water turned into the first trough, while at the same time the deposits of coal which have accumulated against the stops, *a a*, are agitated by the attendants with rakes, with the result that the lighter coal is carried over the obstruction, while the dirt (pyrites principally), being of higher specific gravity, remains behind. The washed coal passes on to an inclined sieve, where all the water is drained away, and thence by a shoot into trucks. As soon as all the coal is removed from the washing troughs, a hole in the bottom (shown at *b b*, in Fig. 653*a*) is opened at the lower end, the vertical stops are lifted out of position, and the accumulations of dirt are swept down and pass away through the hole, which is then closed up again. The vertical stops are returned, and as by this time the second trough contains a full charge of unwashed coal, the stream of dirty coal and water is diverted into the first trough, and a similar series of operations to those just described carried on in the second channel.

It is obvious that a large amount of labour is required. To reduce this charge, mechanically moved rakes are employed, the



Figs. 653 and 653*a*.

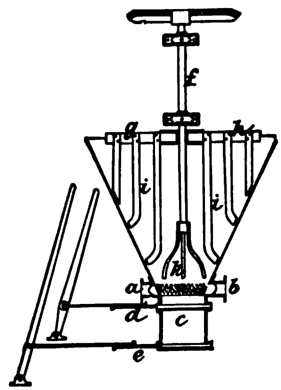


Fig. 654.

best form of which are those raking backwards, not forwards, or the unwashed material is likely to be pushed over the dam. The amount of water required is also very great, and the quantity of coal that can be treated is limited. Although the cost of working is large, yet upkeep and first cost are low, and in the hands of an intelligent trustworthy attendant the ordinary trough washer gives good results.

The Elliott washer has been designed to be automatic in its action, and to dispense with the services of a skilled attendant, but to retain the simplicity and low-working cost of the old form of trough washer. It is automatic and continuous in its action, and the necessity of changing the flow of water and coal into a second trough while the dirt was removed from the first has been avoided. The washer is constructed with a wrought-iron trough 18 inches wide, having sloping sides, being widest at the top and narrowest at the bottom. At each end of this trough a sprocket wheel is fixed on which a chain rides, and attached to the chain, at suitable distances and at right angles, are scrapers which correspond with the inside shape of the trough.

These scrapers form dams which are slowly moved up the trough against a stream of water. The trough is fixed at a suitable inclination, the coal is admitted at the centre of its length, and the water at the highest end, and as it runs to the lowest end carries with it the coal which is lighter than the dirt. The dirt settles in the scrapers, and is conveyed by them against the stream of water to the upper end, where it is discharged.

Robinson's Washer.—This well-known machine consists of an inverted truncated cone, with a diameter at the top about four times that of its diameter at the bottom (Fig. 654). At the base of the cone is fitted a water-jacket, *a b*, into which water under pressure can be brought so as to pass into the machine through a series of perforations placed all round the cone, the diameter of these holes being generally about ½ inch. Still lower is a cylindrical chamber, *c*, controlled by two slides, *d* and *e*, movable by the levers as shown. A strong shaft, *f*, is fixed vertically, exactly in the centre of the cone, and to it, through the medium of a cast-iron crosshead, are bolted four arms, two of which are shown at *g* and *h*. Each of these arms carries three iron bars, *i i*, projecting downwards and curved round at their lower extremity, in order to work close against the sides of the cone. The central vertical shaft terminates in four arms, *k*. Rotation is effected by bevel gearing.

The principle of this machine is the one common to all current classifiers—viz., that if two equal-sized particles of different specific gravities are allowed to drop through a stream of water, by regulating the velocity of the water it can be arranged that the particles of highest specific gravity shall continue to fall, while the lighter ones are driven upwards. Within certain limits, it is not necessary that the particles treated should be all of the same size, but it is perfectly clear that, unless some preliminary sizing takes place, there is a danger of either coal passing away with the water, or dirt being carried up with the coal, both of which results are unprofitable and undesirable.

The actual operation of washing is conducted in the following manner:—Coal is introduced at the top of the cone and falls into the water, and is kept in a state of agitation by the revolving arms. Situated some distance above the machine is a cistern, from which water under pressure is brought and introduced into the base of the cone through the pipes *a* and *b*, the regular distribution being effected by the holes in the plates already alluded to. The water-pressure is so regulated that it is sufficient to lift up all the particles of coal and carry them over the top of the cone, while it is not strong enough to force up the dirt, which falls downwards and accumulates in the base of the cone. Its removal is effected by the two sliding doors. As a rule, *e* is closed. When the space between *e* and *d* is full, *d* is closed and *e* opened, and the dirt discharged. The washed coal, after passing away at the top, is received on a perforated plate, and the greater part of the water drains away.

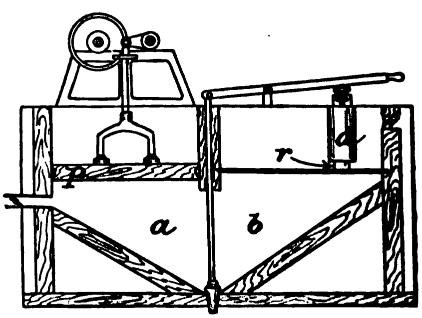


Fig. 655.

The success of this machine depends to a very great measure on the carefulness and attention of the attendants. The chief points are the time given to flushing, and the regulation of the discharge of the dirt. The machine is compact and occupies little space; it is also strongly constructed, and is not liable to break down.

Coppée Machine.—A great many of the very largest washing establishments are fitted either with the Coppée or Lührig machines, both of which are identical except in small details. Two different machines are used, one for washing the coal from ⅜ inch upwards, called the "nuts washer," and the other called the "felspar machine" for washing coal of sizes from ⅜ inch down to powder.

The nuts machine (Fig. 655) is of the ordinary continuous jig type, and consists of two compartments, *a* and *b*, in one of which the piston works, while the other is provided with a perforated strainer, slightly inclined from front to back. The piston, *p*, receives an up-and-down motion by being connected to cranks on a horizontal shaft, and the amount of this throw can be varied from 1¼ to 4 inches. An opening, *w*, runs along the front of the washing compartment, and through this clean coal continuously passes away. The shale is discharged through a small cylindrical compartment, *d*, connected to the side of the casing, but which starts above the level of the strainer,

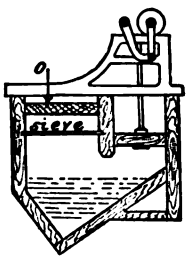


Fig. 656.

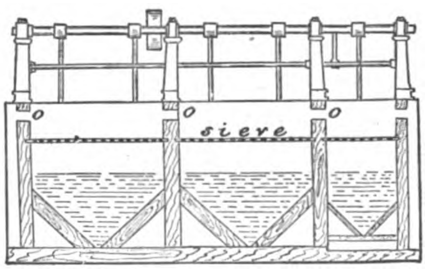


Fig. 657.

leaving a free space between the strainer and the lowest end of the compartment of about 3 inches. It is open at both ends and communicates with the outside of the machine through the opening, *r*. It is provided with a sliding door which regulates the discharge of the shale.

When the unwashed coal is introduced into the machine and the piston descends, it drives water into the compartment, *b*, and lifts the bed of the material resting on the strainer. On the return stroke, the heavier dirt falls faster than the lighter coal, while in the upstroke the lighter coal is lifted farther than the heavier dirt; the result is, that the two substances separate into layers, the coal being, of course, the highest.

The felspar washer is of similar construction, but differs materially in its method of working. It consists of a box, divided into two compartments by a longitudinal partition, in one of which the piston works as before (Figs. 656 and 657). It is also generally divided into two or sometimes three compartments in the direction of its length, each communicating with the other by openings, *o*, along the side, and through these the washed coal passes away. In the nuts washer, the holes through the sieve are smaller than the size of the material being treated, and consequently no discharge takes place through them, In the felspar machine, they are larger than the material, and the dirt passes through the sieve into the lower part of the apparatus. Three sieves are generally employed. The dirty coal is introduced at one end and gradually passes down over the remaining gratings, the clean material being finally discharged at the opposite end.

The chief peculiarity is the introduction of a layer of felspar, from 2 to 3 inches thick, on each sieve, whose specific gravity is greater than that of the material to be concentrated, and yet less than that of the gangue. The sizes of the particles of this bed are larger than the holes in the sieve. The whole framework of the machine is filled with water up to the level of each sieve, and as the pistons work up and down, a volume of water is forced through the holes in the bottom of each sieve, lifting the bed and the layer of material on it, and then allowing the whole to fall again on the return stroke. The lighter coal rises to the surface, and the heavier dirt gradually finds its way through the bed of felspar, when it falls into the bottom of the compartment to be removed from time to time. It is essential for thorough cleaning that the size of the felspar should be as small as allowable, and that the particles of mineral forming the bed should be of convenient density, have well defined rectilinear angles, and be of great durability to resist wear and tear. A point of considerable importance is the proper regulation of the delivery of water, which is controlled by a tap; upon this depends the progress of the material and the time it is operated upon.

For very dirty coal, perhaps no machine does its work so efficiently as this; indeed, everyone gives it the character of removing dirt. It is, however, expensive in the first cost, but requires little attention. Much depends upon the percentage of dirt originally present in the coal. If it is small, and, say, one-half of it is removed, the coke from the resulting product is a fair one; on the other hand, where the dirt amounts to from 15 to 3c per cent. and only 3 to 10 per cent. is taken away, the coke is very bad. With a dirty coal, probably it is best to use machines of this type.

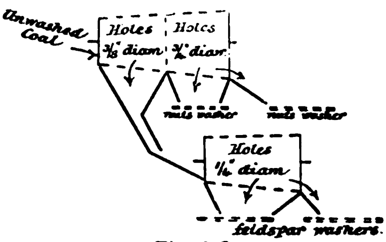


Fig. 658.

Fig. 658 gives a diagrammatic representation of a washery in South Wales treating about 200 tons per day. The fine coal from the screens (bars 1 inch apart) is raised by a bucket-elevator and delivered into a revolving screen, and separated into three portions: (1) the large, which passes over and goes to a "nuts" washer; (2) a size between $\frac{3}{4}$ and $\frac{3}{8}$ inch, also treated in a "nuts" washer; (3) the size below $\frac{3}{8}$ inch, which is carried off by a stream of water and delivered into a second revolving screen, having perforations $\frac{1}{4}$ inch diameter. Two sizes are made here—(1) $\frac{3}{8}$ inch to $\frac{1}{4}$ inch; and (2) $\frac{1}{4}$ inch to nothing. These are washed separately and then re-united.

The nuts washers are situated a floor above the felspar machines, and all the coal from them after washing is delivered on to a pair of rolls and crushed, and is afterwards mixed with the washed coal from the felspar machines, the whole being raised by a bucket-elevator, and then carried by a revolving screw and stored in four bunkers, each holding about 40 tons. Each one is filled consecutively, and the discharge is so arranged that the coal stands in each as long as possible in order that the water may drain away.

One small engine, about 15 inches cylinder by 3 feet stroke, does all the work, and there are only two men employed in the building—viz., an engineman who looks after the machinery on the first floor (engine, felspar washers, and pump), and an attendant who looks after the "nuts" machines and regulates the discharge into the bunkers. In addition, one man is employed outside to see that the slack is being delivered all right from the screens. The cost of an entire installation for washing 200 tons per day would be from £2000 to £2500. About 1000 gallons of water are lost per hour, this being, say, 10 per cent. of the total quantity used, and the life of a plant is variable, depending in a great measure in the way it is looked after. In bad cases it may be five years, in good, fifteen years.

Baum Machine.—The principal feature of this machine is the use of compressed air at a pressure of from 1·5 to 2 lbs. per square inch, which is alternately sent into and exhausted from the water-box, for producing the oscillation of the water up and down, in place of the ordinary reciprocating piston. The compressed air is controlled by a valve, *a* (Fig. 659), and enters the water chamber, *b*, through a piston valve, *c*, driven by an eccentric and link, *d*. Holes, *e*, through the piston cylinder are provided for the exhaust air. The coal to be treated is admitted at *f*, and in some cases a valve, *g*, is employed to regulate the supply of water, although as a rule the coal is brought to the washers down gently inclined channels by a small current of water, and in such cases the valve, *g*, is dispensed with. The cleaned coal passes away over the bridge, *h*, while the shale is removed through two sliding doors, *i*, controlled by handles, as illustrated, and falls down into the bottom of the box from whence it is carried away by the spiral conveyor, *l*. Neither in the coarse nor in the fine jiggers is any felspar bed employed. In the former machines the valve makes from 50 to 70 strokes per minute, and in the fine jiggers from 75 to 110 strokes per minute.

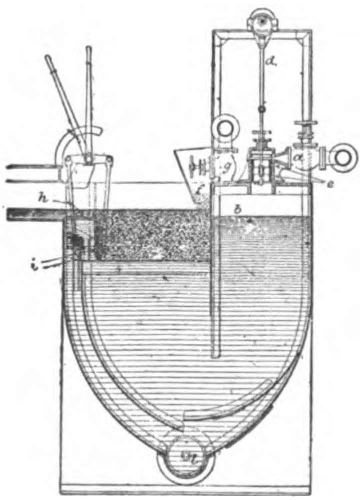


Fig. 659.

It is claimed* that, in addition to the mechanical advantages of absence of noise and shocks and diminished driving power required with this machine, it possesses a superiority over piston jiggers in the fact that the rise of the water is practically accelerated during the whole of the stroke, so that a greater proportion of the stroke is effective for causing separation, and that while the suction action which takes place during a portion of the return stroke of the piston

* *Fed. Inst.*, vii., 159.

in ordinary jigging machines has a tendency to set the bed in a compact mass and prevent separation, no such action follows in this machine. Indeed, it is said to be so effective in this respect that the fine jigging machines can be worked without allowing the coal to rest on the sieve at all, passing indeed through the jigger the whole time in a floating condition.

Conclusions.—The relative advantages of coal washing have been fully considered in a paper by Mr. R. de Soldenhoff * and in the discussion which followed. The interesting point is the absolute cost of washed coal, after charging the cost of the unwashed coal delivered to the machine. For example, a certain number of tons of coal are delivered to a washing machine, which if not washed would in the ordinary course of affairs be sold for a certain sum per ton, the impurities contained in them being weighed with the coal. During the process of washing the greater part of these impurities is removed, and the resulting product weighs considerably less (at Dowlais 4697 tons of unwashed produced 3433 tons of clean coal, the remainder was dirt and loss in washing; the latter amounting to 2·72 per cent. on the 4697 tons, or 3·59 per cent. on the 3433 tons). So many tons are actually lost which could have been sold at the market rate, and these represent a certain sum of money which, being divided by the number of tons of *washed coal* recovered, gives a certain amount which must be added to the cost of washing.

As the value of the unwashed coal increases, so does this charge, and a point may easily be reached where it neutralises the increased value of the washed product, especially if the coal is sold, not coked. In the latter case (coking) the advantages of producing coke with little ash are great, less flux is required for the furnace, and less slag is produced and also less coal has to be handled. Washing might easily make an uncokable coal into a cokable one; as a very impure coal, although a caking one, may, owing to the large amount of ash in the coke, be unsaleable.

There is another point which must be specially noted: the same water must not be used over and over again for washing, without some efficient filtering arrangement, or the lustre of the coke will be completely lost. At Earnock Colliery, Lanarkshire, the water is pumped on to the top of the dirt-heap, and allowed to percolate through it before being used again. Settling tanks do not entirely remove the difficulty.

Dry Coal Cleaning.—Messrs. Basiaux and Léonard † describe an apparatus for cleaning coal by means of an air blast at Rhein-Preussen Colliery, Germany. The coal is first separated by a trommel into five sizes the largest of which, 1 to 2 inches in diameter, goes direct to the coke ovens; the others pass each to a separate cleaner, where the coal is spread out in a trough about 6 feet 9 inches long by 2 feet broad, divided by a horizontal perforated plate into an upper and lower chamber. One end of the trough is in communication with the air blast, the other with the cleaned coal dust-chamber, from which, however, it is separated by a sloping screen, the bottom end communicating with a hopper placed below the trough. In the lower compartment of the trough is an endless belt, which carries the coal to be cleaned in an opposite direction to the air blast.

The air blast blows the pure coal-dust through the screen, and the

* *So. Wales Inst.*, xiv., 88. † *Rev. Univ.* (2ᵉ Série), ix., 135.

larger coal against the screen, down which it slides into a hopper, while the stones, too heavy to be affected by the blast, are carried forward by the endless band into another hopper.

The clean coal gave 7 per cent. of ash, and the stones (high) 45 per cent. of coal. The cost of cleaning (exclusive of interest and depreciation of capital) was given at 0·79d. per ton.

An air blast has been successfully used at several collieries as an adjunct to wet cleaning. The small coal is first subjected to the action of an air current in order to drive off the very fine dust which otherwise acts prejudicially during the subsequent washing. At La Grange Pit, Anzin,* about 12 tons per hour of fine coal up to 0·20 inch is brought by a spiral conveyor and dropped down in a sheet on to a short table set at an angle of 45°, where it is acted upon by a thin but wide horizontal air blast having a speed of about 87 feet per second. The lighter dust is blown over the edge of the shutter while the larger pieces fall down and pass away to the water classifier.

Briquettes.—A great part of the small coal produced at numerous collieries is unsuitable for coking, and can, in many instances, only be utilised by compressing it into blocks of patent fuel called briquettes. The grains of coal possess no adhesive power, and consequently some agglomerating material has to be mixed with them before they are introduced into the press. Numerous substances have been suggested, but all have given way to artificial pitch which is the solid residue obtained from the distillation of coal tar. The consistency of the coal-tar pitch is of importance; it must be hard enough to be broken and powdered easily, but soft enough to become pasty when subjected to steam heat.

While the grains of coal must not be too small or they require an excessive amount of pitch, they must not be large, and consequently it is usual to first pass the coal through a disintegrator where it is broken up into grains the size of coarse gunpowder. A certain proportion of finer particles is advantageous as these fill in the interstices between the larger grains and produce a more homogeneous briquette. In Great Britain washed coal is rarely employed, but the opposite condition of affairs exists throughout Europe, and is responsible for a distinct difference in the preliminary preparation of the paste before it reaches the press, as almost invariably in the latter cases the crushed coal is passed through some form of drying furnace before going to the pug mill of the compression machine, which is rarely, if ever, done in Great Britain. Although the expense of operating such a furnace apparently increases the cost of production, it has been found that dried coal requires less pitch for agglomeration than the undried mineral, and that the reduction in cost in this item more than compensates for the expense of working the furnace.

The shape and size of the briquettes is dependent on certain economical considerations. For manufacturing purposes the rectangular form is usually employed, the blocks varying in weight from 8 to 20 lbs. Large blocks are apt to be less solid in the interior than on the outside, while the labour cost of preparing the smaller blocks will obviously be greater than that of the larger ones. Undoubtedly the uncompromising shape of the briquettes manufactured in Britain has prevented their use for domestic purposes. In Europe every shape is made varying from an ordinary brick to ovoidal per-

* *Ann. des Mines* (9e Série), xi., 123.

forated bullets about the size of a goose's egg. The former are often perforated and the blocks frequently grooved so that they may readily be broken into smaller pieces more suitable than the larger ones for domestic fires. Large quantities are made every year, and the demand is increasing. The only objection against them is the rather dense and nasty smoke produced on burning, but this can be kept down to reasonable limits by reducing the quantity of pitch to the minimum consistent with proper cohesion.

Two distinct classes of presses are employed; in one the briquette is subjected to compression on both sides, while in the other type compression only takes place on one side. Theoretically, the former must produce a briquette of more equal density on both sides than the latter, but it has been stated on good authority * that the difference is more imaginary than real. Single compression machines possess one advantage over those employing double compression, in the fact that each mould may be arranged to carry a compression piston with it, so that accuracy of movement in the table is not essential. This accuracy is difficult to obtain, and any deviation from it is liable to result in a serious accident with the double compression machines as the pistons have to enter the moulds. In spite of this fact, double compression is considered such an advantage throughout Europe, where the manufacture of briquettes has probably reached a degree of excellency unapproached elsewhere, that it is employed in the majority of instances.

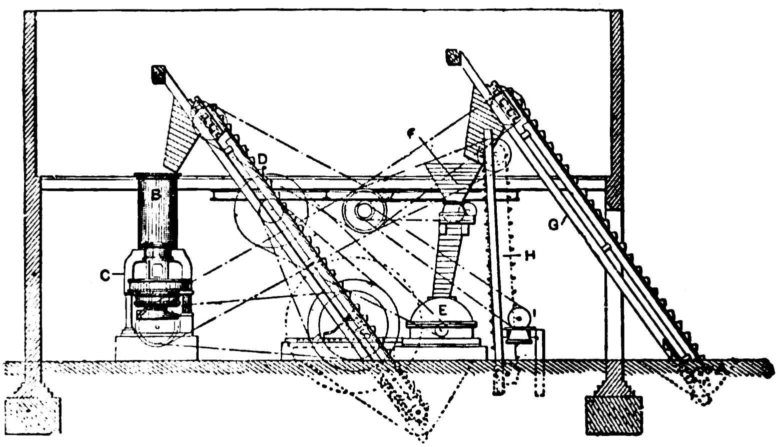


Fig. 660.

Before the mixture of coal and pitch enters the moulds of the press it is invariably passed through a vertical pug mill some 3 to 3½ feet in diameter and from 6 to 8 feet high, and heated until it is quite pasty. The mill contains revolving arms which turn over the paste and force it downwards, and may be heated either by a steam jacket or have steam injected directly into it. In either case the steam should be superheated or large quantities will be needed, while, in addition, if the steam is not superheated, and is injected directly into the pug mill, the condensation is so large that the

* *Inst. C.E.*, cxviii., 239.

resulting briquettes contain an excessive amount of moisture. On the other hand, a certain amount of water should be present when compression takes place in the moulds to serve as a lubricant between the particles of coal and to enable them to slide easily on one another. Unless the coal is previously heated in a drying furnace too much steam would be required to properly heat the pug mill by steam jacketing it, and consequently direct injection is more economical.

A typical British artificial fuel plant is illustrated in Fig. 660. The small coal is tipped from waggons into the pit, A, and is raised by the bucket elevator, G, to the distributor, F, where it is mixed with a definite quantity of pitch which has been placed by hand in the mill, I, roughly crushed there, and afterwards raised by the elevator H. The pitch is not ground small in the mill, I, but is only broken into fragments of such a size that they will readily pass through the distributor, F, which consists of a fluted roller with unequal openings working in a case. Definite proportions of coal and pitch, which can be easily altered to suit the conditions, are thus delivered into the shoot leading to the disintegrator, E, where both grinding and intimate mixing take place. The ground mixture is raised by the bucket elevator, D, and delivered into the pug mill, B, into which

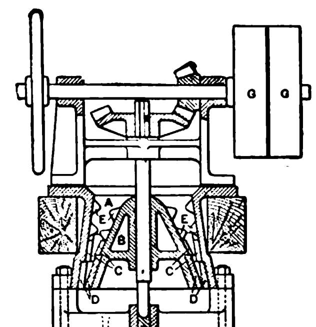


Fig. 661.

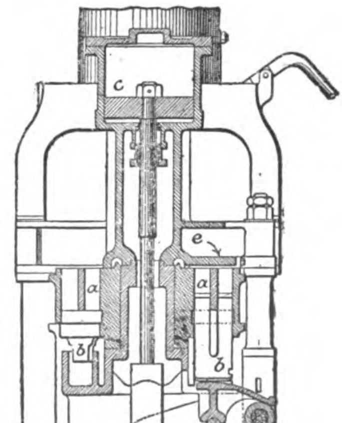


Fig. 662.

steam is blown through three nozzles. The mass after being thoroughly heated falls on to the revolving plate of the press, C, and is made into briquettes. The mill manufactured by the Uskside Engineering Co. for roughly grinding the pitch is shown in Fig. 661, and consists of a cone revolving in a conical casing, the former being driven through bevel gearing and belt pulleys, G. The upper part of the mill is lined with coarse teeth, E, cast on, while the lower part consists of fine hard steel teeth, C, which are renewable when worn. The degree of coarseness obtained can be varied by raising or lowering the central cone by means of the lever, F, at the bottom. The pitch is fed in by hand at A.

The fuel press designed by Mr. A. J. Stevens is illustrated in Fig. 662. The pasty mixture of coal and pitch passes from the pug mill into the feeding pan of the machine, and is forced into the moulds, *a*, which are cast in a circle round the die table. Each mould is fitted with a compression piston, *b*, and when a full mould reaches the position shown steam is automatically admitted beneath the piston in the cylinder, *c*. This is connected through the piston-rod with a lever, *d*, on which the pistons, *b*, rest; these are consequently raised, and the paste is forced against the pressure plate, *e*, thus forming the briquette. The table continues its travel, one mould at a time, and the compression pistons moving up an inclined plane gradually lift the briquette out of the mould in about one quarter of a revolution, and deposit it on the surface of the table from whence it is moved by a scoop.

A typical French plant as constructed by Messrs. Biétrix & Co. is shown in Fig. 663. The washed coal which has been allowed to drain for thirty-six hours is tipped into the pit, *a*, raised by the bucket elevator, *b*, and carried by the spiral conveyor, *c*, to the centre of the drying furnace, *d*, from which, after treatment, it is discharged into

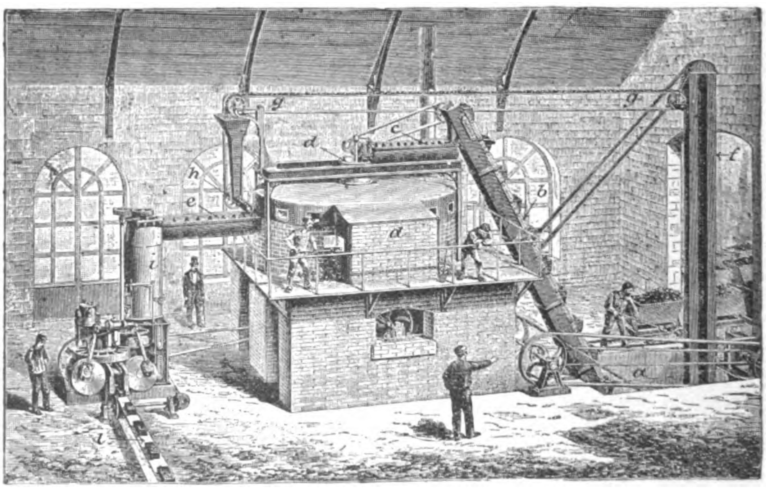
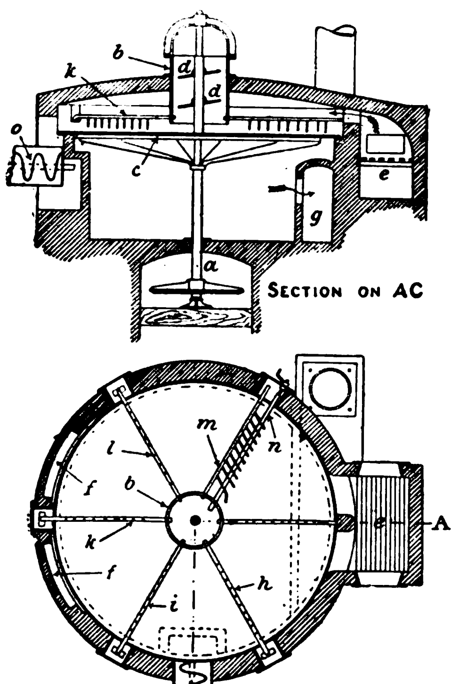


Fig. 663.

the spiral conveyor, *e*. At this point it is mixed with a definite proportion of pitch, usually about 8 per cent. The pitch is first broken by a pair of toothed rolls having projecting teeth, those of one roll fitting between those of the other, and then passed to a Carr's disintegrator which breaks it up into the size of coarse sand. It is afterwards lifted by the bucket elevator, *f*, on to the carrying belt, *g*, which drops it down a shoot into the small conveyor, *h*. By properly proportionising the sizes of the driving pulleys, the quantity of pitch delivered to the conveyor, *e*, can be varied as desired. The mixture of pitch and coal is then carried to the pug mill, *i*, which is steam jacketed, and, after further heating and mixing by revolving arms, is fed on to the mould plate of the machine and compressed into blocks which are subsequently delivered on to the carrying belt, *l*, and conveyed to the waggons. As the coal is first dried in a furnace, the briquettes contain a very small amount of moisture, and, in addition, less pitch is required, as the coal is softened to a certain extent by the heat. Messrs. Biétrix & Co. after an experience of many years have avoided the direct use of steam as a heating medium, finding that the presence of moisture should be avoided in the manufacture of homogeneous briquettes.

The furnace is circular, with an arched roof strengthened by a wrought-iron casing. A vertical shaft (*a*, Figs. 664 and 665) passes up through the furnace, and through a cast-iron cylinder, *b*, in the roof which carries the top bracket for the shaft. This shaft after passing through the floor is supported by an adjustable footstep, and has keyed on it near the bottom a bevel wheel driven at such a speed as keeps the briquette press fully supplied. The table, *c*, is fixed to the shaft, and above it are fixed the knives, *d*, which direct the coal fed in by the conveyor at the point, as previously described. The gases from the furnace, *e*, first pass over the coal on the table, then down two side flues, *f f*, in the walls of the oven, and return beneath the table to the flue, *g*, and chimney. There are six openings in the walls of the chamber, through four of which are inserted radial arms, *h*, *i*, *k*, and *l*, supported at their inner ends by the cylinder, *b*, and carrying rakes which continually turn over the coal and spread it over the table The fifth opening carries two bars, *m* and *n*, one fixed and the other movable, connected by a series of scrapers, the inclination of which can be varied by turning the handle attached to *n*. In this way the coal is guided from the centre to the circumference, as the inclination at which the scrapers are set determines the length of time that the coal remains on the table ; it is finally swept off through the sixth opening into the conveyor, *o*. The usual speed of the table is from three to four revolutions per minute, and the coal generally remains in the furnace from three to seven minutes, average five minutes ; it has 7 to 8 per cent. of moisture on entering, and leaves with about ½ per cent. The temperature varies from 100° C. to 200° C., but as considerable



Figs. 664 and 665.

quantities of steam are generated and the coal is being continually turned over, it neither ignites nor loses its gases. The furnace is continuous in its action and only requires the services of one attendant.

The general appearance of the Biétrix press is illustrated in Fig. 666, and a cross section in Fig. 667, the same reference letters being employed in both instances. The mixers in the pug mill, *b*, are driven by gearing, *c*, and the paste passes down into the feed pan, *e*, which extends over the revolving disc, *d*. As this plate is horizontal and has three of its moulds exposed to the feed scrapers at one time, it is always properly charged. It is provided with a series of short roller pegs, *f*, projecting downwards, which engage with a cam groove, *g*, on the shaft, *h*, driven by a cogwheel, *i*. This cogwheel is driven by a pinion in the centre of the machine which also gears into a second cogwheel and gives motion to the shaft, *h′*, on the right-hand side. In this way the plate is turned, and at each turn locked in position while the presses enter the die, motion only taking place when the plungers are out of the moulds. Cranks, *k k′*, are keyed on the shafts, *h h′*, and are connected through the rods, *l*, to the twin lever, *m*, which carries the upper plunger, *n*. This lever has its fulcrum at *o*, on the ram of a hydraulic cylinder, *q*, and the cylinder itself is connected through a link, *p*, to the lower twin lever, *r*, carrying the bottom plunger, *s*, and having its fulcrum at *t*. When the lever, *m*, is drawn down by the rods, *l*, the plunger, *n*, enters the mould and compresses the paste against the lower plunger, *s*, which remains stationary until the resistance of the briquette to compression prevents much further motion. A reaction takes place and the upper lever then turns about *n* as a centre, and acting through

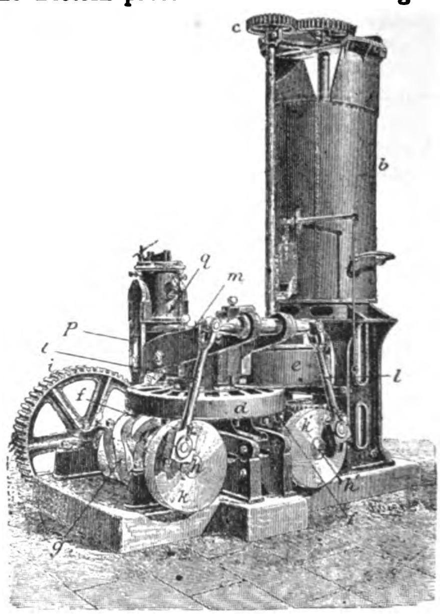


Fig. 666.

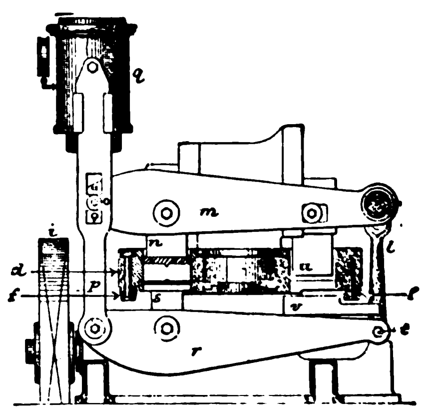
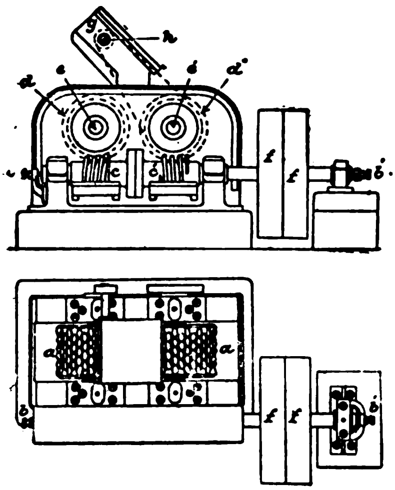


Fig. 667.

the ram cylinder, *q*, and links, *p*, lifts up *r* about *t* as a fulcrum, and causes *s* to rise, compressing the briquette on its lower side. The briquettes are pushed out of the moulds by the ram, *u*, on to a rocking table, *v*, which tips them on to a travelling belt. The function of the hydraulic cylinder, *q*, is to regulate the degree of pressure applied to the briquettes and to prevent a breakage should any hard substance get into the press by accident. This cylinder is supported by the links, *p*, and moves with the lever, *m*, whose fulcrum, *o*, is attached to the piston-rod of the cylinder. This fulcrum is capable of sliding in slots, *a*, and does so whenever the pressure exceeds that at which a spring valve is set on the hydraulic cylinder.



Figs. 668 and 669.

Of the machines making ovoid shapes, the Fourquemberg press seems to be most in favour. It consists of two cylinders (*a a*, Figs. 668 and 669), in rolling contact, the faces of each cylinder being provided with recesses corresponding exactly with those of the other. As the cylinders revolve through the motion transmitted from the pulleys, *f*, through the worms, *c c'*, and the worm wheels, *d d'*, which are keyed on the shafts, *e e'*, carrying the cylinders, the recesses form closed moulds and compress the paste enclosed in the cavities. The ovoid blocks so formed pass down with the revolving cylinders and are discharged at the bottom. As the two worms, *c c'*, act in contrary directions, all pressure is taken off the plummer blocks; adjusting screws, *b b'*, are provided for adjusting the shaft longitudinally. The paste is fed into the hopper, *g*, and its descent and distribution evenly over the upper surface of the cylinders is assisted by radial arms attached to the shaft, *h*. The cylinders are hollow and are heated by a steam jet.

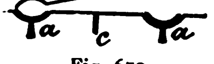


Fig. 670

In another type of machine two plates are employed, the lower one fixed horizontally and the upper one inclined at an angle. The horizontal revolving plate on which the paste is fed is provided with two rows of egg-shaped cups (*a a*, Fig. 670), from the bottom of which project vertical spindles. The upper plate is provided with two rows of oval recesses which correspond with the cups in the lower plate. The two plates turn on shafts, *b* and *c*, and during the revolution approach each other, and at this moment the lower cups are raised up by a cam which pushes up the spindles to which they are attached, and by these means the briquettes are compressed. A little further on the revolution the two plates separate again, and the cups being still further raised, the briquettes are discharged.

The unavoidable waste in manufacture is considerably larger with ovoid balls than with rectangular blocks, owing, in the first place, to the spaces between the moulds on the cylinder, but more particularly to the tendency of the balls to crumble, due to the rolling action by which they are produced. The waste which varies from 4 to 10 per cent. can be minimised by making the rollers of as large diameters as is reasonable, by increasing the percentage of pitch and moisture in the paste, and by the careful and regular feeding of the paste into the machine. Although rectangular blocks possess advantages due to the ease of manufacture and the facility with which they can be stored and transported, yet ovoid balls which correspond with "nut coal" are more useful in special cases. There is little or no breakage during transportation owing to the absence of sharp corners, and as they do not require to be broken before use there is no waste from this cause. For domestic purposes they are certainly more convenient owing to the manner in which combustion is assisted by the tendency the balls have to arrange themselves in the most advantageous position in the fire-grate, leaving numerous and regular passages between for the circulation of air and flame.

Both oblong and ovoid briquettes are frequently perforated for the purpose of ensuring more rapid combustion. In the Biétrix press, the upper piston is provided with a series of projecting pins which enter the paste before compression begins and are then held stationary by springs during the remainder of the movement. The revolving machines have a comb suspended between the tangential surfaces, and each ball is formed around a pin.

Of the many other binding materials which have been used as a substitute for pitch, such as lime, treacle, and starch, none have proved satisfactory in practice, as the briquettes have a tendency to soften and disintegrate more particularly under the action of rain. More satisfactory results have been obtained with the Velna process where petroleum or mineral tar only is used for enriching culm or other inferior combustibles, a briquette being produced from such material which is claimed to possess a heating power 30 per cent. higher than good coal. Petroleum residues are mixed with any convenient animal fat, and the whole saponified with soda to an emulsion which is used as a binding material, and by this means the culm, slack, or coal dust is cemented together. For the rest, any type of briquette machine can be used, the only special machinery needed being a mixing tub. These briquettes ignite much more quickly than coal, consequently time is saved in getting up steam; they are solid, keep any length of time, and there is little smell and no oozing. The quantity of the binder used is from 5 to 10 per cent. and the emulsion costs in Belgium about 50 shillings per ton or from 2½ to 5 shillings per ton of briquettes. They are said to be non-explosive, and, as a test, 24 lbs. was put into a retort at the Brussels Gas Works and heated to 1500° C.; gasification took place without any explosion or accident whatever.

The danger of spontaneous combustion in briquettes has been alluded to by the Prussian Steam Boiler Association, and instances given of stores that have ignited spontaneously after being exposed to the sun's rays for a long time, but competent authorities from the Ruhr district dispute that view, and state that although the briquettes are hot (122° F.) when leaving the press they may be sprinkled with water to hasten cooling, and can be safely loaded into waggons and forwarded to their destination after standing a few hours.

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