This Book is the property of the General Electric Company and must be returned to the Assistant General Foreman when you leave the Testing Department.

No.

Instructions

FOR

Testing Electrical Apparatus

GENERAL ELECTRIC COMPANY
TESTING DEPARTMENT
SCHENECTADY, N. Y.

June, 1914 No. Y-435

Fig. 1
SCHENECTADY WORKS, GENERAL ELECTRIC COMPANY

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GENERAL INSTRUCTIONS FOR TESTING

Introduction

This book is intended to give a general outline of the methods and precautions to be followed in test. Every one making tests must become familiar with its contents, and will be held responsible for carrying out tests in accordance with the methods and regulations outlined. If, after reading the description of any test, the tester is doubtful about specific points, he should refer the matter to the Head, or Assistant Head of the Section for further instructions before undertaking the work.

Instructions regarding wiring, starting, and operating machines as given in this book must be followed out carefully and conscientiously, and under no circumstances will deviations be allowed unless permission has first been received from those in authority. The importance of carefulness must be realized at the outset, since practically all accidents likely to happen to men or apparatus are due to carelessness or lack of appreciation of operating conditions. Any man doing careless work, or taking any risks that may have serious results, renders himself liable to discharge. No one must handle any wiring, connect or operate any switchboard or apparatus unless he is entirely familiar with all the conditions having reference to the test. In addition to being thoroughly familiar with the contents of this book, every one is expected to keep himself informed regarding instructions that are issued from time to time by the Heads of the Testing Department. Such instructions are posted, when issued, on the various section and general bulletin boards provided for that purpose.

CHAPTER 1

TESTING EQUIPMENT

Electrical Power

In order to test apparatus under operating conditions it is necessary to provide power at various voltages and frequencies so that either direct current or alternating current apparatus may be readily operated. Direct current power in the Testing Department is obtained either direct from the steam plants in the works located in Building No. 13 and Building No. 61, or from synchronous motor-generator sets installed in the various testing sections, the motors of which operate from the 40 cycle alternating current shop system. The regular direct current shop circuits furnish power at 125 volts, 250 volts and 500 volts. By using other shop generator sets connected in series with the above circuits, intermediate and higher direct current voltages may be obtained where testing conditions so require. These shop generators are commonly known in the Testing Department as "boosters" or "exciters." These generators alone may be used for furnishing small and moderate amounts of power at variable voltages and where close and variable voltage control is required. The regular shop circuits carry a fluctuating factory and railway load and, therefore, cannot be relied upon to give close voltage regulation. The latter must be used, however, wherever large amounts of power are required, in which case the voltage regulation must be effected by means of shunt boosters in series, the fields being controlled so as to maintain the proper terminal voltage.

Direct current power above 500 volts is used chiefly for the testing of high voltage direct current railway motors, and is obtained either by boosting the 500 volt shop circuit by an auxiliary generator or by means of a 1200/2400 volt 1000 kw. three unit set. In all cases when using a "booster" where it is not necessary to have one side of the 1200 volt circuit grounded it should be so wired that there will not be more than 600 volts between either side of the circuit and ground, since the 500 volt shop circuit is permanently grounded on one side. This condition can be readily obtained by connecting the boosting generator to the grounded side of the shop circuit. It must be understood in this connection that, in all testing work, no ground is to be used as a return circuit; that is, all circuits must be metallic. The 250 volt shop circuit has a grounded neutral; the 125 volt shop circuit is obtained between either side of the 250 volt circuit and the grounded neutral. All direct current shop circuits are wired through circuit breakers and switches permanently mounted on switchboards in each testing section. These circuit breakers and switches control the whole power in their section; they must, therefore, all be opened whenever power is no longer required.

Each of the principal testing sections is equipped with a number of small direct current generators capable of giving a variable voltage for testing work which are known as "exciters," because they are used frequently for field excitation. These generators are direct motor driven, steam turbine driven, engine driven, or belted sets. Turbine driven sets consist of a Curtis turbine driving one or two generators. When the turbine drives two generators, the switchboard is arranged so that the two armatures can be connected in series or multiple. Belted sets are considered as temporary testing sets and are only used in emergency, since their use requires greater care and attention. Their operation is also a possible source of danger, in consequence of the possibility of slipping or breaking belts, etc.

When an exciter runs in series with a power circuit in order to "boost" or "buck" the voltage the following points require careful consideration. *Under no circumstances must the source of driving power be disconnected while the exciter carries load.* Therefore, no machine must ever be used in such cases unless it is equipped with a speed limiting device in good working order, which will automatically open the circuit breaker of its armature circuit, should the machine begin to operate at excessive speed. Particular care should always be taken to see that all safety devices, in operation with such machines, are in good working condition before using them. All permanently installed motor-generator sets have a speed limiting device and low voltage release installed on the motors and generators. These are wired in series, so that in case the speed rises suddenly, both motor and generator circuit breakers will be automatically opened and the set shut down. For the same reason, if the power supply from which the sets are driven fails all breakers will be opened automatically. On direct current turbine driven sets the circuit breaker tripping coils are wired so that, when the emergency governor operates, their circuits are broken and the breakers in the generator armature circuit are opened.

Turbine driven generators should not be used to "buck" the shop voltage, since engine driven and turbine driven sets rely only on their friction and windage losses to prevent their speed from increasing when the direct current generator is "motoring."

Measurement of ohmic resistance is one of the most common tests and it frequently requires much skill to obtain consistent results. Special measuring booths are located in the various testing sections, fitted with measuring sets provided with D'Arsonval galvanometers. The resistance bridges and resistances used are especially adapted to the work. The measuring sets are supplied with storage batteries to furnish current for making the measurements. Care must be taken when charging the batteries to see that they are not charged at too great a rate, also that a high discharge rate does not last for too long a period. Occasionally the battery acid should be tested to see that it maintains the proper specific gravity. This test is made by a hydrometer.

In order to prevent vibration, the galvanometers are carried on piers, having no connection with the building foundations. It is essential that the galvanometers be carefully protected from vibration or shock, otherwise, resistance measurements cannot give accurate results.

Alternating current generators and motor-generator sets are furnished for generating and converting alternating current power at the various voltages and frequencies required in testing apparatus. Taps, from the 40 cycle alternating current shop circuit supplying 110 volts, are located in the principal testing sections. These are generally used for supplying power for the excitation of high potential testing transformer sets. As this power is supplied at a constant voltage of 110 volts, a potential regulator is employed with the high potential testing transformer, in order to obtain the high potentials necessary for the various types of apparatus tested. The wiring arrangement of a high potential testing set is shown in Fig. 2.

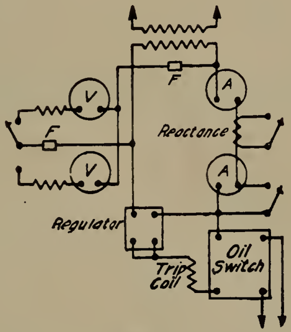


Fig. 2

WIRING ARRANGEMENT OF HIGH POTENTIAL TESTING SET

The Testing Department uses a 2000 kw. 25 cycle, 13,200 volt turbine driven generating set located in Building No. 61 for miscellaneous power tests. From this set power is distributed by means of high tension lines to Buildings Nos. 16, 12 and 114. This set is also used for supplying power to the railway at Wyatts Crossing and a considerable amount of railway testing is done by its agency. When such work is being carried on, an extensive system of high tension lines is connected to this machine, consequently the circuit has considerable capacity. When this circuit is in use, therefore, testers should be cautioned not to come in contact with any part of the circuit, or with the leads attached to it, since its capacity may give rise to a voltage sufficient to produce fatal results.

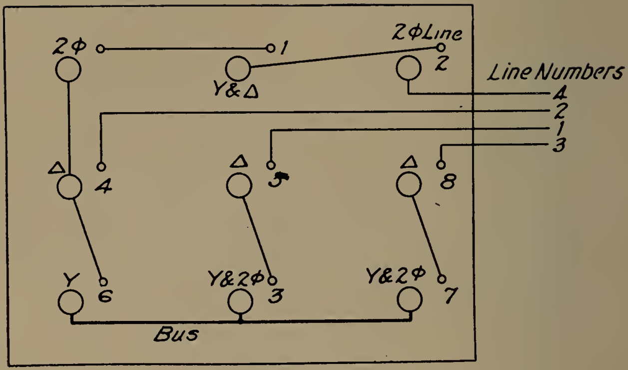


Fig. 3

PLUG CONNECTION BOARD FOR SHOP ALTERNATORS FOR CONNECTING △, Y or 2 PHASE

O Indicates front contact
° Indicates back contact

To Connect	Plug	Connecting
△	△ plugs	5 to 3, 4 to 6, 2 to 1, 7 to 8
Y	Y plugs	2 to 1, 3 to 6 to 7
2φ	2φ plugs	3 to 7, 6 to 1
3-phase lines = 1, 2 and 3.		
2φ lines { phase No. 1 = 1 and 3 (Line Nos.). phase No. 2 = 2 and 4 (Line Nos.).		
Remove **ALL** plugs to remove voltage from outgoing lines.		

No one working on this circuit, or other circuits of high voltage in the Testing Department, should approach nearer than 12 inches to the circuit, because actual contact is by no means always necessary in order to receive a dangerous shock. Due to high static capacity and other peculiar conditions, it is extremely important that the Head of the Section investigate thoroughly other sections which have taps to these lines and make sure that

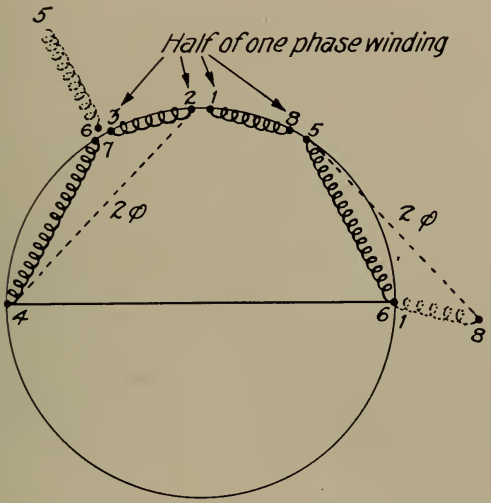


Fig. 4

DIAGRAM SHOWING INTERNAL CONNECTIONS OF PLUG BOARD FIG. 3 AND PHASE RELATIONS. PHASE WINDINGS ARE PERMANENTLY CONNECTED TO BACK CONTACTS AS SHOWN BY NUMERALS

they are not, and will not be in use, before anyone is allowed to operate this machine. This must be done in order that all taps may be properly protected when not in use, and also that no accidents may occur, due to misunderstandings. No wiring whatever should be done on this circuit while it is alive. In all cases, tests being operated from this circuit must have oil switches interposed between the test wiring and the lines so that connections to the lines may be made through these switches. Wherever temporary switches become necessary they must either be located at such a height or be protected by a mechanical barrier so that men cannot accidentally come in contact with them. Oil switches, permanently installed in the different testing sections for connecting to the lines mentioned above, must be kept locked open when power is not being drawn from the lines. The Head of the Section is responsible for seeing that these matters are attended to.

Larger amounts of power may be obtained from the three unit set in Building No. 61 consisting of an ATI-16-5600-300-10,000 volt, 40 cycle synchronous motor driving an ATB 24-6250-300, 4000/2300 volt, 60 cycle and an ATB 10-6250-300, 13,200/6600 volt, 25 cycle alternator. (See page 459 for nomenclature.) By the use of a bank of transformers a wide range of voltages may be obtained and distributed to the various testing sections. This set is very convenient for taking zero power-factor heat runs on large alternators.

A 1500 kw. three unit set consisting of two MPC 8-750-600, 250 volt generators driven by a 40 cycle synchronous motor is so wired that the two generators may be connected in multiple or series for supplying power at 250 or 500 volts.

In addition to these sets there are others situated in the various sections convenient for power or for "feeding back" tests or for the conversion of direct to alternating current or vice versa. The armature terminals of all alternating current generators are connected to high tension switch panels. By this means, the armatures, when their windings permit, may be readily connected Y or △ three-phase, or two-phase. Although such switchboard panels are insulated for 15,000 volts, the same caution, nevertheless, should be observed in operating them as though the lines were bare conductors. The armature coil terminals are each marked on the terminal board. One of the panels is shown in Figs. 3 and 4.

Steam Power

A considerable amount of steam is used for the testing of steam turbines, marine engines and for driving turbine and engine driven exciter sets, steam pumps, etc. Steam is supplied from power houses located in Buildings Nos. 13 and 61 and is conveyed to the Testing Department through underground mains in the yards. The steam pipes are placed overhead in all buildings. These mains are well lagged with asbestos covering and contain a sufficient number of expansion joints to take care of all expansion and contraction. Gate valves are located in the mains at the boiler houses and also just inside the building in which the testing section is located. Motor operated emergency valves are installed in the important mains, so that the steam supply may be shut off by closing a switch in the testing section. *Each man working in the steam test should know where these switches are located, so that he may be able to close these valves quickly if necessity arises.* These valves must be regularly tested at least once a week to insure certain operation. Steam separators and traps are connected in all mains at the proper points to take care of condensed water. Steam is distributed from the mains to the various section testing stands by leading off pipe branches. These branches are of sufficient size to test any machine that will be placed in the particular testing stand. At each stand the branch steam mains are fitted with two steam valves, viz: a special Globe Valve, which may be used to throttle steam for machines under test, when necessary, and another valve which is never to be used for throttling. This arrangement prevents any steam leaking through the branch when not in use. Each valve is furnished with a handwheel of sufficient diameter, so that no additional leverage should be necessary in opening or closing.

All steam valves must be tightly closed, using the handwheel fitted to the valve. The handwheel should then be given a slight backward turn in order to free the stem sufficiently to take care of expansion and contraction. If these precautions are observed the valve may always be easily operated by the handwheel. Each branch main valve is furnished with a small by-pass valve. When it is possible to obtain a sufficient supply of steam through these by-pass valves to carry on a test, they should be used in preference to throttling with the large valve. Drip cocks are in all cases located between the main valve and the machine or throttle valve. These drip cocks must always be open when steam is not flowing through the main in which they are located, and should be left open until steam is flowing freely through the main. That is, wherever condensed water can collect in dead-ended mains, a drip should be provided to carry this water away as fast as it collects, in order to prevent a water hammer in the main. A water hammer may produce enormous stresses in a steam main, hence great care must be taken to prevent its development. If water is likely to collect in the main, the supply of steam should be entirely shut off and all water must then be removed before re-opening the steam valve and attempting to use the main again.

In each section having large steam mains, there are regularly appointed men, whose duty it is to operate all valves with the exception of the throttle valve at the machine under test. The tester should, therefore, ask these men to operate any valve except the throttle valve, which may be operated by the tester himself. Small by-pass valves should also be used in every case gradually to warm up a steam main before allowing steam to flow into it through the opening of the main valve. By using the by-pass valve in this manner, with all drips open, the main can be gradually brought to its running temperature, after which the large valve giving the full flow of steam may be opened.

All exhaust steam piping is arranged to permit the exhaust steam being passed into the heating system of the factory, into the atmosphere direct, or into surface condensers. Wherever possible, condensers should be employed in order to economize steam. Whenever steam heat is required, however, exhaust steam may be passed into the heating system. Steam should only be exhausted into the atmosphere direct in exceptional cases where it cannot be utilized as just mentioned.

Shop Motors and Generators

The Testing Department equipment includes a large number of 125, 250, and 500 volt direct current machines of various sizes, which are always available for driving generators under test. They can also be used as a load for motors receiving test, in which case they are run as generators. Many of these machines are shunt wound; a large number, however, are provided with a series field winding and also with commutating poles. Ordinarily when using such machines as motors, they are operated as shunt machines. Sometimes, however, these motors have to operate in multiple and it is then necessary to use a certain proportion of the series field on one machine in order to give the proper speed equalization. Such cases, however, are special and definite instructions should be obtained before operating the combination.

When operating as motors, machines should never be separately excited, unless the test requirements so demand. In such cases, precautions must be taken to prevent loss of motor field, due to the fields being excited from one source and the armatures from another. When shop machines are operated as motors they must have the speed limiting switch mounted on the shaft, connected to the trip coils on the breakers placed in the armature circuit, so that in case a motor begins to run too fast it will automatically be shut down.

When using direct current machines as compound wound motors, the following precautions must be observed. The series fields must not be connected differentially. They must have only sufficient series field to give the required regulation. Should excessive series field be used and the shunt field adjusted under full load conditions to give normal speed at normal load, the speed may rise to a dangerous point if the load falls suddenly. When machines are so used great care should be exercised in operation to prevent any condition occurring which may give a dangerous rise in speed. When such special conditions occur it must be clearly understood that some one man connected with the test must watch the machine continuously. He is responsible for seeing that accidents, due to excessive speed, cannot occur.

In all cases the general condition of machines, especially the condition of commutators, brushes, bearings, etc., must be frequently and carefully noted and any defects reported to the Head of Section.

When using the shop apparatus, it is as important to take the same precautions in wiring and starting for test as are taken in the case of the apparatus for production. These precautions are detailed in the following pages.

Several of the shop motors used by the Testing Department are alternating current synchronous motors. In most cases, these are permanently connected to a direct current generator. It is often necessary, however, to erect and operate synchronous motors temporarily for production tests.

When starting a synchronous motor the precautions must be observed that are explained in Chap. 11. They must always be run at unity power-factor, unless the special requirements of the test are such that this cannot be done. Since the greater number of these motors are occasionally operated under variable loads, the value of the field current should be watched to see that the armature current is of the proper value for unity power-factor. Should a motor fall out of synchronism, in consequence of excessive overload, or otherwise, the armature circuit must be opened immediately to prevent injury to the winding from overheating. When shop generators and motors are being used the lubrication of their bearings must always be inspected at starting and also at definite intervals during operation to keep the bearings cool and prevent overheating. In addition, the instructions on bearings given later must be observed.

Safety Devices

In a department such as the Testing Department it is essential that proper guards be used in all cases which might be considered as in any way likely to be the cause of an accident. With this in mind special testing equipment which is referred to in other pages of this book has been furnished. Under no circumstances should switches, circuit breakers or other controlling devices be used which are not properly equipped with handles, washers, etc. *There is in each testing section a stock of these parts and the Head of Section is responsible to see that none of these parts is missing.*

All circuits, whether high potential or low potential, which are installed permanently are marked so that all can be identified at any time. With very few exceptions current transformers must be used as a matter of safety when taking measurements on high potential circuits. Whenever a connection is made to permanent circuits, proper protection must be afforded by oil switches, circuit breakers or contactors.

All shaft extensions which are exposed must be guarded. All couplings and belts must be guarded either by a permanent fence constructed of pipe work, or a portable fence designed for this purpose.

Speed limiting devices (see page 113) must be installed on all shop apparatus in which excessive speed is possible and should be adjusted at least once a week to operate at 10 per cent above normal speed. Whenever speed limiting devices cannot be permanently installed they must be used temporarily.

Safety valves and atmospheric relief valves are also permanently located wherever necessary on permanent steam piping. They should be installed whenever necessary on temporary piping in order to insure safety. Great care must be taken in locating these devices in reference to steam mains, air compressor work and air tanks. The tests and apparatus given above are vitally important for the safe operation of the testing equipment, and the Head of the Section must insist that they be closely followed.

Switchboards and Floor Stands

Section switchboards are connected to the permanent wiring to obtain flexibility. These are so designed as to minimize the amount of temporary wiring as much as possible. The switchboards are of two classes; viz. those connected to high voltage circuits (above 600 volts), and the low voltage switchboards (600 volts and below).

Fig. 5

FRONT OF HIGH TENSION SWITCHBOARD, PLUG TYPE

The high voltage switchboards consist of a number of slate panels provided with high tension insulators, to which the permanent wiring terminals are attached leading from the permanently installed alternating current generators, transformers, and "floor stands." At some distance behind the slate front of the board, a second set of high tension insulators is carried on an iron frame, which are also fitted with terminals connected to horizontal busses running throughout the length of the board. Since with this arrangement, generators, floor stands, and transformer terminals are located in vertical lines, whereas busbar terminals are located horizontally, it is possible to pass from one panel to any other panel on the board by inserting switches between the front and back sets of terminals. The metallic terminals used on these boards form the contact points for plug switches. These plug switches are designed so that having removed or inserted a plug, all live parts are thoroughly protected.

No plug switch must be used for connecting or disconnecting the front and back systems of contacts if there is any voltage on them. The switching system must be considered merely as a transfer scheme and must always be operated as such.

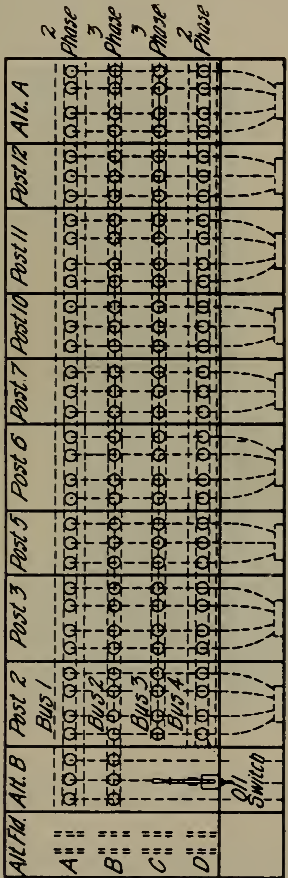


Fig. 6
WIRING DIAGRAM OF SECTION SWITCHBOARD

It will be readily seen by referring to Fig. 5 and to diagram, Fig. 6, that great flexibility is obtained, since any generator connected to a switchboard may be readily transferred to any "floor stand" or to any bank of transformers. Furthermore, any "floor stand" may be immediately connected with any other "floor stand" by merely inserting plug switches at the board.

"Floor stands" are so located in each testing section that all high voltage apparatus may be installed near them, thus reducing to a few feet the length of high tension cable which is required for the machine in test. The "floor stands" carry disconnecting switches and oil switches, through which the final connections can be made between their terminals and the

Fig. 7
FRONT OF HIGH TENSION FLOOR PANEL

terminals on the high tension switchboard panel. One of these stands is shown in Figs. 7 and 8.

Green and red "tell tale" lights are located on all switchboard panels and also on the "floor stands." They are automatically operated whenever an oil switch on the "floor stand," or a plug switch on the switchboard is opened or closed. When a red lamp is burning either at the "floor stand" or on the switchboard panel, it indicates that the terminals are in use, and connected to another circuit. If red lights are burning, it is, therefore, necessary to investigate carefully all panel connections before making any changes. When, however, a green lamp is burning it indicates that the panel, or "floor stand," is free, and may therefore be used. For example: A red light burning on the "floor stand" indicates that the oil switch has been closed on the corresponding "floor stand" panel and that

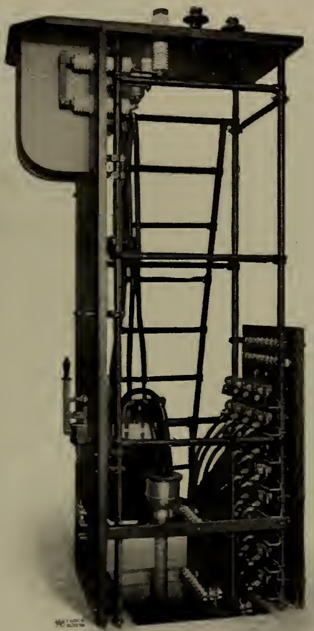


Fig. 8

HIGH POTENTIAL FLOOR STAND SHOWING INTERIOR WIRING AND CONSTRUCTION

the terminals of the "floor stand" panel are alive. Again, if a red light is burning on the "floor stand" its switchboard panel has been connected by the plug switches to another panel, consequently, the "floor stand" terminals may be alive. Hence, the red light acts as a danger signal. It should never be entirely trusted, however, and the same care should always be taken as though "tell-tale lights" did not exist.

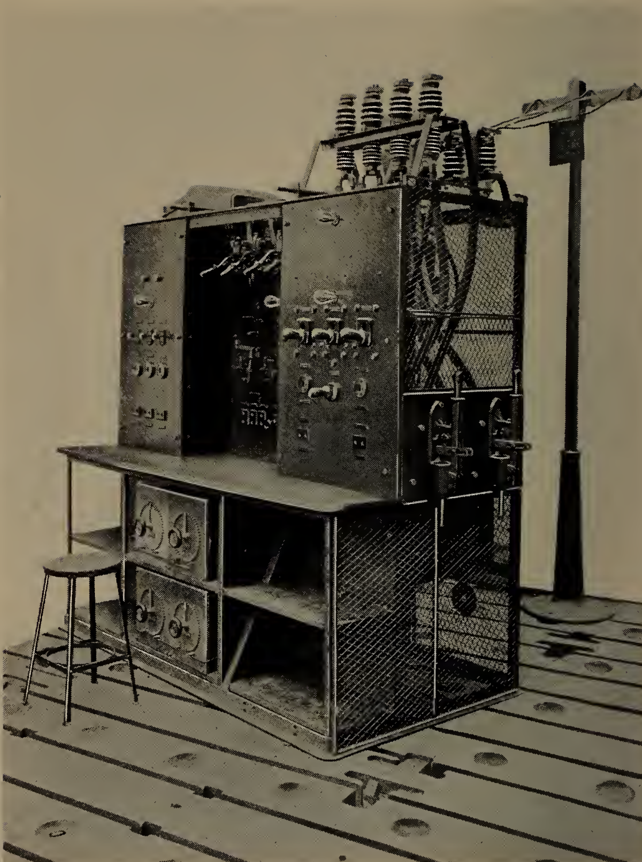


Fig. 9

HIGH POTENTIAL PEDESTAL AND TESTING TABLE

Connections are brought out at the top of the "floor stands" through high potential bushing insulators to terminal blocks mounted on the insulators. All this wiring is permanent. From the terminal blocks, temporary lines must be run to the high potential testing table. A second row of insulators is provided on the top of the "floor stands" which must be used only as strain insulators. The temporary cables running to the testing table must be securely fastened to these insulators. By this means the strain on the connections at the terminal blocks is relieved and wires cannot drop to the floor if they become disconnected. The insulators are arranged so that cables can be taken off at any angle with a safe distance between them.

If temporary wiring has to be carried some distance, high potential pedestals must be used to support the spans as shown in Fig. 9.

The testing table shown in Fig. 9 is the standard type of high potential table used in the Testing Department. These tables are constructed so that all high potential wiring is protected, and it is impossible to make contact with it when the table is in use. High voltage and low voltage circuits within the table are placed in separate compartments and insulated from each other. Tables are built of asbestos, wood, angle iron and expanded metal. The a-c. compartments contain an oil switch, potential transformers, and current transformers.

High voltage connections are made at the top of the table as on high potential "floor stands." The secondaries of the current and potential transformers are connected to binding posts in their respective compartments, forming the terminals of the permanent wiring leading to the instruments on the front or operating side of the test tables. All current transformers should have a capacity of 5 amperes for the secondary. Transformer secondaries should be kept grounded on one side when in use. A detailed print of the wiring circuit will be found mounted on each table. All instrument switches and terminals are properly and plainly labeled. All table wiring is permanent and insulated for a maximum working voltage of 15,000.

The d-c. compartment is wired for all the circuits of two d-c. machines for voltages not exceeding 600 volts. The table is furnished with double-pole 500 ampere 600 volt circuit breakers. For all currents above 300 amperes, terminals are provided for the standard ammeter shunts used in the Testing Department. When using currents above 500 amperes the circuit breaker on the table must be cut out of circuit and breakers of larger capacity wired in the circuit external to the table. When direct currents are read direct, ammeter jacks are provided which allow the insertion or removal of the instrument in circuit without interrupting the circuit.

Though these tables are fitted with safety devices and interlocks, etc., in order to render all protection possible, operators must treat them as if no protection exists. In other words, great attention must be given to all details of operation, and in no case should connections be changed by throwing switches, etc., unless the operator feels certain of the correctness of so doing.

All d-c. switchboards recently installed are of the plug terminal type, but they differ radically from the a-c. plug boards. The older d-c. boards are equipped with bolted terminals. Figs. 10 and 11 show the front and back views respectively of a direct current switchboard of the plug type. These boards carry terminals, circuit breakers and switches for all d-c. shop circuits. Switchboards are interconnected with each other and by means of underground cables are connected to small "pit switchboards" or "posts" or "floor stands" conveniently located. These are generally fitted with plug terminal connections, and are connected permanently to the d-c. switchboards. All exciter sets are also connected to the d-c. switchboards. Hence, any "stand," "pit," "exciter," etc., can be readily connected to any part of the test desired.

Fig. 10

FRONT OF D-C. SECTION SWITCHBOARD

In making connections on any of the "plug boards" plugs must not be allowed to strike the slate panels and chip or crack them. See what connections are required, then carefully insert the plug in its receptacle, entering it to the locking position. If these precautions are taken the least damage will be done in case of short circuit. The ampere rating of each switchboard terminal is placed above it. No cables or terminal must be overloaded.

All field plugs must be carefully locked on insertion so they cannot accidentally be pulled out.

All "pits" and "stands" must be kept clean and free of rubbish.

Cables with defective insulation or having defective plug terminals must not be used, but must be sent by the Head of Section to the repair shop as soon as the defect appears. All cables must be kept on cable racks when not in use.

The following example illustrates the general procedure to be followed in the wiring of high voltage alternating current circuits. To connect a shop alternator to a high voltage machine on the testing floor near the high potential "floor stand," see that the oil and disconnecting switches are open, then connect the alternator, at the armature terminal board, to give the proper voltage and phase combination. Connect the machine by temporary wiring to the high potential terminals on the "floor stand." When the machine is ready to start, a transfer bus should be selected which is not in use on the high potential switchboard. The alternator armature should then be plugged in on the transfer bus, after noting that the alternator oil switch is open. Next plug the panel connected to the proper floor stand to the same bus, and close the alternator oil switch. On closing the circuit at the "floor stand" panel, a red lamp lights up and indicates that the connection of the alternator has been made up to this point. The disconnecting switches should then be

Fig. 11

BACK VIEW OF D-C. SECTION SWITCHBOARD

closed at the "floor stand." Finally, the oil switch on the "floor stand" should be closed and a red light burns on the corresponding panel of the high potential switchboard, showing that the panel is connected through the high potential "floor stand" to the circuit. The oil switch in the test table must be employed to open and close the high tension circuits, if required during the test. In all cases oil switches should be used to "make" or "break" alternating current circuits, where such circuits carry an appreciable amount of current.

In all high voltage work proper precautions should always be taken to insure against accident in handling circuits. In all cases where temporary circuits of high voltage are used, they must be thoroughly protected by mechanical barriers and danger signals; and white tape should be used wherever it is advantageous as an additional warning.

Water Boxes

It is often necessary in testing to dissipate electrical energy through a resistance. When it is necessary to use resistances as a load for large machines, the water box has been found most convenient. The water box, as used in the Testing Department, is an iron box mounted on porcelain insulators. Suspended above the box by insulators is a triangular iron blade which can be lowered into the box. When the water box has been filled and the resistance adjusted by the addition of salt, the resistance may be varied by lowering or raising the plate in the liquid which is admirably adapted to close adjustment.

The box is mounted on porcelain insulators; it should, however, always be considered as grounded. In connecting the boxes to grounded shop circuits, the grounded side should be connected to the cable leading to the box, and the ungrounded side should be connected to the plate. When using water boxes as a load on three-phase circuits, the cables leading from the box should be connected together to form a Y connection, and the phase cables should be connected to the plates.

Before loading a machine on a water box, the salt solution must be adjusted for the voltage and current required. To do this, apply a low voltage to the box and note the current. If this is not possible add fresh water to the solution until the resistance is sufficiently high to prevent an excessive rush of current when the bottom of the plate enters the solution.

The majority of water boxes in the Testing Department are equipped with hydraulic cylinders for operating the triangular plate. These consist of vertical cylinders fitted with a piston and piston rod from which the plate is suspended. Water is forced into the cylinder, or released from it by two electrically operated valves, one for raising, and the other for lowering the plate. Small cables run from the electrical valves to a small distributing switchboard, whence leads may be carried to any of the testing tables, and connected to operating switches. Water boxes can be operated from any section by this method of remote control. If it is desired to operate water boxes in multiple, the cables leading to the control valves must be connected in multiple, and a single operating switch will control any number of boxes.

Unless special permission has been received more than 2300 volts must not be connected to water boxes unless they are specially insulated.

The standard water box used will dissipate 75 kw. continuously without excessive heating. If the water in the boxes is allowed to boil, the resistance regulation becomes very unsatisfactory. Arcing may then occur and set up electrical surges. Hence, the temperature of water boxes must always be kept well below the boiling point, either by allowing cold water to run into them continuously while under load, or if necessary by reducing the load.

To prevent arcs and therefore excessive voltage rises, water boxes must never be used to open alternating current circuits.

Field Rheostats

The Testing Department is equipped with many wire resistance boxes of small and moderate current capacity. These resistances are not grounded upon the frame, but should always be so treated in order to insure safety and freedom from accident. For this reason, the frames should always be insulated from one another and also from ground. All rheostats are marked with their resistance and maximum current carrying capacity, so that the proper resistance for a test can be readily selected. Defective rheostats must never be used in test, but must immediately be sent by the Head of the Section to the repair shop. Permanent motors are generally equipped with their own starting resistance. When starting motors for test, series resistances of large current carrying capacity must often be used. In such cases the water box is the best type of resistance. When starting motors with a water box the voltage drop across the box must be reduced to a small value before the motor is thrown directly across the line.

Transformers

Each test section is equipped with permanent transformers. Additional transformers are also available for special tests, or for use when the regular transformers are in operation. Permanently installed transformers should be used whenever possible to save wiring cost and time and to obtain the advantages and safety afforded by permanent wiring. On the permanent banks of transformers the primary and secondary terminals are brought out to terminal boards with the plug switches for making the various transformer coil connections required with the cables leading to and from the bank. The primary terminal boards are insulated for 15,000 volts between lines, and any combination ordinarily desired can be obtained by inserting plugs in the proper terminals. The plug switches must be considered only as a ready method of connecting up the transformer coils. *They must not be used for connecting or disconnecting live circuits.* The boards are thoroughly insulated, but must always be treated as unprotected, when high voltages are used.

The secondary coils are connected to a low tension plug type switchboard where they may be connected by plug terminals to cables running to any part of the test. Each plug terminal is labeled so that no wrong connection should be possible, if ordinary care is observed.

If temporary transformers are used, they must be properly installed and wired so that safe operation is secured. All cases must be grounded by substantial ground wires or cables, the case and ground terminals must be in good condition and fitted so that they cannot work loose. Never sit or stand on the top of a transformer when connecting or disconnecting it. Always use step ladders for this purpose and see that the transformer is not alive before touching its leads or terminals.

CHAPTER 2

THE USE AND CARE OF INSTRUMENTS

Care of Testing Instruments

All measuring instruments for testing work must be obtained from the general instrument room, or from branch instrument rooms located in several of the testing sections. The instruments, while in this instrument room, are in the charge of a man who is responsible for their condition and calibration before they are given out for testing work. When instruments are taken from the instrument room by the tester he must receipt for them to the man in charge of the instrument room, and be responsible for the proper use and care of them. In all cases, the man signing for testing instruments must be responsible for their return to the instrument room in as good condition as they were received by him. In case instruments are damaged, a report must immediately be made out by the man in whose charge they are and turned in with the instruments to the man in charge of the instrument room.

All instruments are provided with a mirror under the needle. To eliminate parallax and obtain the correct reading, sight the needle when it exactly covers its mirror image, then without altering the position, read the intersection of the needle with the inner scale circle. It should be remembered that while the scale on most d-c. instruments is equally divided, so that the errors of observation are nearly the same in actual amount in all parts of the scale, the percentage error varies inversely with the deflection. Therefore, when accuracy is required the instrument must not be read at a low point on the scale.

Before using any instrument it should be carefully inspected to determine whether the needle is free and rests at zero. No instrument which sticks at any part of the scale should be used nor should an instrument be used which has a zero error. Instruments containing permanent magnets should not be carried through strong magnetic fields, as the accuracy of the instrument is liable to be affected.

Nearly all instruments have polished steel pivots and jeweled bearings; dropping the instrument on the table or striking it against another instrument will injure these pivots, causing the needle to stick.

Curves and certificates should be at hand for correcting the instrument readings before starting a test.

These precautions apply in general to the use of electrical instruments, but do not include all the precautions which must be taken. Intelligence must always be used when using instruments and measuring devices. Precautions which apply especially to certain types of apparatus will be noted in the following pages referring to various instruments employed. *It must be noted that, while the metallic case of a testing instrument is presumably insulated from the terminals and current carrying* *parts, it may become accidentally grounded. When using such instruments, therefore, on high potential circuits, the tester should always remember that this condition may occur. He should consider that the case is at the same position as its terminals. He should never touch the metallic cases of instruments when they are connected to high potential circuits. If it becomes necessary to tap an instrument case to see if the needle is sticking, small insulating rods must be used. Lead pencils must not be used.*

Phase Rotation Indicator

The general form of phase rotation indicator is shown in Fig. 12.

It consists of a laminated iron ring with four windings about 90 deg. apart.

For two-phase, all four windings are used, while for three-phase but three are used. The terminals are stamped 1, 2, 3, 4, and should be connected to corresponding terminals on the a-c. machine under test. These indicators are intended to run from the residual magnetism of the machine.

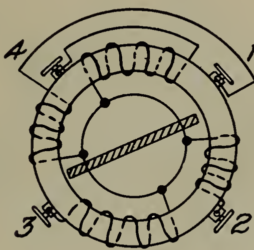


Fig. 12
PHASE ROTATION INDICATOR

The rotor consists of a bar pivoted at the center. This bar should rotate in the same direction as the machine under test. While this is the general principle of the indicator, there are several forms used in the department. They should all be operated, however, from the residual magnetism of the machine.

The above sketch shows the general construction of the indicator. The phase angles are not absolutely correct but are sufficiently accurate for practical purposes.

The Compass

The compass or magnetic needles used for indicating polarity are of the ordinary commercial type. This instrument is not used very frequently in the testing department since there is danger of its polarity being reversed in strong magnetic fields. Care must therefore be taken when using it.

Steam Engine Indicators

Steam engine indicators are of the standard commercial type and are used to take indicator cards generally on marine engines. The following points must be considered: The connecting cord must not stretch, the indicator cylinder must move freely, the paper must be smooth and held firmly on the cylinder, and the pencil must mark plainly and move freely.

The size of spring used in the indicator must be selected so as to give as large a card as possible. Generally speaking, the larger the card the more accurate the results. The spring must be kept in good condition and must be frequently calibrated in order to insure accurate results.

A Planimeter should be used to measure the area of indicator cards.

In using it always set the vernier and scale at zero. The pivot point should be securely located and the tracer moved in one direction around the indicator card back to the starting point. The roller wheel should roll on a flat unglazed surface to secure accurate results.

Balances and Scales

In using balances and scales the no-load position should always be noted, as a zero error may exist. Always hold balances, when measuring, by the hook at the top. After using platform scales the beam should always be either dropped or locked to avoid damage to knife edges, which a blow may otherwise cause. All scales and balances used for important readings must be frequently checked against standard weights in order to insure accuracy.

Manometers and Anemometers

Manometers are used for measuring low air pressures, i.e., up to 4 or 5 ounces. For measuring pressures up to 2 ounces they consist of two vertical cylinders located parallel to each other upon a proper base through which a connection is made from one leg to the other. The cylinders or "legs" are partially filled with water. In some cases the two legs have a cross section ratio of 10:1. When pressure is applied above the water in one leg the water is forced downward and the water in the other leg rises a corresponding amount. Hence, when the cross section of the legs is the same the pressure is equivalent to the difference in level between the water in the two legs, whereas if the ratio of cross sections is 10:1, a water rise in the small leg will measure a pressure equivalent to a water column 1.1 times the height read. Such an arrangement permits of accurate observation of pressures. The difference in water levels is generally read on a "hook" gauge provided with a properly arranged screw and corresponding scales.

The common "U" tube, consisting of a glass tube bent in the form of a letter "U" is frequently employed. One side of the tube carries a scale, by which the difference in height of water in the two legs can be read. In all cases the zero point must be carefully noted, before applying pressure. This reading must be added or subtracted, as the case may be, from pressure readings.

Anemometers are used to measure the velocity of air. Such meters are not very accurate even at their best and must not be used where accurate results are desired. In such cases the calibrated orifice or "pitot" tube method of making air measurements must be employed.

Pressure and Vacuum Gauges

Pressure gauges must not be subjected to extreme heat, because their accuracy will be affected. With steam pressure gauges, "U" shaped or circular loops must be used in the pressure pipes leading to the gauge. These form a trap that holds sufficient water to fill the operating spring of the gauge, thus protecting it against the high temperature of the live steam and keeping it comparatively cool. Vacuum gauges also

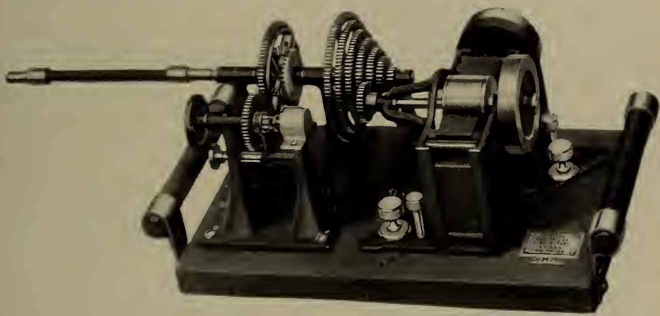


Fig. 13
SLIP INDICATOR

must not be subjected to extreme heat. All gauges must be regularly checked with standards to make sure they are correct when used on important work.

The Hydrometer

The hydrometer is used to measure the specific density of liquids. It is used in the testing department in connection with storage batteries to insure that the electrolyte is kept at the proper density.

Slip Indicator

Measurement of the slip of an induction motor at any load is made by means of a slip indicator such as is shown in Fig. 13. This slip indicator is a convenient arrangement for comparing mechanically the angular velocities of two shafts, one of which is driven at a constant speed by the synchronous motor of the slip indicator and the other at the speed of the motor under test by means of a flexible coupling between them.

The indicator is mounted on an iron base, fitted with a handle at each end, for carrying or handling it. The synchronous motor is very simple in construction. It has a bipolar stator, and a four-pole rotor without winding. The shaft carries a fly-wheel on one end and on the other a 32 tooth brass gear wheel, which may be made to mesh with any one of a nest of seven gears, mounted on a parallel shaft, by shifting the motor on the brass plate. By loosening two screws passing through slots in the sole plate of the motor, the latter may be shifted to any desired position, exact alignment being secured by dowel pins. The various gears are provided to enable the synchronous motor to drive the parallel shaft at different speeds, thus adapting the instrument for testing motors with various numbers of poles.

The parallel shaft is equipped at its other end with a bevel gear wheel meshing with two pinions of a differential gear. Meshing with these pinions on the other side is another bevel gear, carried on a shaft the other end of which carries the flexible coupling by which it is connected to the machine in test. A short auxiliary shaft behind the differential gear has, on one end, a gear wheel meshing with the large wheel of the differential gear, and on the other end a small handwheel by which to hold this shaft.

A clutch, operated by a lever, connects the auxiliary shaft to a cyclometer which registers the number of revolutions of the auxiliary shaft. The gear ratio makes one revolution of the auxiliary shaft equal to one-half revolution of the differential gear.

The indicator is used as follows:

With the voltage normal and the speed of the alternator held constant at normal frequency of the motor, the indicator is connected to the induction motor shaft by means of a "split tip." The bevel gear, on the shaft carrying the split tip, is driven at the speed of the induction motor. By holding the large gear of the differential stationary by grasping the hand wheel on the auxiliary shaft, the synchronous motor is mechanically brought up to the speed of the induction motor by power transmitted through the other side of the differential and the nest of gears. On closing the line switch on the synchronous motor it will immediately fall into step with the alternators and run at synchronous speed. Should it fail to do so on the first trial, a second or third trial in the same way will usually be successful. With the synchronous motor running and driving one bevel gear of the differential at synchronous speed, and the induction motor driving the other bevel gear at the speed of the induction motor, the large gear of the differential will rotate and drive the auxiliary shaft and cyclometer. In this way, the difference between synchronous speed and the speed of the induction motor is mechanically recorded, and it is only necessary to read the cyclometer for some definite length of time (usually one minute) to know the exact number of revolutions by which the two speeds differ.

In Fig. 13 the gear wheel of the synchronous motor shaft is shown meshed with the gear wheel of the "nest" having the same number of teeth (32), adapting the indicator to test a four-pole induction motor, since the rotor of the synchronous motor has four poles. The other gears of the "nest" have

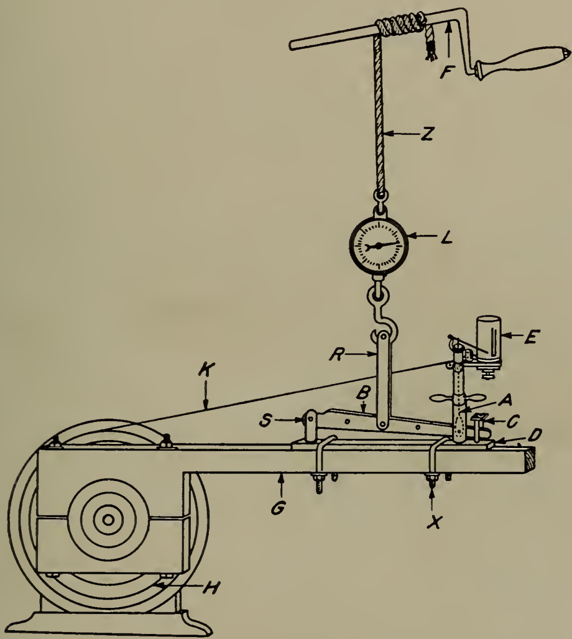


Fig. 14

STATIONARY TORQUE RECORDER

16, 48, 64, 80, 96 and 112 teeth, respectively, providing for testing induction motors with the various numbers of poles, commonly built.

Stationary Torque Recorder

Some alternating current motors have a starting torque which varies considerably according to the position of the rotor at starting. In many cases, therefore, the variation of starting torque at different rotor positions must be measured.

This information can be most satisfactorily obtained by using a graphic recording torque meter. Fig. 14 is a sketch of an instrument that is successfully employed in the Testing Department for quickly and accurately obtaining this torque. In this sketch *G* represents a form of lever commonly used. It is clamped around the pulley or the shaft of the motor under test. A wooden disk *H* is provided, of triangular cross section radially. On its conical surface a series of ⅛ in. grooves is located to accommodate the cord *K*. This cord rotates the drum *E* of a steam engine indicator on which a record of the variations in the torque is traced. The post *A* supporting the indicator is hollow, and a rod connected to the lever *B* at the lower end and bearing against the spring of the indicator, transmits any movement of *B* to the spring, and in turn to the pencil bearing upon the drum. The lever *B* is provided with a number of holes so that it can be attached to the stirrup *R* at various distances from the fulcrum *S*, by which means different leverages can be secured. By this adjustment, and by clamping the complete apparatus to the lever arm at different distances from the motor shaft, the maximum travel of the recording pencil on the drum can be kept within the limits normal for the indicator spring used. The shaft and crank *F* are supported at right angles to the lever *B* by an iron pipe frame not shown in the sketch. The spring balance *L* is used only in calibrating the apparatus and is then disconnected and the rope *Z* connected directly to the stirrup *R*. The calibration of this instrument should be made as follows:

With no tension on the rope, pull the cord *K* and revolve the drum *E*, thus recording the zero line on the paper record. Raise the outer end of the lever above the horizontal position and with the cord *K* in that groove on *H* which gives the proper rotation to the drum *E*, slowly lower the lever by means of the crank *F* to a position considerably below the horizontal plane passing through the axis of the motor. This line gives the value $W-F$. Where *W* is the weight of indicator lever arms, etc., tending to rotate the rotor and *F* is the friction of the motor bearing. The lever is now slowly raised to a position correspondingly above the horizontal plane and a third line obtained on the indicator drum, measuring the value $W+F$. The lever is now blocked and held in a horizontal position and the crank *F* turned until the spring balance reads 10 lb. By means of a cord, the drum is rotated and a line drawn upon it correspondingly to 10 lb. pull. This may be repeated and the indicator card calibrated through the range required.

After the indicator calibration record has been made the spring balance is removed and the rope *Z* connected directly to the stirrup *R*. Having determined the direction of rotation of the motor when supplied with power, the line switches may be closed, using about one-half normal voltage on the motor. By means of the crank *F* and the rope *Z* the lever arm is rotated through an arc equal to that employed in obtaining the friction curve and a record made. Make a similar record while lowering the lever through the same arc. While the lever is ascending, the record measures the value $W+F+T$, where T is the torque of the motor under test; descending, the record gives $W-F+T$. From the five curves, so obtained, the torque at any position is readily obtained.

On these motors the cycle of torque variation usually repeats itself regularly during a revolution. It is, therefore, only necessary to continue the record throughout one of these cycles. The indicator card has blanks for recording the machine rating, number, and all other information necessary in connection with this test. These cards should always be filled out clearly before being sent to the Calculating Department.

The Ballistic Galvanometer

The Ballistic Galvanometer when used to measure magnetic flux or electric quantity must be supported on a pier to eliminate vibration. It may be located either beside the apparatus under test, if a pier is available at that place, or at a distance, usually in the laboratory.

In measuring magnetic flux an exploring coil, usually of a few turns only, is employed enclosing the flux at any convenient point. As the exploring coil voltages are ordinarily very low, no particular care is required for insulation except to guard against mechanical abrasion.

The method for obtaining the necessary change of flux may be either by withdrawing an exploring coil, by reversing the current producing the flux, or by making or breaking the current. For permanent magnets the first is the only way possible. For electromagnets the second method is the more usual, the exploring coil being wound permanently in place. If the current is broken without reversal, the measurement is subject to an error due to residual magnetism; which in a continuous iron circuit (no air gap, as in a stack of ring punchings) sometimes gives a remainder of over three-quarters of the whole flux (as may be seen in a hysteresis loop). Similarly if the current is made, an error occurs if the flux does not start from zero value.

The expression for computing the flux is $F=kRD/N$, where k is the constant of the galvanometer, R the resistance (external +galvanometer resistance), D the observed deflection, N the number of turns of the exploring coil. If the galvanometer is one with considerable damping, k will vary greatly with the resistance, being constant only at high resistances, and the curve or table giving the k values must be referred to. If only relative values of flux are required, for instance, the variation of flux with generator field current, no value of k need be obtained, the flux being proportional to RD, the product of resistance and deflection.

In computing the flux it is necessary to note carefully whether, as is usually the case, the constant of the galvanometer is given for a reversed current, and whether the observations correspond. For instance, in calibrating, the current is usually reversed, and flux observations of a permanent magnet made by withdrawing the coil must always be multiplied by two, if the ordinary k of the galvanometer is used.

When observing quantitatively, see that the whole flux change occurs before the galvanometer coil has moved through any considerable portion of its swing. This is readily tested by waiting a fraction of the galvanometer period, perhaps a second or two, before pressing the key, after which there should be no deflection.

The swing of the galvanometer coil is stopped either by short circuiting through a proper key, if the galvanometer is damped considerably, or by a counter torque obtained by applying in the proper direction a small fraction of the voltage of a cell through a suitable reversing key.

The calibration of the ballistic galvanometer is usually accomplished by reversing the current in a long air solenoid with an exploring coil surrounding the middle. The flux at the middle of the solenoid is $4\pi nAI/10$, where n is the number of turns of the solenoid per cm., A the area and I the current (in amperes).

SPEED AND FREQUENCY

The primary standard for speed is an accurate speed counter and a reliable chronometer. The Company's chronometer is checked by Washington time, as time record is made on the laboratory through a special wire, daily at noon.

Secondary or Working Standard

The Company's working standard is a liquid tachometer having a scale 36 inches long and graduated from 300 to 1200 revolutions per minute. This tachometer is coupled to a small variable speed motor, to the other end of which is connected through a nest of gears the tachometer to be tested. By means of these gears the tachometer under test can be run in either direction and at speeds which are multiples of the range of the standard. This working standard is checked weekly by the standard speed counter and a watch which has been compared with the chronometer.

The working standard for the vibration frequency indicator is a current interrupter of the vibration type, operated by the working standard tachometer and motor. For the Thomson station type, a machine running at the required frequency, checked by a speed counter and watch, constitutes the working standard.

Tachometers

The Company has in use the following types of tachometers: Veeder Liquid, Schaeffer and Budenburg portable, Niagara portable, Dr. Horn portable, Hopkins' electric portable and Frahms vibration portable.

All portable tachometers should be checked running in both directions, as it is frequently found that they differ somewhat in their calibration whether run clockwise or counter-clockwise. By "clockwise" is meant clockwise rotation of the tachometer shaft looking at the *spindle* end.

Tachometers like the S.&B., Niagara and Dr. Horn types when run continuously need oiling every 3 or 4 hours. The best grade of clock oil only should be used on them. This type, although it is apparently strong and compact, is nevertheless a delicate instrument and should be handled as carefully as any other measuring instrument.

The Veeder liquid tachometer is a centrifugal pump arranged to pump the liquid from a small reservoir into a glass tube, the height of the liquid in the tube rising or falling with the speed. This type of tachometer has a small plug that can be screwed into or out of the reservoir, changing the level of the liquid in the reservoir and tube by displacing some of the liquid in the reservoir and thereby adjusting the zero. In the later types of Veeder tachometers, the zero is the lower surface of the inverted cone at the foot of the glass tube in the reservoir. The meniscus of the liquid in the column should be level with the lower surface of this cone. The liquid used is *grain alcohol* slightly colored with red aniline dye. Wood alcohol should not be used as it corrodes the shaft, causing the bearings to leak. If the tachometer leaks, it should be returned to the Standardizing Laboratory to be repacked.

The Hopkins electric tachometer consists of a small magneto which generates about 200 millivolts at full speed and is used with a portable millivoltmeter or, where permanently installed, with a station instrument.

There are two kinds of vibration tachometers; one is tuned to respond to the vibration of the machine, due to the speed; the other is an electromagnetic type. The former, however, is not satisfactory where more than one machine is running, as the reeds respond to the vibration of a machine adjacent to the one being tested. The electromagnetic type can be used conveniently when an accurate speed measurement is required at some distance from the machine. Not more than the rated voltage should be applied, as excessive voltage will cause a burn out.

Frequency and Speed Indicators

G-E Type H frequency and speed indicators are of the switchboard type and are convenient for use on testing stands. The two instruments differ in the scale only, one being graduated to read frequency and the other the normal speed and a certain high and low percentage of the machine speed on which it is used. In using these instruments, adjustments for wave shape must be made by shifting the arms on the resistance box used with the instrument before beginning a test. This can be done by measuring the speed of the machine by means of a speed counter and watch, and moving the arms until the instrument reads correctly. Both of these types are iron clad (shielded) instruments, and, therefore, they are not affected by stray fields.

Frahm's system vibration frequency indicators and *Hartman and Kempf frequency indicators* are similar to the electrically operated vibration tachometers but are graduated to read frequency. They have a voltage range of from 250 to 50 volts and a frequency range of from 90 to 22½ cycles. In the former (Frahm) the voltage adjustment is made by means of four taps on the resistance; the binding posts being marked +, 65, 100, 130, 180 and 250. In the latter type (*H* and *K*) a small button is provided on the end for cutting in or out resistance when the instrument is first connected to the circuit. This button should always be in the 250 volt position, and after connection has been made, the button should be turned until the right amount of resistance has been cut out to correspond to the voltage applied.

These instruments possess important advantages over tachometers in that they may be located at the testing table so that the instrument readings may be observed and the speed controlled by one man. They can be read more accurately and are not influenced by the direction of rotation. They may also be used to read the speed of d-c. machines or machines which are under-excited. For this purpose a current interrupter is provided on the shaft of a centrifugal tachometer. This interrupter is provided with binding posts which must be connected in series with the frequency indicator and a 125 volt d-c. circuit. They are also provided with disks having several contact points. For a disk having four contact points the frequency indication would be the same as that of an eight pole alternator.

It is not safe to use these frequency meters for measuring the speed of a machine under test when it is first started, since they cannot always distinguish between 20 cycles or 40 cycles in consequence of the fact that both a 20 cycle and a 40 cycle reed will vibrate at 20 or 40 cycles. The speed should be roughly set to that desired, by reading the tachometer dial, after which it can be exactly adjusted by the frequency meter. Due to the many advantages of these instruments they should be employed wherever possible, in place of the ordinary tachometer for testing work.

WAVE SHAPES

The term wave shape is used to denote the generator e.m.f. wave, at no load. The voltage from a potential transformer secondary is transmitted to the Standardizing Laboratory, where the oscillograph is connected in. As the oscillograph current is only about 0.2 ampere, the load on the potential transformer is inconsiderable.

Generator potential waves at various loads of unity or other power-factors are sometimes required. When a series of waves is taken, the oscillograph is brought near to the generator or apparatus under test, and is in charge of an operator from the Standardizing Laboratory.

Current waves are taken with the oscillograph connected across a shunt (similarly to a millivoltmeter). The resistance of the shunt should be selected to give a shunt potential drop of at least 0.2 volt. A current transformer of suitable rating may be used with a small shunt in the secondary.

The flux distribution on generator or motor pole faces is determined by obtaining the potential wave of a narrow exploring coil, usually of only a few turns, on the armature. In d-c. generators or motors the wave of potential between commutator bars is sometimes taken. Where temporary slip rings are used duplicate brushes should be placed on each ring to avoid the effects of chattering.

When two waves, or three waves, are required together, taken in their proper phase relation, such as the potential and exciting current waves of a transformer, they are recorded together by two elements or three elements in the oscillograph.

The Oscillograph

The oscillograph, on account of its short period (about 1/6000 second) can be applied in a great variety of tests where a knowledge of rapidly varying currents or voltages is required.

For the oscillograph a d-c. circuit of about 8 amperes is required to operate the arc, field, shutter, and film-driving motor: the source is usually the 125 volt shop circuit.

The oscillograph current proper is small; about 0.2 ampere. For current curves a shunt potential drop of at least 0.2 volt is required, as the resistance in the oscillograph is 1 to 2 ohms. One, two or three oscillograph elements may be used, the instrument being regularly built as a three-element oscillograph. The insulation between the elements is sufficient to stand several times the ordinary 110 volts.

The oscillograph indication is adapted to the voltage by adjustable resistance.

Its use for wave shapes is considered in preceding paragraphs.

For currents and voltages on opening or closing a circuit the oscillograph is placed near the point of operation so that the operation may be effected during the period of exposure of the oscillograph. Where the operation is in response to a signal it is usually not practicable to make the exposure much less than a second. If it is necessary to have the record to a larger time scale so that the film must be driven faster than 60 rev. per min. for a shorter exposure than a second, the operating mechanism and the oscillograph shutter are actuated by one operator, or are connected together either mechanically or electrically. In some tests the exposure can include more than one revolution of the film, that is, the record may go more than once along the film. In some cases the film revolves much more slowly, to give an exposed record of several seconds or even a minute or more.

For short-circuit tests of alternators, three-phase, quarter-phase or single-phase, two oscillographs are usually used together, one on the armature, and one on the field. If the record ends before the transient is over, an auxiliary exposure is sometimes made a few seconds later to obtain the permanent short-circuit condition of the alternator. It is customary to connect a resistance load across the exciter in parallel to the generator field. For three-phase short circuits, shunts are connected in, one in each phase, on the ground side of the switch.

Where the duration is required, and is not otherwise given, as frequently occurs in d-c. tests, one oscillograph element can record on an alternating current timing wave of known frequency; for instance, the 40 cycle shop circuit.

Visual inspection on the screen, sometimes with the help of a moving mirror, is made for adjustment to a suitable scale, where practicable, before the formal photographic record is taken.

RESISTANCE MEASUREMENTS

Unit Employed

The unit employed is known as the "International Ohm." It is represented by the resistance offered to an unvarying electric current by a column of mercury at 0 deg. C., 14.4521 gm. in mass, of a uniform cross-sectional area, and 106.3 cm. in length. The cross-sectional area of this column is approximately 1 sq. millimeter.

Primary Standard

The Company's primary standards consist of two 1 ohm units of the Bureau of Standards form and two 1 ohm units of the Reichsanstalt form, which are compared with the Government Standards at Washington and certified to by the Bureau of Standards. These certificates give the temperature at which the units are correct and the temperature coefficient, if any; *i.e.*, the correction factor to apply when the temperature of the unit differs from the standardizing temperature.

The Company has also other units of the same forms varying in resistance from 0.0001 to 10,000 ohms which are used as standards in connection with the 1 ohm units.

Working Standards

These consist of several current carrying units of various current capacities and resistance values. They are frequently compared with the primary standards referred to and also with each other.

CLASSES OF RESISTANCE MEASUREMENTS

There are three general classes into which resistance measurements may be divided. These are "Medium," covering a range from 1 to 100,000 ohms; "Low," covering a range below 5 ohms; and "High," covering a range above 50,000 ohms. It will be noted that the division line between the classes is not very definite, i.e., the several ranges overlap each other.

Medium Resistance Measurements

For the measurement of medium resistance the "Wheatstone Bridge" and the "Slide Wire Bridge" are used.

Two types are in use, the "Post Office" pattern and the "Decade" type. Both operate on the same principle. In the "Post Office" type the resistances composing the rheostat are all connected in series and the reading is obtained by adding *all* the values of the plugs that are *out* when a balance is obtained. In the "Decade" type (also the dial type) only one plug is used for each decade, and the reading is obtained directly, by noting the values against the plugs that are *in* when a balance is obtained. It is, of course, understood that in both cases proper account must be taken of the ratios as plugged in the "arms" of the bridge. Also, in both cases, only one plug in each arm must be used and the values must be taken from the plugs that are *in*. The following remarks will apply to both types of bridge.

Good Contacts

All plugs and other contacts should be kept clean and bright. The plugs should be cleaned every time the bridge is used or, if in constant use, at least every day. This may be done by wiping them with a piece of soft cloth or waste applied with the finger. *Never* use emery cloth or polishing powder. The key contacts may be cleaned by putting a piece of heavy paper between them, pressing the key and pulling the paper out. If very much corroded, a piece of worn *crocus* (not emery) cloth may be used.

It is essential that all plugs should be tight. It is not necessary to use much force, in fact this should not be done. The plug should be given a slight rotary motion, at the same time applying a gentle pressure. In removing the plugs, give them a rotary motion in the *same direction* as when they were inserted. The rotary motion should be in a clockwise direction, to prevent unscrewing the plug heads.

Using Keys

To operate the keys (if they are in proper condition) only a firm steady pressure is necessary. Pounding the keys must not be allowed, since it ruins them. This applies to all testing keys, as well as to bridge keys.

Choice of Ratios

In using the Wheatstone Bridge, it is best that the resistance in the arms and the resistance in each of the four bridge arms should be as nearly equal as possible, as this gives the most sensitive arrangement.

Most bridges have a capacity of 1 to 9999 or 10,000 ohms in the rheostat, with ratios for multiplying or dividing the rheostat plugging by 1000. It is not advisable where other means are at hand to use the 1/1000 or 1000/1 ratios, except on a bridge of unusually accurate resistance adjustments, as the 1 ohm coils are not as accurate as those of greater resistance. Avoid using 1 ohm coils as far as possible.

Temperature Coefficient

For ordinary bridge work in the factory and in general work (outside of the laboratory) the temperature coefficient of the bridge may be neglected, as it is too small to be appreciable within the limits of the work under consideration. The temperature coefficient of the material in test, however, must always be considered; if an allowance for it is necessary to secure the desired accuracy, it should be made. Apparent disagreement between different departments frequently arises which on investigation will often be found to be due to a disregard of the temperature coefficient of the material under test.

Should it be necessary to make a temperature correction for the bridge, great care must be taken to measure the temperature of the bridge coils correctly. A thermometer placed in the bridge box often does not nearly indicate the correct temperature of the coils, especially if the surrounding temperature is rapidly changing. The bridge should be kept in a nearly constant temperature and the indications of the thermometer in the box should remain substantially constant for at least one hour, preferably for two or three hours.

SLIDE WIRE BRIDGE

This is a modification of the Wheatstone Bridge, the slide wire forming two arms of the bridge and corresponding to the ratio arms in the Wheatstone.

Ohmmeter

The so called "Sage" ohmmeter is essentially a slide wire bridge arranged for portable use where approximate values are sufficient.

This instrument is useful for special jobs and is found very convenient, especially on outside work, *i.e.*, where no fixed bridge is available, such as in a power station, car barns, etc. Its sensitiveness and consequently its degree of accuracy is largely dependent on the hearing of the observer and the condition of the dry cell batteries forming a part of the instrument and supplying the necessary current for making a measurement. A telephone receiver of the "watchcase" pattern is used on this bridge in place of a galvanometer to determine when balance is obtained.

Instructions already given regarding contacts and plugs apply. In addition the slide wire and "contact finger" should be given proper attention. The wire can be wiped off with the finger or a soft cloth when dirty. The contact finger may be cleaned with crocus cloth.

Under no circumstances use any emery or crocus on the slide wire as this will ruin the bridge. The bridge should be tested before starting on an outside job, to see if it is in working order, as the batteries deteriorate even when standing idle. Never leave the bridge connected, as metallic dirt or conducting material sometimes collects in the plug holes which may short circuit and spoil the battery if the receiver switch is not in working order, as occasionally happens. This switch should receive occasional attention.

The so called Weston ohmmeter is a low range voltmeter with a scale graduated to read in ohms. It will give fairly

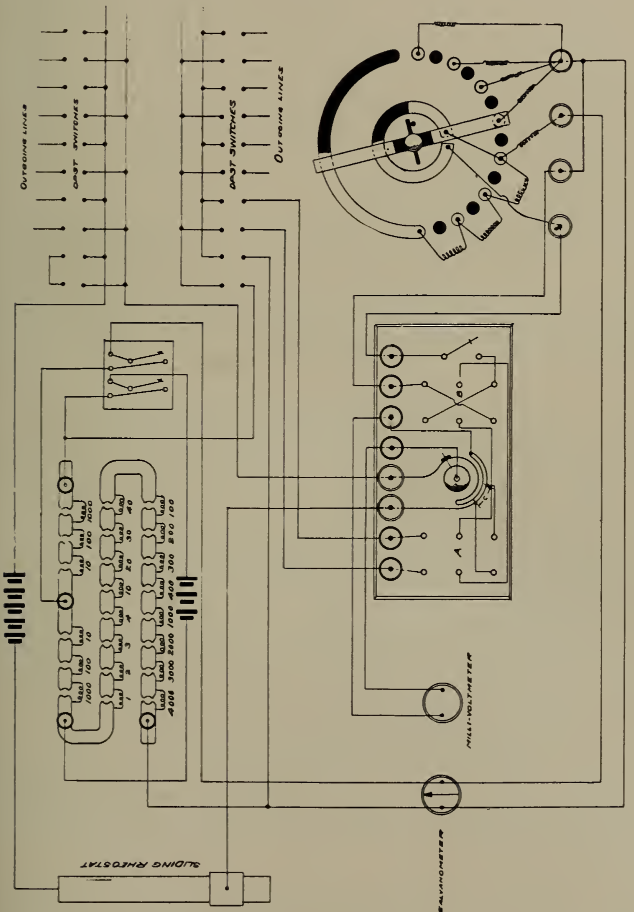


Fig. 15
WIRING DIAGRAM OF LOW RESISTANCE MEASURING OUTFIT

accurate results if the potential employed is constant and its value properly taken into account. The inverse ratio of deflections of the instrument without and with the unknown resistance connected in series is a measure of the resistance in ohms. It is further described under the section on "High Resistance by D-C. Voltmeter."

The "Evershed" ohmmeter is a true ohmmeter, because the scale readings are directly given in ohms and are independent of the current or voltages used. This outfit is not to be discussed here as its use has not been adopted. It is a valuable device for certain purposes; for further information refer to the makers or agents.

A comparison of the Evershed with the methods used in the Sage and Weston ohmmeters show why the latter two are not true ohmmeters. The Evershed apparatus is also used for high and insulation resistances.

Low Resistance Measurements

Under this heading are included the "Thomson Bridge," sometimes called "Double" Bridge, and the "Drop Method," using an ammeter and voltmeter or their equivalents. Fig. 15 shows the wiring for a special application of the drop method. This is used where the outfit can be permanently installed and a special operator employed; therefore, further explanation will not be given here.

THE THOMSON BRIDGE

This is a modification of the Wheatstone Bridge and is suitable for use with low resistances, as its arrangement removes the objection to the former, viz., the resistance of connections and plugs. It is also a modification of the "Drop Method" discussed later, but the accuracy of the results is not directly dependent on the value of the current employed. As this device is in the nature of a permanent fixture and a special operator is generally employed for its use, further explanation is not considered necessary.

The instructions, already given, in reference to contacts, plugs, slide wire, etc., also apply here. If a slide wire bridge is not provided with a roller the contact *must not be moved* until it is released from the wire. Failure to observe this will soon ruin the wire, especially if it is of small diameter.

DROP METHOD (DIRECT CURRENT)

For this method current and potential measuring instruments of suitable ranges are required, *simultaneous readings* being taken on each; from these readings the resistance is calculated by Ohm's Law ($R = \frac{E}{I}$).

The Current Standard must be connected in series with the resistance to be measured, and, where practicable, a suitable adjustable resistance for controlling the current. The volt standard is connected across the resistance to be measured, so as to measure its potential drop. A non-inductive resistance may be connected in series with the voltmeter to alter its sensitiveness if required. This resistance should have a current capacity equal to that of the voltmeter.

The instruments should be so chosen that the deflections obtained are reasonably large, in order to reduce the error of observation as much as possible. The current used should be sufficient to give a good deflection on the ammeter. It must not, however, be great enough to heat the resistance under test and thereby change its resistance. This point is very important and frequently overlooked; the greater the temperature coefficient of the material of the resistance the more important it becomes. If the current employed in making the measurement is not steady, two observers should take observations, one reading the ammeter and the other the voltmeter. Simultaneous readings should be taken, each reading being repeated several times, the average reading being used to determine the final result. Neglect in considering the ratio of the resistance of the voltmeter used to that of the apparatus under test sometimes introduces errors. If the ratio is large (2000 or more) the

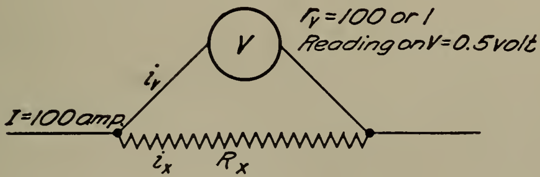


Fig. 16

law of divided circuits can be neglected and the result obtained from Ohm's Law as previously stated. If the ratio is small, allowance must be made, since a part of the current is shunted through the voltmeter, which is also measured by the ammeter.

To illustrate this point take the following example, as per Fig. 16:

By Ohm's Law $R_x = \frac{0.5 \text{ volts}}{100 \text{ amperes}} = 0.005$ ohms. Whereas making the allowance for shunted current through V (where $r_v = 100$ ohms) we get $R_x = 0.00500025$ or 0.005 per cent, a difference too small to consider for this class of work. This is found as follows:

The current i_v through V is equal to the drop across R_x or $\frac{E}{r_v} = \frac{0.5 \text{ volts}}{100 \text{ ohms}} = 0.005$ amperes. Now $i_x = I - i_v$ or $100 - 0.005 = 99.995$. Since the value of R_x is equal to $\frac{E}{i_v} = \frac{0.5}{99.995} = 0.00500025$, the value as given above. Again supposing $r_v = 1$ and following the same reasoning we get $R_x = 0.005025$ or 0.5 per cent, a difference which is too large to be neglected.

High Resistance Measurements

Under this heading, "High Resistance D-C. Voltmeter," "Insulation Resistance Measuring Sets" and "Meggers" are considered.

HIGH RESISTANCE D-C VOLTMETER

A high resistance instrument (50,000 ohms or more) is generally used for high resistance measurements. For lower resistances, lower voltages and a lower resistance voltmeter may be used. The Weston ohmmeter belongs to this class. In these cases on the voltmeter, the deflection is directly proportional to the current flowing through it, and inversely proportional to the resistance of the circuit with constant potential across it.

A constant potential of about 500 volts is usually employed. This voltage reading is determined by connecting the terminals of the supply directly to the voltmeter. The resistance to be measured is then connected in series with the voltmeter and a second reading made and noted. The resistance X is then given by the formula $\frac{R_m}{R_m+X}=\frac{D_m}{V}$; Then $R_m + X = \frac{VR_m}{D_m}$ where R_m = resistance of the voltmeter used; D_m the deflection of the voltmeter with resistance in series; V the voltage of the supply when taking reading D_m, and X is the resistance sought.

If the value of X is large relative to R_m it is not generally necessary to subtract R_m to get X, and this is not usually done.

In making these measurements do not attempt to use a voltmeter which reads lower than the voltage of supply, as in case the resistance is omitted the instrument is likely to burn out. Do not try to get results by this method unless the supply is steady and constant or a second voltmeter is connected directly to the line all the time with a second observer for taking simultaneous readings. When two instruments are used do not get their resistance values mixed; the resistance of the instrument reading the voltage is immaterial.

A suitable reflecting galvanometer calibrated to read in volts may be used in place of the voltmeter. The method and calculations are the same as described above.

INSULATION RESISTANCE TESTING SETS

The principle of operation is similar to that of the d-c. voltmeter, a shunt box being added to increase the range of the galvanometer which is used in place of the voltmeter in the other method.

The galvanometer constant $K=\frac{D\times S\times R\times C_2}{10^6\times C}$ and the resistance $=\frac{K_2}{D_2S}$ where D = deflection of galvanometer when taking constant; D_2 when making observation; S = multiplying factor for shunt; R = resistance in ohms in series when taking constant; C and C_2 = number of cells used when taking constant and observation respectively.

Complete instructions are furnished with the portable outfit when sent out. The permanent outfits work on the same principle and are generally installed with other testing apparatus where a special operator is available.

The following points should be mentioned. The various parts of the entire outfit, including the connecting wires (both internal and external), must be properly insulated from each other and from earth to prevent leakages. If this is not done, leakage currents may pass through the galvanometer and not through the resistance being measured, thus falsifying the results.

If the resistance being measured lies between the earth and some conductor, as is the case with a lead covered cable, one side of the galvanometer should be connected directly to earth, taking precaution to insulate the rest of the circuit well. To form an earth, a bare wire may be used grounded to earth, to which one side of the galvanometer is connected. With this arrangement, if any leakage occurs, the leakage current is shunted by the galvanometer and does not affect the readings. Where possible, leakage should be eliminated, but reasonably correct results can be obtained by testing, changing over the connections and averaging the results.

When making insulation measurements on cables installed underground, tests should be made for earth currents. To do this, disconnect the battery and short-circuit the terminals to which the battery was connected. Then, connect to ground and to line and observe the galvanometer deflection. If there is no deflection no earth currents exist, if there is a deflection of constant direction and amount a dead resistance equal to the internal resistance of the battery can be substituted in place of the short-circuiting wire and the amount and direction of the galvanometer deflection can again be observed. This deflection is added to or subtracted from the deflection obtained when making the test, before dividing into the constant. Since the battery resistance is small compared to the resistance under test, it can usually be neglected and the deflection used as obtained with the short-circuiting wire. If the earth currents are very appreciable or unsteady in amount or direction, the test should not be taken until the conditions are more suitable.

Chloride of Silver Dry Cell Batteries are generally used to supply the current for these resistance measurements.

These cells are very quickly ruined by short-circuiting or using them on too low a resistance. The cells should never have less than 5000 ohms per cell connected in series with the circuit connected to them.

Never put into the battery covers wires or other material which could short-circuit the cells. The space between the covers and cell tops may seem to be a convenient place to carry spare wire but this practice causes trouble. Abrasion of the insulation on the lead wires supplied with the batteries may short-circuit the cells, and must be watched.

The cells should be tested before using to see that they are in good order (giving about 0.8 to 1 volt). In any case the e.m.fs. of the cells must be sufficient to allow the operator to get correct results. The resistance of the voltmeter used should be at least 5000 ohms, or if several cells in series are tested at once, the voltmeter resistance in ohms must be at least 5000 times the number of cells tested in series.

It frequently happens that some of the cells in a battery give only a fraction of their proper voltage; in such cases the voltage of each individual cell must be considered when making a test, and the total voltage must not be estimated merely from the number of cells in use, but actually measured.

Wherever possible, cells below normal voltage should be rejected and replaced by new cells.

The "*Marcuson Portable Testing Battery*" is used when an outfit is permanently installed. As this is a form of storage cell it will stand an appreciable amount of current as compared with the Chloride of Silver Dry Cell Battery. The voltage is also more dependable and being about twice as much per cell requires only half the number of cells.

The galvanometer shunt boxes and series resistances are marked with different units from those used on the portable outfits and a slightly different formula is used but the principle and general arrangement are the same. As there is a special operator where more sets are installed, further mention will not be made here.

MEGGER

This instrument, developed by Sidney Evershed, of London, combines, in one convenient case, both the measuring instruments and the current supply apparatus. The current is furnished by a magneto generator operated by a hand crank. Those in use by this Company are known as "Constant Pressure Meggers," and the drive is through a slip device so that the proper speed is maintained after having once been reached. The proper speed can easily be determined after a few trials. It is only necessary to turn the crank fast enough, as the generator cannot be driven at too high a speed.

The insulation to be measured is connected between the two terminals, the crank turned, and the insulation resistance read directly from the scale while the crank is being operated. If one of the conductors surrounding the insulation is earth, this should be connected to the terminal on the megger marked "earth."

Before a measurement is taken all leads should be disconnected and the index set to "infinity." This is done by turning the crank and bringing the index to read "infinity" by operating the index adjuster.

These instruments are made in several capacities ranging from 40 to 2000 megohms full scale deflection and should be selected according to the resistance to be measured.

The magneto in these instruments generates a voltage as high as 1000 and a very uncomfortable shock may be received. Care should therefore be used in handling the leads or touching the terminals when the magneto is in operation.

The instrument is very conveniently portable and for outside work is generally to be preferred to the insulation resistance sets.

MEASUREMENT OF ELECTROMOTIVE FORCE

The unit of electromotive force is the international volt. This is the electrical pressure, which, when steadily applied to a conductor the resistance of which is one international ohm, will produce a current of one international ampere. Weston Standard Cells whose e.m.f. is certified to by the National Bureau of Standards are used as a primary standard of e.m.f. in the Standardizing Laboratory.

The Potentiometer

To compare an e.m.f. directly with the standard, the potentiometer is used. The e.m.f. of the standard cell is balanced against the drop of potential caused by passing current through the potentiometer shunt from a storage cell. This shunt consists of a series of adjusted resistance coils and a slide wire marked to scale. By setting the contacts of the circuit containing the galvanometer and the standard cell at scale points indicating the exact voltage of the standard cell, and adjusting the storage battery current until the circuit balances and the galvanometer reads zero, the potentiometer becomes direct reading. Any external d-c. voltage not exceeding 1.5 volts may then be read by balancing it against the drop across a suitable part of the potentiometer shunt. For extreme accuracy, a small correction is made to allow for known differences in the resistance of the various sections of the slide wire. To measure higher voltages a multiplier is used which will reduce 15, 150 or 750 volts to the 1.5 volts required for the potentiometer.

Voltmeters

For a working standard of direct voltage a G-E laboratory standard d-c. voltmeter is used, and for alternating voltage a G-E laboratory standard a-c. voltmeter. These are frequently calibrated to the primary standard. In the case of the a-c. instrument, reversed readings are made in calibration, to insure agreement between the a-c. and d-c. calibrations. The instruments to be calibrated are compared with the working standards by means of a system of multipliers which give the necessary range to the working standard.

For the measurement of direct voltages, G-E Type DP2 D'Arsonval voltmeters are used. There are also a few Weston instruments still in use. These give a range from 1 to 750 volts with full scale reading, and, by means of multipliers, up to 3000 volts. These instruments operate by the torque produced on a movable, current-carrying coil located in the field of a permanent magnet. A very powerful stray field may partially demagnetize or cross-magnetize the instrument and permanently change its calibration. The DP2 instruments are shielded; some of the

Weston instruments are not. The unshielded instruments are easily affected by stray fields. These instruments are also made up as millivoltmeters with low resistances, with low scale readings from 200 millivolts up.

Never connect any instrument marked "Millivoltmeter" or "Special Meter" across higher voltage than it reads, otherwise the instrument will burn out. To measure voltage higher than the capacity of the instrument a multiplier may be placed in series with it. Then if E is the corrected reading of the voltmeter, V the voltage to be measured, R_v and R_m the resistances of the voltmeter and of the multiplier,

$$V = E \times \frac{R_v + R_m}{R_v}$$

or, two voltmeters may be placed in series and careful simultaneous readings taken; the sum of the two corrected readings is the voltage to be measured. One of the two voltmeters may be considered as a multiplier for the other; then if E_1 and E_2 are the corrected readings on the two instruments at one point, and E is the corrected reading on the first instrument at any other point,

$$V = E \times \frac{E_1 + E_2}{E_1}$$

For both a-c. and d-c. instruments the Standardizing Laboratory furnishes a curve and sometimes a certificate. On these curves the correction to be added to or subtracted from the instrument reading is plotted against the indication of the instrument. The certificate shows the comparison of the readings of the instrument with those of a correct standard. These curves and certificates should be used to correct readings and to determine the proper reading for any voltage required.

The Laboratory also furnishes a constant, K, for d-c. instruments which are used in the Testing Department. This constant K is such that if $V =$ corrected voltage and $E =$ reading of of the instrument,

$$V = K \times E$$

From this $E = \frac{V}{K}$

Therefore, to obtain the reading on the instrument which corresponds to the voltage required, divide the correct voltage by the constant of the instrument. Since these constants are never far from unity, the equation

$$E = (2 - K) \times V = V + (1 - K) \times V$$

is nearly true. This is the most convenient method for getting the proper reading.

Illustration: 110 volts required, $K = 1.003$

$$\begin{aligned} E &= V + (1 - K) \times V \\ &= 110 + (1 - 1.003) \times 110 \\ &= 110 - 0.003 \times 110 \\ &= 109.67 \end{aligned}$$

This constant should be used only to make an approximate correction and should not be used where an accuracy of 0.5 per cent or better is desired.

D-C. voltmeters should be disconnected from field circuits while the field switch is being opened, because of the inductive kick, which frequently bends the needle. They should also be disconnected from synchronous motor or synchronous condenser fields, while the machines are starting from the a-c. side because of the high alternating voltage developed by transformer action in the field windings during starting. This voltage will sometimes puncture or burn out a voltmeter.

A voltmeter should always be connected through a double-pole switch, and should be kept out of circuit when not in use, as its readings may change with long continued heating. The cover glass should never be rubbed before reading on account of the electrostatic effect on the needle. If a cover glass shows electrification, it may be discharged by moistening it with the breath. No moisture should be allowed to reach the inside of the instrument.

Two types of Thomson voltmeters are generally used for the measurement of alternating voltage,—Type P and Type P3. The P3 instrument may also be used on direct voltage without sensible error, but the P instrument must not be so used for accurate work unless nearly full scale readings are taken. These instruments have a range of from 15 to 750 volts full scale reading.

On account of the spreading of certain parts of the scale, an a-c. voltmeter cannot be used with accuracy as low on the scale as a d-c. instrument. In general a P instrument should not be used below ⅓ its maximum reading. The P instruments, containing no permanent magnets or shields, are also sensitive to the action of stray fields, especially if this field alternates at the same frequency as the voltage applied to the instrument. They should, therefore, be kept away from masses of iron and from cables carrying heavy currents, and should be placed at least two feet from other instruments. The P3 instruments are much less sensitive to stray fields, and may be placed within two inches of one another without sensible error.

Cables carrying heavy currents, whether direct or alternating current, should be kept close together. They must never pass on opposite sides of a machine standing on an iron floor. If an instrument reads alike in four positions 90 deg. apart, it is unaffected by stray fields. Protection from stray fields for an unshielded instrument is sometimes obtained by placing the instrument in an open topped iron box. The accuracy of the indication, however, may be slightly changed by the proximity of the iron to the field of the instrument.

Care should be taken that voltage leads are always connected to the points between which the difference of potential is to be read. Thus, in reading volts across the armature on a compound wound d-c. machine, the leads should be attached to the brushes, while in reading volts across the machine they should be attached to the outer end of the series field and the brush ring of opposite polarity. In any circuit where voltage drop is measured, the resistance of an extra connection in the main current circuit included between the voltmeter contacts is often sufficient to cause serious error. Only the voltmeter current should flow through the voltmeter leads.

Potential Transformers

For most commercial alternating voltages a 130 or 150 volt voltmeter is used in connection with a potential transformer. The transformer voltages given in the following table are in common use. In addition to this list of standard transformers, there are in the Testing Department a few transformers of other descriptions for special uses.

STANDARD POTENTIAL TRANSFORMER VOLTAGES

Primary Volts	Secondary Volts
OIL INSULATED, IRON CASE	
13200	110
11000	110
DRY INSULATED, IRON CASE	
6600	110
5500	110
DRY INSULATED, MARBLE BASE	
3300	110
2200	110
1100	110
550	110
220	110
DRY INSULATED, PORTABLE, WOODEN CASE	
1100/2200	110/220
550/1100	110/220

Most of these transformers are designed for use at any frequency from 25 to 60 cycles. They are tested with a load of a single instrument at from 80 to 120 volts secondary and should not be loaded with more than two instruments nor used outside this range of voltage or frequency except when special arrangements have been made with the Standardizing Laboratory and the transformers have been checked under the proper conditions. The transformer primary must be connected to the line and the secondary to the instruments.

In the portable type there are four primary and four secondary terminals, from which three voltage ratios may be obtained; viz., series multiple, multiple multiple or multiple series connection. For series connection, the two inner terminals are connected and the lines or instrument leads are connected to the two outer terminals. For multiple connection, the two terminals on one side are connected to one line or lead and the two on the opposite side are connected to the other. The cases of the iron potential transformers should always be grounded. No changes should ever be made in connections with the high potential on.

MEASUREMENT OF CURRENT

The primary standard of current is the silver voltameter which is used for comparison occasionally. The practical standard used is a set of very accurate standard current-carrying resistances. The voltage drop across these resistances is measured by the potentiometer. The current value is then obtained by multiplying the voltage by a constant depending on the resistance used.

A G-E laboratory standard millivoltmeter used in connection with a multiplier and set of shunts constitutes the working standards of direct current. The working standards for alternating current include a series of Kelvin balances covering a wide range of currents. The working standards are calibrated from the potentiometer, reversed readings being used for the balances. The portable instruments are compared with the working standards.

For the measurement of direct current, G-E Type DP2 ammeters and some Weston ammeters are used. The DP2 instruments are self-contained with full-scale readings from 150 milliamperes up to 30 amperes. The Weston instruments are self-contained up to 200 amperes. The DP2 millivoltmeters of 200 millivolts full scale are used with G-E portable shunts from 30 to 3000 amperes capacity. For higher ranges manganin oil-cooled shunts are used in connection with the same millivoltmeter. There are also some 500, 1000, and 2000 ampere shunts of 400 millivolts drop at rated current which are used in connection with 400 millivolt Weston instruments. For heat runs where high accuracy is not required, Thomson station shunts ranging up to 15,000 amperes are used with DP2 millivoltmeters of 60 millivolt full scale. This combination has an appreciable temperature coefficient, and should not be used for accurate measurements without special instructions from the Standardizing Laboratory.

In reading a millivoltmeter attached to a shunt, assume the end of the scale to represent the rated amperes of the shunt, and read the result accordingly. To correct for instrument error, multiply by the instrument constant, or use the certified values. In case the millivoltmeter and shunt have been certified as a unit, the correction shown in the certificate includes errors of both instrument and shunt. If the instrument error is separately certified, correction may be made for the shunt error by multiplying by $\frac{E}{IR}$, where E = rated volts drop of the shunt, I = rated current of the shunt, and R = actual resistance of the shunt.

This correction is very small, and may usually be neglected.

For measuring current beyond the capacities of the instruments at hand, two ammeters may be placed in multiple; but both instruments must be read simultaneously at every point. If two shunts are used in multiple, millivoltmeters must be connected to each and readings taken on both.

For the measurement of alternating current, Types P and P3 ammeters are used. The general statements as to voltmeters apply equally to ammeters of the same type. The ammeters are somewhat more likely to produce stray fields, especially the high current instruments. Ammeters should be protected by a short-circuiting switch, which is kept closed except when reading.

The usual method of measuring high alternating currents is by using current transformers in connection with low reading ammeters. The standard commercial G-E transformers have a 5 ampere secondary. These are used in the Testing Department for all purposes. Current transformers have a core and windings like a low voltage, high current power transformer, but are insulated to stand considerable voltages, but they should never be used on circuits whose voltage exceeds that given on the nameplate. The ratio given by the Laboratory for a point is accurate at that point, but the ratio varies somewhat for lower or higher currents. The secondary should not carry more than two instruments. The secondary circuit of a current transformer must never be open while current flows through the primary. If this precaution is not taken, there is danger of the transformer overheating and thereby breaking down the insulation. There is also danger to anyone handling the secondary, owing to its high voltage. Opening the secondary while current flows in the primary also magnetizes the transformer core, which causes a change in the ratio of currents and in the phase angle between them. The transformer should, if subjected to this high magnetization, be carefully demagnetized before being relied on for precision work.

Demagnetization may be carried out by putting at least one-half load primary current through the transformer with 10 ohms or more connected to the secondary, in series with the instruments to be used. This resistance should then be gradually reduced to zero, by steps of one ohm or less. All these transformers can be used on circuits operating at 25 to 125 cycles.

To measure the currents in a three-phase circuit, two equally rated current transformers and three ammeters are necessary. The primaries of the two transformers are placed in two of the lines; the secondaries are connected with like polarities together (straight connection); a common connection is added so as to short-circuit both secondaries. One ammeter is placed in each separate transformer secondary circuit; the third ammeter goes in the common line, and reads the current in the third phase. Where both voltage and current are small, as in the testing of small induction motors, three similar current transformers should be used to avoid unbalancing the circuit.

MEASUREMENT OF POWER

There is no primary standard of electrical power in practical use. Wattmeters for general use are tested on direct current; for special accuracy, particularly under low power conditions, alternating current is used for the test. In the d-c. test, 100 volts, as given by a laboratory standard voltmeter is applied to the potential circuit of the wattmeter, and current, measured on a laboratory standard ammeter, is sent through the wattmeter current circuit. The product of the volts and amperes gives the true watts. Readings are taken direct and reversed and the average is used as the true a-c. value. When the a-c. test is made, the wattmeter is compared directly with a calibrated dynamometer. If a test at low power-factor is desired, the phase position of the voltage supplied to the potential circuits of the instrument and the standard is controlled by a phase shifting transformer.

P and P3 instruments are used in the Testing Dept. Their potential circuits are for 150 volts, with current circuits ranging from 1 to 200 amperes. The full scale readings range from 150 to 20,000 watts. The P instruments are the more sensitive to stray fields.

Never apply more than the rated voltage to the potential circuit. The current circuit will carry up to three times the rated amperes for a short time. The accuracy of the wattmeter depends but slightly on the ratio of current and potential applied. Wattmeter readings may be corrected by reference to curves or certificates as previously stated for voltmeters. Current and potential transformers may be used with wattmeters where the current or potential is larger than the wattmeter rating. The secondaries of current transformers used on polyphase circuits with wattmeters should not be interconnected.

When wattmeters are used with current or potential transformers, the potential circuit, current circuit, and case of the wattmeter should be connected together with a light fuse wire, to prevent differences of potential between the coils and case.

If R_w is the corrected reading of the wattmeter, C the certified ratio of the current transformer, and P the certified ratio of the potential transformer,

$$\text{True watts} = P \times C \times R_w$$

When reading a small power at a moderately high voltage on a wattmeter, the wattmeter reading may be affected by the losses in the instrument itself. If the current flowing in the voltage circuit of the wattmeter passes also through the current coil, the wattmeter reads the losses in its potential coil. If a voltmeter is similarly connected, the wattmeter reads its losses also. If E is the applied voltage and R the resistance of the loss circuit, then, since the circuit is practically non-inductive, loss $= \frac{E^2}{R}$.

If the wattmeter and voltmeter are so connected as to prevent the current in the potential circuits from flowing through the current coil, the wattmeter reads the losses in its current coil, and the voltmeter reads the drop through the wattmeter current coil in addition to the voltage across the load. These errors are nearly always negligible. If the wattmeter reads the losses in potential circuits, a measure of the amount of the losses may be had by reading the wattmeter, after opening the load circuit so as to leave all instruments connected to the main lines. This is called reading stray power, and is a good check for leakage losses.

In measuring the watts in a two-phase circuit, each phase should be considered as a separate single-phase circuit. The sum of the readings on two wattmeters gives the total watts.

In a three-phase three-wire circuit two wattmeters should be used. The current coils should be placed in two of the phases and each potential coil connected from that phase in which its current circuit is placed, to the third phase. The algebraic sum of the wattmeter readings gives the total watts. The higher reading wattmeter is always positive; the lower reading is positive if the power-factor is above 0.5, negative if it is below 0.5. To determine by test whether the reading is positive or negative, open the phase to which the wattmeter in question is not connected. This leaves a single-phase circuit on the wattmeter; if the wattmeter still reads forward, it will give positive values on the three-phase connection. If it reads backwards, it gives negative readings on three-phase.

To read the watts in a three-phase four-wire circuit, three wattmeters should be used. The current coils should be connected in the three-phase lines, and each potential coil should be connected from the line in which its current coil is placed to the neutral line. The total watts equal the sum of the corrected indications of the three wattmeters. The same method may be used on a three-phase three-wire system by connecting the potential circuit of the three instruments in Y, thus forming a neutral point for the instruments. The instruments must have equal resistances in the potential circuits. If potential transformers are used with the primaries connected in Y on a three-phase three-wire circuit, the secondaries should be connected in delta to the potential circuits of the wattmeters.

If a wattmeter potential circuit is not absolutely non-inductive the current in it will have a slight phase displacement relative to the voltage across the wattmeter terminals. This is equivalent to a change in the phase angle between the voltage and current of the main circuit as read on the wattmeter. Hence, wattmeters are subject to an error, from which ammeters and voltmeters are free. If a current and a potential transformer are used

TABLE I. CORRECTION FACTORS FOR PHASE ANGLE $\left\{ \frac{\cos \theta}{\cos \theta_2} \right.$

Use with lagging load with $(\alpha+\beta+\gamma)$ positive — Use with leading load with $(\alpha+\beta+\gamma)$ negative

$\alpha+\beta+\gamma$	APPARENT POWER-FACTOR $\cos.\theta_2$										
	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90
5′	0.9855	0.9904	0.9928	0.9943	0.9953	0.9966	0.9974	0.9980	0.9985	0.9989	0.9993
10′	0.9710	0.9808	0.9857	0.9887	0.9907	0.9933	0.9949	0.9961	0.9970	0.9978	0.9985
15′	0.9565	0.9712	0.9786	0.9831	0.9860	0.9899	0.9924	0.9941	0.9955	0.9967	0.9978
20′	0.9420	0.9616	0.9714	0.9774	0.9814	0.9866	0.9898	0.9922	0.9940	0.9956	0.9971
25′	0.9276	0.9520	0.9643	0.9718	0.9768	0.9832	0.9873	0.9902	0.9925	0.9945	0.9964
30′	0.9131	0.9424	0.9571	0.9661	0.9722	0.9799	0.9848	0.9883	0.9910	0.9934	0.9956
40′	0.8841	0.9232	0.9429	0.9548	0.9629	0.9732	0.9797	0.9844	0.9880	0.9912	0.9942
50′	0.8552	0.9040	0.9286	0.9436	0.9537	0.9665	0.9747	0.9805	0.9850	0.9890	0.9928
1°	0.8262	0.8848	0.9143	0.9323	0.9444	0.9598	0.9696	0.9766	0.9820	0.9868	0.9914
10′	0.7971	0.8655	0.8999	0.9210	0.9350	0.9530	0.9645	0.9726	0.9789	0.9845	0.9899
20′	0.7681	0.8463	0.8857	0.9097	0.9257	0.9463	0.9594	0.9687	0.9759	0.9822	0.9884
30′	0.7391	0.8271	0.8713	0.8984	0.9164	0.9396	0.9543	0.9647	0.9729	0.9800	0.9869
40′	0.7101	0.8079	0.8570	0.8872	0.9071	0.9329	0.9491	0.9608	0.9699	0.9777	0.9854
50′	0.6811	0.7887	0.8427	0.8759	0.8978	0.9261	0.9440	0.9568	0.9668	0.9755	0.9839
2°	0.6521	0.7695	0.8284	0.8646	0.8885	0.9194	0.9389	0.9529	0.9638	0.9732	0.9824
10′	0.6230	0.7502	0.8140	0.8531	0.8791	0.9126	0.9337	0.9488	0.9607	0.9709	0.9808
20′	0.5940	0.7309	0.7996	0.8417	0.8697	0.9058	0.9286	0.9448	0.9576	0.9686	0.9793
30′	0.5649	0.7116	0.7853	0.8303	0.8604	0.8990	0.9234	0.9408	0.9545	0.9663	0.9778
40′	0.5359	0.6924	0.7709	0.8189	0.8510	0.8922	0.9183	0.9368	0.9514	0.9640	0.9763
50′	0.5068	0.6731	0.7566	0.8074	0.8417	0.8855	0.9131	0.9328	0.9483	0.9617	0.9748
3°	0.4778	0.6538	0.7422	0.7960	0.8323	0.8787	0.9080	0.9288	0.9452	0.9594	0.9733
10′	0.4487	0.6343	0.7277	0.7845	0.8228	0.8718	0.9028	0.9247	0.9420	0.9570	0.9717
20′	0.4196	0.6148	0.7133	0.7731	0.8134	0.8650	0.8976	0.9207	0.9389	0.9547	0.9701
30′	0.3906	0.5953	0.6989	0.7617	0.8040	0.8582	0.8924	0.9166	0.9358	0.9523	0.9685
40′	0.3615	0.5759	0.6845	0.7503	0.7946	0.8514	0.8871	0.9126	0.9327	0.9500	0.9670
50′	0.3325	0.5564	0.6701	0.7388	0.7852	0.8445	0.8819	0.9085	0.9295	0.9476	0.9654
4°	0.3034	0.5369	0.6557	0.7274	0.7758	0.8377	0.8767	0.9045	0.9264	0.9453	0.9638
10′	0.2743	0.5177	0.6412	0.7159	0.7663	0.8308	0.8714	0.9004	0.9232	0.9428	0.9621
20′	0.2452	0.4985	0.6268	0.7045	0.7569	0.8239	0.8662	0.8963	0.9260	0.9404	0.9605
30′	0.2161	0.4793	0.6124	0.6930	0.7474	0.8171	0.8609	0.8922	0.9168	0.9380	0.9590
40′	0.1871	0.4602	0.5980	0.6816	0.7380	0.8102	0.8557	0.8881	0.9136	0.9356	0.9573
50′	0.1580	0.4410	0.5836	0.6701	0.7285	0.8034	0.8504	0.8841	0.9104	0.9332	0.9557
5°	0.1289	0.4218	0.5692	0.6587	0.7191	0.7965	0.8452	0.8800	0.9072	0.9308	0.9540
10′	0.0998	0.4026	0.5548	0.6472	0.7096	0.7896	0.8399	0.8759	0.9040	0.9284	0.9524
20′	0.0707	0.3834	0.5404	0.6358	0.7002	0.7828	0.8347	0.8718	0.9008	0.9260	0.9507

TABLE II. CORRECTION FACTORS FOR PHASE ANGLE $\left\{ \frac{\cos \theta}{\cos \theta_2} \right.$

Use with lagging load with $(\alpha+\beta+\gamma)$ negative — Use with leading load $(\alpha+\beta+\gamma)$ positive

$\alpha+\beta+\gamma$	APPARENT POWER-FACTOR $\cos \theta_2$										
	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90
5′	1.0145	1.0096	1.0071	1.0057	1.0046	1.0033	1.0025	1.0020	1.0015	1.0011	1.0007
10′	1.0289	1.0192	1.0142	1.0113	1.0092	1.0066	1.0050	1.0039	1.0029	1.0022	1.0014
15′	1.0434	1.0288	1.0213	1.0170	1.0138	1.0099	1.0075	1.0059	1.0044	1.0033	1.0021
20′	1.0578	1.0383	1.0284	1.0225	1.0185	1.0133	1.0100	1.0077	1.0059	1.0043	1.0028
25′	1.0723	1.0479	1.0355	1.0282	1.0231	1.0166	1.0125	1.0097	1.0074	1.0054	1.0035
30′	1.0867	1.0575	1.0426	1.0338	1.0277	1.0199	1.0150	1.0116	1.0088	1.0065	1.0041
40′	1.1156	1.0766	1.0568	1.0450	1.0369	1.0265	1.0200	1.0154	1.0117	1.0086	1.0055
50′	1.1445	1.0958	1.0711	1.0563	1.0462	1.0332	1.0250	1.0193	1.0147	1.0108	1.0069
1°	1.1734	1.1150	1.0853	1.0675	1.0554	1.0398	1.0300	1.0231	1.0176	1.0129	1.0083
10′	1.2023	1.1342	1.0995	1.0787	1.0646	1.0464	1.0350	1.0269	1.0205	1.0150	1.0096
20′	1.2311	1.1533	1.1136	1.0899	1.0737	1.0530	1.0399	1.0307	1.0234	1.0171	1.0110
30′	1.2600	1.1725	1.1278	1.1010	1.0829	1.0595	1.0449	1.0345	1.0262	1.0192	1.0123
40′	1.2888	1.1916	1.1419	1.1122	1.0920	1.0661	1.0498	1.0383	1.0291	1.0213	1.0136
50′	1.3177	1.2108	1.1561	1.1234	1.1012	1.0727	1.0548	1.0421	1.0320	1.0235	1.0150
2°	1.3466	1.2300	1.1703	1.1346	1.1104	1.0793	1.0598	1.0459	1.0349	1.0256	1.0163
10′	1.3754	1.2492	1.1844	1.1462	1.1195	1.0858	1.0647	1.0497	1.0377	1.0277	1.0176
20′	1.4042	1.2683	1.1985	1.1578	1.1286	1.0924	1.0696	1.0534	1.0406	1.0297	1.0189
30′	1.4329	1.2875	1.2126	1.1693	1.1377	1.0989	1.0745	1.0572	1.0435	1.0318	1.0201
40′	1.4617	1.3066	1.2267	1.1809	1.1468	1.1054	1.0794	1.0609	1.0463	1.0338	1.0214
50′	1.4905	1.3258	1.2409	1.1925	1.1560	1.1120	1.0844	1.0647	1.0492	1.0359	1.0227
3°	1.5193	1.3449	1.2550	1.2041	1.1651	1.1185	1.0893	1.0684	1.0520	1.0379	1.0240
10′	1.5480	1.3637	1.2690	1.2147	1.1742	1.1250	1.0942	1.0721	1.0548	1.0399	1.0252
20′	1.5769	1.3824	1.2831	1.2253	1.1832	1.1315	1.0990	1.0758	1.0576	1.0419	1.0264
30′	1.6056	1.4012	1.2971	1.2359	1.1923	1.1379	1.1039	1.0795	1.0603	1.0438	1.0276
40′	1.6344	1.4199	1.3111	1.2465	1.2013	1.1444	1.1087	1.0832	1.0631	1.0458	1.0288
50′	1.6632	1.4387	1.3252	1.2572	1.2104	1.1509	1.1135	1.0869	1.0660	1.0478	1.0300
4°	1.6920	1.4575	1.3392	1.2678	1.2194	1.1574	1.1184	1.0906	1.0687	1.0498	1.0313
10′	1.7206	1.4764	1.3532	1.2788	1.2284	1.1638	1.1232	1.0942	1.0714	1.0518	1.0325
20′	1.7491	1.4952	1.3672	1.2898	1.2374	1.1703	1.1280	1.0979	1.0742	1.0537	1.0337
30′	1.7777	1.5141	1.3811	1.3007	1.2463	1.1767	1.1328	1.1015	1.0769	1.0557	1.0348
40′	1.8062	1.5329	1.3951	1.3117	1.2553	1.1831	1.1376	1.1051	1.0796	1.0576	1.0360
50′	1.8348	1.5518	1.4091	1.3227	1.2643	1.1896	1.1424	1.1088	1.0824	1.0596	1.0372
5°	1.8634	1.5707	1.4231	1.3337	1.2733	1.1960	1.1472	1.1124	1.0851	1.0616	1.0384
10′	1.8920	1.5896	1.4371	1.3447	1.2823	1.2024	1.1520	1.1160	1.0878	1.0636	1.0396
20′	1.9205	1.6084	1.4511	1.3557	1.2913	1.2089	1.1568	1.1196	1.0906	1.0655	1.0408

there is usually a further phase difference between primary and secondary current in the former, and between primary and secondary voltage in the latter. The result of these three angular changes is a change in the phase relation in the wattmeter. The total change rarely exceeds 2 degrees, and is frequently less than 30 minutes. At or near unity power-factor its effect on the reading is inappreciable; but at a very low power-factor large errors may result.

Correction for Phase Angle

Correction of wattmeter readings for errors due to phase angle of wattmeter, current transformers, and potential transformers, may be made as follows:—

A—Single-phase circuits.

(1) Correct all instruments for scale error.

(2) Obtain α, the equivalent phase angle of the wattmeter, from the certificate. (This is very small for the P and P3 wattmeters, and can usually be neglected.)

(3) Select β, the phase angle between the primary and (reversed) secondary currents of the current transformer, from the certificate, using the reading of the ammeter in series with the wattmeter.

(4) Select γ, the phase angle between the primary and (reversed) secondary voltages of the potential transformer from the certificate, using the reading of the voltmeter in parallel with the wattmeter.

(5) Determine $\cos\theta_2$, the apparent power-factor from the readings of the ammeter, voltmeter and wattmeter (corrected according to No. 1) by the formula

$$\text{Power-factor} = \frac{\text{Watts}}{\text{volts} \times \text{amperes}}$$

(6) Add algebraically α, β and γ, using the signs as given in the certificates.

(7) Select the correction factor from Tables 1 or 2. In these tables a series of values of $(\alpha+\beta+\gamma)$ is given in the left hand column; in the first line across the top of the columns is given a set of values of the apparent power-factor ($\cos\theta_2$.) The correction factor is found in the column under the proper apparent power-factor in line across the page from the proper value of $(\alpha+\beta+\gamma)$. For values lying between those given in the tables, interpolation will give sufficient accuracy for most cases.

Table 1 should be used when $(\alpha+\beta+\gamma)$ is a positive angle and the power-factor of the circuit supplying the wattmeter is lagging, or when $(\alpha+\beta+\gamma)$ is a negative angle and the power-factor of the circuit is leading.

Table 2 should be used when $(\alpha+\beta+\gamma)$ is a positive angle and the power-factor is leading, or when $(\alpha+\beta+\gamma)$ is a negative angle and the power-factor is lagging.

(8) True watts = wattmeter reading corrected according to (1) × certified ratio of current transformers × certified ratio of potential transformer × correction factor for phase angle.

If the greatest accuracy or values outside the limits of the table are required, the following method may be used:

Follow (1), (2), (3), (4) and (5) as given herewith. If $\cos\theta$ represents the true power-factor of the circuit, θ being considered a positive angle for lagging current and a negative angle for leading current,

$$\theta = \theta_2 + (\alpha + \beta + \gamma)$$

Then

True watts = wattmeter reading corrected according to (1) × certified ratio of current transformer × certified ratio of potential transformer $\times \frac{\cos\theta}{\cos\theta_2}$

$\frac{\text{Cos}\ \theta}{\text{Cos}\ \theta_2}$ is the correction factor given in Tables 1 and 2.

B—Three-phase three-wire circuits with currents and voltages balanced.

When two wattmeters or a polyphase wattmeter are used with similar current transformers whose secondaries are equally loaded and not interconnected the total watt reading may be corrected for phase angle by the same method as on single-phase, using the apparent power-factor of the three-phase circuit which is

$$\frac{\text{Total wattmeter reading}}{\sqrt{3} \times \text{volts (delta)} \times \text{amperes of one line}}$$

instrument corrections being applied as per (1).

C—Other polyphase circuits.

On three-phase four-wire circuits, three-phase three-wire circuits, whose currents or voltages are unbalanced, and two-phase circuits each wattmeter should be treated as a separate single-phase instrument obtaining the apparent power-factor from its reading and of the voltmeter and ammeter in the same phase, consequently using a different correction factor for each wattmeter. On a three-phase three-wire circuit using the two-wattmeter method, it should be noted that the current is frequently leading in one wattmeter and lagging in the other.

MEASUREMENT OF POWER-FACTOR

The power-factor of a single-phase circuit $= \frac{\text{Watts}}{\text{volts} \times \text{amps.}}$

It is usually obtained by using the readings of the voltmeter, ammeter and wattmeter.

In a balanced three-phase circuit, the power-factor may be obtained from the two wattmeter readings. If a is the phase angle, the power-factor $= \cos a$, and R is the ratio of the smaller to the greater wattmeter reading,

$$Tan\ a = \frac{1-R}{1+R}\sqrt{3}$$

The principle of the General Electric Company balanced three-phase power-factor meter uses this fact. The elements are so combined into one instrument that the position of the pointer depends on the ratio of the watts. The instrument is quite accurate, and independent of frequency.

The volt-amperes in a balanced three-phase circuit are equal to the product of the amperes per line, the volts between lines, and the square root of three.

CHAPTER 3

ASSEMBLY OF MACHINES FOR TEST

HANDLING MATERIAL

When erecting large apparatus for test, methods of handling and transportation are of prime importance. Each piece of apparatus must of course be handled with reference to its special construction. Practically all of the handling of the larger machines and parts is done by the crane men and crane followers, but each test man should become familiar with the correct methods of handling such material and see that such work is carried on in the approved manner.

There is a great difference between ropes and slings used for hoisting. In ropes the wear can always be seen by the strands becoming frayed, loose, or cut. A chain, except for a few bruises, will not show any signs of weakness, even though, at the same time, it may be full of small cracks which cannot be seen by the naked eye, or it may be much crystallized by long use.

Care should be used in every case to see that satisfactory slings and ropes are used to lift apparatus.

There are many varieties of hitches and knots, some of which are shown on the following pages.

Wire cable slings occupy a very important place in hoisting and have been found very satisfactory when carefully used.

In using slings of any kind care should be taken to see that one section does not lie on top of another and thus put an undue strain on the outer section.

It often happens when a rope sling is used double that the ends of the rope are passed through the double part. Unless this is done carefully the effect of only one part will be obtained instead of two.

Increased Stresses Due to Angle of Slings

When a weight is lifted by two or more slings connected to the crane hook and making an angle with each other, the increase in the stress of the individual slings must be considered. On account of this angle between the two sets of slings the stresses on each set is greater than half the total load, and increases very rapidly as the angle between the sling and the work is decreased. An angle of 45 degrees between the sling and the work makes the stress in each sling ¾ of the total weight, and the collapsing force between the two points of attachment to the work is equal to ½ the weight. This collapsing force acts in a direct line between the two points of attachment. If the work is ring shaped, it would tend to deform the ring. A spreader of sufficient stiffness should be used between these two points to resist this collapsing force. It will be seen that eyebolts are not suitable for attaching the slings to the work unless a spreader is used to relieve them of this side pull, which would put a *heavy bending moment* on the shank of the bolt.

Reducing the angle between the sling and the work to 30 degrees makes the stress in each sling equal to the total weight and the collapsing force is also equal to the total weight. Such a small angle should never be used if avoidable.

The following tables show how the safe load becomes very much smaller when the slings are used at an angle instead of a straight pull.

SAFE LOAD IN LB. ON MANILA ROPES AND SLINGS

Rope Diam. in In.	Two Part Sling, Vertical Load	Two Part Sling, 60° Angle	Two Part Sling, 45° Angle	Two Part Sling, 30° Angle
½	500	435	355	250
⅝	1000	870	710	500
¾	1500	1300	1065	750
⅞	2000	1750	1420	1000
1	3000	2600	2125	1500
1¼	4000	3475	2830	2000
1½	5000	4340	3540	2500
1¾	8000	6940	5665	4000
2	10000	8680	7080	5000
2¼	13000	11285	9200	6500
2½	16000	14880	11325	8000

SAFE LOAD IN LB. ON WIRE CABLE OR SLINGS

Wire Cable Diam. in In.	Two Part Sling, Vertical Load	Two Part Sling, 60° Angle	Two Part Sling, 45° Angle	Two Part Sling, 30° Angle
½	4000	3470	2830	2000
⅝	6500	5625	4590	3250
¾	9000	7800	6350	4500
⅞	12000	10400	8500	6000
1	16000	13870	11300	8000
1¼	24000	20800	17000	12000
1½	38000	32900	26900	19000
1¾	50000	43300	35300	25000
2	64000	55500	45250	32000

SAFE LOADS FOR EYEBOLTS

When it is necessary to use eyebolts for lifting loads no greater strain should be allowed than given in the table on page 61, which gives the safe load in pounds up to and including bolts 2¼ in. in diameter.

It should be understood that to obtain the greatest strength from an eyebolt, it must fit reasonably tight in the hole into which it is screwed, and the pull applied in a line with the axis of the screw.

Eyebolts should never be used if considered the least faulty. They should never be painted when used for miscellaneous lifting, as paint is very apt to cover up flaws. They should be tested occasionally by tapping gently with a hammer but not sufficient to bend or to otherwise injure them. If it does not impart a good ring one of two things is the reason. It may fit too loosely in the hole, or there may be a flaw.

Where a bolt is to be used for anything like its maximum load it should be screwed in tight with a bar and given a gentle tap with a bar or hammer to see if it imparts a solid feeling. If not, it should not be used.

The strains set up in an eyebolt when used at an angle are very severe, due to the bending action of the bolt, and it is very liable to break where it is screwed into the work. This is shown very clearly by the table on page 61, that gives the safe load when used for a direct pull, and also shows how the strength of the bolt rapidly decreases according to the angle that may be used.

SAFE LOAD ON ROPES AND CHAINS

The tables on page 62 give the safe loads which may be put on manila rope, wire cables, and chains. The first column gives the diameter of the rope or chain, the second column gives the safe load which the rope or chain is to carry singly. In a sling where the strain is carried by two ropes or chains, the load given in third column should be used. In a sling where four parts of the rope or chain carry the load, the figures in the fourth column should be used. Figures are in tons of 2000 lb. each.

The figures given in the above table are for cases in which the slings are in constant use and subjected to ordinary shop practice. Where cables of known high tensile strength are used these figures may be increased proportionately.

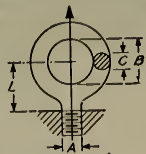
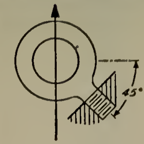
The loads for manila rope should be used only when the rope is in fairly good condition; when badly chafed or worn the load should be reduced in proportion.

As there are a great many different kinds of material to handle in the various parts of the Works, and in order to familiarize those engaged in the actual handling of these materials, a short table of the weights of the various materials is given on page 62.

The weights of cast iron, steel, copper and lead are given in pounds per cubic foot. The weights of wood, concrete, stone, earth, brick, mortar and marble are also given in pounds per cubic foot.

The weight of shafts is given per lineal foot.

SAFE LOAD ON EYEBOLTS WHEN LOADED IN DIRECTION OF ARROW

	DIMENSIONS IN INCHES						
	Size of Eyebolt A	B	C	L	Load in Direction of Arrow Lb.	Load in Direction of Arrow Lb.	Load in Direction of Arrow Lb.
Drop Forge Steel 9000 Combined Stress in Lb. per Sq. In.	½-13	1½	$\frac{7}{16}$	1½	1100	51.5	37.6
	$\frac{9}{16}$-12	$1\frac{9}{16}$	$\frac{17}{32}$	1⅝	1500	69.8	51
	⅝-11	$1\frac{11}{16}$	⅝	1¾	1800	89.5	65.6
	¾-10	$1\frac{13}{16}$	¾	2⅛	2800	136	100
	⅞-9	$1\frac{15}{16}$	$\frac{13}{16}$	2¼	3900	208	153
	1 -8	$2\frac{1}{16}$	$\frac{15}{16}$	2½	5100	280	207
	1¼-7	$2\frac{5}{16}$	$1\frac{3}{16}$	2⅞	8400	503	372
	1½-6	$2\frac{9}{16}$	1⅜	3¼	12200	770	576
	1¾-5	$3\frac{1}{16}$	1½	3⅝	16500	1080	805
	2 -4½	$3\frac{1}{16}$	1⅝	3⅞	21800	1440	1140
Welded D.B.G. Iron E.L. 2800 Lb. per Sq. In. 6000 Combined Stress in Lb. per Sq. In.	1¾-5	3	1¼	3¼	10000	800	600
	1¾-5	4	1½	4	11000	660	486
	2 -4½	5	1¾	4½	14000	884	655
	2¼-4½	6	2	5¾	16000	1050	770

SAFE LOAD IN TONS, VERTICAL LOAD

MANILA ROPE				WIRE CABLE				CHAINS			
Dia. of Rope in In.	Safe Load in Tons			Dia. of Rope in In.	Safe Load in Tons			Dia. of Chain in In.	Safe Load in Tons		
	Single Rope	Two Part	Four Part		Single Rope	Two Part	Four Part		Single Chain	Two Part	Four Part
½	⅛	¼	½	½	1	2	3½	¼	½	⅞	1½
⅝	¼	½	¾	⅝	1¾	3¼	6½	⅜	1	1¾	3
¾	⅜	¾	1¼	¾	2½	4½	9	½	2	3½	6
⅞	½	1	2	⅞	3¼	6	12	⅝	3	5	9
1	¾	1½	2½	1	4	8	16	¾	5	9	15
1¼	1	2	3	1¼	6	12	24	⅞	6	10½	18
1½	1¼	2½	4	1½	10	19	36	1	8	14	24
1¾	2	4	6	1¾	13	25	48	1⅛	11	19	33
2	2½	5	8	2	16	32	60	1¼	13	23	39
2¼	3½	6½	11					1½	18	32	54
2½	4½	8	13								

WEIGHTS OF VARIOUS MATERIALS

Material	Weight per Cu. Ft. in Lb.	Weight per Cu. In. in Lb.
METALS		
Cast iron	450	0.26
Steel	489	0.28
Copper	552	0.32
Lead	709	0.41
WOOD		
Ash	45	
Pine	38	
MISCELLANEOUS		
Concrete	155	
Stone	180	
Earth	72 to 110	
Brick	100 to 150	
Mortar	100	
Marble	180	

SHAFTING

Diameter in In.	Weight of Shafting in Lb. per Lineal Ft.
6	95
8	169
10	264
12	368
14	517
16	676

Approved Methods of Handling

Fig. 17 to 39 show some of the approved methods of handling apparatus in the factory.

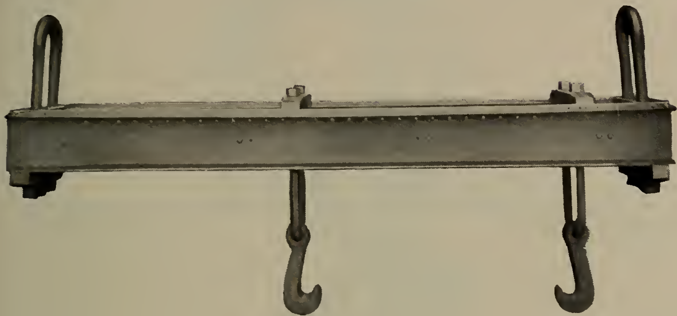


Fig. 17

TWO CRANE EQUALIZER

Used with two cranes of different lifting capacities, when lifting a load of greater weight than the safe capacity of one crane. For example: in the case of a weight of 90 tons, which is to be lifted by two cranes; one having a capacity of 60 tons, and the other a capacity of 30 tons. The hooks of the equalizer should be located so as to bring the center of the weight one-third of the length of the beams away from the end attached to the 60 ton crane. This arrangement brings two-thirds of the weight on the 60 ton crane and one-third of the weight on the 30 ton crane.

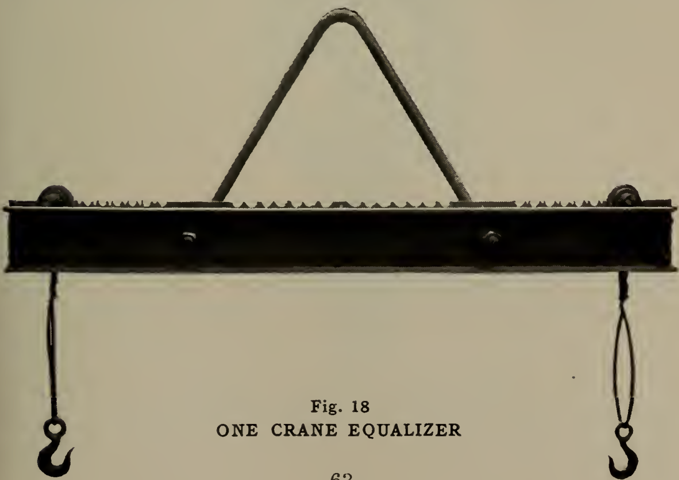


Fig. 18

ONE CRANE EQUALIZER

Fig. 19
BLACKWALL HITCH

Exceedingly useful where material is to be drawn along the floor, or for hauling cars on a level, or where the hitch is to be made quickly, or where a change is frequently required.

Fig. 20
CLOVE OR DOUBLE HALF HITCH (METHOD OF MAKING)

Fig. 21
CLOVE OR DOUBLE HALF HITCH

Very useful in the hands of a trained rigger, but, except for hauling, should not be generally used where other slings are available.

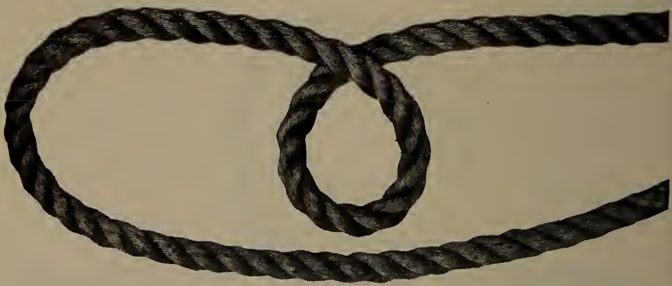


Fig. 22
BOWLINE KNOT

First position necessary in making a bowline knot.

Fig. 23
BOWLINE KNOT

Second position necessary in making a bowline knot.

Fig. 24
BOWLINE KNOT

Third position and completed bowline knot. If properly made this knot cannot slip.

Fig. 25
BOWLINE ON A BIGHT

The "bight" of a rope is that part which is doubled. There should be very little occasion for using this knot outside of the riggers' department.

Fig. 26

SQUARE OR REEF KNOT

Used only for joining two ropes together. This knot cannot slip.

Fig. 27

STUDDING SAIL HITCH

May be used very properly for hoisting timber or such material.

Fig. 28

SHEET BEND IN EYE

Generally used for an adjustable sling. It can be adjusted quickly, and is a safe and useful sling in the hands of trained riggers.

Fig. 29
TIMBER HITCH

Used principally for hoisting rough lumber.

Fig. 30
TIMBER AND HALF HITCH

Very useful for hoisting shafts or timbers in a vertical position.

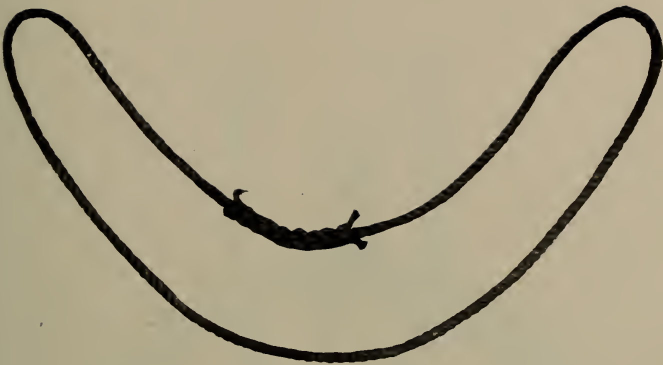


Fig. 31
SPLICED ROPE SLING

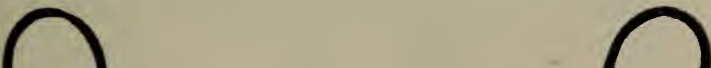


Fig. 32
LIFTING BLOCKS

A method of protecting the cable on sharp corners is by means of the corner blocks shown.

Fig. 33
WIRE CABLE SLING

Proper way of using in connection with a hook.

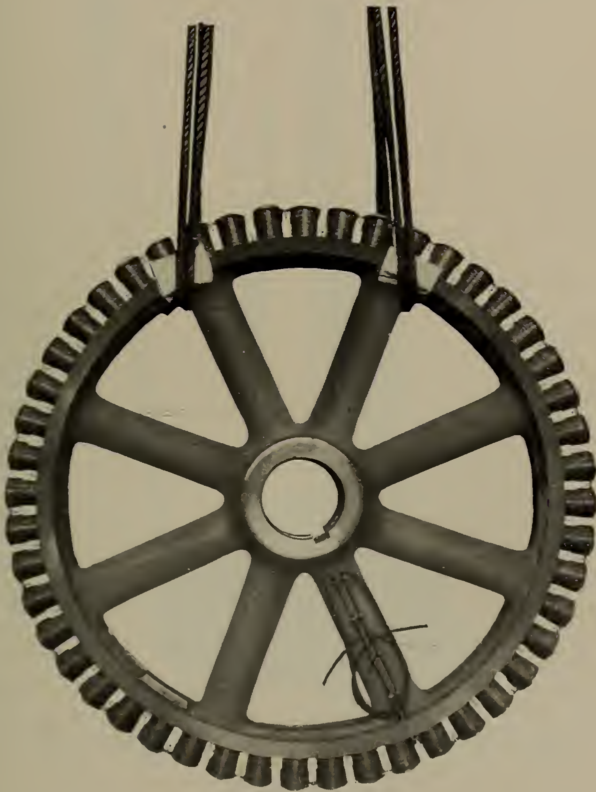


Fig. 34

LIFTING REVOLVING FIELD

Two or more double slings should be used, depending upon the weight, the slings to be placed behind two adjacent arms and protected by means of padding.

Fig. 35

PROPER WAY TO LIFT AND TURN REVOLVING FIELD (FIRST POSITION)

A double set of slings should be used on the main hoist to lift the field high enough for turning; padding being used wherever necessary to protect the slings from sharp corners.

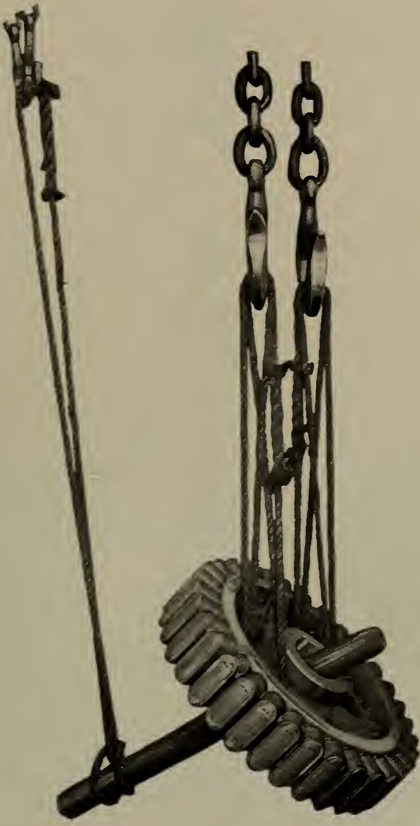


Fig. 36

PROPER WAY TO LIFT AND TURN REVOLVING FIELD
(SECOND POSITION)

The field having been hoisted high enough for turning, a piece of timber or scantling should be placed through the bore of the field, the other end of the scantling to be connected to the "small hoist" by the sling; then by lifting on the "small hoist" and lowering on the "main hoist" the work is turned over. Great care should be used, especially against chafing or cutting of the slings.

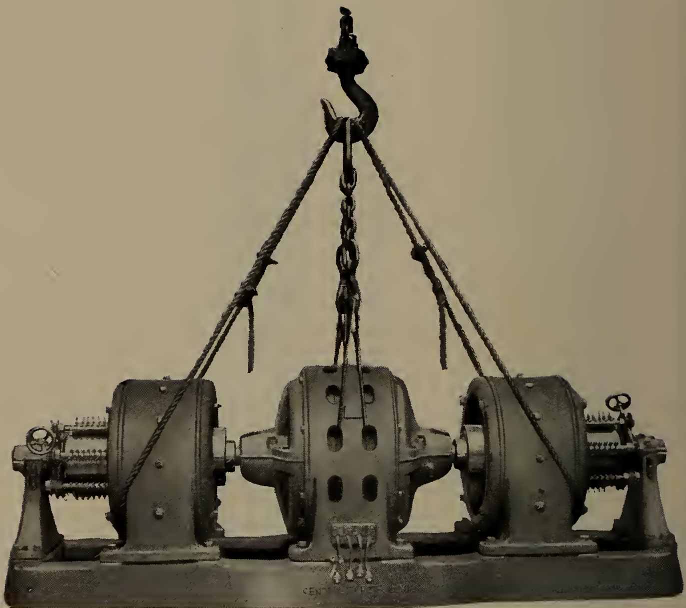


Fig. 37
LIFTING MOTOR-GENERATOR SETS

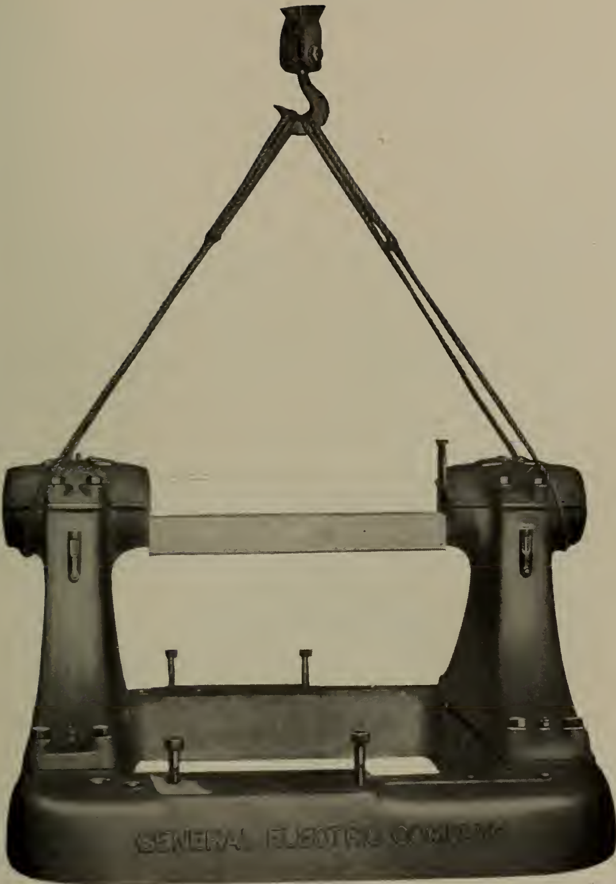


Fig. 38

LIFTING A BASE WITH STANDARDS

Frequently a base and standard are lifted and no provision is made for any lateral strains that may occur; tending to place an unnecessary strain on the bolts fastening the standards to the base. When such a lift is to be made a piece of timber should be placed between the bearings to relieve the strain, as shown.

Fig. 39
METHOD OF LIFTING ARMATURE TO ASSEMBLE IN BEARINGS

ERECTING MACHINES FOR TEST

Blocking—General Remarks

The cast iron bases, blocks, rails, etc., used for temporary foundations for machines in test are called "blocking."

In setting up a self-contained machine, that is, one with its own base, shaft and bearings, the only blocking necessary is that required to allow the stator to clear the floor and it should be placed so that the bearings and frame are well supported.

The blocking, in all cases, should be as low as possible and the necessary height should be obtained with the least number of sections. Many machines come to test without base, shaft or bearings, and the test blocking must be arranged to meet such conditions.

All blocking must be securely clamped or bolted in place, the latter method being preferable. The height of blocking necessary is found by measuring the distance from the supporting foot to the bottom of the stator. If the machine has a base, the thickness of the base should be subtracted from this measurement.

Shafts

All self-contained machines are tested on their own shafts. The assembling of the shaft in the rotor will be discussed later.

Machines without base, shaft or bearings require the use of a temporary or shop shaft and bushings of the right size to fit the shaft and the bore of the rotor.

Shop shafts should be frequently tested in a lathe to be sure that all parts of the shaft run true. The bushings should also be carefully inspected to see that they are free from burrs and are not worn either on the inside or outside. In assembling shafts in rotors care must be taken to see that the shaft and bore are clean and free from burrs.

Lubricate the shaft and bore thoroughly with a mixture of white lead and lard oil.

If bushings are to be used, slip one bushing on the shaft and introduce the shaft into the rotor and slip the other bushing into the other end of the rotor hub.

When bushings are used on a shop shaft the rotor is held in position by a collar on each side of the hub. Where a shaft is used without bushings there will be pressure enough obtained to hold the rotor in position without the use of collars. The collars should not obstruct the air passages of the armature.

In pressing shafts into the rotors of self-contained machines great care must be exercised to see that the rotor is located on the shaft in the exact position called for on the drawing, otherwise the end play will be defective.

The most accurate method of locating the rotor on the shaft is as follows:

From the shaft drawing lay off the distance on the shaft from the center of a journal to the center line of the rotor; measure back from this point the distance from the center line of the rotor to the back end of the hub. When the rotor is in the correct position on the shaft the end of the hub will be at this point.

In measuring from the center of the rotor to the end of the hub several different points on the circumference of the punchings should be taken, as owing to the unevenness of the punchings one distance might be a little greater or less than the average distance, and the average distance is the one that should be used.

The shaft is usually started into the bore with a heavy ram swung from the crane, a piece of heavy fiber being held between the end of the shaft and the ram to prevent injury to the shaft. The shaft is then placed in the hydraulic press and forced in. As soon as the rotor reaches the correct point on the shaft the power must instantly be released.

The pressure usually required between shaft and bore is five (5) tons per inch of diameter of shaft on horizontal machines. A pressure of four (4) tons per inch will pass, but below this amount the pressure obtained should be reported to the proper superintendent who will decide whether it will pass.

The bore is usually scraped to a standard pin gauge and the allowance for pressure is made on the shaft.

Bushings

Bushings one-half (½) inch or less in thickness are usually made of steel. The thicker ones are made of cast iron.

In order that the bushings may go on the shaft and into the bore without excessive ramming which would soon destroy them, they are bored from 0.001 to 0.003 in. larger, and turned from 0.001 to 0.003 in. smaller than standard.

This will make a comparatively loose fit between the shaft and rotor and the rotor must be held in position by some form of clamp or set-screw collar.

This looseness though immaterial on most large machines is sometimes troublesome on small ones, especially small high speed direct current machines as it may cause unbalancing, or it may cause the commutator to run eccentric and thus cause poor commutation. For this reason, a shaft without bushings should be used whenever it is possible.

Couplings

Shop couplings are required to be driven on and off shafts easily; they therefore do not have a very tight fit and so must be held in place with a set-screw the same as used with a pulley.

Whenever a flange coupling is put on a shaft it should be faced off either in a lathe or in its own bearings to insure that the face runs in a plane perpendicular to the center line of the shaft. The set screw should be tightened before facing the coupling.

If a coupling has been faced off and then removed from the shaft it will probably run out of true when it is re-assembled on the shaft, so it is better to test a coupling every time it is assembled on a shaft. In facing off a coupling on a shaft in a lathe it is of the greatest importance to see that the *journals* run true when the shaft is turning on center because when the shaft is in its bearings it is the journals that determine how the coupling runs and not the lathe centers.

In connecting two shafts with a flange coupling the face of each half of the coupling must revolve in a plane perpendicular to the center line of the shaft and the center line of one shaft must be a continuation of the center line of the other.

The first condition is assured by facing off the couplings as described above, and the second condition is obtained in various ways.

For example, the bearings in which the shafts turn may be located and aligned by stretching a fine wire between the centers of the two outboard bearings and adjusting the position of the other bearings to this line. In this case, allowance must be made for the natural sag of the line, which depends on the length and tightness of the line. For tables of sag and method of using steel wire for aligning shafts, see article by A. H. Nourse in the *American Machinist* of March 5th, 1908.

The usual method of aligning two shafts with flange couplings is to bring one coupling up to the face of the other and as nearly into the correct position as can be judged by the eye, and then to move the pillow block by a bar or jack until the faces of the couplings are exactly parallel to each other. This condition can be determined by gauging the distance between the faces. If a gauge can just be inserted in the space between the coupling at several different points, the faces are parallel. The height can be adjusted very readily as it is usual to have the couplings made with a projecting ring on the face of one half and a corresponding recess in the face of the other one. Care should be taken to see that the coupling bolts are a good fit in the holes, otherwise each bolt may not be equally stressed and some bolts may shear off.

Several designs of flexible couplings exist; but two types are much used in the works. One coupling consists of two parts of four arms each, the arms of one part interlocking with those of the other. These arms are separated by rubber buffers. The other type has its two parts laced together by a leather belt.

In flexibly connecting two shafts the shafts need not be exactly in line, although they should be so adjusted as closely as possible, without spending too much time on the alignment.

Assembly

Apparatus delivered from the Manufacturing Department can be divided into two general classes, viz., self-contained machines which are delivered completely assembled; and machines which may or may not be self-contained, but which are delivered to test partially or wholly dismantled. It is usually the practice to align and center in the machine shop before delivery to test, all machines having their own bases, whether they are delivered completely assembled or not. It is, therefore, important to consider the precautions and methods which have been found necessary in assembling apparatus for test.

Cast iron bases, especially those used in connection with medium size and large apparatus, do not possess the necessary stiffness to allow them to be erected without proper support on the iron floor or testing blocks. Care must, therefore, be taken when setting machines in the testing stand to see that there are no chips, or lumps, under the blocking or base which may spring the base or destroy the alignment. It is well to measure the distance between pillow blocks after the base and lower half of frames are in place (in the case of split frame machines), before the rotating parts are placed in the bearings.

All reference marks or assembly marks (usually numbers) on machines, except on those of the vertical type, will be found at the right hand side of the machine when facing the commutator or connection end. When the machine, therefore, is properly assembled, all marks should appear on that side.

Before placing the shaft in its bearings, the surface of bearings and journals should be well oiled. After the shaft carrying the rotating parts has been assembled, a measurement should be made of the air gap. If the air gap is not uniform, or does not agree with the drawings of the machine, the trouble must be rectified. The gap can be equalized on top and bottom by inserting shims under the frame feet. If the gap does not equalize laterally it is usually corrected by shifting the frame and redoweling the frame feet to the base.

Air Gap

The measurement of air gaps is important on all apparatus. Air gaps on direct current machines are measured in the following manner: With the armature stationary, the gap should be measured at both the commutator and pulley ends, the measuring scale being inserted under each pole tip, without including the chamfer of the tip. A mark should then be placed on the armature circumference under the center of a given pole and the armature revolved through one pole span. The air gap measurement should be taken at the new position at the commutator end and so on for successive poles. The first set of measurements is known as the "stationary gap"; the second set as the "revolving gap."

An eccentricity test of the armature is made by marking a point on one pole piece and measuring the air gap between this point and several equally space points around the surface of the armature punchings. These readings at once show if the armature will run true. If the armature will not run true the matter should immediately be reported to the office.

On commutating pole machines the air gap measurement is taken under the center of the commutating pole. It is also necessary to measure the distance between the tip of each commutating pole and the adjacent tip of the main pole. The maximum allowable variation in this measurement is $\frac{3}{32}$ in. Should this amount be exceeded the matter should be referred to the office for instructions before proceeding with the test.

Air gap measurements are taken on alternating current machines with the revolving field stationary, and also by revolving it in a similar manner to that given above for "stationary" and "revolving gap" on direct current machines, except that the air gap measurement on a-c. machines is taken at the center of the pole piece both on the front and back ends. In measuring the "revolving gap" it is not necessary to take the air gap measurement under each pole. The measurement need only be taken at points spaced 45 mechanical degrees apart. That is, eight (8) sets of measurements are required for the "revolving gap."

The average gap as taken must check with the requirements as given on the Engineering Instructions. Fifteen (15) per cent variation is allowed between the maximum and minimum readings when measured from iron to iron and 20 per cent variation is allowed when measured over the binding wire. On machines using shims the average gap must be as close to Engineering instructions as can be obtained with a 14 mil shim.

Since the air gaps of induction motors are small, and since a uniform gap is important, they are measured by special gauges provided for that purpose. In using these gauges they are passed completely through the motor air gap from end to end of the punching. This gap measurement is taken at several points about the circumference of the rotor with it stationary and revolving in a similar manner to that indicated above.

Testing instructions which are issued from the office, in the case of special machines, give the length of air gap required for a particular machine, hence, the length of air gap measured should be checked against this information. If discrepancies exist, the matter should be immediately referred for instructions, before starting the machine for test. When air gap measurements are made, a critical inspection should be made of the clearance between the rotor and windings or other parts, to insure that it is sufficient to allow the machine to operate without any surfaces striking or rubbing together. This may occur if the windings project unnecessarily and in no case must clearances be so small as to be unsafe. Should such cases occur, the trouble must be corrected and the proper clearances obtained before the machine is started for test.

Air gap measurements should be made from iron to iron whenever possible and never from the wooden wedges of the armature.

Brushes

In preparing commutating machines for test, the brushes must be equally spaced around the commutator, 180 electrical degrees apart. The brushes on a stud must align properly with each other, and with the commutator bar from the front to the back end of the commutator. To space the brushes place a strip of paper tape around the commutator and mark the paper where the ends overlap. Remove the paper tape and divide it with a scale, or dividers, into as many equal divisions as there are poles on the machine. Then replace the paper around the commutator and paste the overlapping ends together. Space the brushes by the marks on the paper, taking care that the holders are clamped to the stud in the proper position.

In some cases brushes are run trailing and in others leading, with reference to the direction of rotation. Radial brushes are also sometimes used.

When the brushes have been set, fit them to the commutator surface. To do this, use a strip of sandpaper between the com-

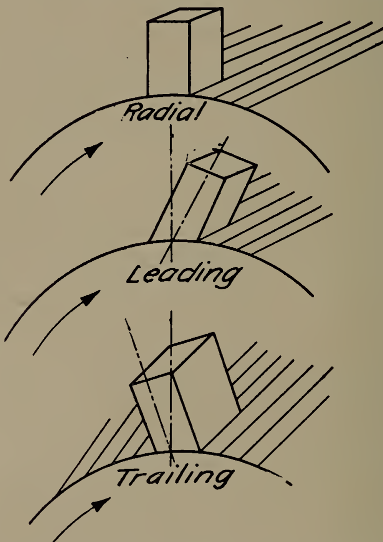


Fig. 40

RADIAL, LEADING AND TRAILING BRUSHES

mutator and brush face. Coarse sandpaper is used first to obtain an approximate fit. Follow with very fine sandpaper. A close and accurate fit with the commutator is essential to get good commutation tests. When sandpapering, the sandpaper must be held close to the commutator to prevent rounding the tip of the brush when drawing the sandpaper away. The sandpaper should be drawn *in the direction of rotation.* These instructions apply also to fitting carbon brushes on collector rings. When the sandpapering of the brushes is finished, the resulting carbon dust must be blown from the armature or rotating part. The air blast should be directed away from the rotating part, so that the carbon dust is carried completely away and cannot drift into the windings. The leading, trailing, and radial brush setting is shown in Fig. 40.

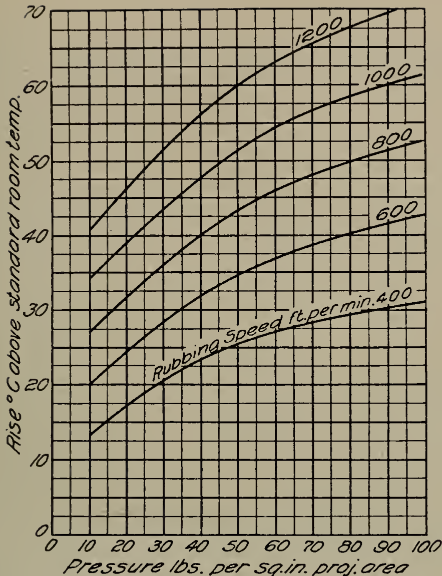


Fig. 41
OIL RING BEARING, STILL AIR, ROOM TEMPERATURE 25° CENT.

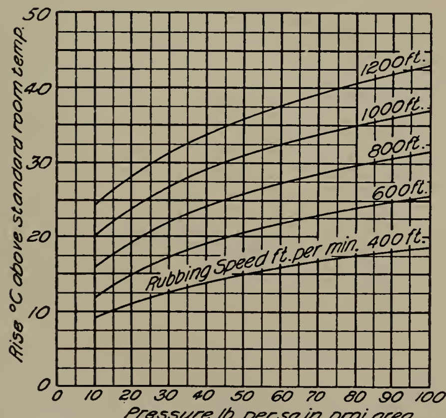


Fig. 42
OIL RING BEARING, WELL VENTILATED ROOM TEMPERATURE 25° CENT.

In case copper gauze brushes are used a form and file, or emery paper, must be used to fit them to the commutator or collector ring. Copper brushes are now seldom used on commutators. Copper leaf brushes, as used on synchronous converters, are so constructed that no special fitting is required. They must, however, be properly adjusted in the holder to make good contact upon the slip ring.

Bearing Lubrication

When oil-ring lubrication is used, the lubricating oil must not be allowed to get so low in the oil well that the ring does

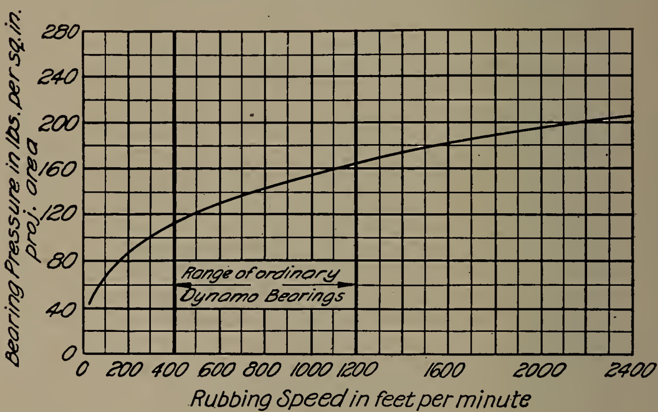


Fig. 43

SAFE MAXIMUM PRESSURE ON BEARINGS FOR EACH SPEED

not dip into it. If this instruction is observed satisfactory lubrication will be obtained for all ordinary bearing pressures and rubbing speeds. For high bearing pressures, or high speeds, some form of forced lubrication is used. The oil is forced into the bearing either on the bottom, or the lower quarter and enters the bearing at a point such that the revolving shaft draws the oil under the shaft. Oil from forced lubricated bearings is usually returned to an external cooling tank, where its temperature is reduced before being again pumped into the bearing. Oil rings and forced lubrication are occasionally used on the same bearings, so that if the oil pressure fails the rings supply enough oil to prevent danger, until the oil pressure can be restored.

A properly designed bearing may run hot from the following causes: Oil rings sticking; scarcity or poor quality of lubricating oil; excessive local pressure in the bearing; insufficient relief on the sides of the bearings; improper alignment and excessive belt pull, or current flowing from frame to shaft.

The remedy for the greater part of these troubles is obvious. In the case of excessive local pressure in the bearing, or insufficient relief on the side of the bearing, the remedy is to remove the high spots on the babbitt or bearing metal with a scraper and increase the side clearance.

Allowable bearing pressures, speeds, etc., are given in Figs. 41, 42 and 43.

Before starting a machine all bearings must be filled with the proper amount of oil. Bearings should be inspected to see they have not been carelessly filled, viz., that oil has not been spilled on the bearing housing, or bearing shell, or upon other parts associated with the bearing, otherwise, a false impression may be obtained as to oil leakage or throwing when under test. To give the bearing a critical test for oil leaking

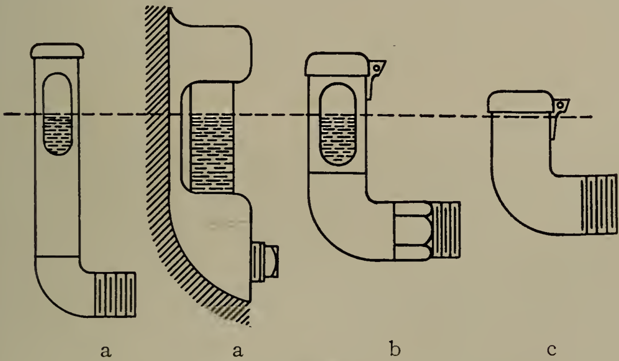


Fig. 44
TYPES OF OIL GAUGES

or throwing, the dividing line between cap and bearing pedestal and between bearing brackets, should be painted with whiting. The end of the commutator or field spider adjacent to the bearing should also be given a white coating, so that it is possible to detect, after a comparatively short run, the slightest leakage or throwing of oil.

Bearings with the end of the bearing shell visible should be filled with oil until it touches the lower part of the shell at the end of the bearing housing. Where the end of the bearing shell cannot be seen the bearing should be filled to within 3/8 in. of the top of the visible portion of the oil gauge glass; in the case of sight gauges to within 1/8 in. of the top of the gauge. In the case of overflow gauges having no glass, a record of the distance of the oil level from the top of the gauge must be made, in every case, upon the Testing Record. Gauges with glass tubes so placed as to show the oil level (Fig. 44a) are used on bearings of large machines, and stand pipe gauges (Fig. 44b) on small and medium size machines. Overflow gauges (Fig. 44c) are those with the top of the stand pipe fitted with a hinged cap.

Oil gauges on most induction motors are of the overflow type, and should be filled to within 1/16 in. of the overflow. As already stated, no oil must be spilled upon the bearing parts. In filling bearings a funnel must be used and the oil inserted through the sight holes for the oil rings, or through the opening above the shaft at the end of the bearing housing.

During test no oil should be allowed to leak or be thrown from the bearings upon the rotating parts, or windings. This is especially true with reference to commutating machines, where it is important that lubricating oil be kept away from the commutator, brushes and fittings. Should oil-leaking or throwing on these parts be detected during the test, the test should immediately be discontinued and the cause of leakage removed. If bearings under test rise in temperature 40 degrees cent. or more, above the room temperature, it should be reported to the office as a defect, since no properly designed bearing should heat above 40 degrees rise under normal conditions. It will usually be found that a greater temperature rise is due to a faulty bearing.

Thrust Bearings

There are two classes of thrust bearings; those which depend upon a film of oil between two flat plates, and those which have either hardened rollers or balls rolling between two hardened surfaces. The first class may be sub-divided into (a) those which are supplied with oil under pressure and (b) those which revolve in a bath of oil. In both these classes the bottom plate is stationary and the top one rotates with the shaft.

In the pressure thrust bearing the two plates are recessed for about half their diameter and the remaining annular ring is scraped or ground to a true surface. Scraping is perhaps preferable to grinding as in a ground plate there is a possibility of particles of the abrasive becoming imbedded in the surfaces and causing them to cut. The bottom plate usually rests upon a spherical surface which allows the plates to align themselves in their proper relative positions. The oil is led from the pump or accumulator to the recess between the plates and the pressure raised until the plates separate and the oil passes out between the plates and up along the shaft to the overflow where it escapes and returns to the pump or cooling tank.

It is obvious that the pressure per sq. in. required to separate the plates is a function of the superincumbent weight and the area of the bearing plates. The limit of allowable pressure per sq. in. on this type of bearing is the capacity of the pumps or accumulator, as the friction is purely fluid friction and the plates do not come in contact with each other. If an accumulator is not used it is necessary to interpose between the pump and the thrust bearing some form of baffler which will cause a back pressure on the pump above that required to separate the plates of the thrust bearing. This difference in pressure between the two sides of the baffler should be from 25 to 40 per cent of the pressure required to lift the plates. For example; if it requires 1000 lb. per sq. in. to separate the plates, the pump should show a pressure of from 1250 to 1400 lb. per sq. in. This insures a uniform flow of oil through the plates, which condition is absolutely necessary for correct operation of this class of thrust bearing.

The amount of oil which should be passed through a pressure thrust bearing varies with the diameter of the plates and this amount in gallons should be about 100 per cent of the diameter of the plates in inches. Thus a 20 inch thrust bearing requires about 20 gallons per minute.

In operating this kind of a thrust bearing some reserve source of oil pressure, such as a spare pump, should be at hand in case of the failure of the one in service. Both pumps should be on the line constantly and each pump should be capable of supplying the necessary amount of oil to the bearing. If one pump fails the other can carry the load while repairs are being made. A check valve should be placed in the line from each pump so that the oil cannot escape if a valve or some other vital part of the other pump should fail.

The other style of plate bearing revolves in a bath of oil and is grooved in such a way that the top plate draws a film of oil between itself and the bottom plate.

A type of thrust bearing of this kind is a segment bearing. The novel feature of this bearing is a series of adjustable surfaces mating with a continuous thrust collar. The parts carrying these adjustable surfaces are referred to as "shoes" or "segments" and are free to adjust themselves, thus bringing about uniform distribution of load over the entire bearing surface and, further, and more important, adjust themselves at a slight angle with the collar and thus glide or skim over the oil film which adheres to it.

The "shoes" consist of heavy steel blocks faced with babbitt, their upper faces forming the adjustable bearing surfaces. Each "shoe" fits into a recess in the body casting and is mounted on a spherical topped block in contact with another spherical topped block below, which provide the adjustment to running conditions.

Below each shoe seat is an adjustable wedge for raising and lowering to bring about a uniform distribution of load.

Machines equipped with bearings of this type require a considerable amount of power to start, consequently, they are usually assembled in the Testing Department with a pressure step bearing underneath them so that they may be easily started. The "step-block" is then lowered until the machine is supported from the upper thrust bearing.

Unusual care should be exercised in first starting bearings of this type and the machine should be brought to speed very slowly to be very certain that the bearing is operating properly.

ROLLER BEARINGS

The roller type of thrust bearing (see Fig. 45) consists of several hardened steel rollers held in a brass retainer and arranged radially to the shaft. The rollers revolve between hardened and ground steel plates, one of which is stationary and the other revolving with the shaft. In this form of bearing the oil is not under pressure but must be supplied quite liberally. The oil must enter as close to the shaft as possible so that the centrifugal force may throw the oil out across the surface of the disks. Rapid starting of a new roller bearing often causes trouble by scoring or drawing the temper because the hardened steel plates as they come from the grinder are not in proper condition for a bearing surface. This trouble can be avoided by lapping the plates or by running several hours at slow speeds thus giving the plates a chance to smooth themselves. The amount of oil that should pass through a bearing of this type is very indefinite.

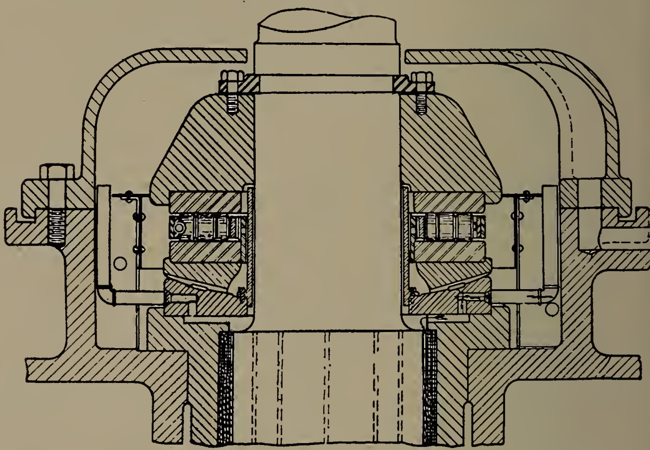


Fig. 45

VERTICAL ROLLER THRUST BEARING

The sole function of the oil is to keep the bearing cool and just what this amount may be for a particular bearing is hard to predict but will probably be from 10 to 14 gallons per minute on bearings up to 30 in. diameter. In any special case it is better to be guided by the advice obtained direct from the manufacturers of the roller bearing in question.

Roller bearings have been made as large as six feet across the disks and carry 2,500,000 lb.

Balance of Rotating Parts

Static Balance

Rotating parts are usually balanced by putting them on a shaft and laying the shaft on two parallel rails called balance ways. The balance ways must be carefully leveled and well supported to prevent deflection from the weight of the piece to be balanced. After the correct amount of balance weight has been determined, a suitably formed weight is made and securely fastened to the inside of the rim, or at a point at the same distance from the center as that at which the temporary weights were supported. The weights should be so fastened that they will not produce a shearing stress on the bolt or other fastening holding them in place. In revolving fields the weight should be placed on the inside of the rim. In this case the bolt has only to keep the weight from falling out when the machine is at rest.

On d-c. armatures, pockets are generally provided into which melted lead is poured and hammered into place.

On slow speed machines it is not necessary to get accurate balance, especially on heavy fields. On a 2000 or 3000 kw. field running about 120 rev. per min. an unbalanced weight of 50 lb. would probably not be noticed. Vertical machines must be more accurately balanced than horizontal ones.

Dynamic Balance

A field with good static balance will not necessarily be in good balance when running. It is often necessary to rebalance a rotor dynamically after the machine is assembled.

The shaft must be straight before any balancing is done. This can be determined by holding a pointer or pencil to the shaft and revolving the shaft slowly. If the pointer touches all points, the shaft is straight and the work of balancing may proceed. If it does not touch all around, the shaft is sprung and must be straightened before the rotor is balanced. On very heavy rotors it is not possible to balance them statically as a whole, because their weight will press the shaft sufficiently into the ways to prevent the rotor from taking its natural position. In this case the parts are balanced separately as carefully as possible and the whole is afterwards dynamically balanced, if necessary.

To locate roughly the position proper for balancing, hold a pencil or chalk so that the high side of the shaft strikes it as the shaft revolves at normal speed. On a rigid shaft this mark will indicate the heavy side, but on a flexible shaft it will probably show the light side of the rotating part. Put some weight on the side opposite the mark and try again. If the balance is better, the weight is in the proper place and the mark will be found to extend further around the shaft. If the balance is worse, the weight is on the wrong side. If the mark is found to have moved, weight should be added at the new point. If the mark is found on just the opposite side, too much weight has been added.

Pulleys

Pulleys are made of various materials such as cast iron, steel, steel rims with cast iron centers, wood rims with cast iron centers, paper rims with cast iron centers, etc. Paper pulleys are in common use, especially in the smaller sizes and when not subjected to dampness, they are preferable to cast iron or steel on account of their higher coefficient of friction. Steel pulleys have the advantage over cast iron in that they will stand a higher speed, are much lighter and are not liable to have hidden cracks or flaws. A pulley should be made with a bore of such size that it will go on the shaft without pressure and should be held in place with set screws. All pulleys, especially cast iron ones, should be rigidly inspected frequently for cracks or other flaws. A speed of 5000 ft. per min. produces a tensile stress of about 1200 lb. per sq. in., which is the usual working stress allowed for cast iron pulleys. There are men detailed in the Testing Department whose business it is to inspect all pulleys after they are put on machines and again before machines are started. *The practice of having pulleys inspected each time before a machine is started must be rigidly adhered to.* It is very essential that the shaft extend clear through the hub of the pulley. This will give the pulley a maximum working strength and will insure its not coming off the machine while it is running. The set screws in these pulleys must be inspected to see that they are in good condition, that the threads are not damaged, and that they extend through the hub to the key in the shaft.

Flange pulleys are cast iron pulleys with a steel center. These are readily adapted to any machine by first fitting a coupling to the shaft and then bolting this flange pulley to the coupling. New centers are readily obtained for these pulleys so that they may be easily kept in first class condition. It is good practice to operate pulleys between 4000 and 5000 ft. per min. When not in use, they must be placed in the store-house provided for that purpose.

Belts

Leather belts are much used in the Testing Department and a considerable amount of power is transmitted by them. In no case, however, should a belt carry more than 400 kw. Whenever possible, endless belts must be used, as they are stronger and do not cause fluctuations in the electrical instruments as do laced belts. Laced belts must be examined very carefully before starting a test to see that the lacings are in first class condition, and all belts must be inspected before being used to see that they are riveted properly and in no way defective. The size of belt to be used must be carefully calculated by the Head of Section, and in no case should it be left to the judgment of the shop men. The belts must never be wider than the pulley, nor be allowed to run with one end overlapping the edge of the pulley, as this will surely injure the belts. They should be run with the tight side on the bottom if possible, and must be kept free from oil as this reduces the capacity very much and causes slipping on the pulley. Quarter turns in belts must be avoided if possible as this stretches the belts on one side and greatly reduces their capacity. Under no conditions is a belt to be overloaded; if it breaks it may seriously damage apparatus or injure men working in the vicinity. Belts, must, therefore, be regarded as sources of danger and possible accident. When not in use they must be returned to the store-house where they will be inspected and repaired by a man employed for that purpose.

Whenever belts are running near an aisle, or passage way, guards must be so placed that men cannot fall, be thrown, or drawn into them. The testing tables should never be set in a line with a running belt and work should be so arranged that an employee must not work continuously in line with belts, unless proper mechanical guards are provided. Whenever a belt is found defective, it must be returned to the repair shop for repairs.

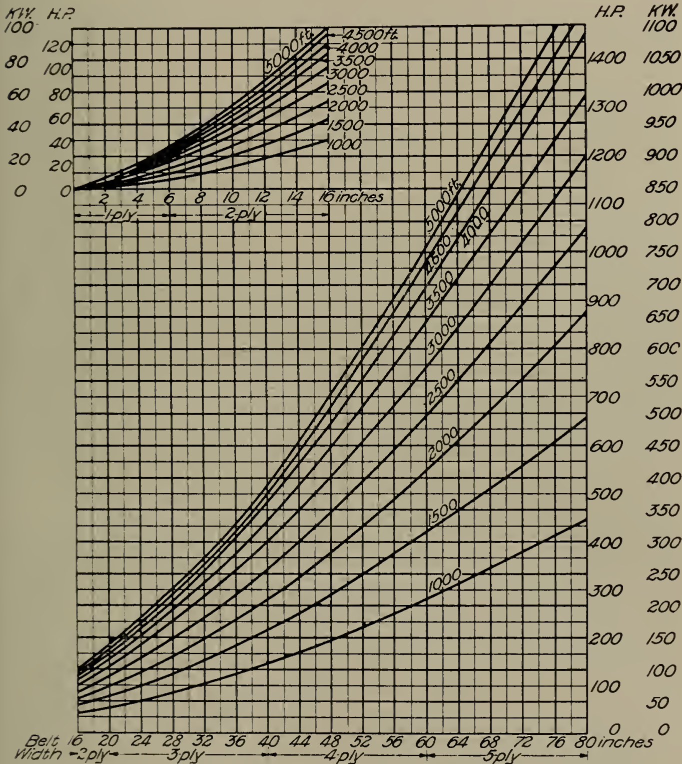


Fig. 46

WIDTH OF LEATHER BELTS

Fig. 46 and the data on page 94 show the carrying capacity of leather belts of various widths and thicknesses when running at speeds of from 1000 to 5000 ft. per minute. It is not permissible to operate a belt in the Testing Department at a higher velocity than 5500 ft. per minute.

When a belt is started for the first time it must be very carefully watched to see that it runs properly on the pulley, and has the proper tension. Under no circumstances must an employee lean against, sit or stand upon, or pass through a belt even though it is not running. It is equally important that neither tools, nor articles of any description be laid upon belts after they are placed on the pulleys.

DATA IN CONNECTION WITH WIDTH OF LEATHER BELTS

The curves in Fig. 46 have been plotted from the following data:

Coefficient of friction = 0.4.
Arc of contact = 165°.
Weight of leather belting = 56 lb. per cubic foot.
Centrifugal force = 0.012 V^2 (with velocity in ft. per second.)
$T_1 = 1$. $T_2 = 0.316$.

Ratio tight over slack side $= \frac{T_1}{T_2} = 3.1643$.

Torque or pull $= T_1 - T_2 = 0.684$.
Greatest tension $= T_1 + 0.012\ V^2$.
Average thickness per ply $= \frac{3}{16}$ in.
Working tension per sq. in. = 275 lb. for laced belting.
H.p. or kw. per inch in width of $\frac{3}{16}$ in. thick.

H.p.	Kw.	
1.05	.783	for 1000 ft. per minute.
1.56	1.163	for 1500 ft. per minute.
2.03	1.514	for 2000 ft. per minute.
2.46	1.835	for 2500 ft. per minute.
2.855	2.129	for 3000 ft. per minute.
3.18	2.372	for 3500 ft. per minute.
3.447	2.57	for 4000 ft. per minute.
3.63	2.71	for 4500 ft. per minute.
3.73	2.78	for 5000 ft. per minute.

Width of Belt	**Curves Plotted with the Following Thickness**
Up to 6 in.	1 ply belting varying from $\frac{3}{32}$ in. to $\frac{9}{32}$ in.
6 in. to 20 in.	2 ply belting varying from $\frac{9}{32}$ in. to $\frac{15}{32}$ in.
20 in. to 40 in.	3 ply belting varying from $\frac{15}{32}$ in. to $\frac{21}{32}$ in.
40 in. to 60 in.	4 ply belting varying from $\frac{21}{32}$ in. to $\frac{27}{32}$ in.
60 in. to 80 in.	5 ply belting varying from $\frac{27}{32}$ in. to $1\frac{1}{32}$ in.

	Belts are to be Used in the Following Widths
Up to 2 in.	varying by ¼ in.
2 in. to 5 in.	varying by ½ in.
5 in. to 10 in.	varying by 1 in.
10 in. to 36 in.	varying by 2 in.
Above 36 in.	varying by 4 in.

	Pulley Face to Exceed Width of Belt
Up to 2 in.	+ ¼ in.
2 in. to 5 in.	+ ½ in.
5 in. to 10 in.	+ ¾ in.
10 in. to 24 in.	+1 in.
24 in. to 36 in.	+1½ in.
Above 36 in.	+2 in.

Before starting a test, the man responsible for the test must see that no one is in contact with the belt, and that nothing has been left lying upon it or where it may fall into it, while running.

Truing Commutators

The condition of a commutator determines to a great extent the satisfactory operation of the unit in service. A true periphery and a perfectly smooth surface are two requisites to satisfactory service.

To secure these conditions is the aim of all commutator truing devices. There are two methods now recognized for truing commutators, viz., a turning tool and slide rest, supplemented by sandpaper, or some form of commutator grinder.

In turning commutators some sort of a slide rest with a tool holder must be provided. In the Testing Department there are several sizes built on the same general plan, but differing principally in the length. The slide rest is held rigidly in such a position that the point of the tool is about on a level with the center of the commutator and movable parallel to the surface thereof. A very sharp diamond-point tool and a fine feed should be used. The cutting speed should be about 350 ft. per min. The end play must be eliminated by some means, usually by tying a board in such a position that it holds the armature securely against one oil deflector. After the commutator has been trued up as carefully as possible with the tool the final finish is obtained with either sandpaper or carborundum paper. Emery in any form should never be used because of the metallic particles which it contains.

The objection to turning commutators is: first, that the cutting tool breaks the mica instead of cutting it; second, because of the different densities in mica and copper, the tool does not give a perfectly uniform surface and leaves the commutator bars a little higher in the center than on the edges; third, it is necessary to take a deep cut with the tool to get the required "bite" for cutting; fourth, the tool must be supplemented with sandpaper; fifth, the tool wears rapidly and must be replaced by another or re-ground during the process of turning. This is especially true when turning a commutator when the machine is run as a motor. When a tool is replaced in the middle of a cut it is difficult to prevent a score or a slight ridge being left where the new cut begins which can be removed only by taking another cut off the whole length of the commutator. This results in great waste of copper and decreases the life of the commutator. In truing a grooved commutator, that is, one from which the side mica has been cut out, it is very difficult to keep from carrying the copper across the slots when using a turning tool. This, of course, would necessitate cutting out the bridges of copper which on a commutator of any size means a considerable loss of time.

The other, and perhaps the better method of truing commutators is with a commutator grinder. This consists essentially of a small motor geared to a spindle which carries an abrasive wheel, the whole being carried on a slide rest similar to that used in turning commutators. The advantages of a commutator grinder over a turning tool are many; there is only one disadvantage. The commutator can be ground with the machine running at normal speed and carrying full voltage. The grinder does not have to be so rigidly supported as the turning tool, and there is no danger of gouging the commutator as is the case with a turning tool. Grooved commutators can be ground with practically no bridging of the copper between bars. A commutator grinder can be installed, and the commutator ground without shutting down the machine. The commutator grinder produces an absolutely true surface from the fact that the grinding is done when the armature is running at normal speed. It is often the case that a commutator which runs true at slow speed will run eccentric at normal speed.

Another important feature of the commutator grinder is the arrangement for catching all the copper dust. This consists essentially of a hood enclosing the grinding wheel leaving just enough opening for the wheel to come in contact with the commutator. A discharge pipe fitted with an ejector using compressed air produces a vacuum sufficient to draw all the chips away from the wheel and deposit them in a bag which is fastened to the end of the suction pipe.

The disadvantage of a grinder is that it cannot remove copper as rapidly as a turning tool, and if the commutator has been allowed to become deeply grooved by the wear of the brushes, time would perhaps be saved by turning it, rather than grinding it. On the other hand, if the commutator is given the attention due it and attended to before the grooves become of appreciable depth, it will not only be better for the commutator to be ground, but it will prevent the necessity of removing a large amount of copper as would have to be done if the commutator were turned.

Correcting End Play

If a machine is properly leveled the rotor will revolve without rubbing either oil deflector when there is no field on the machine. If this is found to be the case, but that when field is put on the rotor pulls either one way or the other, it shows that the magnetic center of the field and armature do not lie in the same plane. This may be caused by the rotor being out of place on the shaft, or by the stator being out of its proper position on the base. It is evident that the defective end play may be corrected by moving either the rotor or frame. Whichever is found wrong should be made right, although perhaps it might be cheaper to move the stator than the rotor.

The stators of the larger machines are not doweled till after the machines have been set up and tried out for both air gap and end play.

If the machine were being installed outside where there were no facilities for pressing the shaft in or out of the rotor, the best and certainly the cheapest way of correcting end play would be to move the frame on the base and redowel.

If there is not sufficient clearance between the frame holding-down bolts and the holes in the feet, the holding-down bolts could have the body turned down as far as the depth of the thread, the reduced part being made of a length about ¼ in. greater than the thickness of the foot and measured from the under side of the head. This will allow a much greater movement of the stator and will not weaken the bolt if it is not reduced below the root of the thread. This method of correcting end play is sometimes used in the Testing Department, but after test the defect is always remedied by the shop, so that the proper position of the stator may be obtained without the use of the reduced bolts.

CHAPTER 4

PREPARATION OF APPARATUS FOR TEST; INSPECTION; WIRING; OBSERVATIONS DURING OPERATION

Preliminary Inspection

It is the aim to have all apparatus delivered to the Testing Department from the manufacturing department in a completed condition including fittings and all other parts.

When apparatus is delivered, the man in whose charge it has been placed should make a very careful inspection for mechanical defects and should see that all parts as assembled check with the Testing Instructions.

The following are some defects which may appear: Copper bridges formed between the bars over the side mica of the commutator, due to improper turning; bent end conductor or commutator leads; improper brush staggering; damaged insulation of armature and field spools; broken insulating boards on fields; insufficient clearance between bare electrical terminals or conductors and ground; poor joints between electrical conductors; loose terminals; bus rings or other connections improperly supported; brush pigtails too long or touching the armature risers; too little clearance between a brush stud or various parts of fittings and ground; incorrect spring pressure; defective spacing of collector ring taps; defective spacing of lubricating brushes, etc. It should be noted that laminated pole tips are not bent and that cast pole tips are of approximately uniform thickness on all the main poles of the machine. All oil rings in each bearing should be visible through the bearing cap oil cover and the bearings should be properly filled with oil as described on page 87. See that the brushes on collector rings ride properly on the rings and do not overlap.

In fact a test man should place himself in the position of the customer and if anything about the machine does not appear right he should report it to the Head of Section.

It is the duty of the Head and Assistant Heads also to look over the apparatus, but the man in charge of the machine will be held directly responsible. *The Head or Assistant Head of Section must place the brushes of d-c. machines on the mechanical neutral and sign the Testing Record to that effect.*

The above inspection should also be made on all machines upon which changes have been made by the shop to make sure that no foreign material has lodged in the machine.

Wiring

Though a great deal of the wiring in testing work is temporary, it must always be done as neatly as possible, due regard being paid to safety. All circuits should be protected by signs or barriers, where there is danger of any one coming in contact with them. Conspicuously lettered danger signs are used to indicate the nature of the circuit. In addition to this, white tape is used around cables or apparatus carrying high voltages. After a tester has completed the wiring of a machine, he should notify the Head of Section, or Assistant Head of Section, to inspect the same. The Head of Section, or Assistant Head of Section, must then assure himself that it is satisfactory, and if so, enter his approval upon the Testing Record sheet and sign his name.

The following general rules should always be followed in wiring apparatus for test. First, procure the print of connections, which will be furnished by the Head of Section. The apparatus must then be connected up in accordance therewith. A copy of this print is sent to the customer with the apparatus, to help him in its installation.

Checking the wiring during test serves the double purpose of detecting errors in the print, or wrong connections in the apparatus. It is consequently of considerable importance.

In wiring apparatus for test, all the wiring should be completed before any of the circuits are connected to the source of power, to prevent the necessity of handling live circuits while wiring. Where possible, one hand only should be used for connecting or disconnecting low voltage live circuits where an intervening switch cannot be used for making final connections. It must always be remembered that any circuit may become grounded and that some circuits are permanently grounded. The 125, 250, and 500 volt direct current shop circuits are permanently grounded. Hence, in all cases, circuit breakers must be wired on the positive side of the "125 volt" and "500 volt shop" circuits. As the "250 volt shop" is a part of the three-wire system with grounded neutral, a circuit breaker must be used on each side.

Opening direct current motor and synchronous motor fields is likely to break down the insulation of the apparatus, *and in the case of a d-c. motor, the motor will run away.* Wherever binding posts and connectors, as used for rheostats and small fields, are employed, a length of unbroken insulation should be stripped from the end of the temporary field wire, so that the portion stripped can be passed through the binding post and bent back over the terminal. A complete loop is thus formed which prevents the circuit being broken, even though the clamping screw in the binding post or terminal works loose. It is not safe to insert in the binding post the bare end of a wire which has previously been used, since it may be fractured.

When a motor field is wired through the field ammeter switch, the wire leading to the switch terminal and thence to the ammeter should be continuous, the switch simply serving to short-circuit the leads near the ammeter terminals. Motor field circuit breaking switches must be located so that they cannot be opened accidentally. The field switches must be provided with a holding clip, or other fastening. Single-pole switches must always be used in all field circuits.

In all cases, circuit breakers must be used for breaking direct currents of appreciable value. Oil switches must likewise be used on all alternating current circuits, when currents and voltages of any magnitude are in question. Never break an alternating current circuit either by water box, or by an ordinary air-break switch, otherwise abnormal voltages may be produced and strain the insulation of the apparatus. All direct current generator and motor armature circuits must, therefore, contain a circuit breaker of sufficient capacity to open the maximum current delivered by the machine under test. When "feeding back" tests are made on direct current machines, two circuit breakers must be used, one in the supply circuit, and one in the motor-generator circuit through which the load energy is exchanged between the machines.

All transformers with iron cases must have their cases grounded by a substantial wire, or cable, leading to ground. This lead must be substantially connected to the transformer case and to ground, so that it cannot be accidentally disconnected.

Temporary switches, circuit breakers, etc., should never be attached to a test table or switchboard which is permanently equipped. They should be mounted on rheostat stools, or temporary stands. All temporary cables and wiring must be properly insulated from iron floors, frames, and ground. High voltage alternating current lines must be carried at a sufficient height so that they cannot come in contact with men walking under them. This also applies to disconnecting and oil switches. Cables must be kept a sufficient distance apart to take care of the potential difference between them. They must be mechanically supported so they cannot drop from their fastenings to the floor. High tension wires must be carried to the testing table from the rear. They must not be carried over the heads of men working at the test table. All wires and circuits carrying more than 600 volts, must be regarded as high voltage. No one must approach closer than 1 foot to high voltage circuits, since many circuits possess sufficient capacity or voltage to arc over before contact is made.

Starting Up

Before starting a machine for the first time, the tester must assure himself that all instructions contained in Chapter 3, and in the preceding paragraphs have been rigidly followed in reference to the mechanical and electrical conditions, the wiring of the various circuits, lubrication, etc. The belt lacings must be watched to prevent them opening during test. Pulleys must be inspected by the regularly appointed Pulley Inspector to make sure they are securely fastened on the shaft and that they are mechanically strong. All keys, set screws, or other rotating parts which may catch in the clothing, or injure others must be properly protected. All keyways must be provided with covers or guards. All shafts carrying one-half of a solid coupling must have that part boxed in, so that workmen may not come in contact with the sharp edges which usually exist. No loose articles must be allowed inside any rotating or stationary parts. All belts must be guarded by substantial guards.

If a machine has been standing for any length of time, before it is started again the same precautions must be observed. These points are strongly emphasized in reference to all vertical apparatus, where the danger of dropping things into a machine, while running, or of workmen leaving tools in dangerous places on or about the machine is very much greater than with horizontal apparatus.

When apparatus is first started it should be brought to speed very slowly and carefully watched to see that everything is correct as the speed increases to normal value. Reliable tachometers, or speed indicating devices must be used in starting to prevent a dangerous increase of speed. Oil rings must be examined at slow speed to see if they are carrying sufficient oil to the bearings. In the majority of cases, oil rings should turn when the machine is running at ¼ normal speed, and should properly lubricate the bearings.

The balance of the rotating parts should be carefully noted until the machine has reached its normal rated speed. If the apparatus does not run without vibration the matter should be reported as a defect. The vibration must be remedied before the test proceeds. Vibration due to the running of the machine may indicate lack of balance, whereas it may be really due to improper alignment, or to springing of the shaft. When unbalancing occurs in operating machines running above 1200 rev. per min. correction must be made by dynamic balancing as in Chapter 3.

Preparation for Heat Runs

Heat runs are taken primarily to determine the amount of temperature rise on the different parts of a machine while running under a specified load. This rise in temperature is measured either by the rise in resistance of the current carrying parts or by means of thermometers, or both. The results obtained by the rise in resistance, as a general rule, are used only as a check on the results obtained by reading thermometers placed on the different parts, the temperature rise of which it is desired to determine. Guarantees, except in special cases, are always based on the rise by thermometer.

Thermometers should be carefully examined for broken mercury columns before being placed on a machine. They should not be inverted and in no case should they be placed on a machine so that the bulb is on a higher level than the other end.

Before starting a heat run thermometers should be placed on the stationary accessible parts of the machine indicated by the Testing Record. Each thermometer should be attached with the bulb in contact with the part of which the temperature is required and should have the bulb covered with a sufficient amount of putty to secure it to the machine and to shield it from being affected by the surrounding air. Extreme care must be exercised regarding the amount of putty so used, as too much putty is as bad as too little. Just enough should be used to do the work required. There should be no restriction of the natural windage of the machine or radiation from the coil whose temperature is being measured.

Thermometers which are to register the temperature of air ducts should be so placed that the bulbs cannot make contact with the iron laminations while the machine is running. Thermometers which are liable to be shaken off by continued action of windage, or slight vibration, should be securely fastened to the machine.

When placing thermometers on field coils, care should be taken to see that they are not placed on the fiber strips protecting the outside terminals. These fiber strips run from one terminal to the other and form a non-conducting wall between the coil and its outside insulation, and thus do not represent the true temperature of the coil. Coils above the horizontal center line of the machine should be used as the top of the machine is usually somewhat hotter than the bottom. On small machines two thermometers will be sufficient on the coils, but larger machines should have at least four.

One thermometer will be sufficient on the frame of small machines, but two or more should be used on the large units. At least two thermometers should be used on the laminations and ducts of small machines, and at least four should be used on larger machines.

Any large machine requiring a considerable floor space should have the room temperature taken at four or more different near-by points, and at a sufficient distance away so as not to be affected by the windage and radiation of the machine.

The machine should be shielded from currents of air coming from adjacent pulleys, belts and other machines, as unreliable results are obtained when this is not done. A very slight current of air will cause great discrepancies in the heating results, consequently a suitable canvas screen should be used to screen the machine under test, or the machine causing the draught should be shut down. Great care must be used, however, to see that such screen does not interfere with the natural ventilation of the machine under test. Care must always be taken to see that sufficient floor space is left between machines to allow free circulation of air.

During the progress of the heat run the different parts of the machine should be carefully watched for excessive heating of any part, including the bearings. A sufficient number of thermometers and amount of putty should be made ready to take all the final temperatures of the revolving parts after the machine is shut down, and the man in charge of the machine, if it is a large one, should obtain temporarily several extra men to help apply the thermometers and record the results.

On shutting down, thermometers should be placed on all the revolving parts as specified on the Testing Record.

All small commutators should have at least two, and large ones at least six thermometers applied at different points extending the whole length of the commutator from the armature risers to the outer end.

The thermometers must be applied as speedily as possible, and the resistances of the various circuits measured immediately after the machine stops. If any thermometer shows an unusually high temperature as compared with others it must be immediately checked by placing other thermometers on the same part. Reliable results depend directly upon promptness and speed, and nothing should be allowed to interfere with the carrying on of this work. To avoid repetitions of runs the machines must be shut down quickly.

Readings should be taken of all thermometers every two minutes until they begin to fall.

In calculating the rise of temperature the room temperature should be taken as the average of the last two readings recorded during the heat run.

Temperature Coils

In order more accurately to determine the temperatures of the inaccessible windings of large machines, coils of small wire known as "temperature coils" are sometimes imbedded in the slots with the main winding. The rise in temperature of the main winding is found from the rise in resistance of these temperature coils and, consequently, accurate measurement of the cold resistances of these coils is of the utmost importance. During the heat run, readings should be taken of the resistances of these coils at the same time that the thermometer readings are taken. All readings must be very carefully made as a small error made in the resistances of these coils makes a very appreciable difference in the final temperature obtained. The rise in temperature may be calculated from the formula given on page 112.

OBSERVATIONS AND COMMENTS DURING OPERATION. REPORTING AND CORRECTING DEFECTS

On all Testing Records a number of questions are given concerning the operation and condition of the machine during the test, which should be intelligently answered by the men conducting the test.

A close watch should be made for undue heating of bearings. While running under load, no bearing should rise more than 40 deg. cent. above the room temperature. In case such a rise occurs, the bearing should be scraped and the test repeated. Any machine showing a bearing temperature rise of 25 deg. cent., during an "equivalent load" run, should have the run continued till bearing temperatures are practically constant, unless the temperature continues to rise rapidly. In any case, note should be made if the bearing temperatures rise above these limits and the fact should be reported as a defect.

A record should be made of any oil throwing or leakage during test, and the matter reported at once. In the case of oil throwing on d-c. machines, the test should be discontinued until the defect is remedied.

All covers must be assembled in place so that it is impossible for any foreign matter accidentally to get into the machine.

All staging around machines must be substantial and secure.

End play should be tried both with and without field on the machine. This matter should be recorded on the Record Sheet. If the end play is defective it may be repaired as given on page 96.

During a heat run, machines set upon shop blocking should have the blocking and holding-down bolts examined at least every 24 hours to prevent the machine from pulling over or the bearings from loosening.

Any connections not checking with the connection print or wiring diagram should be reported.

All machines should be carefully watched for any unbalancing or change in alignment. A defect of this nature may appear after the machine has been running for some time even though the balance and alignment may have seemed perfect at the beginning of the run.

Record should be made of binding bands, commutator shrink ring or any other part running out of true.

Commutators sometimes become noisy during operation, due to brush friction. This may be remedied by a slight occasional lubrication of the commutator surface. The noise may be due to the brushes chattering, in which case no lubrication must be used, but the defect reported at once. Chattering may be caused either by poor commutator surface or an improper setting angle of the brushes.

One or two brushes may glow and become very hot on a stud carrying a number of brushes, while the other brushes run cool and without sparking. This is known as selective commutation and is due to difference in brush pressure, composition or contact resistance which cause some of the brushes to carry more than their share of the current, thus overheating them and giving poor commutation. In order to remedy this difficulty, it is usually necessary to change either the brushes or brush pressures, or possibly both.

The brushes should be examined to see that they do not stick in their holders.

Collector rings with rough joints, eccentric collector rings or ones running out of true should be reported at once.

Unless the line circuit of a machine or the circuit supplying excitation to the fields is grounded, grounds developing in the armature, fields, or fittings during test may not at once become apparent. During the high potential test any defect of this nature is readily shown, however, and should be reported at once in order that repairs may be made immediately.

The spacing and alignment of field poles, especially in the case of commutating pole machines, should receive the most careful attention. Poor alignment is usually indicated when the air gap is measured.

The checking of polarity (see page 111) at once indicates the reversal of any field coils.

In three-phase machines the reversal of any phase will cause a considerable unbalancing in the voltage across phases. The reversal of one coil will be shown in a similar manner, but the unbalancing is not so pronounced. In quarter-phase machines these defects will be shown by the phase rotation test only. See page 172. The test of balancing voltage and current and of phase rotation should, therefore, be carefully taken.

Stationary Apparatus

The instructions already given in reference to rotating apparatus very largely apply to stationary apparatus. The following points must also be carefully observed in testing the latter, including transformers, regulators, compensators, switches, relays, etc.

Careful inspection must be made for mechanical or electrical defects when preparing stationary apparatus for test. The precautions already given in reference to wiring should be followed. All valves, tripping devices, contacts and insulation should be examined.

Wherever cases or receptacles are oil filled for insulation purposes, see that the proper amount of oil is put into them before test. During the test the tanks and receptacles must be carefully inspected for oil leakage, due to blow holes in castings, oil plugs, oil gauges, or due to siphoning through the leads. Adjustments of springs, weights, contacts, gauges and air gap clearances must be made before testing, so far as is practicable. No metallic particles must be allowed to drop or be thrown into transformers, regulators, etc., during test; otherwise breakdowns of insulation may result.

When testing stationary apparatus, it is rarely possible to tell from inspection whether the apparatus is "alive" or not. Hence there is all the more reason, on high voltage apparatus, to make use of signs and barriers, to eliminate danger and prevent shocks.

CHAPTER 5

TESTING RECORDS

For the purpose of recording the results of standard tests, various Testing Records are used to suit the different classes of apparatus. Before a standard test is made, the tester must provide himself with one of the Testing Records. He should immediately fill in all blanks and headings, with all the data concerning the machine which can be entered before the test is started. All entries must be made at once upon the Testing Record and never on "scrap paper." These Testing Records (which should contain all the results of the standard test) must be checked at the conclusion of each test to insure consistency of readings and that full and complete explanations have been made concerning the machine under test.

One man is appointed in each section to approve the results of each individual test immediately upon its completion. In all cases the written approval of this man must be obtained for each test before the next test is started.

The completeness of these records is of the greatest importance, since they are used when passing the machine for shipment and are finally filed in the Data Department, where they are accessible for reference for the Designing Engineer and others who desire to know the characteristics of the particular machine. It is, therefore, necessary to make accurate, neat and orderly entries on the Testing Record, and supplement them with sufficient data fully to inform any one who has not personally taken part in the test. Then, if reference is made to them afterwards, no question can arise as to the meaning of any of the readings or observations made.

In general, the Testing Record is intended to be a complete and accurate history of the individual machine while in test and, therefore, every effort must be made to carry out this idea.

Special tests must be recorded on special Record Sheets. As these tests are special and often involve new or peculiar conditions, careful notes and explanations, with diagrams if necessary, should be entered to make clear the conditions under which the test was conducted.

The date of making the test, together with the name of the individual making it must always be recorded on all Testing Records and Record Sheets. In addition, whenever exhibition tests are made for our own Engineers, or for a customer's Engineer the Record Sheet must give the names of the Engineers who witness the test. Records of tests taken under the direction of a customer's Engineer must be plainly marked so that they may be distinguished from any other tests which may be taken on the machine. It is frequently necessary to furnish the customer with "certified copies" of tests in lieu of his sending an Engineer to witness the tests and check up the guarantees. Wherever Engineering instructions request "certified copies" of the test, all the necessary tests and information must be recorded on the Record Sheet so that "certified copies" can be made, demonstrating that all guarantees have been met.

The reasons for all check tests should be plainly stated on the Testing Record.

When tests have been finished, all records in reference to them are sent to the Calculating Room, and such calculations made as required. Curves showing the characteristics of machines are plotted and filed with the corresponding Record Sheet. It is the function of the Calculating Room also to check up results on the Testing Records with those of duplicate machines already shipped; and, where necessary, to refer Testing Records on newly designed machines to the Engineering Department for their approval before passing the machine for shipment. As soon as the Calculating Room is assured that the test proves that a given piece of apparatus is satisfactory and has the characteristics required for our guarantees, it approves the Testing Record and the machine is listed on the "Daily Test Report."

The "Test Report" is issued daily, copies being sent to all persons interested in the shipment of the machine. It is the official notification that the apparatus is satisfactory in all respects and may be shipped.

The majority of apparatus tested is listed upon this "Test Report." Certain small mechanisms and parts which only require a slight electrical test are passed for shipment, bearing the Testing Department stamp only, to show that they have been officially tested.

Since the system of passing apparatus is largely founded on the test records, it is essential that these records be complete in every detail.

CHAPTER 6

METHODS OF CONDUCTING STANDARD TESTS

In the manufacture of armatures and fields for electrical apparatus, many of the "faults and weaknesses" of material and errors of workmen can be disclosed by what may be termed "stationary testing." Faults and weaknesses may arise as follows: Through a wrong application of insulation, or through mechanical faults in it. The use of wrong material for conductors, leads, etc. Wrong assembly or connections—workmen's mistakes.

Direct current armatures are tested for grounds, short-circuits, open-circuits, and high resistance joints before being sent to the Testing Department. In testing for grounds a high potential is applied between winding and core; the potential depending upon the class of apparatus tested. When a ground develops in test, if it cannot be located by inspection it must be referred to the Armature Department. In no case is it to be located by smoking the insulation.

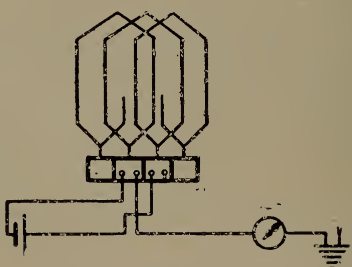


Fig. 47

TESTING FOR GROUNDS

If a low resistance ground has developed it may be quickly and accurately located by the following method: A low voltage current is passed through the armature winding from a commutator bar to the one adjacent to it, which is sufficient to give a readable deflection on a galvanometer or milli-voltmeter (as shown in Fig. 47). A line is connected to a galvanometer to ground, the other galvanometer connection being placed on one of the commutator bars. Then pass the supply and galvanometer leads from segment to segment, until a full deflection is obtained and zero reading when the leads are moved one segment further. The grounded coil then lies between the bars, for which full deflection was obtained.

A "bar to bar" test is usually made to disclose short-circuits open-circuits, and other similar faults. For this test the windings connected to two adjacent commutator segments have their resistance measured by the "drop of potential method," as indicated in Fig. 48. Storage batteries should be used and a special electro-magnetic D'Arsonval galvanometer. With this arrangement readings can be obtained rapidly, as the instrument is "dead beat."

Measuring the ohmic resistance of the winding will sometimes reveal a wrong connection, which, on a bar to bar measurement, would give a uniform deflection all around the commutator. Series or wave windings may sometimes have all the conductors joined in series, but in the wrong order, so that the armature is inoperative. In the case of multiple or lap windings, double, triple or even quadruple spiral re-entrant windings are possible, whereas a single spiral is required. In taking a resistance measurement for brush to brush or a running resistance of the armature, see that the measurement is made from the proper commutator segments. For multiple or lap windings, the resistance measured from diametrically opposite points divided by half the number of poles squared will give the true running resistance, while with a series or wave winding the

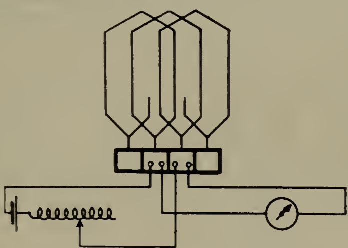


Fig. 48

TESTING FOR OPEN CIRCUIT

resistance should always be taken at points 180 electrical degrees apart. For example, take a four-pole armature with a lap winding and 360 commutator segments. This should have its resistance measured between bars No. 1 and No. 181. The resistance divided by four will give the running resistance. With a wave winding on the same armature, the resistance measurement should be taken between bars No. 1 and No. 91, this resistance being the true running resistance.

Alternating current armatures and fields are similarly tested for grounds, short-circuits, open-circuits, wrong connections, polarity, etc. In testing for grounds the same methods and similar apparatus are used as for direct current machines, except that with alternating current the voltages generated and used are usually higher and, consequently, the testing voltages are correspondingly higher and greater care must be taken in testing. All high potential tests must be made with carefully calibrated electrostatic voltmeters that have been checked with a spark gap. The testing equipment should be as near the apparatus as possible, since the additional capacity of testing lines may raise the voltage at the receiving end much above that at the generating end. Unless this precaution is taken, excessive voltages may be applied which may damage the insulation. In case a ground develops a resistance measurement will generally locate the point at which it occurs, unless each phase has two or more multiple circuits. In the latter case it may be more readily located by opening one or more cable joints and separating the circuits.

A measurement may then be taken in the following manner: First, measure the resistance of the grounded circuit or phase. Second, measure the resistance to ground by connecting one line to ground. Third, measure the other end of the resistance to ground, by connecting one measuring line at the other terminal of the phase and one to ground. If all measurements have been accurately made the sum of the second and third will be equal to the first, and the location of the ground will be as far from one terminal as the measured resistance from that terminal to ground is of the total resistance of the circuit.

This test is shown in Fig. 49, which represents a single circuit, or phase, of an alternating current machine, with a

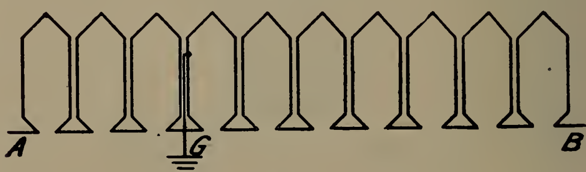


Fig. 49

TEST FOR GROUNDS ON AN A-C. ARMATURE

ground as shown. If the resistance between A and B is one ohm, between A and G 0.35 ohm and between B and G 0.65 ohm, the location of the ground is 35/100 of the distance between A and B, from A. As 10 coils are in the circuit the measurements show that the fourth coil is grounded, counting from A.

In the case of an alternating current winding the ohmic resistance measurement will not always detect a wrong connection, such as a reversed coil, pole section, or phase; since, although the copper resistance would be measured correctly the total winding might be partly reversed and, therefore, inoperative. Such faults may be discovered by a polarity or impedance test, with alternating current. For this purpose a single-phase current can be used, since a reading may be taken on the different circuits, or between pairs of terminals successively by shifting the testing lines until the whole windings have been tested.

Short-circuited coils on moderate size machines can be readily tested by using a wound electro-magnetic yoke excited with alternating current. This yoke is dropped over a portion of the armature coil after the coils have been placed in their slots. The yoke and armature form an alternating current transformer, with the yoke winding as primary, and the armature coil as secondary. If there is a short-circuited turn, layer or coil in the armature, the magnetizing current in the yoke winding rises. If the current is maintained a short time, the insulation on the short-circuited section will warm up appreciably, or burn sufficiently to indicate the defective coil.

On larger size alternator armatures, tests may be made for short-circuits by passing alternating current through the armature coil itself. In this case it is usually necessary to increase the reactance of the coil by placing a magnetic bridge over its armature slots after it has been assembled in the core.

The above tests may be made with the apparatus at rest. The Armature Department, therefore, uses them for detecting faults and correcting them before delivering the parts to the Testing Department. These faults can be more readily corrected when apparatus is being wound, with a resulting saving in time and cost. It is, however, sometimes necessary to test by these methods, after apparatus has been received in the Testing Department, in order to locate faults which have developed later.

As soon as the spools are assembled on a machine and before the frame is taken from the spool assembly stand the windings should be tested electrically for resistance and high potential. They should also be tested for polarity of the poles by exciting the field coils. These tests check the assembly of spools and their position upon the frame. In testing field coils for polarity all field windings must be tested separately to ascertain that the series, shunt and commutating pole windings are wound and assembled so as to give the required polarity. Polarity may be tested by use of a compass, but the compass must not be carried too near to the poles, as it may be demagnetized, or even reversed. To test for the opposite polarity of alternate poles, bridge two pole tips with a piece of soft iron. If the polarity of the poles differs the piece will be strongly attracted, whereas if the poles are of the same polarity much less attraction will be exerted.

Drop on Spools

With a given current flowing through the field the voltage drop on any one spool of a direct current machine should in no case be more than 4.5 per cent higher or lower than the average drop, and on alternating current machines no spool should vary more than 7 per cent either way from the average. If the drop is outside of these limits, the matter should be referred to the office for instructions. The field spools for alternating current apparatus are assembled on the field spider in the Armature Department, hence it is necessary to take only a resistance measurement per spool before using them for a test. In recording drop on the spools of alternating current machines, they should be numbered in a clockwise direction facing the collector end, and beginning at the spool next to the opening in the field for spool No. 1.

In direct current machines spool No. 1, either main or commutating is always the top spool or the next adjacent in a clockwise direction facing the commutator end.

Resistance

When testing a machine a very careful record must be kept of the resistances of all windings. Most armatures when delivered to test are fitted with equalizer rings which make it impossible to obtain the true armature resistance. The Armature Department's tag attached to the armatures when received in the Testing Department gives the armature resistance which was obtained before the connection of the equalizer rings. The tester must, therefore, record on the Testing Record the measurement of resistance from this tag. The armature resistance is rarely measured in the Testing Department. Such cases are specified when required. The shunt field resistance is obtained by the "drop method," using an ammeter and voltmeter. This measurement is required on each machine before a test is started. For measuring the series field resistance a special galvanometer measuring set must be used, with which the various testing sections are provided. As a considerable amount of the resistance of a series field may consist of the contact resistances between the spools, all connections must be carefully cleaned and clamped tightly together, before taking the resistance.

After the heating test on any machine, the resistances of the various parts are again measured and the rise in temperature may be calculated by the following method:

Let Rt_2 = hot resistance of copper measured at the temperature t_2.

Rt_1 = cold resistance of copper measured at the temperature t_1.

Then $t_2 = (238 + t_1)\ \frac{Rt_2}{Rt_1} - 238$

The rise obtained from this formula should then be corrected according to the standard rules of the A.I.E.E. for variations from 25 deg. cent. in the observed room temperature.

Insulation Resistance

A measurement of the insulation resistance is occasionally taken upon direct current machines and alternators. The government requires this measurement in most cases. An insulation resistance measurement is frequently taken on alternators of 2300 volts and above. On commercial apparatus generally, the measurement of insulation resistance, however, is unnecessary, since the materials used have ample dielectric strength and the slight leakage which a low insulation resistance would indicate is unimportant. This test when required is taken by the "d-c. voltmeter method of measuring high resistance" as given on page 42. In case the insulation resistance is lower than required, due to dampness, the machine should be baked either by the method described for making equivalent load tests (page 144) or by placing the machine in a baking oven.

High Potential Test

This test is taken by applying an alternating voltage between the various windings of a machine and from the current carrying parts to ground. Fig. 2 shows the connections for one of the standard high potential testing sets. Unless otherwise specified all high potential tests should be taken as given on the Standing Instructions for the machine in question. When the high potential test is applied to a moderate or large sized machine or piece of apparatus, such machine must be entirely surrounded by white tape and should have placed on it in a conspicuous place the standard high potential signs to make doubly sure that no one comes in contact with it. A sufficient number should stand guard around it to make sure that no one is injured.

On small apparatus the standard high potential signs should be used and but one man need stand as guard. Small machines need not be surrounded with white tape.

After finishing the high potential test all oil and disconnecting switches must be opened before the high potential testing cables leading to the apparatus are handled. All temporary and high potential testing cables must be disconnected from the testing transformers or high voltage source at the conclusion of the test.

Adjustment of Speed Limiting Device

Many d-c. machines are equipped with a device for limiting the speed in case of loss of field or any other condition which might cause excessive speed. These devices must be adjusted to operate at 15 per cent above the normal speed of the machine under test (10 per cent for shop machines). This device is a centrifugal device in which a revolving weight acts against a spring and operates a switch connected in the circuit of the low voltage trip coil of the circuit breaker.

Figs. 51a and 51b give diagrammatic views of the latest type of this device. In order that it may operate properly the following adjustments must be made:

With the weight moved outwards to the maximum distance, a clearance of $\frac{1}{16}$ in. as shown in Fig. 51b must be allowed between the centrifugal weight and the link when the switch is open. This clearance must be allowed in order to prevent the weight from hammering the switch after it has been forced open. With the switch blade wide open and with the weight at its maximum distance outwards, there must be $\frac{3}{16}$ in. clearance between the nearest point of the switch and the centrifugal weight. A clearance of ¼ in. must be allowed between the switch blade and the clips when the switch blade is in its extreme "out" position, as shown in Fig. 51b.

The adjustments of the clearance of the switch and centrifugal weight can be obtained by finishing their respective stops (on the short end of the switch and the hook shaped stops on the ring), to the proper dimensions. If too much material has already been removed from the stop, it may be drilled and tapped for a screw or plug which can then be finished to the proper dimensions.

All of the clearances given are the minimum that are obtained when the weight is rotating.

After these clearances have been adjusted, the spring should be adjusted, if necessary, so that the centrifugal weight strikes the switch and forces the switch blade from the clips when the speed has reached the specified limit. The springs are adjusted

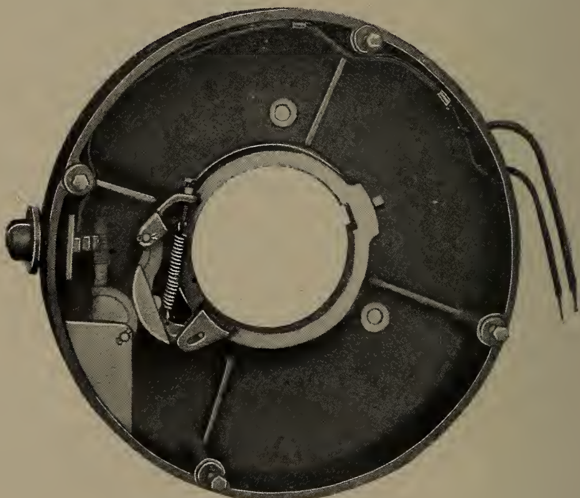


Fig. 50

SPEED LIMITING DEVICE (EARLIER TYPE)

so that the weight operates on the switch when the speed has risen 15 per cent above normal. The method of spring attachment and therefore of adjustment will be clear from the figures.

The switch shown in Fig. 50 is arranged to short-circuit the low voltage trip coil of the circuit breaker and should be adjusted with the clearances shown in Figs. 52a, b, c. In this case the revolving weight drives the switch blade into the switch contacts.

Figs. 52a, b, c also show diagrammatically a type of switch which is adjusted by varying the notch in which the loose end of the spring is placed. The number of the notch in

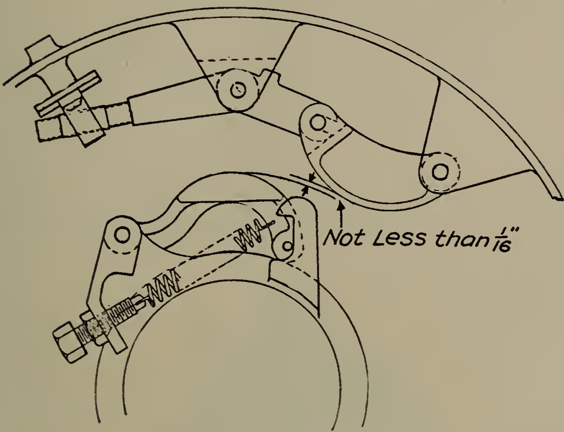


Fig. 51a

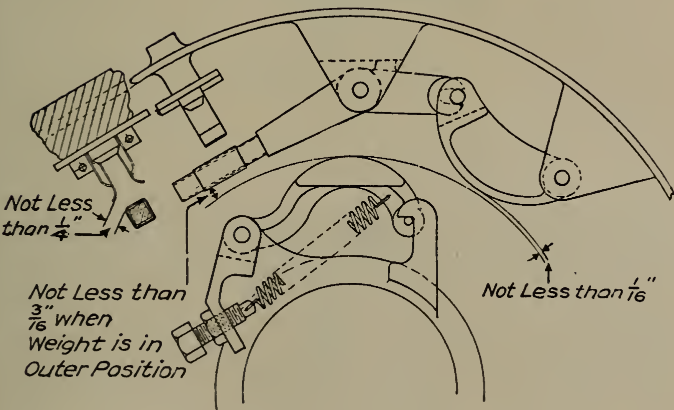


Fig. 51b

DETAILS OF SPEED LIMITING DEVICE (LATER TYPE)

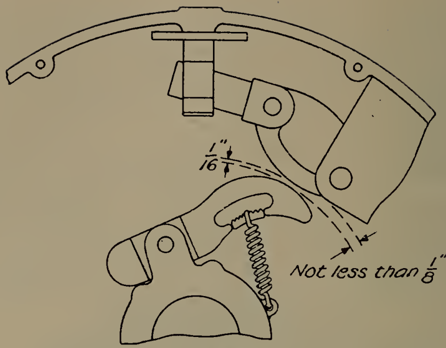


Fig. 52a

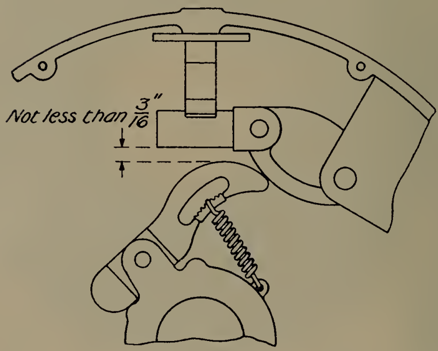


Fig. 52b

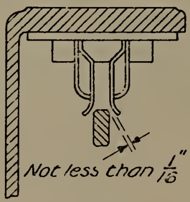


Fig. 52c

DETAILS OF SPEED LIMITING DEVICE (OLD TYPE) which correct adjustment is obtained must be recorded, and the speed at which it trips; also the tripping speed and number of the notch on each side of the correct one. The notches are numbered beginning at the one nearest the pivot.

In adjusting any speed limiting device several check readings must be taken at the final position to make certain that the device is set at the proper point.

Adjustment of End Play Device

Many machines, especially synchronous converters, are equipped with an end play device to cause an even wearing of bearings, commutator and collector rings. These devices are

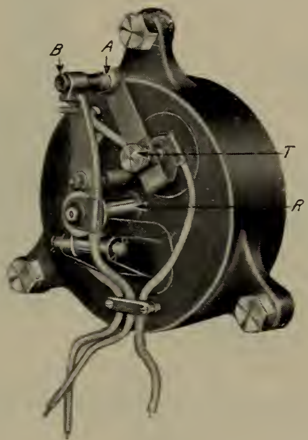


Fig. 53

MAGNETIC END PLAY DEVICE

of two types, viz., magnetic and mechanical. Before any adjustments are made great care must be used to see that the machine is perfectly level, that it floats in the mid position of its end play with field on, and that it has the correct amount of end play.

The *magnetic end play device*, see Fig. 53, causes the armature to oscillate by the same principle as is used in an electric bell. It should be wired as shown in Fig. 54, using a source of supply whose voltage equals the normal voltage of the machine under test. To adjust the device set contact (A) by means of the thumbscrew (T) until it firmly touches contact (B). This is done with the armature in the mid position of its end play. When the contacts come together the circuit is closed through the coil and the electromagnet pulls the end of the shaft toward it. When the shaft comes toward the magnet it pushes the rod

(R) against the arm carrying contact (B) which opens the circuit, releasing the magnetic pull on the end of the shaft so that the armature is pulled back in the other direction by the field of the machine. The momentum of the armature carries it beyond the mid position of the end play and the contacts come together again. The pull of the electromagnet is not exerted fully until the armature has traveled away from the device some distance beyond the mid position. The pull is then established and causes the armature to return to mid

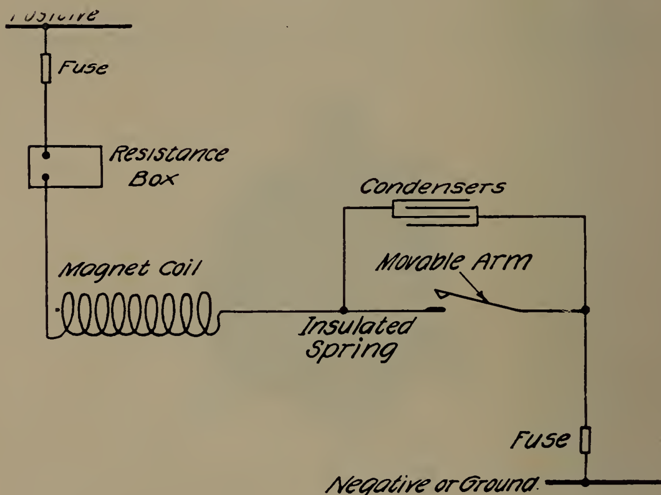


Fig. 54

CONNECTION DIAGRAM FOR MAGNETIC END PLAY DEVICE

position. This cycle is then repeated. A rheostat is provided to adjust the magnetic pull of the device to that of the fields, so that the armature may oscillate the full distance of end play allowed without bumping the bearings. After final adjustment has been obtained, the amount of resistance included in the rheostat should be measured and recorded on the Testing Record.

A condenser is connected across the contact to suppress the spark when the circuit is opened.

The bushing through which the push rod passes should not be lubricated, as it is provided with specially prepared graphite for self-lubrication.

The *mechanical end play device* is shown in Fig. 55, and consists of a ball running in a raceway held in a block which is held in a shell. This shell is screwed into a three armed casting which is bolted to the end of the pillow block of the machine. This ball makes contact with a plate on the end of the shaft of the machine. The shell in which the raceway block is held should be screwed into the position at which the ball will just make contact with the plate when the armature is in the mid position of its end play. The ball must be in its lowest position and the spring which is in the shell must not be set up tight but must have sufficient play to take up the force of the end thrust. As the center line of the raceway block is at an angle

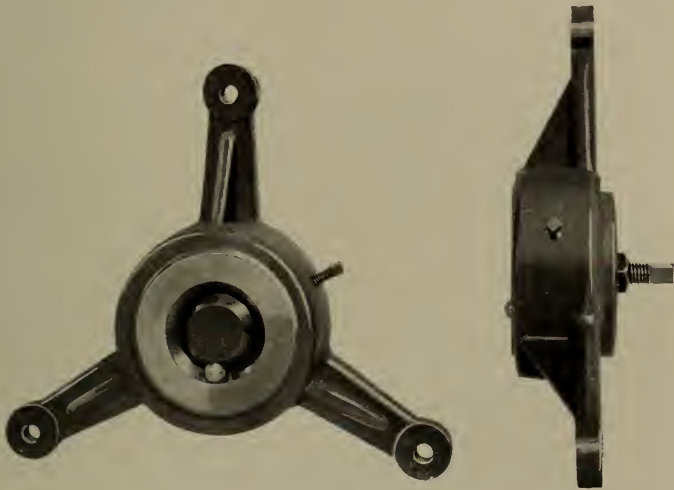


Fig. 55

MECHANICAL END PLAY DEVICE

with the center line of the shaft, the friction between the ball and plate will cause the ball to be carried up and during the revolution it will throw the shaft its full distance. The ball will then fall back and the pull of the field will cause the armature to return and the cycle to be repeated. Adjustment should be made of the tension of the spring so that the armature will swing through the range of its end play and yet not bump the bearings. It may be necessary to change springs. When the exact position of the ball has been determined, the shell may be held in place by screwing down the plug in the side of the three armed spider.

Saturation

In order to ascertain the characteristics of the magnetic circuit, a test known as "saturation" is made. The characteristic curve may be obtained by either of the following methods: "generator saturation," or "motor saturation."

Generator Saturation

The test usually made is "generator saturation." To obtain a saturation curve by this method, the machine is driven as a generator, preferably at normal speed. If, however, a set of readings is known for one speed, they can be obtained for any other by direct proportion. Hence a saturation curve taken at any constant speed at once gives the saturation curve at any other speed. The brushes of direct current machines should always be set on the neutral point and the machines run preferably at no-load speed when taking a no-load saturation curve.

In taking a saturation curve on polyphase alternating current generators, a reading of the voltage across each phase must be taken at normal field current, to see if the phases are properly balanced. If they do not balance, they must be made to do so. On synchronous converters careful readings must be taken of the direct voltage, as well as the alternating voltage between all phases with the field excitation giving normal voltage. The phase voltages must also be closely balanced.

The usual method of taking a generator saturation curve is to hold the speed constant, and then increase the field current step by step until at least 125 per cent of the normal voltage of the machine is reached, taking readings at each step simultaneously, of volts armature, volts field, and amperes field. After reaching the maximum value of the field current, without opening the field, reduce the current gradually in four or five steps, and again take readings to determine the value of the residual magnetism at various points along the curve. Special care must be taken to insure accurate readings at and above normal voltage, since with alternating current generators, this is the portion of the curve used for calculating the regulation under load. Whenever saturation curves are taken, a record of the air gap from iron to iron must be made upon the Record Sheet, together with the armature and field specifications.

Motor Saturation

When it is inconvenient or impossible to drive the machine as a generator, a "motor saturation" may be made. In this case the machine is operated as a free running motor. The driving power must be furnished from a variable voltage circuit. A certain voltage is impressed upon the armature and the motor field weakened or increased in the case of direct current machines to give normal speed, and a record made of the volts armature, amperes armature, amperes field, volts field, and speed. The starting voltage should be at least 50 per cent lower than the normal voltage of the apparatus. The applied voltage at the armature should be increased by steps to 25 per cent above normal value, and the field increased correspondingly to keep the speed constant, the same readings being recorded at the various steps as before. Readings should also be taken at three or four points as the impressed voltage and field current are lowered to approximately the values at the beginning of the test.

Care should be taken when testing direct current apparatus, as unstable electrical conditions may develop, and excessive speeds result. The circuit breaker in the armature circuit of the motor driving the machine must, therefore, be accessible to the tester reading the speed.

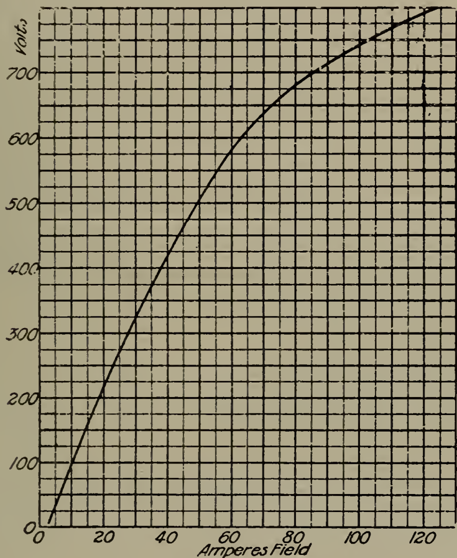


Fig. 56

SATURATION CURVE ON A 500 KW., 600 VOLT, 20 POLE, 360 R.P.M. 3-PHASE, 60 CYCLE, A-C. GENERATOR

On alternating current apparatus, the machine is run as a motor and the impressed voltage varied as already described. The speed is independent of the motor field in this case, and instead of regulating the motor field for speed it should be regulated to give mimimum input current at each voltage. Readings should be taken of voltage impressed, amperes armature, amperes field, and volts field. With induction motors it is only necessary to impress variable voltages at constant frequency and record readings of impressed volts armature, amperes armature, and speed.

The calculation of saturation tests is very simple, as it consists only in applying instrument correction factors and ratios, and plotting upon coördinate paper, volts armature as ordinates and amperes field as abscissæ. Fig. 56, and Calculation Sheet No. 1, show the results of a saturation test made by either of the above methods.

Core Loss

Three methods are used to measure the core losses on rotating direct current apparatus and alternating current synchronous apparatus. They are known as follows: "running light core loss," "belted core loss," and "deceleration core loss."

The following conditions must be obtained with direct current apparatus in order to give satisfactory results: Brushes must be shifted on the commutator to the mechanical neutral point. They must have their normal tension and the commutator must be clean, so that the normal operating commutator and brush friction values are obtained. This test, wherever possible, must be made after all the others have been finished, in order to have a glossy commutator with its surface in good operating condition. The driving power should be supplied from a variable voltage circuit that is not subject to sudden fluctuation. Readings must not be taken when the rotating parts are accelerating or decelerating.

Running Light

This test is made by running the machine free as a motor. It is made on most d-c. generators and motors which are given a running test and occasionally on alternating current synchronous apparatus.

When "running light" tests are made on direct current generators, the observations must be made with full load field flux. The potential applied to the armature must be equal to the normal rated voltage of the generator *increased by* the IR drop in the armature at full load. With this voltage impressed, the field current is varied until normal speed is obtained, when careful readings must be made of armature current, armature voltage, field current, field voltage and speed.

If the machine in test is a direct current motor, the voltage applied to the armature should be equal to the normal rated voltage of the motor, *less* the IR drop in the armature under full load. The field current is then adjusted to give normal speed and electrical and speed readings taken, as outlined above for direct current generators.

The power supplied to machines running free will equal that absorbed in bearing friction, brush friction, windage, and core loss, when the armature I^2R losses have been subtracted.

In making records of these tests, the Testing Record must clearly show whether the running light current consists of the armature current plus the shunt field current, or whether it is the armature current alone. To check this point, open the armature circuit with the shunt field circuit closed, and note whether any current is indicated on the ammeter reading the power supplied. If no current is indicated, the reading indicates the armature current alone, otherwise, the running light current is equal to the sum of the armature and field currents. To obtain "running light" core loss tests, only a single field winding must be used for excitation; this must be a shunt field winding.

In the case of series wound motors the field should be separately excited and extreme care should be taken to see that the motor does not lose its field.

In order to obtain running light core loss upon alternating current synchronous machines (in which class synchronous converters are not included as the core loss test on these machines is similar to that on direct current machines), they should be operated as synchronous motors at the proper frequency and rated voltage. For the best results, both frequency and voltage must have a steady value.

With normal voltage on the armature, the direct current field should then be varied until minimum armature current is obtained. Readings should then be taken of amperes and volts of all the phases. At minimum input current unity power-factor is obtained and, therefore, the power to drive such machines will be the volt-ampere input. Wattmeters may be used in addition to check the volt-ampere readings. This measurement includes friction and windage losses, together with open-circuit core loss, plus the I^2R loss in the armature. If the value of the core loss need not be separated from the other losses, the test is useful for checking up full load efficiencies.

Belted Core Loss

By means of the "belted core loss" method the core loss can be separated from the bearing friction, brush friction and windage. A small direct current motor is used to drive the machine under test as a generator at its rated speed. A belt drive between these machines is most commonly used, but wherever great accuracy or a high speed is necessary, direct drive by means of a coupling is often used.

The driving motor for this test should be such that good commutation is obtained for all loads required by the core loss test with a fixed setting of the brushes; and with the maximum volts on the machine under test, it should carry not more than 50 per cent of its normal rated capacity. Ordinarily a good rule to follow is to select a motor, the rated capacity of which is approximately 10 per cent of the rated output of the machine under test. When the brush setting to give the best possible commutation at all loads has been obtained, the brushes should be left in that position throughout the test. The commutator surface should be in first class condition and should have the brushes closely fitted to it.

The belt should be of minimum width and weight to carry the load without slipping. When testing motor-generator sets, synchronous converters and other machines that do not require belts in practice, the tension of the belt must be kept as low as practicable so that the bearing friction is not increased on account of belt pull. Endless belts should always be used in preference to laced belts.

The diameter of the pulleys should be so selected that the driving motor will run at or near its rated speed when the machine under test is running at its normal speed.

The driving motor should have its field separately excited from a constant source and other wiring so arranged that readings may be taken of amperes armature, volts armature, amperes field and speed. The volt-wires should be firmly attached to brushes on two adjacent studs. The brushes so used should be insulated from the holders so that the true volts armature may be obtained. Previous to starting the test, careful resistance measurements must be made of the armature of the driving motor.

The machine under test should be wired as a separately excited generator with provision for reading volts armature, volts field, amperes field and speed.

The test should then be carried out as follows: The field of the driving motor should be adjusted to about normal value and held constant, and the speed regulated by varying the voltage applied to the armature terminals. Careful readings should be taken to make sure that no belt slipping occurs. This is done by taking simultaneous readings of speed of both the driving motor and the machine under test: (a) with no field on the machine under test, (b) with normal field excitation. The two readings of speed should be identical. The machines should be run a sufficient length of time to allow the friction to become constant. This will be the case when the input to the driving motor becomes constant when driving the machine under test without any field excitation.

Throughout the entire test, readings must be taken at absolutely constant speed when the rotating parts are neither accelerating nor decelerating.

Readings should be taken as follows:

(a) Take the input to the driving motor with no field on the machine under test and with all brushes down on the commutator.

(b) Take the input with field on the machine under test to give normal volts with all brushes down on the commutator.

(c) Take the input with all brushes raised from the commutator and with the same field current in the machine under test as for the preceding reading.

(d) Take the input with all brushes raised and with no field on the machine under test.

The difference between the first and fourth readings is brush friction. The difference between the second and first readings and also the difference between the third and fourth readings is core loss. The core loss should be the same with the brushes down as with the brushes up, and the two results obtained should check within 6 per cent before proceeding with the test. Starting with zero field on the machine under test observations of the input to the driving motor should be made at various values of the field up to that which will give 125 per cent normal voltage, and at least half the readings should be taken between 90 per cent and 110 per cent of the normal voltage.

The "friction reading" with zero field excitation on the machine under test should be repeated at least three times during the progress of the test; namely, at the beginning, again near the mid point of the curve and finally at the end of the test.

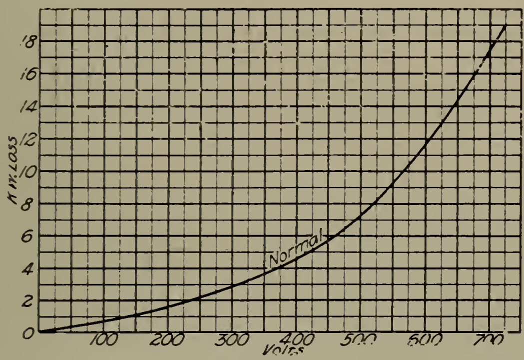


Fig. 57

OPEN CIRCUIT CORE LOSS ON A 500 KW., 600 VOLT, 20 POLE, 360 R.P.M. 3-PHASE, 60 CYCLE, A-C. GENERATOR

As the amperes field of the machine under test are increased the volts armature of the driving motor should also increase because of the increased IR drop in the armature.

The driving motor should then be unbelted and a "running light" reading taken on it as follows: Without changing the brush shift hold the same amperes field as was held during the core loss test and take a reading of the input to the motor to give the same speed as was read on the driving motor at the beginning of the test. The volts armature should be lower than for any reading taken during the core loss test.

To check the results of the core loss as the test proceeds the power input to the driving motor required by the core loss at a given excitation should be plotted against volts armature generated. This should give a curve similar to Fig. 57.

Correcting the motor input at the various field strengths by deducting the I^2R loss in the armature of the driving motor and subtracting the power input to the driving motor with zero field on the machine in test, the core loss is left corresponding to the various field strengths. By subtracting the "running light" input to the driving motor from the input with zero field on the machine in test, the bearing friction and windage losses of the machine under test are obtained.

No pulsation or sudden variations must occur in the armature current of the driving motor which might vitiate the power readings. It is advisable to wire an inductive winding in series with the armature of the driving motor in order to steady the motor armature current.

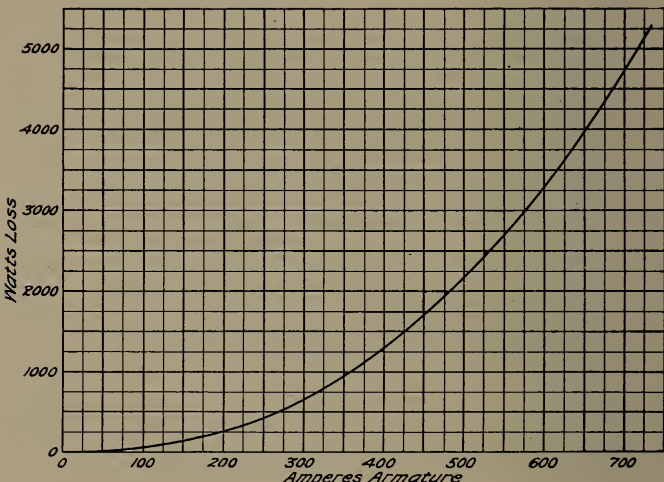


Fig. 58

SHORT CIRCUIT CORE LOSS ON A 500 KW., 600 VOLT, 20 POLE 360 R.P.M., 3-PHASE, 60 CYCLE, A-C. GENERATOR

In making out reports of core loss the following data regarding the machine under test should be recorded on the Testing Records in addition to the electrical readings already mentioned: *viz.*, circumference of commutator; circumference of shunt and series field spools; height of shunt and series field spools; number and width of commutator bars; size and material of brushes; number of studs and brushes per stud; brush pressure per brush; rating of driving motor together with its armature and frame number; type and rating and serial number of the machine under test.

On series motors core loss tests should be taken at several different speeds covering the range of the speed curve. The method used is identical with that described above and will be considered in connection with railway and series motor tests.

Synchronous alternating current machines generally have loss measurements taken as outlined above on open-circuit (see Calculation Sheet No. 2), and also with the armature of the machine under test short-circuited. In the latter case the increase in power supplied by the driving motor over that required by the friction loss is plotted as ordinates against the amperes armature as abscissæ, or the open-circuited armature voltage due to a given excitation. A curve is obtained

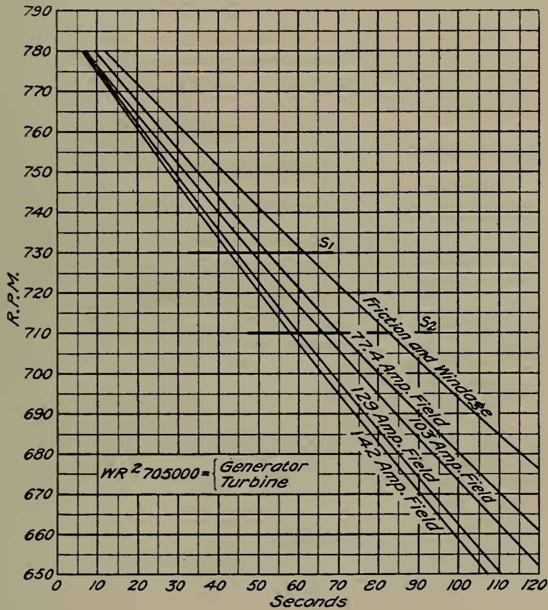


Fig. 59

DECELERATION CURVES ON A 3000 KW., 2300 VOLT, 720 R.P.M. 60 CYCLE, 3-PHASE, A-C. GENERATOR

similar in character to the open-circuited core loss curve. Such test is commonly known as "short-circuited core loss." Fig. 58 shows the results of such tests after all correction factors have been applied. In making this test careful measurements must be made of the resistance of the short-circuited armature circuit including all leads, before and after the test, since to obtain the true short-circuited core loss the I^2R loss must be subtracted. Observations should be made with the short-circuited armature current at least 200 per cent of its normal full load value. (See

Calculation Sheet No. 3.) Care must be taken not to overheat the windings.

Deceleration Core Loss

It is often necessary to determine the core loss, friction and windage losses of large machines when it is impracticable to employ the "belted core loss" method. The "running light" reading alone does not allow the separation of the core loss from friction and windage. A method known as the "deceleration core loss" is used for this purpose. Such tests

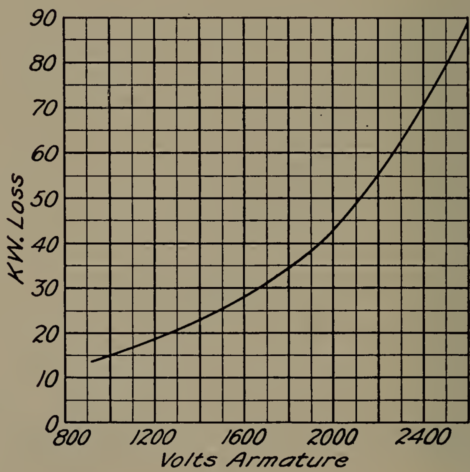


Fig. 60

OPEN CIRCUIT CORE LOSS CURVE FROM DECELERATION CURVES IN FIG. 59

are employed regularly on turbine-driven units, and it is very convenient to use them in connection with certain vertical waterwheel-driven generators, and other exceptionally large horizontal alternators and direct current machines with a considerable flywheel capacity.

A running light reading at normal speed and normal voltage should be taken to give the driving power necessary under that condition. Where this is not practicable, the moment of inertia of the rotating part must be known. This can be very accurately calculated for the majority of machines from their mechanical dimensions, as given by the working drawings.

The test is as follows: First drive the machine with no field at a little above normal speed, and then suddenly cut off the driving power and observe the deceleration, then do the same thing with full field on the machine. In the first case the deceleration is due to the retarding force (friction and windage), in the second case due to these factors plus core loss. Readings of the speed of the rotating parts should be taken at sufficiently frequent intervals to obtain a uniform and reliable curve. A set of these curves is shown in Figs. 59 and 60. With the aid of these curves together with a "running light" test, or a calculation of the kinetic energy of the rotating parts, a determination of the value of the core loss, and also of the friction and windage, is readily made. The following is a brief derivation of the formulæ used in calculating such results by either method.

If W = weight.
r = radius of gyration.
S_1 = speed in r.p.m. at time T_1
S_2 = speed in r.p.m. at time T_2.
Wr^2 = flywheel effect.

Then the kilowatts loss may be found from the following:

$$\frac{^{*}2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{(T_2 - T_1)} = \text{kw. lost in decelerating from } S_1 \text{ to } S_2$$

with any particular field excitation.

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* This formula gives the average power loss from S_1 to S_2 and may be derived as follows:

If M = mass
v = linear velocity at radius of gyration
ω = angular velocity
S = speed in r.p.m. corresponding to angular velocity
g = 32.2 ft. per sec. per sec.
E = kinetic energy at speed S and time T
E_1 = kinetic energy at speed S_1 and time T_1
E_2 = kinetic energy at speed S_2 and time T_2
P = power

The kinetic energy of a moving body at any instant is $\frac{1}{2} Mv^2$. $M = \frac{W}{g}$ and for a rotating body $v = r\omega$ and $\omega = \frac{2\pi S}{60}$.

Hence $E = \frac{1}{2} Mv^2 = \frac{W}{2g}(r\omega^2) = \frac{W}{2g}\left(r\frac{2\pi S}{60}\right)^2 = 0.00017\ Wr^2S^2$.

$E_1 = 0.00017\ Wr^2\ S_1^2$ (1)

$E_2 = 0.00017\ Wr^2\ S_2^2$ (2)

The energy consumed between T_1 and $T_2 = E_1 - E_2$ but for (1) and (2) $E_1 - E_2 = 0.00017\ Wr^2\ (S_1^2 - S_2^2)$ in foot lb.

Power $= \frac{\text{Energy}}{\text{Time}}$.

$\therefore P = \frac{E_1 - E_2}{T_2 - T_1} = 0.00017\ Wr^2 \frac{(S_1^2 - S_2^2)}{(T_2 - T_1)}$ ft. lb. per sec.

Multiplying by the proper constants to reduce to kilowatts we have

$\text{kw} = 0.00017\ Wr^2 \frac{(S_1^2 - S_2^2)}{(T_2 - T_1)} \times \frac{746}{1000} \times \frac{1}{550} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{(T_2 - T_1)}$ which is the average power loss for speeds from S_1 to S_2.

(Continued on page 130)

If T_3 and T_4 are respectively the times at which the speeds S_1 and S_2 occur with no excitation on the machine, then in this case the loss in kw. $= \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{(T_4 - T_3)}$

§The kw. core loss is then the difference between the results obtained from the above two formulæ.

With deceleration core loss records the same data must be entered upon the record sheets that are required in connection with the belted core loss method. Calculation Sheets 2 and 3 show the standard method of calculating test results, open-circuited and short-circuited, taken by the belted core loss method. Calculation Sheet 4 shows the method employed in calculating results of deceleration core loss, either by using the value of Wr^2, or the running light test.

Input-Output Test

It is sometimes required that the efficiency of a machine, or motor-generator set be measured by the input-output method. The measurement of the power input to the motor or the output from the generator is then required. The efficiency of the set will then equal

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To find the loss at any particular speed use the following method:

$E = 0.00017\ Wr^2 S^2$. If ds is the infinitely small change of speed during the infinitely short time dt then

$$\frac{dE}{dt} = \frac{d\,(0.00017\ Wr^2 S^2)}{dt} = 0.00034\ Wr^2 S \frac{dS}{dt} \text{ or } \frac{dE}{dt} = KS \frac{dS}{dt}$$

But $\frac{dE}{dt}$ is a rate of change of energy or power and $\frac{dE}{dt} = P$

$$\therefore P = KS \frac{dS}{dt}.$$

Having obtained a deceleration speed-time curve we can get P for any value of S. Since $\frac{dS}{dt}$ is the slope of the curve and can be obtained by drawing the tangent to the curve where S has the desired value. Substituting values of S and $\frac{dS}{dt}$ in the above equation gives the value of P.

§ If the kw. "running light" has been obtained,

$$\text{kw ``running light''} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{(T_2 - T_1)} = K_1 \frac{Wr^2(S_1^2 - S_2^2)}{(T_2 - T_1)}$$

$$\therefore Wr^2 = \frac{\text{kw. ``running light''}\ (T_2 - T_1)}{K_1(S_1^2 - S_2^2)}$$

$$\text{also kw. friction} = \frac{K_1 Wr^2(S_1^2 - S_2^2)}{(T_4 - T_3)}$$

or substituting for Wr^2

$$\text{kw friction} = \frac{(T_2 - T_1)}{(T_4 - T_3)} \times \text{kw. ``running light.''}$$

Hence knowing the "running light," the friction can be calculated and the core loss separated from the "running light."

$$\frac{\text{Total output of generator}}{\text{total input to motor}}$$

The efficiency of the generator equals

$$\frac{\text{Total output of generator}}{\text{input to motor} - \text{motor losses}}$$

The efficiency of the motor equals

$$\frac{\text{Output of generator} + \text{generator losses}}{\text{input to motor}}$$

In the case of induction motors, input-output test is sometimes taken by the string brake method, which is discussed in Chapter 12.

The input-output method of measuring efficiency is one of the most difficult tests which the Test Dept. is called upon to make, and is subject to considerable inaccuracy.

This method of the direct measurement of the efficiency of a machine should preferably be made by using a duplicate machine for power or for load. This is especially true of motor-generator sets. The two sets should be wired up for feed back test and the electrical losses supplied to the direct current machine, unless it is possible to secure a source of alternating current whose wave form is identical with that of the alternating current motor under test.

Great care must be exercised in wiring the machines for this test. The voltmeters, reading the voltage of the input and the output, should be wired as near to their respective machines as possible.

The secondaries of the current transformers should be wired directly to the instruments and not through any switches or contacts of any kind, and the wiring must be continuous, i.e., without any splices. The alternating current wattmeters, reading the input, must be placed some distance apart. All instruments should be carefully tested for stray fields. If the machines have series fields, these must be disconnected.

Before the machine is started the wiring must be thoroughly inspected by the Head of the Section or one of his assistants. The complete set of instruments, transformers, etc., must be specially calibrated before this test is commenced. No reading should be taken until the instrument pointers are steady and extreme care must be taken to have all readings simultaneous. No man should read more than two instruments and preferably there should be one man for each instrument reading directly the input and the output.

The resulting errors from the input-output method are likely to be large, since any inaccuracy in instruments, or personal errors in reading, influence the results directly. The errors in reading the instruments may be partially eliminated by taking several readings at each load and using the average of all these readings. Even with the best conditions for making the input-output test it is still much more preferable to ascertain efficiency by measuring the losses directly. By adding all the losses to the output at any load the input at that load may be obtained. The output divided by this result gives the per cent efficiency. The same per cent errors in instruments or instrument readings in loss measurement test influences the results of the efficiency calculations only indirectly; consequently the latter method is superior for ordinary testing.

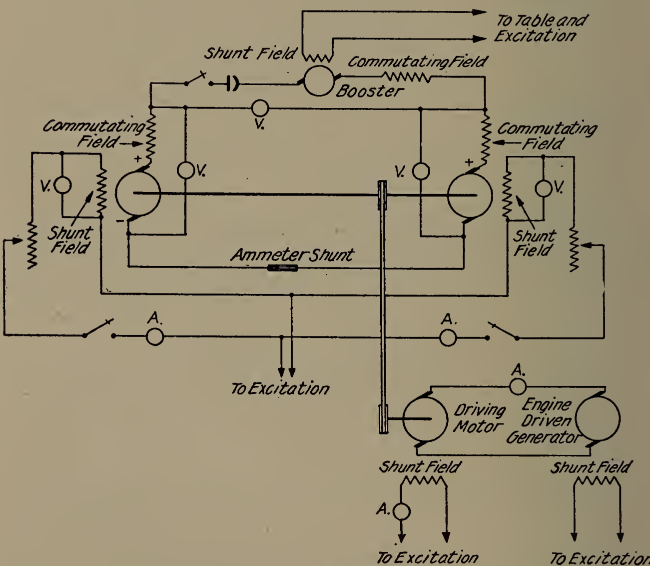

Fig. 61

CONNECTIONS FOR LOAD LOSS TEST

Load Loss Test

As stated in the section on input-output tests it is much more desirable to ascertain the efficiency of a machine by measuring the losses directly. However, there are some machines which when loaded show a loss which cannot be measured or calculated directly from the no-load test. This additional loss is known as "load loss."

To obtain the efficiency of a machine under load without making the input-output test, the method of measuring the I^2R loss by means of a booster and observing the input to a separate driving motor which supplies the rotation and core losses is used. This test requires two similar machines coupled and wired together, as shown in Fig. 61. The driving motor should preferably be direct connected so as to eliminate the belt loss.

After the machines have run a sufficient time under load to reach constant temperatures they should be shut down and the IR drop between the two machines taken at the terminals of the machines at currents corresponding to the loads at which the load loss is to be observed. These readings will give the approximate booster voltages required for the different loads.

The machines should then be run until the friction is constant. Then take several core loss readings on each machine with the voltage varying from 75 to 125 per cent of normal. Also take careful readings of the input to the driving motor with both machines excited to give normal voltage. The difference between the motor input (less its own losses) for normal voltage on the machines and for friction (less the driving motor losses) is the core loss at normal voltage.

Readings should then be taken at various loads holding the voltage on the generator constant at normal, and the booster supplying voltage at 10 per cent below the normal drop as obtained at standstill; at normal drop; and at 10 per cent above normal drop for each load. As the booster and the driving motor are furnishing all the losses the sum of the power supplied by these two machines should be practically the same for the above readings for any given load. This variation in booster voltage is made in order to check each point under slightly different instrument readings.

When a complete set of readings is taken the machines should be shut down and the IR drop again observed for the various currents used in taking the IR drop at the beginning of the test. Take the average resistance obtained from the drop at the beginning and at the end of the test and use this for calculating the I^2R to be deducted from the power supplied the two machines under the different loads.

The load loss for two machines will then equal the total power supplied by the booster and the driving motor minus the I^2R loss of the circuit minus the I^2R loss of the driving motor armature minus the driving motor input at no-load normal voltage on both generators or motors under test.

As this method gives a fairly accurate measurement of the total losses under full load, or at any per cent of full load it is a direct method for measuring the load loss and the efficiency. However, it requires the most accurate work. The same amount of care in the calibration of instruments and transformers, in the wiring of the machines and in reading the instruments is required as is necessary for the input-output test. The effect of brush shift on the load loss is very noticeable. The load loss may also be affected by the condition of the brush contact surface and by the condition of the commutator. It is, therefore, important not to disturb the brushes or commutator after the tests have been commenced.

Maximum Output

The maximum output of direct current compound wound generators is dependent upon their commutation, or heating limitations, hence, the maximum output test on these machines is usually a commutation test, which will be described later. As in shunt wound generators the voltage falls with the load at constant field excitation, the maximum output is not always limited by commutation. It is not usual to make maximum output tests, however, on the above machines, since they possess little practical interest.

In the case of induction motors, the maximum output, or breakdown point, is a matter of considerable importance. If sufficient power is available, the motor is loaded in successive steps, beginning at zero load up to the breakdown point. During this test readings of volts armature, amperes armature, speed, and motor output are taken and plotted. It is essential that the voltage and frequency of the power circuit from which the motor is operating be held constant. It is also important that readings be taken quickly at overload currents, and that the motor be allowed to cool between such readings, or it will overheat. Where sufficient power is not available to take a breakdown test with normal voltage impressed on the armature of the motor, a voltage considerably below normal is used, viz: ¾, ½, or even ¼ voltage. It is then necessary to calculate the full voltage results from those obtained at the lower voltages. This may be done by increasing the power output proportionally to the square of the ratio of normal voltage to the lower voltage.

All maximum output tests on synchronous motors, unless stated to the contrary, should be made with a field excitation giving minimum input armature current for a given load. Readings must, therefore, be taken of volts armature, amperes armature, amperes field and volts field with various loads from no load to that load which will cause the motor to break from synchronisn, adjusting the field strength for each reading to give minimum input. The speed of a synchronous motor will be constant until the point of breakdown is reached, whereas that of an induction motor will decrease from no load to the breakdown point.

In case sufficient power is not available to make a maximum output test upon a synchronous motor at its normal rated voltage, its voltage may be reduced below normal, as described for induction motors. If the minimum input is obtained when the readings are taken, the output of the motor at normal voltage may be determined in the manner described for induction motors.

The wiring for this test must be arranged so that the armature circuit of the motor can be opened immediately when it breaks from synchronism.

Wave Form—Potential Curve Between Brushes

In the determination of wave form of a d-c. machine the following method should be used: The machine should be run at normal speed and voltage. A pair of voltmeter leads separated a distance equal to the width of one commutator bar is placed on the commutator under the center of one pole and moved from bar to bar over to the center of the next pole of like polarity, the voltage being read at each step. In this way the voltage between bars is obtained for a complete cycle of 360 electrical degrees.

The readings should be corrected and plotted as ordinates against the number of the corresponding bars as abscissæ and a sketch showing the position of the poles should be made on the same sheet in conjunction with the curve obtained.

Wave form on alternators is obtained by the use of the oscillograph.

Over-Speed Test

Very often the Testing Department is called upon to take tests on a machine with the revolving part running at a specified speed above normal to test for mechanical strength.

On all large machines this test is always taken with the rotor placed in a large pit and driven mechanically at the designated speed. Careful measurements are taken by the Mechanical Inspectors of definite parts of the rotor under test and the test then started. The machine should be shut down and check measurements taken at normal speed and at 22, 41, 58, 73, and 87 per cent over normal to see that there is no stretching of the metal or loosening of the different parts.

No over-speed test should be started unless an especially appointed man is present to witness the test.

Small machines are usually run inside the building after being covered with heavy castings as a precaution against accident.

CHAPTER 7

DIRECT CURRENT GENERATORS

The tests on direct current generators may be divided as follows: Preliminary tests; short commercial and adjustment; heating tests; special tests; input-output tests; over speed test; and wave form.

Preliminary tests consist of drop on spools; polarity; cold resistance measure; air gap; checking of armature and field specifications; brush and equalizer spacing; brush alignment; commutating pole spacing; and preliminary inspection, all of which have been explained in preceding chapters with the exception of equalizer spacing.

Equalizers consist of rings or cross connections tapping into equi-potential points on the winding of multiple wound armatures between each pair of poles. These rings prevent inequalities in voltage between brushes of equal potential due to inaccurate centering of the armature. They allow alternating current to flow from the stronger to the weaker pole pieces, which slightly demagnetizes the former and magnetizes the latter, thus equalizing the voltage at the brushes. Not only do these rings prevent an interchange of heavy cross-currents between brushes but they also compensate for inequalities at the pole pieces tending to bend the shaft or overheat the bearings. These rings must be examined carefully to see that the taps are equally spaced and that the connections are tight.

General Instructions

After checking up all of the above points the machine should be turned over slowly and the eccentricity of the commutator carefully measured. If it is eccentric more than 0.005 in. it must be trued according to the method given in Chapter 3, page 95.

The man in charge of the machine should obtain the sheet of Testing Instructions from the Head of Section. The machine should be wired according to the correct wiring diagram obtained from the Head of Section who should then see that the wiring is inspected and checked. The different methods for obtaining load are described in subsequent pages.

It is absolutely necessary that the machine operate correctly when connected according to this print, and any discrepancy in operation should immediately be referred to the Head of Section.

Make provision for reading volts and amperes line, volts and amperes field, and speed.

Using the precautions mentioned in Chapter 4, page 100, the machine may then be started. The brushes should first be set on the mechanical neutral by the Head or Assistant Head of Section, by shifting the brush-holder yoke until the brushes are in line with the center of the pole pieces. This position can be located accurately enough by sight on machines without commutating poles. On commutating pole machines a more accurate method is used which is described later.

If the machine has been assembled and connected correctly it should "build up" when the shunt field switch is closed and all resistance is cut out. To make sure that all the resistance has been cut out of the field circuit, the field boxes may be short-circuited by a short piece of wire temporarily held against the terminals. If it does not build up, the connections should again be checked with the wiring diagram and the polarity and resistance of the shunt field, and the different specifications re-checked. If these prove to be correct, the field switch should be opened and the residual armature voltage noted. If, upon again closing the switch, this decreases or drops to zero, it shows that the machine is not wired properly and that the current tends to flow in the wrong direction through the field. This condition should be referred to the office, as the only way to remedy it would be to change the connections. If, however, upon closing the field switch the residual armature volts do not diminish it may be necessary to "flash the field" by sending a current through it in the proper direction from some external source.

The building up of a series generator is a more complicated operation. The load increases with the voltage and great care must, therefore, be taken in obtaining the correct external resistance to prevent the voltage from increasing rapidly. As it is practically impossible to decrease the external resistance enough (i.e., put the blade of the water box in far enough) to allow the generator to pick up, the usual method is to put the water box blades in and short-circuit one of the boxes with a fuse wire, then close the circuit breaker and switches. If the machine then starts to pick up, and the voltage decreases as soon as the fuse wire burns away there is too much resistance in the water boxes. They should, therefore, be salted (to decrease the resistance) and the operation repeated. Should the resistance in the boxes be too low the load will increase very rapidly and the breakers may have to be opened to prevent the machine arcing over between brushes.

MACHINES WITHOUT COMMUTATING POLES

SHUNT ADJUSTMENT

After the machine builds up in the proper manner a saturation curve should be taken as described in Chapter 6, page 120.

The machine should then be compounded according to the Testing Instruction sheet. This test is very important and the results must be passed by the Head, or Assistant Head of Section. The machine must first be adjusted for good commutation. No fixed rules can be laid down for judging commutation, but Fig. 62 shows a chart covering the various grades of commutation and should serve as a guide in judging this question. The machine should be loaded by one of the methods described under "Actual Load Test" described later.

In order to obtain good commutation on generators without commutating poles, it is necessary to shift the brushes from the mechanical neutral in the direction of rotation to a position that will give satisfactory commutation at both no load and full load. It is not usually possible to obtain sparkless (No. 1) commutation on generators without commutating poles, but it should not be worse than No. 2, as shown in Fig. 62. If it is impossible to obtain satisfactory commutation by shifting the brushes, the matter should immediately be reported to the Head of Section.

After satisfactory commutation has been obtained the position of the brush-holder yoke should be marked with a chisel and the machine then given a cold compounding test as follows:

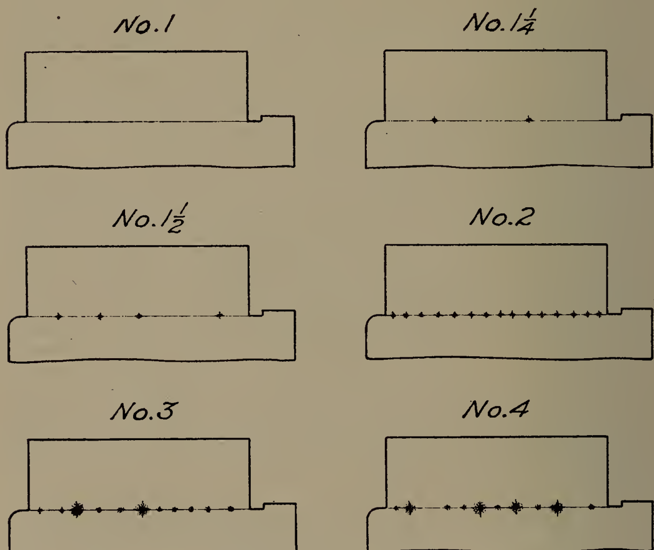

Fig. 62

VARIOUS DEGREES OF GENERATOR AND MOTOR SPARKING

The voltage should be adjusted at no load with a falling field, that is, the voltage should be brought considerably above normal and gradually reduced to normal by "cutting in" the field rheostat. Then without changing the position of the field rheostat normal load should be put on the machine with the speed held constant and a reading taken at full series field of volts armature, amperes, volts and amperes field and speed. The volts armature should rise considerably above the rated full load voltage of the machine. If it does not rise but falls, the series field is either weak or reversed. If the whole series field opposes the shunt field it may be easily checked by tracing out the direction of the current after it leaves the armature. All field spools are wound in the same direction so that only the general direction around the frame need be traced.

The series field may be wound in an opposite direction to the shunt field. To test this, reverse the series field leads. Should the machine over-compound with the series field in the reversed direction from the shunt field, the test should immediately be discontinued until the spools are changed. A report of this defect should be made to the Head of Section.

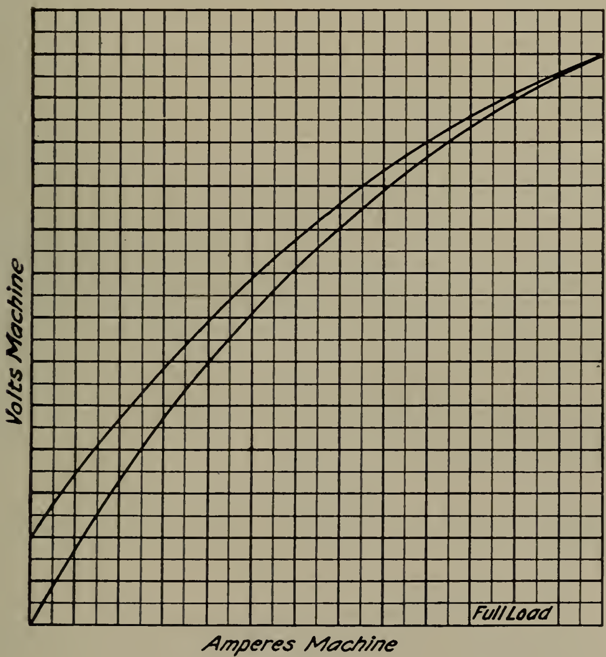

Fig. 63

SERIES CHARACTERISTIC

It may be that only a part of the series field is reversed. In locating a reversed series spool it is best to excite the series field up to 20 per cent of full load current, then either try for polarity or take a potential curve using the series field as a source of excitation. Extremely low voltage will appear on the potential curve, both in front of and behind the reversed spool.

If the machine overcompounds correctly, a shunt should be placed on the series field and adjusted until the specified compounding is obtained. The no-load point should be taken with a falling field as above, then, without touching the field rheostat the load should be applied gradually until full load is reached. A reading should then be taken as above. This process should be repeated until the shunt has been so adjusted that a full load voltage is obtained about one per cent above that specified. This will allow for voltage drop in the armature due to heating. The shunts for the series field are usually made up of cast iron grids as specified in the Engineering Notice.

Machines that are for direct connection to steam engines, etc., should have allowance made for the drop in speed from no load to full load, due to engine regulation.

The shifting of brushes on series generators necessitates good judgment. The brushes should first be given a little more lead with full load than is necessary for commutation. The load should then be gradually reduced, and the commutation noted until zero voltage is obtained. Should sparking occur at any point, a readjustment of the brushes should be made by shifting them back towards the neutral point, provided that full load commutation will so allow.

A series characteristic is taken on all series wound generators. This is done by increasing the load by small steps until full load is obtained, amperes line and volts machine being recorded at each step. The load is then reduced by small steps to no load, the same readings being taken. A curve is then plotted between amperes as abscissæ and volts machine as ordinates. See Fig. 63.

In the case of series machines forming part of booster sets, the guarantee sometimes does not allow this curve to deviate by more than a certain percentage from a straight line. The curve should be taken in all cases with the German Silver shunt in place, if the latter is necessary.

HEATING TESTS

Two methods may be used for making heating tests, i.e., *Actual Load Tests* and *Equivalent Load Tests.*

ACTUAL LOAD TEST

Several different means for obtaining actual load test may be employed, such as the "water box," "feeding back" and "circulating current" methods.

Water Box Method

The "water box" method familiarly known as the "dead load" method, as its name implies, consists in driving the machine by a motor or other means and loading it directly upon a water box. See Fig. 64. This method entails considerable expense, since all the power generated is lost. On large machines requiring a considerable amount of power to be dissipated, several water boxes are connected in multiple. The standard water box used in the Testing Department is designed to dissipate 75 kw. continuously and care should be taken to have the circulating water in the water boxes so adjusted that violent boiling will not occur, as it is difficult to hold the load constant when this occurs. The load should be evenly divided between the different water boxes.

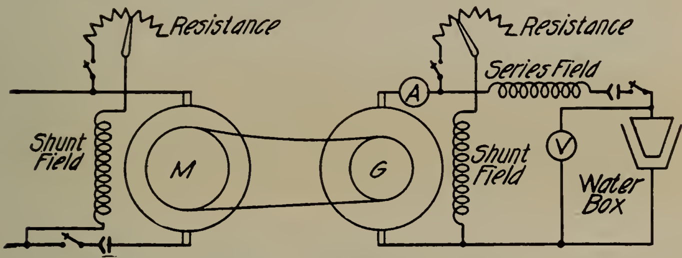

Fig. 64

CONNECTIONS FOR LOADING D-C. GENERATOR ON A WATER BOX

Feeding Back Methods

To obviate the loss of power and reduce the cost of testing the "feeding back" method is used when possible, especially with large d-c. machines or motor-generator sets. In this method the total machine losses are supplied either mechanically or electrically from an external source.

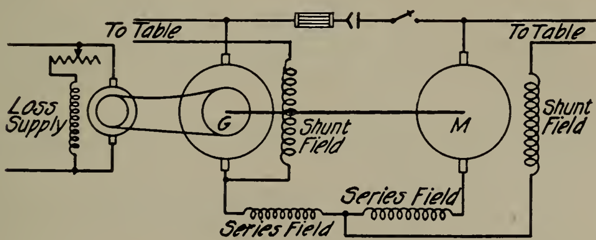

Fig. 65

CONNECTIONS FOR MECHANICAL LOSS SUPPLY FEED BACK

In the *mechanical loss supply* method, two machines of the same size and voltage should be belted or direct connected together and mechanically driven by a motor large enough to carry the losses of the set. Connections are made as in Fig. 65. If the machines have series fields the one to operate as a motor should be so connected that it will run as an accumulative compound wound motor. The voltage of each machine should be brought up as in a generator and the machines thrown together by closing the switch between them when the voltage across it is zero. One machine is then adjusted to act as a motor by weakening its field. This lowers its generated voltage and causes current to flow through the machines which should be adjusted to the required value. The speed is held constant by the loss supply motor. After running at the proper load for the specified time, the heat run should be taken off and tests finished according to the standard requirements.

In the method of *electrical loss supply*, two machines are direct-connected or belted together, and the losses supplied electrically. See Fig. 66. The machine acting as a generator should be run under normal operating conditions of voltage and current. The speed is held by varying the field of the motor. It may be necessary to connect the motor field in series-multiple to obtain the required condition.

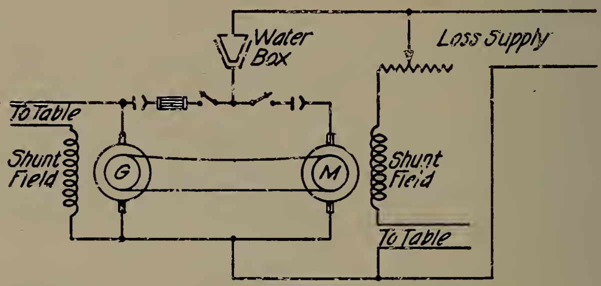

Fig. 66

CONNECTIONS FOR ELECTRICAL LOSS SUPPLY FEED BACK

When Compound Wound Generators are being tested by this method the series field of the motor must be included or the load will be unstable.

Another method of "Feeding Back," often used, is to run the entire load back on the main supply circuit from which the motor is run which drives the generator in test. If the main supply circuit is likely to vary in voltage, it may be necessary to insert resistances between the generator and supply. It sometimes happens that the no-load voltage of the generator is below that of the supply. As changing the line resistances will have no effect at no-load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full-load field current from the no-load current, and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistance.

Two similar motor-generator sets can be tested very readily by the "Feeding Back" method.

As an illustration, suppose each set consists of an induction motor and a d-c. generator. In this case, connections are made as in Fig. 67. The a-c. and d-c. ends of the respective sets are connected together, one set being run normally and the other inverted. The induction generator feeds back on the induction motor, both taking their exciting current from the alternator (A) which supplies the losses. They are started one at a time from the a-c. end, and the d-c. ends adjusted by means of a voltmeter across switch (P). The d-c. motor field is weakened until the ammeter in the d-c. line indicates that normal current is flowing. The weakening of the motor field allows the speed of the inverted set to increase just enough to load the induction generator while it also decreases the counter e.m.f. of the motor a sufficient amount to allow full load current to flow in the d-c. circuit. This load must be

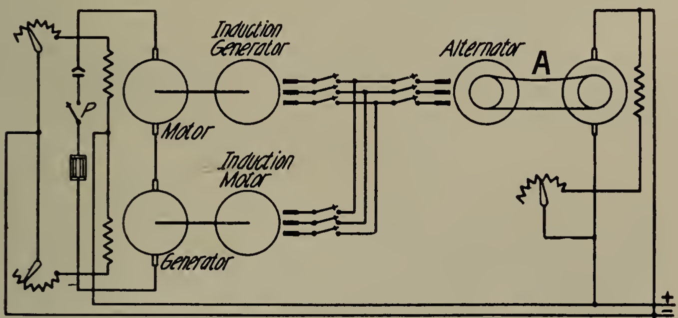

Fig. 67

CONNECTIONS FOR INDUCTION MOTOR-GENERATOR SET FEED BACK

closely watched as it is unstable. Load instability is a rather common occurrence in "Feeding Back," due either to variations in shop voltage or speed.

Circulating Current Method

It will be noted in the "Feeding Back" tests described that it is necessary to weaken or strengthen one of the fields to obtain the load. To conduct the test with the same field excitation on both machines the armature of a separately excited booster may be connected in series with the armatures of the two machines being tested. The machines, connected so that they run at the same speed, are brought up to normal speed by means of the motor supplying the losses. The connecting switch is then closed and the booster field strengthened until normal current flows in the armature circuit, the field current being adjusted to give the same excitation on both fields. The voltage is held across the motor terminals by varying the speed of the loss supply motor.

EQUIVALENT LOAD TEST

Very often it is found impossible to run actual load tests, especially on large machines on account of limited facilities. Equivalent load tests have consequently been devised in which the heating of a machine at a certain load may be closely ascertained without actually loading it.

A direct current machine may be satisfactorily tested in this manner by short-circuiting the armature upon itself or through the series field connected so that it will not build up as a series generator. The shunt field is separately excited from an external source until the required current flows through the armature, or armature and series field. This method is the one usually used for baking and settling the commutator. Amperes armature and field, and volts field should be read throughout the run. When this test is run for a commutator bake, the final temperature of the commutator should be recorded.

A similar method of making an equivalent load run consists in running the generator under reduced kilowatt output by lowering the voltage and keeping the current normal. In this case the fields are all wired in and all readings taken as during a full load run.

NORMAL LOAD HEAT RUN

After the machine has been properly compounded the heat run may be started. Before going ahead with this test, the tester should read carefully all the instructions contained in Chapter 4, regarding the location of thermometers and reading of temperature, etc.

In addition, the brushes and commutator should be in first class condition and under no circumstances should a heat run be started until the brushes have at least a 90 per cent fit. The brushes should be carefully watched to see if they pick up copper, and if such is the case the commutator while running should be cleaned with a piece of canvas and the copper wiped off the brushes. This should be repeated until the trouble is entirely eliminated and the commutator shows a tendency to take on a smooth surface. No heat run should be started if the commutator tends to become gummy, as satisfactory commutation cannot be maintained for any length of time.

During the heat run all conditions should remain normal and the line current, voltage and speed be held as specified on the testing instructions. Amperes and volts field should be read. Readings of all instruments and thermometers should be taken and recorded every half hour. Commutation should be noted and recorded at every reading during the run. The amperes field should increase slightly during the run and the volts field should increase an amount corresponding to the higher temperature of the field coils. When the machine reaches constant temperature, as shown by thermometers, it should be shut down and final temperatures taken of all parts and the hot resistances of the various circuits carefully measured. The rise of temperature by the rise in resistance should be calculated by the formula given on page 112.

OVERLOAD HEAT RUN

All overload heat runs require considerable attention. The machine should first be brought to normal load temperatures before the overload is applied. The overload should be carried only for the specified time, since in many cases the temperature rises rapidly throughout the whole period of the run; hence lengthening or shortening this period a few minutes may cause several degrees difference in the final temperatures obtained. As a general rule, readings of all instruments and thermometers should be taken every fifteen minutes. If the voltage should fall below the rated full load value with normal field, it should be raised to and kept at the rated amount during the run. The amperes and volts field will increase during the duration of the overload.

MISCELLANEOUS TESTS

High Potential Test

After the necessary heat runs and while the machine is still warm the wiring should be removed and the high potential test applied.

Compounding Curve

After the heat runs have been taken and final temperatures recorded, a hot compounding curve should be taken. The hot compounding test is similar to the cold compounding test described on page 138, except that the compounding must be adjusted very close to the value specified on the testing instructions. When this has been done a complete curve should be obtained with readings taken in the following order: No load, full load, ¾ load, ½ load, ¼ load, no-load, and 125 per cent load. The field rheostat must not be moved from the position for the no-load setting. A curve should be drawn with load as abscissae and volts armature as ordinates.

Rheostat Data

After the heat runs, rheostat data should be taken in the same manner as saturation, with the exception that the brushes are placed at the running position instead of the neutral point.

On machines which do not require heat runs, only two points need be taken on the curve, namely, at full voltage and half voltage.

Shunt Regulation

Shunt regulation should be taken on shunt wound generators when requested by the Engineers. A reading should be taken first at no-load normal voltage. Without changing the rheostat, ¼ load should be thrown on and a reading taken of amperes armature, volts armature, amperes field and volts field. Holding ¼ load, the voltage should be brought up to normal and the same readings taken. The load should now be increased to ½ full load, with the rheostat in the same position, similar readings being repeated. This test is repeated for ¾ and full load. With full load on the machine the voltage should then be brought up to normal. With the field rheostat in this position the load is then taken off the machine and the rise in voltage observed. All these entries should be made on the Record Sheet. A curve should be plotted with amperes armature as abscissæ and volts as ordinates. See Fig. 68 and Calculation Sheet 28.

If the voltage should drop to zero when ¼ load is put on the machine, the load should be applied in smaller increments. Speed should always be kept constant throughout the test.

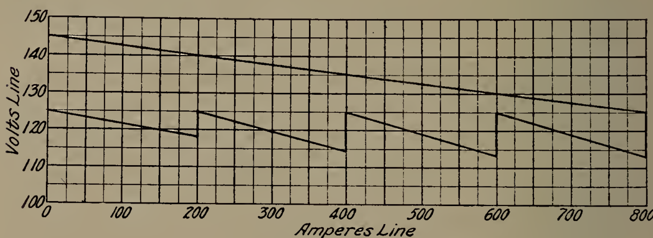

Fig. 68

SHUNT REGULATION CURVE ON A 6-POLE, 100 KW., 600 R.P.M., 125 VOLT GENERATOR

Running Light

Running light readings should be taken before the machine is stripped out. This test is described in Chapter 6, page 122.

Field Compounding

Field compounding is taken when called for by the Engineers. From its results is obtained the additional ampere turns field necessary to overcome armature reaction and IR drop in the machine from no-load to full load. The test is made by separately exciting the field of the machine under test, in order to hold the voltage at its terminals constant as the load is increased from no load to full load. Readings of amperes field, volts field, amperes armature, volts armature and speed are taken at no load and at least three intermediate points between no load and rated load. It is generally required, and usually advisable, to take an observation at 25 per cent overload, if the power is available. All readings should be made with a rising field current. Fig. 69 shows a curve of field compounding in which is plotted amperes field or ampere-turns field as ordinates, and amperes armature as abscissæ. See also Calculation Sheet No. 5.

Stud Potential Curve

This test is sometimes taken on machines equipped with multiple wound armatures which are not furnished with equalizer rings and is obtained as follows:

All the brushes except those on two adjacent studs are raised from the commutator, the voltage is then raised to normal and the field current noted. This field current and the speed must be held constant for all other points on the curve. The brushes on stud No. 3 should now be lowered, those on No. 1 raised and the voltage read between studs No. 2 and No. 3. This should be continued until voltage readings have been taken between each pair of studs. The test should be

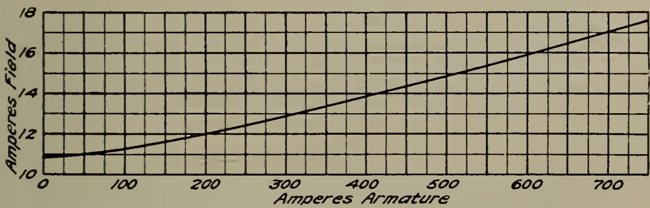

Fig. 69

FIELD COMPOUNDING CURVE ON A 150 KW., 250 VOLT, 225 R.P.M. 6 POLE D-C. GENERATOR (6 BAR BRUSH SHIFT)

made with the field current rising. The maximum voltage variation permissible is 4 per cent of the average value. This test, although similar in name, should not be confused with the bar to bar potential curve taken to determine the wave form of a d-c. machine and described in Chapter 6.

SPECIAL TESTS consist of saturation and core loss, shunt adjustment, compounding and commutation tests. These have all been previously described.

INPUT-OUTPUT TEST, OVER-SPEED TEST, and **WAVE FORM** have been described in Chapter 6.

COMPLETE TEST consists of normal and overload heat runs, saturation and core loss, compounding and commutation tests.

STANDARD EFFICIENCY TEST is made by the method of losses. Page 430 and Calculation Sheet 11 give the method for calculating the efficiency of a d-c. generator. See Fig. 70.

THREE-WIRE GENERATORS

Some direct current generators are provided with collector rings for operation on Edison three-wire circuits. The series field is usually divided and one-half placed on each side of the

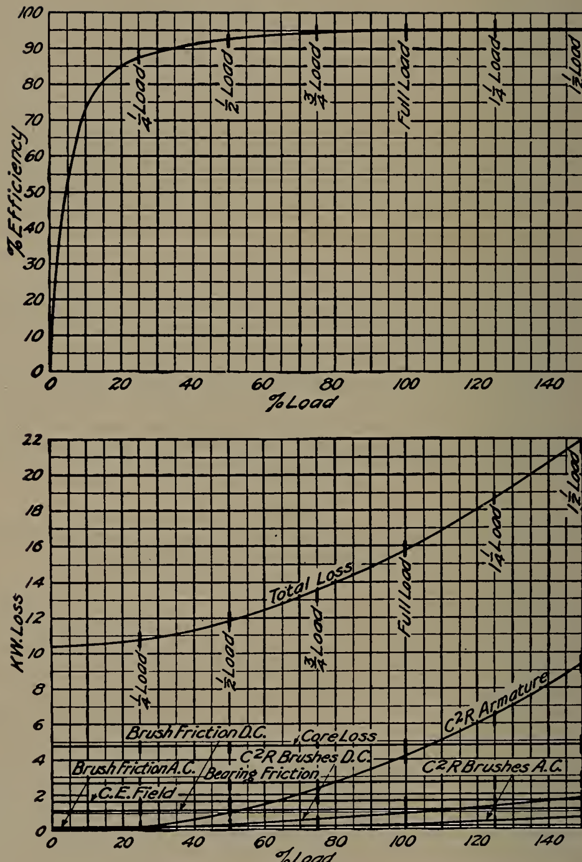

Fig. 70

EFFICIENCY AND LOSSES ON A 100 KW., 6 POLE, 275 R.P.M. 525/575 VOLTS, COMPOUND WOUND D-C. GENERATOR armature, as shown in Fig. 71. Tests are made as on other d-c. generators with the following additional special points:

In compounding a machine, care should be taken to have the shunts in each half of the series field of approximately the same size, and when the correct compounding has been obtained "shunt balance readings" should be taken as follows:

Remove the shunt from one side of the series field and take readings at no load and full load. Replace this shunt and repeat the readings for the other half of the series field. The line voltage obtained on these two readings should check.

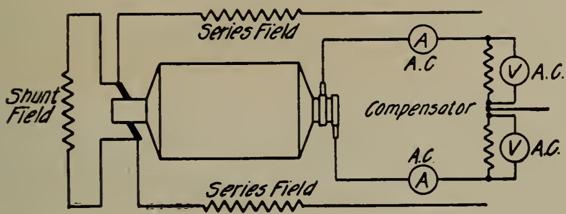

Fig. 71

THREE-WIRE GENERATOR

Unbalanced Readings

If unbalanced readings are required, a compensator should be wired as in Fig. 71. A reading should be taken at no load normal voltage. With no change in the field and holding constant speed, ¼ load should then be thrown on one side of the line and the voltage read from the neutral to each side of the line. Volts and amperes line, volts and amperes field should also be read. One-quarter load should then be put on the other side of the line, giving a balanced load, readings being taken as before. The load should then be increased to ½ load on one side, this procedure being continued until 125 per cent balanced load is obtained and readings taken at each step. Instructions sometimes call for 50 per cent unbalancing, in which case the load is increased 50 per cent at each step instead of 25 per cent.

Revolving Compensator

One type of three-wire generator has its compensator mounted directly on the shaft at the back of the armature and is equipped with only one slip ring.

COMMUTATING POLE GENERATORS

General Notes

The general instructions covering mechanical inspection, measurement of air gaps, drop on spools, etc., applying to all other generators must be followed in testing machines with commutating poles. The function of the commutating pole is to improve commutation and in testing, commutation is, therefore, important. The pole spacing should check within $\frac{3}{32}$ in. as specified on page 82.

The commutating poles produce the necessary flux for neutralizing the effect of armature reaction. This flux prevents the shifting of the neutral point between no load and full load which occurs in d-c. machines not equipped with them. In addition it aids the current reversal in the armature coils at commutation. To obtain the proper reversal without sparking at normal current requires a definite number of ampere turns in the commutating field. The brushes are placed on the mechanical neutral, and if the machine is properly compensated the mechanical neutral will check with the electrical neutral.

Baking Commutators

Commutators of commutating pole machines are baked according to the method on page 144. The brushes must never be shifted under load, so as to produce sparking and heating. They must always be shifted at no-load to insure their not being set beyond the safe limit of no-load commutation, thus rendering it possible for the machine to flash over if the load is suddenly removed. In all cases, the Head of Section or his assistant must be consulted before the brushes on any commutating pole machine are shifted far from the neutral. It must also be remembered that the armature must not be short-circuited through the commutating pole winding when baking a commutator, as in this case the majority of machines will build up as series generators, and the armature current cannot be controlled.

Locating the Neutral

Referring to Fig. 72, one armature coil contained in a pair of slots in the armature core and the corresponding commutator segments are marked for the convenience of the Testing Department. The coils are marked with red paint, and the ends of the corresponding commutator bars are stamped with the letter "O." In a machine with full pitch winding the two red marked armature conductors (A) forming a coil will come one pole arc apart, and in setting the brushes these conductors should be placed directly under the centers of the commutating poles as shown, and the brushes shifted until the center of the brush rests on the center line of the commutator segment corresponding. On a fractional pitch winding the two red conductors will not span a full pole arc, and hence they should be so located that they are equi-distant from the center of their respective poles as shown by the dotted lines B-B, and the brushes set as above. If there is more than one coil per slot, there will be a corresponding number of commutator segments stamped O-O, but the middle one should be used. After the brushes are set the usual tests for building up, saturation, etc., may be continued.

Shunt Adjustment

It is the aim of the Engineers to design the commutating field so that it will operate without a shunt; however, it is sometimes necessary to shunt out some of the current to obtain the proper compensation for satisfactory commutation. A thorough trial should be made, however, with full commutating field. In adjusting for commutation, a compound wound machine may be

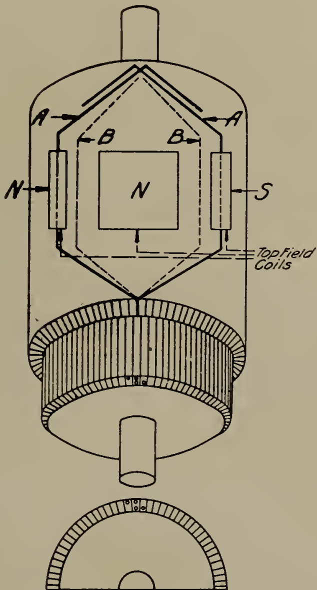

Fig. 72

DIAGRAM SHOWING MARKING OF ARMATURE AND COMMUTATOR FOR LOCATING MECHANICAL NEUTRAL

run with full series field. If the commutation is not satisfactory at full commutating field about ten per cent of full load current should be shunted. If the commutation is improved more current should be shunted until sparkless commutation (No. 1, see Fig. 62) is obtained at all loads up to fifty per cent overload unless otherwise specified.

If the commutation is not improved by shunting current the Head of Section should be notified. Sometimes a slightly better effect is obtained by shifting the brushes forward or backward from the neutral point. This, however, should only be done after all other adjustments have failed, and permission has been obtained from the Head of Section.

If none of these methods gives satisfactory results the trouble may be due to a weak field. This can be ascertained by separately exciting the commutating field and sending a larger current through it than would otherwise be obtained with normal load on the machine. If such procedure improves the commutation the fact must be referred to the Engineers to have changes made.

The iron grid shunts used on the larger machines should be placed so that the edges of the grids are in a vertical position and as near as possible to the position they are to occupy when in actual operation. Care should be taken to see that they contain ample current carrying capacity and do not heat up. If they are allowed to heat excessively the amount of current shunted changes, and thus destroys the commutation of the machine.

When the final brush position has been determined it should be marked with a chisel. On the larger machines a trammel should be made by the shop to assist the customer to assemble the brushes in a correct position. This trammel consists of a steel bar pointed on the ends and of the correct length to mark the distance from two points in the magnet frame to the point on the commutator on which the brushes on one stud should be placed.

After the proper adjustment has been obtained an ammeter should be wired in and the amount of current shunted carefully measured.

Inductive Shunt

Any condition which would suddenly under-excite the commutating field or make it inactive would make the machine sensitive and cause bad sparking at the brushes. If the commutating field is equipped with a grid or German Silver shunt and the machine becomes short-circuited, the inductance of the commutating field forces the instantaneous heavy overload current through the non-inductive shunt and leaves the commutating field without sufficient excitation to neutralize the armature reaction. The electrical neutral immediately shifts and bad commutation results.

To eliminate this trouble an inductive shunt is sometimes used across the terminals of the commutating field in series with the non-inductive shunt. This shunt will be used only when called for by the Engineers, but when so specified it should be in circuit while the commutating field is being adjusted for commutation. The inductive shunt is of low resistance, and is designed to have an inductance greater than the commutating field.

If the machine has an inductive shunt and flashing or violent sparking is produced by throwing a heavy load on and off quickly, try adjusting the air gap of the inductive shunt. With a given winding on the core, the inductance of the shunt may be varied by changing the air gap and the relative inductance of the shunt and commutating winding be thus altered. If the current read on the meter in the shunted circuit quickly falls to zero when a heavy load is thrown off by tripping a breaker, and the brushes show sparking, there is too little inductance in the shunt and its air gap should be decreased. The air gap should be adjusted so as to give minimum sparking when the machine is operating with a highly fluctuating load.

Motor Operation

Some machines are required to run as motors as well as generators. When such operation is specified they are equipped with a switch for reversing the series field, so that they may run as accumulative compound wound motors. Such machines should be tried under load as motors and have shunts adjusted as specified above. If possible the same shunt should be used for motor operation as was obtained when the machine was operating as a generator. In no case should a machine be passed for both motor and generator operation unless it will operate satisfactorily under both conditions without changing the brush position.

Compounding, Etc.

After satisfactory commutation has been obtained the machine should be compounded and other tests taken as described for generators without commutating poles.

THREE-WIRE COMMUTATING POLE GENERATORS

Commutating pole machines equipped for three-wire operation should be adjusted similarly to the above. Care must be taken to see that the shunts on each half of the commutating field are approximately equal.

EXCITERS

Exciters are tested in the same manner as other direct current generators, as previously explained. All 125 volt exciters must give at least 175 volts with full shunt field at no load. Most 125 volt compound wound exciters are compounded at both the rated voltage and at 80 volts. On small exciters the brushes are usually shifted ahead of the neutral point to obtain the compound at 125 volts and a shunt placed across the series field for the 80 volt condition. The latter is only an approximate setting and no attempt is made to get extremely accurate results.

Stability Test

Direct connected exciters should be given a Stability Test. With rated no-load voltage on the alternators, raise and lower the speed 2 per cent above and below normal, noting and recording the voltage change in each case. The change in voltage should not exceed 6 per cent of normal no-load voltage in either case. The no-load voltage setting should always be made with a rising field.

THREE-WIRE BALANCER SETS

In the operation of three-wire circuits the load often tends to become heavier on one side than the other with a consequent unbalancing of the voltage. To obviate this, small motor-generator sets called "balancer sets" are used.

In its most common form the balancer set consists of two similar machines on one shaft or with their shafts coupled together and their armatures connected in series across the outside mains. Each machine is wound for one-half the voltage between the outside mains, and their combined rating in amperes is made equal to the probable difference in load between the two sides of the system. This unbalanced load is carried by the neutral wire taken from the balancer at the point where the two armatures are connected.

When the load on the system is balanced, the two machines run as motors in series across the outside lines, no work is done, and the only current used is that necessary to overcome the losses of the machines running free. As soon as one side of the system becomes more heavily loaded than the other, the drop in voltage on this side will be the greater and the voltage impressed on the machine on this side reduced. The other machine, having the higher voltage, will tend to run faster than the first and drive it as a generator. The machine operating as a motor will act as a load on its side of the system, lowering the voltage on that side, while the generator will supply current to and raise the voltage on the heavily loaded side. The combined current of the two machines equals the unbalanced load of the system and the total effect is to restore the voltage balance of the system. As the unbalanced load on the system may shift from one side to the other, this action of the balancer must also shift. Either machine may at any instant be operating as a motor and the next instant as a generator. As the direction of rotation is always the same it is impossible to tell, without knowing how the load is balanced, which is the motor and which the generator.

Balancer sets are adjusted by loading one side at a time with the required current in the neutral wire.

Fig. 73 shows the connections for a compound wound, commutating pole balancer set connected for loading in the Testing Department. These sets may be shunt wound, shunt wound with commutating poles, or compound wound with commutating poles.

Balancer sets should receive the same preliminary inspection and tests as d-c. generators and motors, and after being wired according to the correct diagram, should be adjusted for commutation, field balance, speed and compounding.

Commercial and Adjustment test consists of balancing tests and the operation of the set to demonstrate that it is a duplicate electrically of machines of the same type already shipped and that it is free from manufacturing defects.

Balancing tests consist of adjusting both machines of the set so that the voltage across each machine shall always be balanced within 2 per cent. The sum of the two voltages will be equal to the applied voltage. The wiring on balancer sets must be done as carefully as that for motors as either end of the set may be operating at any time as a motor. The same precautions, therefore, must be exercised as when operating a motor.

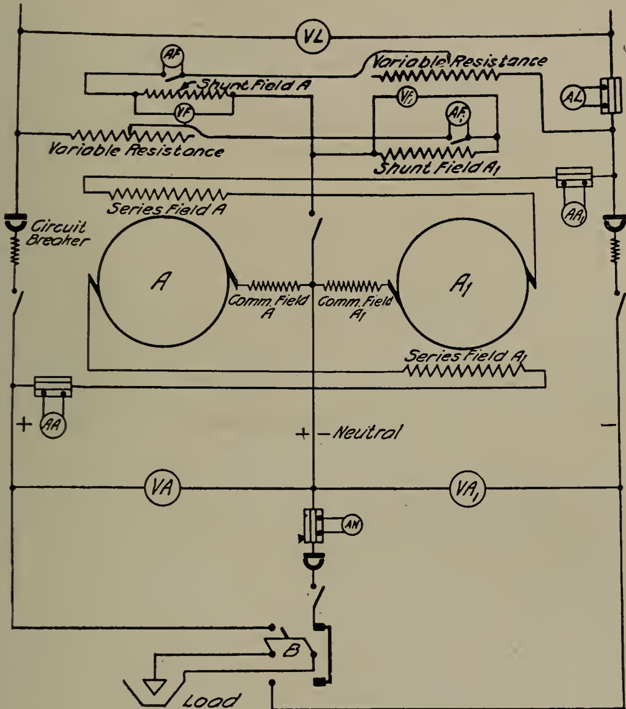

Fig. 73

WIRING DIAGRAM FOR TESTING BALANCER SET

VL = Impressed volts line
VA, VA$_1$ = Volts machine A and A_1
VF, VF$_1$ = Volts shunt field A and A_1
AL = Amperes line
AA, AA$_1$ = Amperes armature A and A_1
AF, AF$_1$ = Amperes shunt field A and A_1
AN = Amperes neutral

Shunt Wound Sets

On shunt wound sets the fields are cross connected and should be adjusted and the brushes shifted to such a position that the proper voltage balance is obtained. One side of the set is loaded at a time as shown in the figure. Satisfactory commutation and speed must also be obtained, and when such condition has been established with one side running as a generator, the set should be reversed and the other side adjusted to correspond. When both sides have been properly adjusted the set should operate with either end running as a motor.

Shunt Wound Sets with Commutating Poles

If the set is equipped with commutating poles, it should be adjusted with the brushes placed on the mechanical neutral as on other commutating pole machines. After good commutation has been obtained (by adjusting a shunt in the commutating field, if necessary), the proper voltage balance should be obtained. It should not be necessary to shift the brushes from the mechanical neutral, but if a balanced condition cannot otherwise be obtained the Head of Section should be notified immediately.

Compound Wound Sets with Commutating Poles

On these sets, the commutating field should be adjusted for commutation and the shunt and series fields adjusted for the proper voltage balance, after satisfactory commutation has been obtained. It should be noted that on a compound wound balancer set the machine operating as a motor runs as a differentially wound machine while the other acts as an accumulative compound wound generator. Therefore, care should be taken in adjustment as the set may have enough series field to cause it to speed up to a dangerous point.

HEAT RUNS, ETC.

After the set has been adjusted the heat runs should be taken by loading one side for the specified time with the required current flowing through the neutral wire. All readings of voltage and current should be carefully checked to see that they are consistent.

Saturation may be taken by operating each machine as an individual generator.

Core loss may be taken on a set with three or more bearings by the method of belted core loss previously described, the belt being run over the coupling between the machines.

On two bearing sets the core loss is obtained by a series of "running light" readings on each machine as follows:

With one end operating as a shunt motor read the input with no voltage on the other (a) with brushes down, (b) with brushes up; then (c) with normal voltage on the generator end with brushes down. These readings should then be repeated with the set reversed. From these the core loss of the set may be calculated.

SPECIAL TESTS consist of saturation, core loss, input-output, commutation and field balancing tests.

INPUT-OUTPUT TEST consists of taking careful measurement of the input and output of the set when connected as during the heat runs.

COMPLETE TEST consists of field balance and adjustment, normal and overload heat runs, core loss or input-output, and commutation tests.

CHAPTER 8

DIRECT CURRENT MOTORS

The tests on direct current motors may be divided in the same manner as for generators.

Preliminary Tests are practically the same as those taken on d-c. generators and the instructions included in Chapter 7 should be carefully followed.

When the machine has been wired according to the correct print, the wiring should be checked by the Head of Section, or his assistant, and it is absolutely necessary that the machine should operate in the proper direction of rotation when so connected. Make provision for reading volts and amperes line, volts and amperes field and speed. Direct current motors may be loaded by the methods given in Chapter 7 or by belting to generators.

Starting

After setting the brushes on the mechanical neutral and observing instructions contained in Chapter 4, page 98, the machine may be started. *You must be absolutely certain that there is a full field on any motor before attempting to start it.* On starting, the speed of the machine must be carefully followed with a tachometer and the circuit breaker must immediately be opened if the speed rises above the prescribed limits.

With the starting rheostat, or water box in the "off" position the terminals of the rheostat or box must be attached across the open main switch AFTER the circuit breaker has been closed. The lower terminal should be attached first. The resistance across the main switch may then gradually be cut out, and if the speed of the motor is all right, should be entirely cut out and the main switch closed. If the motor tends to run above normal speed, the circuit breaker must be opened and the motor shut down. The connections should be carefully checked to see that the field is wired properly. It may be that the field has been connected directly across the main switch. If such is the case the field current will fall rapidly as the starting resistance is cut out and the motor will speed up. To test for incorrect connections in the field, observe the volts field during starting. These will drop if the field is incorrectly connected. Trouble may also be experienced due to reversed polarity, etc., which may be traced out as noted under d-c. generators.

MOTORS WITHOUT COMMUTATING POLES

Adjustment for Speed and Commutation

After the motor has been started it should be adjusted for commutation by shifting the brushes back of the mechanical neutral. This shift is necessary as the electrical neutral of a motor is shifted by the armature reaction in a direction opposite to the direction of rotation. When shifting brushes for commutation the speed of the motor must be carefully watched. With no-load normal voltage and full field a speed reading should be taken, the brushes being shifted so that when full load is on, the speed is not less than 7 per cent below nor more than 3 per cent above normal rated speed. With the machine hot the speed must not vary more than 5 per cent either way from the normal rated speed, consequently the full load speed with the machine cold must be within the limits as given above. The same precautions regarding brush fit and the condition of the commutator should be used as for d-c. generators.

All compound wound motors should be adjusted with full series field. If this cannot be done, the fact should be referred to the Head of Section. The speed must come within 4 per cent of the rated speed when the machine is hot. Differentially compound wound motors should be loaded with care since the series field may be strong enough to overcome the shunt field and cause the machine to speed up and run away. The no-load speed of accumulative compound wound motors should be carefully watched as it may be considerably higher than the rated speed. When the correct running position has been found it should be marked with a chisel and the number of bars shift from the neutral point recorded on the Testing Record.

Speed Regulation

Speed regulation may be defined as the ratio of the drop in speed from no load to full load divided by the full load speed. On a load run this regulation must not exceed 6 per cent.

Heating Tests

After the correct adjustment has been obtained the heating tests may be started. The general instructions in Chapters 4 and 7 should be followed carefully. Motors may be loaded by belting to generators, feeding back, or by the circulating current methods described in Chapter 7.

In using the method shown in Fig. 65, if the machines are motors, the same connections should be made and the machines thrown together. The voltage of the system must be held by the machine running as a generator. The only correct way of obtaining load is by changing the speed of the set, the brushes having previously been set in the running position. Usually the speed will have to be decreased and the difference between full load and no-load speed will be the normal drop in speed for the motors. Cases have occurred where the speed of the motor, due to armature reaction, increased during the load. In "feeding back," this fact is shown by the motor taking an overload at no-load speed in which case the speed of the loss supply must be increased.

In using the method shown in Fig. 66, if two shunt motors are being tested, one machine should be run at normal voltage, current, speed and with full field; the other should be run as a generator with a little higher current and slightly stronger field than it would have under normal condition. The fields of the generator may have to be connected in multiple. The motor should be started first from the electrical loss supply circuit and its brushes shifted for commutation and speed.

After exciting the field of the generator and adjusting the voltage between the machines to zero the circuit may be closed. The machines should then be loaded by increasing the field current of the generator. The brushes must always be shifted carefully while the machines are under load, for a slight change in shift will at once change the load. During the heat run the speed will rise and the field current will fall. After the heat run has been finished and all motor readings taken, the wiring should be changed and the motor readings taken on the machine which ran as a generator.

The circulating current method is used particularly in the testing of series or railway motors. In the latter case the machines are geared to the same shaft.

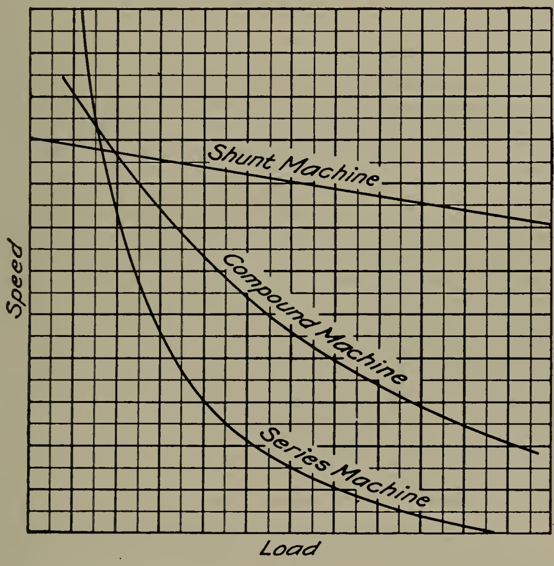

Fig. 74

SPEED CURVES D-C. MOTORS

Running Light

Running light test should be taken on all motors at hot full load speed. The armature current required for running light must not be over 5 per cent of the full load current.

SPECIAL TESTS consist of core loss, adjustment, commutation tests and speed curves.

If special tests are required a *hot speed curve* should be included. From no load to full load, and including several intermediate points, the speed should be carefully read, the voltage being held constant at all loads. A curve should then be plotted with speed as ordinates and amperes as abscissæ. No load and full load points of a cold speed curve should also be

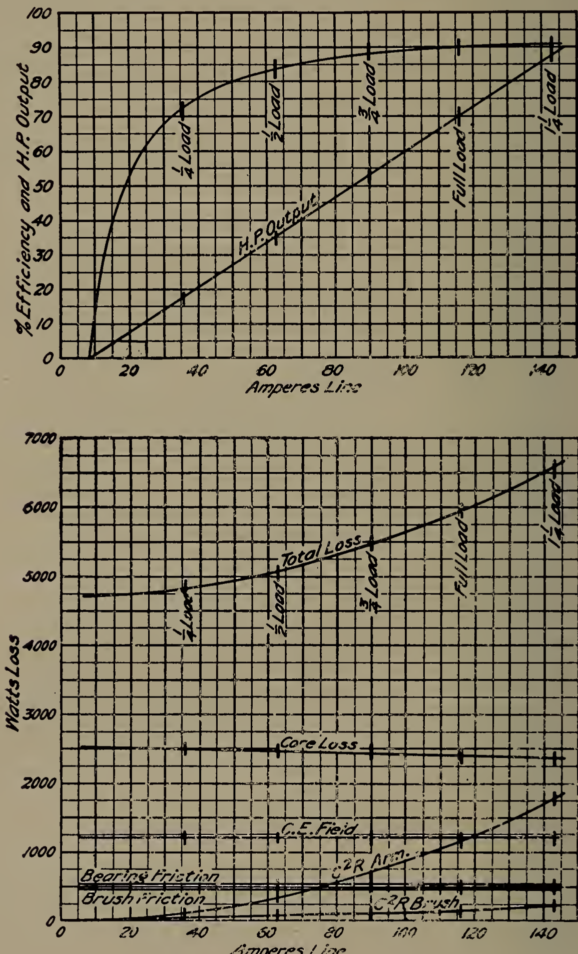

Fig. 75

EFFICIENCY AND LOSSES ON A 70 H.P., 6 POLE, 850 R.P.M., 500 VOLT D-C. MOTOR taken. See Fig. 74. Some motors with a considerable armature reaction give a speed curve which rises as the load increases. All cases of rising speed curve must be referred to the Head of Section.

COMPLETE TEST consists of normal and overload heat runs, saturation and core loss, speed curves and commutation tests.

INPUT-OUTPUT TEST and **OVER-SPEED TEST** are taken in a similar manner as for generators.

STANDARD EFFICIENCY TEST is made by the method of losses. Page 433 and Calculation Sheet 12 show the method used in calculating the efficiency of a d-c. motor. See Fig. 75.

COMMUTATING POLE MOTORS

Adjustment for Commutation

The brushes of commutating pole motors should be placed on the mechanical neutral as explained under d-c. generators. The electrical neutral at no load should then be located by running the machine in both directions of rotation with the same field current, shifting the brushes, if necessary, until the speed comes the same in each direction. The machine should then be loaded with full commutating field and the commutation and speed carefully noted for each direction of rotation. If the commutating field is of the proper strength, commutation should be No. 1 (see Fig. 62). The full load speed of commutating pole motors when hot must be within 5 per cent of the rated speed, and consequently the speed obtained on the above reading should not be less than 7 per cent below nor more than 3 per cent above the rated speed, allowing for a 2 per cent rise in speed when the machine heats up.

If the commutation is not satisfactory, or if the speed should increase from no load to full load, the commutating field should be shunted until black commutation and satisfactory speed is obtained. If with full commutating field the speed falls below the limit given above, the fact should be referred to the office, as no amount of shunting of the commutating field will bring the speed within the limit. With black commutation the motor should show a falling speed characteristic from no load to full load. If the speed rises more than one per cent within this range of load the fact should be referred to the Head of Section.

If satisfactory adjustment cannot be obtained by shunting the commutating field, it may be that the field is too weak. In this case it should be separately excited with a current higher than that which would normally be obtained. If satisfactory adjustment is obtained under these conditions the fact should be referred to the Engineers to have changes made.

After the correct adjustment has been obtained, the brush position should be chisel-marked and a cold speed curve taken. The speed and commutation in both directions of rotation up to the amount of overload specified in the testing instructions should be read and recorded. On DLC and RLC motors the brush-holder yoke should be securely doweled in position after tests are finished.

Some commutating pole motors show a tendency to "hunt" with full commutating field, but this can usually be eliminated by shunting the field. In all cases a notation should be made on the Testing Record regarding this point of stability.

After the final adjustment, an ammeter should be wired in and the amount of current shunted recorded on the testing record. The machine may then be given the heat runs called for and after these have been taken and while the machine is hot, a hot speed curve should be taken using the same range of load as in the cold speed curve.

Other tests are taken as previously described. Running light readings may be taken without disconnecting the series or commutating field, as the extra current required will be small.

Motor and Generator Operation

Quite frequently commutating pole machines are sent out as part of a motor-generator set, and required to operate as either a motor or generator. All such machines must have shunt adjustments made for both methods of operation while the machine is in test. Since the brushes are set on the no-load electrical neutral on almost all machines the same shift is proper for both motor and generator operation. The majority of machines, however, require a different adjustment of the commutating field shunt, for motor operation, to insure the proper speed characteristic. On the majority of commutating pole motors too strong a commutating field will cause the speed to increase as the load increases. This is never permissible. Current must be shunted from the commutating field till the speed at full load and overload is less than that at no-load, giving the motor speed a drooping characteristic.

If a drooping characteristic and good commutation cannot be obtained with the same adjustment, notify the Head of Section at once, so that the proper steps may be taken to correct the trouble. Inductive shunts are used on both motors and generators, and the adjustment of the shunt is obtained in the same way in each case. In adjusting the commutating field shunt of a motor, however, the speed must be carefully noted, as well as the commutation after any change in the shunt is made.

VARIABLE SPEED MOTORS

The variations in speed of variable speed motors may be obtained by either armature or field control.

Two methods of armature control may be used. The first consists in varying the resistance in the armature circuit and is used in work requiring no inherent regulation or constant load. The economy and inherent regulation by this method of control is poor.

The second method of armature control consists in varying the voltage impressed on the motor armature only, the field remaining constant at its full value. The efficiency and regulation obtained by this method of control is good.

In the method of field control the brushes are set to give the best commutation at both speed limits. The variations in speed are then obtained by varying the field.

Commutating pole variable speed motors must have the shunt in the commutating pole field adjusted for the highest rated speed. Speed curves and running light tests should be made at both speed limits.

Shunt wound variable speed motors should have the brushes set for commutation at the speed limits. Speed curves and running light tests should be made at both these speeds.

Some compound wound variable speed motors are not designed to run light, consequently before starting, the smallest load the motor is designed to carry should be ascertained. The Engineering Notice usually specifies the load at which the motor should start. Commutation should be adjusted at the speed limits and the speed carefully recorded. Speed curves should be taken at the speed limits. Running light should be taken at the various speeds.

DIRECT CURRENT SERIES AND RAILWAY MOTORS

The principal type of series motor is the railway motor. Other types, however, are built for use with hoists, air compressors, pumps, etc. As all these motors are designed for intermittent service, the test, unless otherwise specified in the Engineering Notice, is of one hour's duration at full load, the brushes being on the neutral point. The load must *never* be taken off a series motor unless the armature circuit is first opened, otherwise the motor will run away. For the same reason a series motor should always be started under load. All running light tests must, therefore, be made with the field separately excited.

The speed of railway motors and other series motors when hot should never vary more than 3 per cent from the normal rating.

As the tests on railway motors are very complete and their general method applies to any series motor, the tests on railway motors will be discussed more or less in detail. Hot and cold resistances must be taken on all railway motors. The cold resistances, when corrected to 25 deg. cent., must not vary more than 5 per cent from the standard resistance.

High potential must always be applied while the motor is cold and hot. There are Standing Instructions specifying the degree of high potential to be applied to all parts of the different types of motors.

GENERAL TESTS consist of sufficient preliminary tests to warrant Engineering approval for production. It is impossible to define, definitely, the heading, since the tests may include only a few minor tests, or they may include Complete and Special Tests. For instance, it may be necessary to make slight changes, either in the construction or design of a standard motor in order that it may meet special requirements due to peculiar operating conditions, etc. After these changes have been made, tests are conducted to insure the motor meeting such conditions satisfactorily. These tests are included under the general tests. If, after completion, they are found to be satisfactory, Engineering approval is given for the production of the machine in question.

COMPLETE TESTS consist of special tests, thermal characteristics, commutation and input-output. With the exception of commutation, the other tests under this heading will be considered separately.

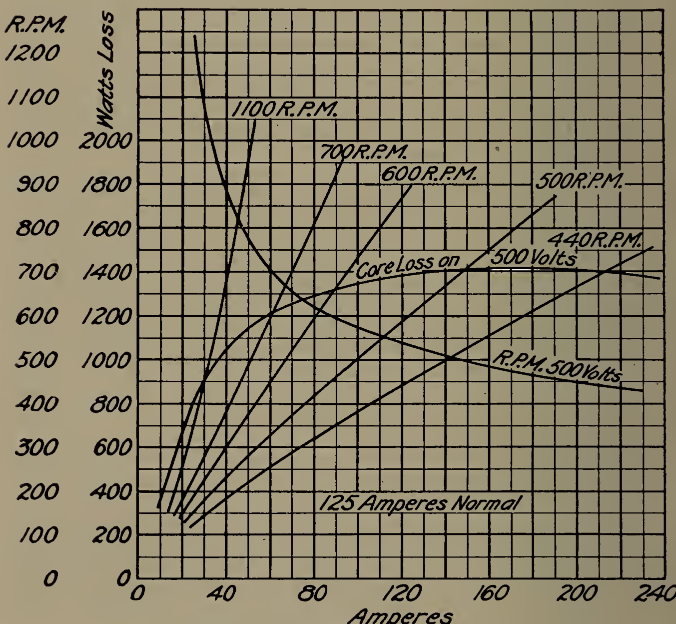

Fig. 76

CORE LOSS AND SPEED CURVE OF A 50 H.P., 500 VOLT RAILWAY MOTOR

Commutating tests on series railway motors should be made by holding normal voltage and operating the machine at loads varying from 33⅓ per cent to 200 per cent normal load.

On series commutating pole motors, Interruption Tests are taken. These consist in opening and closing the motor circuit while the machine is running at various loads and speeds. The machine should stand such tests without arcing over at a line voltage as high as 125 per cent normal. The loads are varied from 33⅓ per cent to 200 per cent normal. Mill motors are tested for commutation by suddenly reversing the direction of rotation under various loads.

DEVELOPMENT TESTS consist of General Tests and Special Tests, and are made when an entirely new type of machine is being developed.

SPECIAL TESTS consist of speed curves, core loss, and saturation tests.

In taking a *speed curve* two similar motors are mounted on a testing stand, the pinion of each meshing in the same gear on a shaft. One motor drives the other as a separately excited generator and is run loaded until the motor is heated to about 50 deg. cent. rise. The speed curve is then taken on the motor rotating in both directions, the voltage being held constant. The resistance of both armature and field should be measured both before and after taking the curve.

Core loss should be taken as on any other machine by the belted method, except that the test should be made at about five speeds. Fig. 76. The lowest speed should correspond to about 175 per cent full load amperes (taken from speed curves) and the highest at about 200 per cent full load speed. During this test the machine is separately excited.

A *saturation curve* may be taken as on any other machine by separately exciting the field. Saturation curves at different speeds may be obtained from data taken during the core loss test.

The speed curves, core losses and saturation are calculated as previously explained. The speed curves and core losses should be plotted on the same sheet against amperes line as abscissæ and rev. per min. and watts as ordinates. From these two sets of curves another can be developed, which will give the core loss of the motor at any speed or current.

The *Thermal Characteristic* should be obtained by making a series of heat runs at varying amperes, allowing sufficient time to get a temperature rise of 75 deg. cent. on any part except the commutator. Each run should be made at the same constant voltage, the current value for each run varying from 50 to 150 per cent normal. If a sufficient number of heat runs be taken on a sufficient number of motors of the same class, type and form, the horse-power rating for 75 deg. cent. rise may be obtained for any length of run from one-half hour to continuous running. Before starting a heat run, cold resistances and temperatures should be taken. After the motor has run continuously for the allotted time, amperes and volts having been held constant with all covers off, and all openings unrestricted, it is shut down, hot resistances measured, and all temperatures taken. The results of the thermal heat run should be plotted, one curve for armature and one for field, against time in hours as abscissæ and degrees cent. rise as ordinates. Through zero and the plotted points corresponding to the different loads, lines should be drawn. The intersections of these lines with the line of 75 deg. cent rise gives the time the motor takes to attain 75 degrees rise with the load corresponding to the plotted point through which the line was drawn. From these curves another curve should be plotted with time as abscissæ and amperes load as ordinates. This is an ampere time curve for 75 deg. cent. rise.

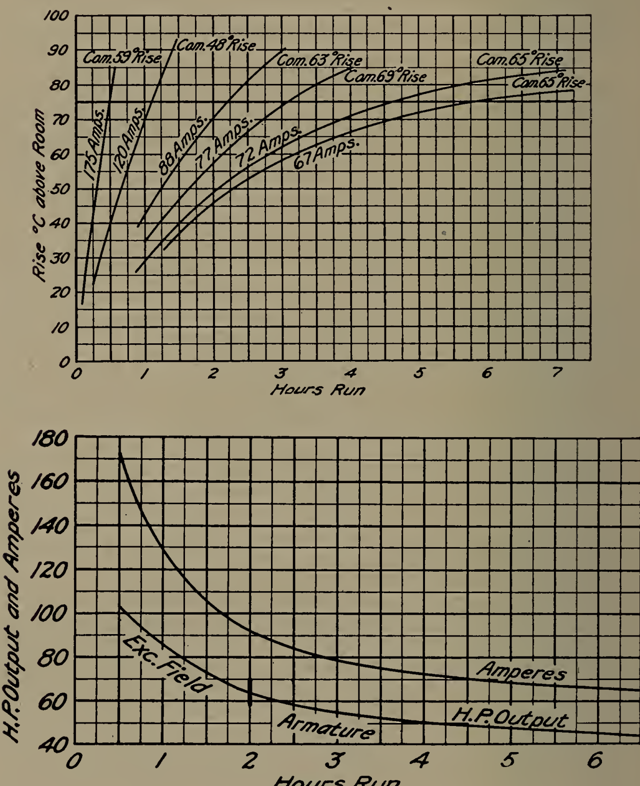

Fig. 77

THERMAL CHARACTERISTICS OF A 100 H.P., 600/1200 VOLT RAILWAY MOTOR

On the same sheet as the ampere time curve is plotted, a curve should be drawn with time as abscissæ and horse power as ordinates, the horse power being calculated from the standard 75 deg. cent. characteristics. See Fig. 77.

In loading railway motors, as in the Speed Curve, two motors are geared together on the same shaft (see Fig. 78), one running as a motor at the rated voltage and full load current and driving the other as a separately excited generator. The separately excited field of the generator is in series with the motor field, thus giving a normal full load excitation. The armature of the generator is connected to a water box, the resistance of which is varied until full load on the motor is obtained. The run is made for one hour, after which temperatures are taken.

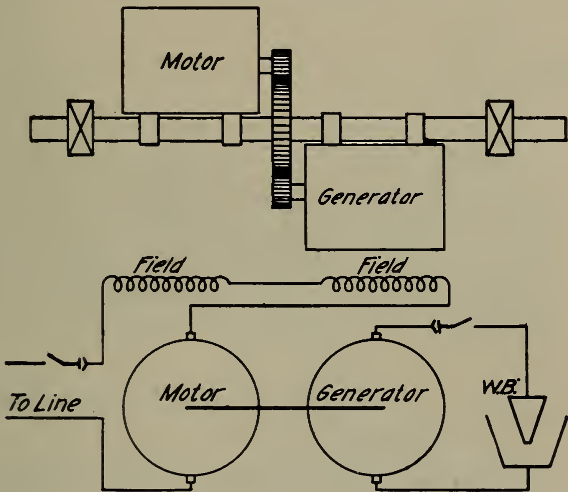

Fig. 78

CONNECTIONS FOR LOADING TWO RAILWAY MOTORS

Resistances are measured and high potential applied both before and after the test, and, before starting, the speed should be checked in both directions of rotation.

The circulating current method is often used in making this test.

One out of every fifty of all types of motors should receive the one hour load run. All 600 volt commutating pole motors, excepting those receiving the one hour load run, should be run under load for ten minutes in each direction of rotation. Other motors having their characteristics well established should receive commercial tests.

COMMERCIAL TESTS consist in running a motor light for a short period. It is the practice to run four motors in parallel, the fields being connected in series and separately excited by a current equal to full load current of the motor. (See Sketch of Connections in Fig. 79.)

With normal voltage held constant across the armatures, the motors are run light for five minutes in each direction of rotation, readings of speed, armature and field current being recorded.

With rated voltage across the motors, the fields should be weakened until about twice normal speed is attained. Under these conditions the machine should be run in each direction for five minutes, the same readings as above being recorded.

Resistance measurements cold only are taken. High potential tests must be made after this run.

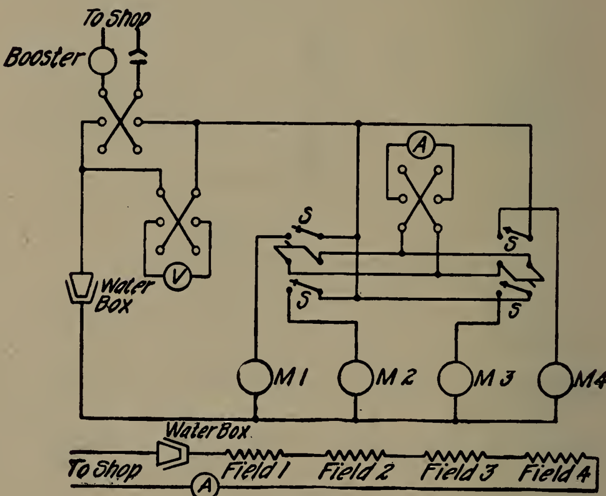

Fig. 79

CONNECTIONS FOR RUNNING LIGHT ON RAILWAY MOTORS

Care must be taken that the resistance at 25 degrees cent. and speed come within the prescribed limits already mentioned.

STANDARD EFFICIENCY TESTS on all series motors *with the exception of railway motors* are made by the method of losses and the calculation is identical with that of any other motor. In this case, of course, the amperes armature equals amperes line. See page 433.

In making an **INPUT-OUTPUT TEST** the motors are geared and connected as for the Load Heat Run and are usually run under full load for one hour up to ordinary working temperatures and to get the bearings in good running condition. Before the load is put on, a careful measurement of the armature and field resistances of the motor, and of the armature of the generator is taken by the drop in potential method. Three differen measurements of each should be made with as many different values of current, which should be near the normal load current.

Holding constant normal voltage, 12 or 15 different loads ranging from as low as possible to 150 per cent load should be put on, the direction of rotation being such that the motor tends to lift from its bearings. Readings at each load should be taken of the amperes, volts armature and speed of the motor and amperes and volts armature of the generator. The direction of rotation should then be changed and several check points taken in speed and amperes, after which the machine should be shut down and hot resistance measurements made.

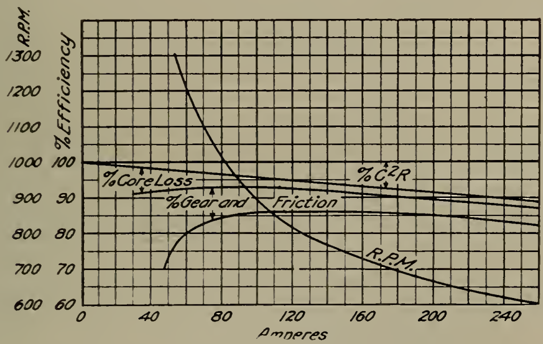

Fig. 80

INPUT-OUTPUT CURVES ON A 100 H.P., 600 VOLT, RAILWAY MOTOR

The Calculation Sheet 8 and Fig. 80 show the method of working and plotting the data obtained from the input-output test. Unless otherwise specified the tractive effort and miles per hour are calculated for 33 in. wheels. The formulæ used are:

$$\text{Miles per hour} = \frac{\text{R.p.m.} \times \text{diameter of wheels in inches} \times \pi}{\text{Gear ratio} \times 1056}$$

$$\text{Tractive effort} = \frac{\text{Amps.} \times \text{volts} \times \text{efficiency} \times 252}{\text{Miles per hour} \times 500}$$

The gear ratio is that between the gear and pinion.

From these characteristics new ones should be plotted, as shown in Fig. 81, the I^2R being corrected for 75 deg. cent. rise, and the gear loss assumed as 5 per cent at full load. If the gear loss from test has to be changed at full load, it should be changed in the same ratio throughout the curve. (See Calculation Sheet 9.)

COOLING OFF TESTS are made by running the motor under full load, with covers off, for one hour, shutting down and reading temperatures as the machine cools down. For the first hour after the machine is shut down, the following temperatures are read every fifteen minutes: the armature, commutator, field, frame, air in the motor, and room temperatures. After the first hour temperatures should be taken every half hour until the temperature of the hottest point is not more than 25 degrees cent. above the surrounding atmosphere.

The results of the cooling off test should be plotted to time as abscissæ and degrees centigrade rise as ordinates. The curves for armature, field, commutator, frame and air in the motor, should all be plotted on one curve sheet.

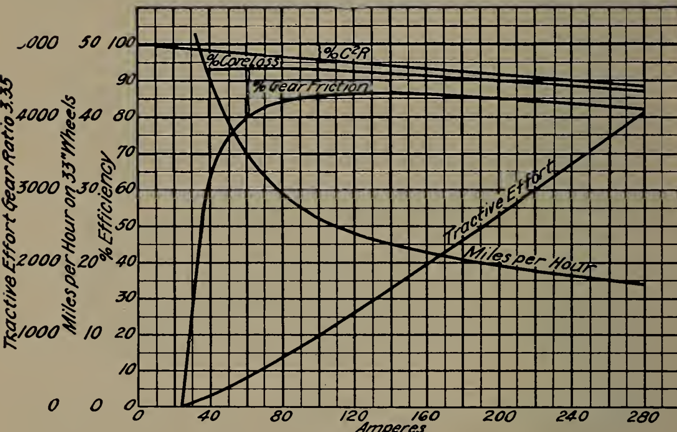

Fig. 81

SPEED, TRACTIVE EFFORT, EFFICIENCY ON A 100 H.P., 600 VOLT RAILWAY MOTOR

DYNAMOTORS

Dynamotors are used to supply current at one-half the line voltage of a system and consist of an armature having two distinct windings and commutators rotating inside a common magnetic circuit, having a shunt winding and also a series winding so connected that it is active only during the period of starting. The tests ordinarily taken consist of dynamic balance of the armature in a special frame, a one hour heat run at rated output and running light readings with normal connections (but with the ground connection removed) and also at reduced voltage with the series field only. After these tests are finished the dynamotor should be thrown directly on the line and starting characteristics and commutation noted.

Core loss when called for, should be taken by the method of motor core loss. Calculation Sheet 27 shows results of a motor core loss on this type of machine.

Input-output efficiency is calculated from the readings taken with the machine connected as for a heat run. Calculation Sheet 26 shows results of such test.

VENTILATION TESTS

Ventilation tests are sometimes taken on Railway Motors. The double pitot tube method is ordinarily used and the velocity and quantity of air delivered calculated using the weight of the standard air. In this case

$V = 4015\sqrt{h_3}$ at the center of the pipe.

$Q = 3654A\sqrt{h_3}$ using the average velocity as given in Chapter 16, page 313.

CHAPTER 9

ALTERNATING CURRENT GENERATORS

The tests on Alternating Current Generators may be divided as follows: Preliminary tests, commercial tests, heating tests, special tests, input-output tests, over-speed test, wave form, location of keyway, voltage regulation and static tests.

Preliminary Tests consist of drop on spools, resistance measurement, air gap and fitting of collector brushes. The precautions specified in Chapter 4 should be carefully followed.

COMMERCIAL TESTS consist of excitation and other readings at no load necessary to demonstrate that the machine is a duplicate of the same type already shipped and that it is free from manufacturing defects.

After the machine has been started a **saturation curve** should be taken as described in Chapter 6, page 120, the curve being taken up to full excitation voltage on the field. Care should be used to see that the voltages in the various phases are balanced.

Synchronous impedance may then be taken. The object of this test is to determine the field current necessary to produce a given armature current when the machine is running short-circuited. Since the regulation of the machine is calculated from the impedance and saturation curves, care should be taken that consistent results are obtained.

The armature should first be short-circuited; then with the machine running at normal speed and a weak field current, the current in each phase should be read. The field current should be increased gradually until 150 per cent normal armature current is reached, readings being taken simultaneously of amperes armature and field and volts field. *Care should be taken not to overheat the windings.*

Although the speed in this test should be held normal a small variation therefrom will not affect the curve, because in the formula, current $= \frac{\text{e.m.f.}}{\text{Impedance}} = \frac{E}{\sqrt{R^2 + L^2 W^2}}$ the term R^2 is small compared with $L^2 W^2$, and as E and W vary proportionally to the speed, the current remains practically constant.

In the calculation of synchronous impedance all readings should be corrected for the constants of instruments and ratios used and a curve plotted on the same sheet as the saturation curve, amperes or ampere turns field being plotted as abscissæ and amperes armature as ordinates. See Calculating Sheet 7 and Fig. 82.

Phase rotation should be taken after these tests are finished by using a "Phase Rotation Indicator" described in Chapter 2, page 25. See Fig. 12. The terminals of the machine under test whether three-phase or quarter-phase should be connected to the corresponding terminals of the indicator. The indicator should operate on the residual voltage of the alternator but if it will not, a small field current should be applied to the machine under test and the voltage should gradually be brought up to a small amount and the magnet of the meter should revolve in the same direction as the rotor of the machine under test when facing the head end. *Be careful not to burn out the indicator.* If it rotates in the opposite direction (a) for a quarter-phase machine, a phase is reversed; (b) for a three-phase machine, either a phase is reversed or the wrong leads have been brought out. The head end of a machine is the end at which the coil to coil

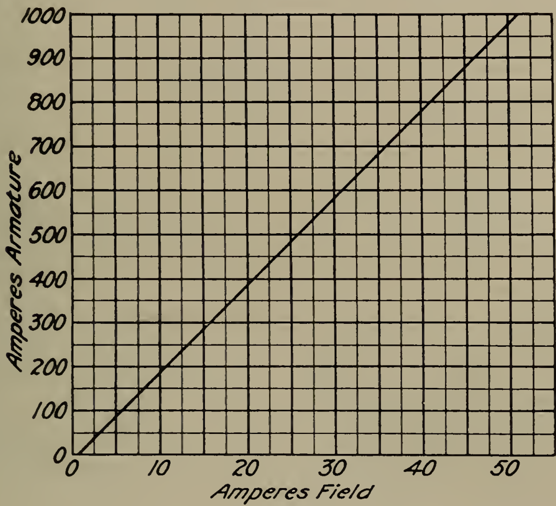

Fig. 82

SYNCHRONOUS IMPEDANCE CURVE ON A 500 KW., 600 VOLT 360 R.P.M., 3-PHASE, 60 CYCLE, A-C. GENERATOR

armature connections are made. Figs. 83 and 84 cover every type of standard connection block, and will assist in numbering the machine terminals for the phase rotation indicator. If the block is on the side of the machine facing the bearing, or on the outside of the frame proper and at right angles to the shaft, the numbers should read 1–2–3 in a clockwise direction. If the block is in any other position, as on the side facing the bearing with the numbers running radially, or on the frame proper with the numbering parallel to the shaft, the same sequence of numbers should exist, but the block has been given a quarter turn in a clockwise direction. In the case of revolving armatures the numbering is always from the inside ring toward the outer.

Magnetic leakage sometimes causes a small e.m.f. to be generated which causes an alternating current to flow through the frame of the machine to the shaft, resulting in the pitting and marring of the latter inside the bearing. A reading should be taken on all alternators of 200 kv-a. and above to ascertain

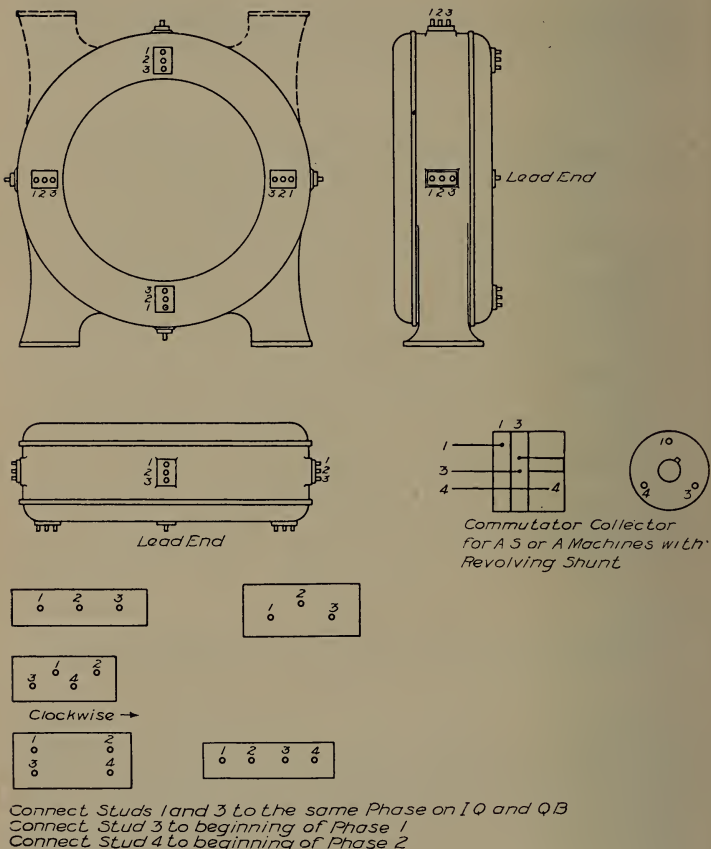

Fig. 83

CONNECTION BLOCKS

whether there is any appreciable current flow from this source. A high reading a-c. ammeter should be connected to low resistance leads, one of which is in contact with the revolving shaft, and the other securely fastened to the frame of the machine.

If an appreciable reading is obtained on the instrument, the fact should be reported as a defect to be remedied by insulating the bearing-standard from the base.

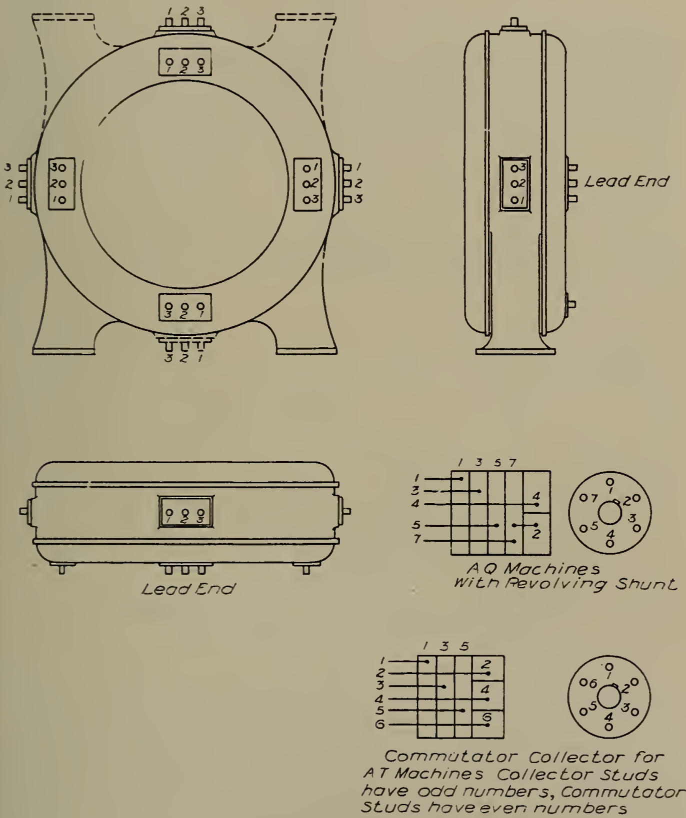

Fig. 84

CONNECTION BLOCKS

All machines rated 1000 kv-a. and above must be furnished with insulation under the bearing pedestal.

HEATING TESTS

Before starting these tests instructions in Chapter 4 regarding thermometers, etc., should be carefully followed. The heating tests on a-c. generators may be divided into two parts; actual load tests and equivalent load tests.

ACTUAL LOAD TESTS

Actual load tests may be taken by the water box method or feeding-back method.

The water box method is similar to that described for d-c. generators. Boxes must be used in each phase and care must be taken to keep the currents in the various phases balanced. The *boxes* in the different phases of a three-phase machine should be connected in "Y", and the leads from the generator under test should be run to the *blades*. Not more than 2300 volts should be applied to the standard water box. Machines requiring a higher voltage than this should have transformers placed in the line. In the various sections there are several water boxes good for more than 2300 volts and these should be used whenever possible, rather than transformers.

Fig. 85

GRAPHICAL DETERMINATION OF CURRENTS FOR A POWER-FACTOR HEAT RUN

Very often it is required to load an a-c. generator at a specified power-factor. In such case a synchronous motor should be connected across the terminals of the generator under test in multiple with the water boxes and should ordinarily be run light, having its field excited to give the required leading or lagging current in the armature circuit of the generator under test. If the latter machine is to be run at leading power-factor the field of the synchronous motor must be excited with a current above its normal excitation for unity power-factor. The machine under test is accordingly run below normal excitation. If a lagging power-factor is specified the conditions are reversed. Wattmeters must be used to determine the power-factor of the circuit. The amount of current to be held in the armature circuit of the synchronous motor floating on the line may be determined graphically as follows. Referring to Fig. 85:

Let AB = full load current of the generator under test (for a normal load heat run.)

Draw angle BAC = the angle whose cosine is the power-factor to be held.

Draw BC perpendicular to AC.

Lay off CD = minimum input current for the synchronous motor running light.

Then BD is the current to be held in the armature circuit of the synchronous motor and AD is the amount of current to be carried by the water boxes. Thus, by holding the synchronous motor current at BD (varying the field if necessary) and loading the generator under test on the water boxes until AD amperes are obtained the load of the specified power-factor is obtained and the heat run may be taken.

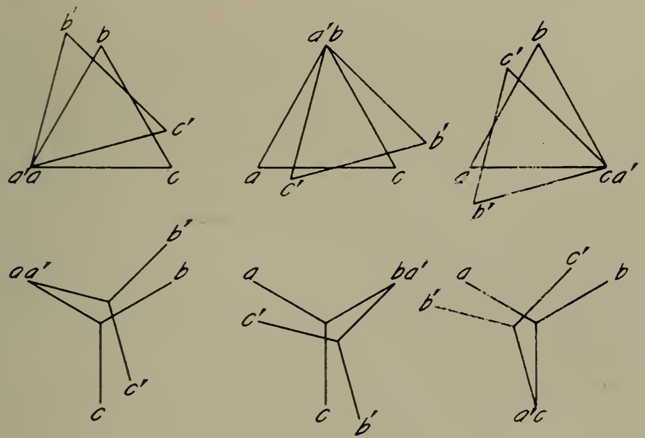

Fig. 86

SHIFTING OF PHASES SHOWN DIAGRAMMATICALLY

"Feeding Back" Method

Two similar alternators may be tested under actual load by direct connecting their shafts and supplying the losses mechanically. It is, however, necessary to shift the stators with respect to each other so that the machines will remain continually out of phase with each other. The vector difference of the voltages thus generated by the two machines will cause a current to flow which may be varied by changing the relative positions of the stators. For example, consider a three-phase machine the phases of which are shown diagrammatically in Fig. 86. The machines should be run at normal speed, with the fields separately excited to a value corresponding to the load at which it is desired to make the test. The value of this excitation should be calculated from the saturation and synchronous impedance curves. With points a and a' connected together the voltage across b and b' should be read, the circuit closed and the value of the current flowing observed. Knowing the voltage between phases a-b, a'-b', and between b and b', the angle of phase displacement may be readily obtained. Should the armature current be considerably greater or less than that desired a further trial will be necessary.

The current value will vary nearly as the angle of displacement so that an approximate value of the angle desired can be found from the value of current and angle previously ascertained. When the value of this angle has been ascertained, the phase displacement should be changed, so as to obtain it as closely as possible. With the machines still connected together as they were originally, the angle of phase displacement previously found will be increased 120 electrical degrees by connecting a' and b. If a' and c are connected, a still further displacement of 120 degrees is obtained. If with any of these connections, the field of one machine be reversed, a still further displacement of 180 degrees is made. With the connection which gives the nearest value of armature current to that required, a further adjustment may be made by shimming the stator of either or both machines up on one side and taking shims out on the other side. The circuits should then be closed and the heat run made for the specified time. Even with the angles of phase displacement possible with the various combinations of connections and field reversals it may not be practicable to get the desired armature current. In this case, unbolt the coupling and shift the rotor of one machine around one or more bolt holes. The "cut and try" operation should then be repeated.

Although thus "cut and try" method is not the best one to use it gives very satisfactory results, especially where it is necessary to make an actual full load test.

Two frequency changer sets consisting of a-c. generators and synchronous motors may also be given an actual load run by shifting the phases of the generators or motors with respect to each other. The losses in the sets should be supplied electrically from the synchronous motor end. The stators of the generators or motors are usually held in cradles, so that they may be rotated to run in phase with other machines, consequently it is necessary only to turn the frames in their cradles to obtain the proper shift. Each different load of course requires a definite relative position of the two stators. The fields should be excited with the field currents necessary for the test as found from the saturation and synchronous impedance curves. One set will operate direct and the other inverted.

If a run is required at a specified power-factor the generator of the set operating inverted should have its field excited at such a value that the specified power-factor is obtained on the generator of the set operating normally. Wattmeters should be used to determine the power-factor.

Equivalent Load Tests may be subdivided into "Open Circuit Heat Run," "Short Circuit Heat Run," "Open Delta Heat Run" and "Zero Power-Factor Heat Run."

The Open-Circuit Heat Run as its name implies consists in running the generator at no load and with a field current which gives a predetermined percentage over normal voltage. The run should be continued until the temperatures are constant and the machine then shut down and the final temperatures recorded. The resistance of the field should be measured carefully both before and after the run. Volts armature and speed should be held constant and readings taken of volts and amperes field.

The Short-Circuit Heat Run consists of running the machine until temperatures are constant with its armature terminals short-circuited through an ammeter and with sufficient excitation in the field to obtain a given percentage over normal current in the armature. Amperes armature and speed should be held constant and readings taken of amperes and volts field. Final temperatures should be recorded and the resistance of the armature both before and after the run carefully measured.

The **Open Delta Heat Run** is sometimes made on large three-phase alternators. The phases of the machine should be connected in delta, one side of which is left open. The machine should be run up to speed, the field excited and the voltage across the opening in the delta measured with a potential transformer and voltmeter. This voltage should be approximately zero. The armature should then be wired to a source of direct current sufficient to supply the amount necessary. One side of the open delta should be grounded to protect the armature of the direct current machine from static strain. The other armature terminals should be carefully insulated. Due to harmonics which may exist in the legs of the delta, an alternating cross-current may flow in the winding. This should be measured by an a-c. ammeter and current transformer (if necessary) inserted in the armature circuit. The amount of circulating direct current necessary is then found as follows:

Let I = normal rated current of machine under test.

V = normal rated voltage of machine under test.

then $I = \frac{\text{rated kv-a.}}{\sqrt{3}\ V}$

Let I_1 = amount of cross current found with field excited as specified above.

I_2 = amount of direct current required.

Then $I^2 = I_1^2 + I_2^2$

$I_2^2 = I^2 - I_1^2$

When this value has been determined the voltage of the machine supplying the circulating direct current should be increased until the desired current is obtained. The field of the alternator under test should then be excited to the value necessary to give normal no-load voltage, and the run continued until temperatures are constant. Careful record should be made of volts armature, volts and amperes field, direct- and alternating-current amperes armature, and speed.

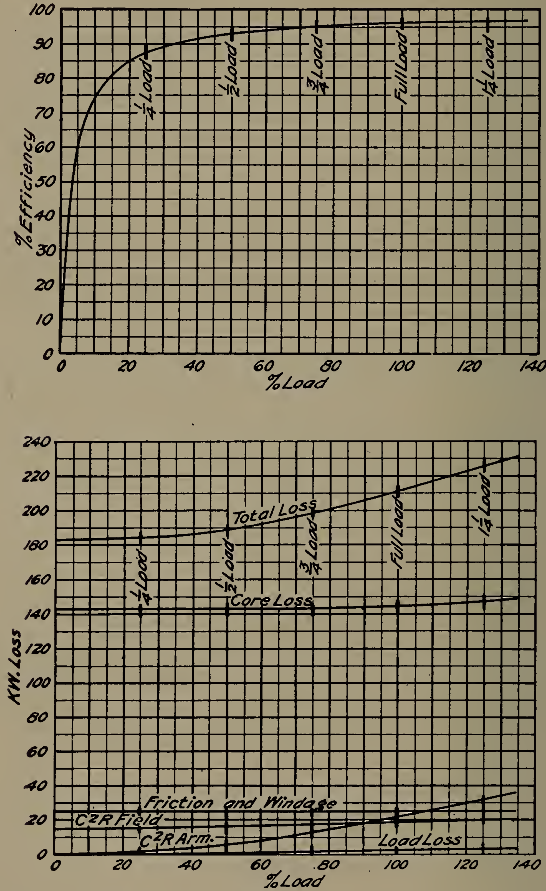

Fig. 87

EFFICIENCY AND LOSSES ON A 5000 KW., 11,000 VOLT, 257 R.P.M. 60 CYCLE, 3-PHASE A-C. GENERATOR

The **Zero Power-Factor Run** is another excellent method of making an equivalent load run and is often used where two machines of approximately the same rating are available. The generator under test is run as a synchronous motor with its field excited to give full load current. The field is usually over-excited, but there may be cases when under-excitation is specified or a test may be called for in which the field will be intermittently over- and under-excited. Readings should be recorded of amperes armature, volts armature, amperes and volts field and speed, and the run continued until all temperatures are constant. Final temperatures should then be taken and the resistances of both field and armature carefully measured.

SPECIAL TESTS consist of saturation, synchronous impedance, open- and short-circuit core loss and wave form. On turbine driven generators air readings will be taken to determine the pressure and amount of air circulating in the various parts of the machine.

INPUT-OUTPUT TEST, OVER-SPEED TEST and **WAVE FORM** have been described in Chapter 6.

COMPLETE TEST consists of special tests and heating tests.

STANDARD EFFICIENCY TEST is made by the method of losses. Page 437 and Calculation Sheet 14 and Fig. 87 show the method of calculating and plotting results.

LOCATION OF KEYWAY

It is often required that two machines whose revolving parts are on the same shaft, or are to be direct connected shall operate in series or multiple. In such case the generated voltages must be in phase with each other, and in order to make sure of this fact the key-ways of the machines must be definitely located with respect to each other. This is done by connecting the fields of the two machines in series and exciting them from the same source of power. The revolving parts are then adjusted and the keyways so located, that upon suddenly opening the field switch, no "kick" is obtained upon a voltmeter connected across any particular phase of either machine. This position can best be determined in the following way: Set the rotating part of the first machine with respect to the stationary part so that no "kick" is obtained on a voltmeter across any one phase when the field circuit is suddenly opened. Then set the other machine so that zero "kick" is obtained on that phase which is to be connected to the phase of the first machine on which zero "kick" was obtained. A definite marking should be made upon the machines so that the shop may cut the key-ways in such position that the relative position of the rotors will always remain the same.

VOLTAGE REGULATION

A test of the voltage regulation of alternating current generators is sometimes made, but more frequently is calculated from the saturation and synchronous impedance curves. In actually determining the regulation, the machine is subjected to normal load with normal voltage held on the armature. With the field excitation held constant, the load is suddenly thrown off and the armature voltage observed. The difference between this voltage and normal voltage divided by the normal voltage is the per cent voltage regulation. Very often, especially on large machines, it is found impossible to run the machine at actual load on account of limited facilities. In such cases it becomes necessary to calculate the voltage regulation from the saturation and synchronous impedance test. This is done as follows:

Let V = normal line voltage.
I = normal line amperes
R = hot resistance between lines.

$$I \text{ for three-phase machines} = \frac{\text{rated kv-a.}}{\sqrt{3}\,V}$$

$$I \text{ for two-phase machines} = \frac{\text{rated kv-a.}}{2V}$$

$v = \dfrac{\sqrt{3}\,IR}{2}$ = voltage drop in armature for three-phase machines.

$v = IR$ = voltage drop in armature for two-phase machines.

Let a_1 = amperes field on saturation curve corresponding to $(V+v)$.

a_2 = amperes field on synchronous impedance curve corresponding to I.

The amperes field required to produce normal rated voltage with full load on the generator will be $a_3 = \sqrt{a_1^2 + a_2^2}$.

Let V_1 = the voltage on the saturation curve corresponding to a_3.

$$\text{Then per cent regulation} = \frac{V_1 - V}{V}$$

If it is desired to calculate the regulation of the machine at a power-factor less than unity then I becomes $\dfrac{I}{\text{per cent power-factor}}$ and a_3 becomes $\sqrt{a_1^2 + a_2^2 - 2a_1a_2 \sin \theta}$ where θ = the angle whose cosine is the power-factor.

STATIC TESTS

Some perfectly standard a-c. generators are given what is known as "Static Test." The resistance and polarity of the field spools are measured and the stationary armature is connected to an alternator of the correct frequency and the voltage necessary to overcome the impedance of the winding is measured at several different current values up to 200 per cent normal. Care should be taken not to overheat the windings. For this test the machine is not assembled in bearings, but the field is placed inside the armature and the air gap measured, after which, the field is removed and the impedance test taken.

WAVE FORM

Wave form is taken with the oscillograph and ordinarily at no load. The Engineers may, however, specify a full load test. In this case the machine is usually "dead-loaded" to eliminate the effect of the wave form of other machines.

CHAPTER 10

SYNCHRONOUS MOTORS

The tests on synchronous motors may be divided as follows: Preliminary Tests; Commercial Tests; Heating Tests; Special Tests; Input-Output; Over-Speed; Wave Form; and Torque Tests.

Preliminary Tests consist of drop on spools, resistance measurement, air gap and fitting of collector brushes. The instructions in Chapter 4 should be carefully followed.

When a machine is run as a synchronous motor extreme care should be used in starting it to see that the field circuit is open and that the voltmeter switch is not closed. The special switch designed for this case must always be used. The field of the synchronous motor acts as the secondary of a transformer, and the voltage induced across the rings at starting may be enough to cause serious injury As the machine comes to synchronism this induced voltage falls to zero and the field switch may then be closed.

COMMERCIAL TESTS consist of excitation and other readings at no load necessary to demonstrate that the machine is a duplicate electrically of machines of the same type already shipped and that it is free from manufacturing defects.

Synchronous motors are ordinarily run as a-c. generators when commercial tests are taken.

HEATING TESTS

Heating Tests on synchronous motors as on other machines consist of actual load tests and equivalent load tests. In making an actual load test the machine is usually excited with a current to give minimum input on the armature as found from the phase characteristic curves which are taken as follows:

PHASE CHARACTERISTIC

The machine must be operated from some a-c. source of correct frequency and at constant voltage. A reading of amperes input on all phases should be taken with zero field on the motor, where possible. Starting with a weak field and reading volts and amperes armature and volts and amperes field, the field should be increased by small steps until the point of minimum input armature current is found. Increasing the field current beyond this point increases the amperes armature. On a no-load phase characteristic curve, the watts input at the lowest point should check very closely with the sum of the core loss, friction and windage losses, since the power-factor is unity on synchronous motors at this point and the amperes field must equal that found for normal voltage on the saturation curve. These points must be checked with each other to see that they agree. With a weak field the current is lagging and with a strong field it is leading. In taking a no-load phase characteristic the current should rise to a value of at least 50 per cent of full load alternating current.

A load phase characteristic should be taken in a similar manner to the no-load. The output is held constant and the amperes load recorded in addition to the readings noted above.

Care must be taken not to overheat the windings. It is impossible to obtain a zero field point during the full load characteristic, since the current would be so large as dangerously to heat the machine and the torque not sufficient to carry full load output.

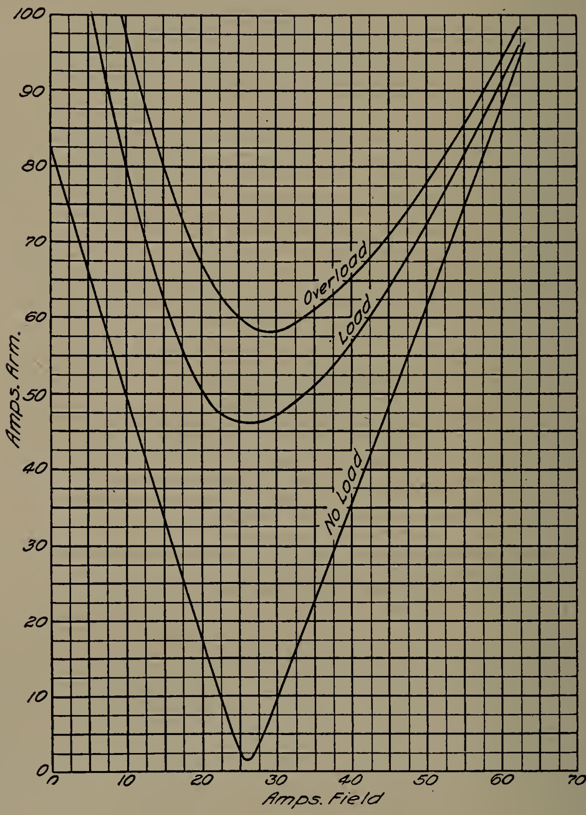

Fig. 88

PHASE CHARACTERISTIC CURVES ON A 187 KV-A., 2300 VOLT, 720 R.P.M., 3-PHASE, 60 CYCLE, SYNCHRONOUS MOTOR

All readings should be corrected for instruments and shunt ratios and a curve plotted between amperes field as abscissæ and amperes armature as ordinates. See Calculating Sheet 10 and Fig. 88.

ACTUAL LOAD TESTS

The actual load test on a synchronous motor is usually made by belting or direct connecting the motor to a d-c. shop generator and exciting the field of the motor for minimum input as found above.

In taking a power-factor heat run, the field of the synchronous motor should be over-excited to give the required power-factor unless otherwise specified. Wattmeters should be used to determine the power-factor.

Synchronous motors which are parts of Frequency Changer sets may be given an actual load run as explained under a-c. generators.

EQUIVALENT LOAD TESTS

Synchronous motors are usually run as a-c. generators when being given equivalent load test.

Sometimes a synchronous motor is given an equivalent load run by loading it on a d-c. generator and running at reduced voltage, having the load brought up to cause full load current to flow in the armature, and having the field held at the value which may be specified.

SPECIAL TESTS

On synchronous motors consist of starting test, saturation, no load and full load phase characteristics, synchronous impedance, core losses and wave form.

Saturation, synchronous impedance, core losses and wave form are taken as for a-c. generators.

Starting Tests

Starting tests are taken as follows: If the motor is of a new type and rating, starting tests should be made both with and without a compensator. In all cases, however, the motor should first be tested without the compensator.

The center line of one pole should be placed in line with the center line of the frame. At the head end of the motor a distance of 180 electrical degrees should be marked off in a clockwise direction from this line. The total length of the scale used should be ⅔ of the distance between the center lines of adjacent poles for three-phase machines, ½ for two-phase machines and ⅓ for six-phase machines. The scales should be divided into *five* equal parts, each division line being numbered. On each one of these scale divisions the center line of the marked pole should be placed and the motor started. Thus five tests are made to insure that the motor will not stick in any position. See Fig. 89.

With one pole moved to position No. 1 and the machine at rest, sufficient current should be sent through the armature to give a reasonable reading of amperes and volts on the various phases and induced volts on the field. The induced volts field should be read with a potential transformer and a-c. voltmeter. The readings with the machine at rest are taken to determine which phase gives the maximum readings of current and voltage so that the latter can be read at the moment of starting.

With the instrument switches adjusted to give the maximum reading, the armature current should be increased until the motor starts. Volts armature, amperes armature and induced volts field should be read simultaneously. The starting volts should now be held constant until the motor comes to synchronism, the time required to reach this point being recorded. The machine attains synchronism when the induced volts on the field fall to zero. Then the machine should be shut down and the tests repeated from each of the other four positions.

Enough time must be allowed between readings so as not to overheat the machine and the current must be left on only so long as is necessary to obtain a reading.

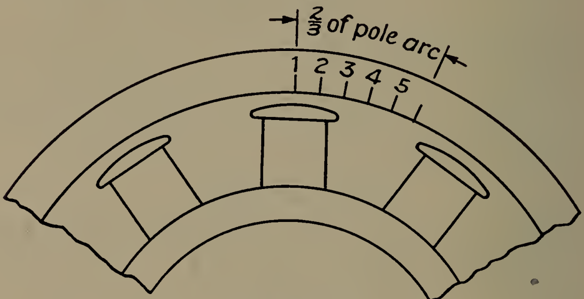

Fig. 89

METHOD OF DIVIDING POLE ARC FOR STARTING TEST ON A 3-PHASE MACHINE

If a motor shows a tendency to remain at half speed the alternating voltage should be increased until the motor breaks from half speed and comes up to synchronism. The voltage required to break the motor from half speed should then be held and recorded until full speed is reached.

All starting tests should be recorded on a special record sheet provided for the purpose and a sketch made showing the starting positions. If the motor sticks at half speed a record should be made of this fact.

If the test is required with a compensator, the motor should be set with its field in the position where the highest starting current is taken and allowed to rest in that position for at least six hours until the oil is well pressed out of the bearings. This is done in order to obtain the worst starting conditions likely to occur in normal operation. Connections should then be made to the lowest tap of the compensator and with normal voltage held on the line, the starting switch of the compensator should be closed. If the motor fails to start, the voltage must at once be switched off and connections made with the next higher taps on the compensator and so on until the motor starts. Readings

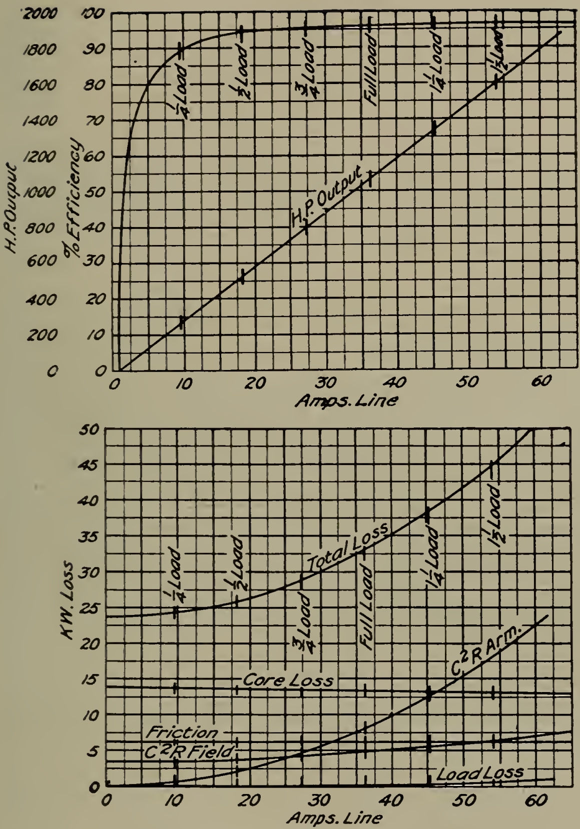

Fig. 90

EFFICIENCY AND LOSSES ON A 1070 H.P., 13,200 VOLT, 500 R.P.M. 25 CYCLE, 3-PHASE SYNCHRONOUS MOTOR

should be taken at rest on each of the taps of the compensator in the starting position to determine the voltage ratio of the taps of the compensator. All these tests should be made with the field circuit of the motor open. During the test with the compensator, enough time should be taken between the trials to allow the compensator to cool, as it is designed for intermittent service only. See Calculation Sheet 24.

INPUT-OUTPUT, OVER-SPEED and **WAVE FORM** have been described.

COMPLETE TEST consists of special tests together with normal and overload heat runs at unity power-factor.

STANDARD EFFICIENCY TEST is made by the method of losses. page 439 and Calculation Sheet 15 and Fig. 90 show the method of calculating and plotting results.

Impedance-Position Curves

An impedance position curve is taken in the same manner as given for Induction Motors on page 215. A curve should be plotted using the average current per phase as ordinates and position number as abscissae.

Torque Tests

Torque tests may be divided into stationary torque and running torque tests.

Stationary Torque tests are made in a similar manner to that given for Induction Motors on page 220, using a spring balance and lever. The rotor is blocked in the position which gives an average of the average current per phase as shown by the impedance-position curve, which should always be taken on a synchronous motor before stationary torque tests. Care must be used to allow sufficient time between readings and to take readings quickly enough so as not to overheat the windings.

Running Torque is taken by running the motor with no field excitation and belted to a d-c. generator, the voltage and frequency of the motor being held constant. The voltage is usually held at one-half the rated voltage of the machine. The field on the belted generator should be held constant at such a value that approximately its normal voltage will be obtained with full speed on the synchronous motor. The brushes used for reading voltage on the d-c. machine should be insulated from the holders. Readings should be taken of volts armature (held constant), amperes armature, watts and speed of the motor under test; and volts and amperes armature, amperes field and speed of the d-c. generator. With no field on the d-c. generator the motor should be started and brought up to as near synchronous speed as it will come, and all readings then taken. Then with field on the d-c. generator but with no load, the test is repeated. The d-c. generator should then be lightly loaded and a new set of readings taken. These tests should be repeated with small increments in load to give about 5 per cent change in the final speed of the motor and should be continued until a reading is obtained with at least 200 per cent of the rated current of the motor. Watch the motor and do not let it become overheated. The tachometer should be checked at all speeds, and care should be taken to use the proper signs for the wattmeters. After the above readings are completed the belt should be removed and running light readings obtained at all speeds used in taking the torque tests. The same field current should be held as in the original test. Curves may then be plotted with speed as abscissae and kw. output and torque as ordinates.

Calculation Sheet No. 23 shows the form used in calculating a running torque test, and Fig. 91 shows the method of plotting the curve.

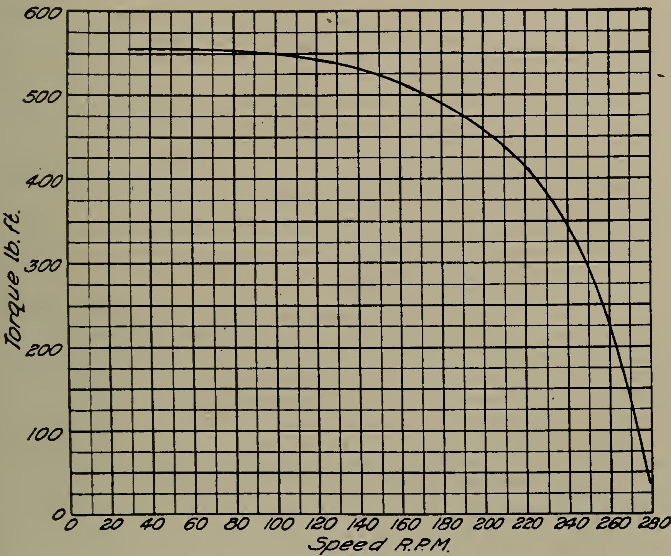

Fig. 91

RUNNING TORQUE CURVE ON A 75 KV-A., 2300 VOLT, 276 R.P.M. 3-PHASE, 60 CYCLE, SYNCHRONOUS MOTOR

CHAPTER 11

SYNCHRONOUS CONVERTERS

Inasmuch as a synchronous converter is a combination of a direct current generator and a synchronous motor the tests taken are somewhat similar to those for the individual machines with certain modifications.

Preliminary Tests consist of drop and polarity, cold resistance measure, air gap, checking of equalizer and collector ring taps, and other tests as specified in Chapters 4, 7 and 10.

It is very important that any error in the winding or assembly of field coils be discovered at the time drop and polarity tests are taken, as most converters do not have their series fields connected in for test, and hence any reversed series field polarity would not otherwise be discovered before shipment. Reliance should not be placed on the compass, but the polarity of adjacent poles should be tested out with two iron bars.

The machine should be examined to see that the bridges on the pole pieces do not project beyond the end of the pole face. The air gap measured between such projecting bridges and the armature is not the effective gap of the machine and any such projections should be reported as a defect if the gap is less than the normal gap.

The cold resistance of the armature must be carefully measured between the different collector rings. On a three-phase armature, measure between rings 1-2, 1-3, 2-3; on a quarter-phase armature, between rings 1-3, 2-4; on a six-phase armature, between rings 1-4, 2-5, 3-6. The resistance of each circuit for any particular style armature should be the same. Ring No. 1 is always the one nearest the armature.

The cold resistance of each field circuit should be measured and recorded.

If necessary the commutator should be baked and trued as for a d-c. generator.

The spacing of the equalizer and collector ring taps should be closely checked by counting the coils from each tap to the next. Occasionally a wrong connection is made, and if not corrected before the machine is run, one or more leads may be burned off and considerable damage done to the armature.

Before any machine is started the wiring should be checked by the Head or Assistant Head of Section and the machine must operate correctly when connected according to the proper diagram of connections.

Short Commercial Test

Short Commercial Test consists in operating the machine at no load for certain definite tests to demonstrate that it is a duplicate electrically of machines of the same type already shipped, and that it is free from manufacturing defects. For this test the machine should be run for one hour as an inverted converter at 110 per cent normal volts across the rings. No-load voltage ratio, balance across rings and running light readings from the d-c. end should be taken. Bearing temperatures should be read.

Speed Limit and End Play Devices

As soon as the machine is running properly the speed limit device should be adjusted to operate as described in Chapter 6.

The end play should then be tried out to see that the field poles and armature are correctly aligned. The machine must be set level and the end play should be equal in both directions. The end play device should then be adjusted as described in Chapter 6.

Phase Rotation

Phase rotation should then be taken to see that the collector rings are connected to the correct taps on the armature. This test is made by running the machine from the d-c. end and using the phase rotation indicator described in Chapter 2.

Brush Setting

Since very little armature reaction occurs in a converter the brushes should be set on the mechanical neutral. It may be found, however, that a slight shift from the neutral may give better commutation under load.

Voltage Ratio

The measurement of the ratio of the alternating to the direct voltage of a converter is one of the important tests and care should be used to obtain accurate results. The machine may be driven from either the a-c. or d-c. end, but a statement as to which method was used must be entered on the Testing Record. When running from the a-c. end, the field should be held at that value which gives unity power-factor as found from the phase characteristic.

In order to check the accuracy of the instruments, two a-c. voltmeters, two potential transformers and two d-c. voltmeters should always be used. During the tests the direct voltage is held constant, and the alternating voltage read between rings 1-2 on three-phase, 1-3 on two-phase, and 1-4 on six-phase machines.

The ratio is taken at no load and full load and should be as follows when taken with the machine running from the a-c. end:

	No Load	Full Load
With direct current	100	100
Single-phase	71.5	73
Two-phase (measured on diam.)	71.5	73
Three-phase	61	62.5
Six-phase (measured on diam.)	71.5	73
Six-phase (measured on adj. rings)	35.8	36.5
Six-phase (measured on alternate rings)	61	62.5

Converters with commutating poles may give values 1½ per cent greater than the above.

The amount of pole face arc will change the ratio. Any variation from these values greater than .2 per cent must be referred to the Head of Section, so that it may be investigated and brought to the attention of the Engineers.

The standard shunt wound converter gives a very nearly constant ratio of alternating to direct volts at all loads, so any fluctuation in the a-c. supply affects directly the direct voltage delivered. Such machines are unsatisfactory when much variation in load occurs.

When it is required to vary the direct voltage on such standard machines, the applied alternating voltage must be changed. This may be done by using transformers with a dial switch, or by an induction regulator, or a synchronous a-c. booster.

By adding a series field winding to the standard machine if it is required to operate with sudden changes of load, a practically constant voltage can be obtained either by introducing reactance into the a-c. circuit, or by making use of the inductance inherent in its feeder circuit. This is possible since an alternating current passing over an inductive circuit will decrease the potential if lagging and increase it if leading.

A converter running as a synchronous motor requires a certain field excitation to give the minimum input current to the armature. Varying the excitation either way changes the input current, so, by using sufficient reactance in the a-c. circuit from which the converter receives its power, the alternating voltage at the converter terminals may be increased or decreased by increasing or decreasing the exciting current. By adjusting the shunt excitation of the compound wound machine so it gives a no-load lagging current of about 25 per cent of full load current, and adjusting the series field to give a slightly leading current at full load, the impressed voltage at no load will be lowered and that of full load increased automatically. Hence with proper adjustment of the series field and sufficient reactance, the same direct voltage will be delivered at no load and full load.

The ratio may be independently varied by making use of a split field-pole, as in "Split Pole Converters."

HEATING TESTS

The heating tests taken on converters usually consist of actual load test taken either by the "water box," "feeding back" or "circulating current" method.

"Water Box" Method

When loading a converter on a water box see that all cables from the transformers to dynamometer boards and to the a-c. rings of the machine are of the same length and capacity. All contacts must be cleaned and brightened before connection. Equal resistance will thus be obtained per phase and unbalancing in the a-c. circuits external to the armature prevented. In wiring the d-c. circuit the series field and its shunt are disconnected.

In wiring converters, as with all other high current d-c. machines, both sides of the circuit should be laid close to one another. No iron, such as a bearing pedestal or a section of the frame, must lie within the loop of the circuit, since it will become magnetized and materially affect the operation of the machine and instruments. Always divide the shunt field into at least four sections, by a "break-up switch." This switch must always be open while starting from the a-c. end, since due to transformer action and relative number of turns of the field and armature, a high voltage is induced in the field at starting.

Always wire the positive brush ring of the machine through a breaker to the blade of the water box, and the negative ring to the box of the water box. Connect enough boxes in multiple so that none will be overloaded. Make provisions for reading amperes and volts armature (a-c. side); amperes and volts armature, amperes and volts field (d-c. side) and the speed of the alternator.

To start the machine close the a-c. line switches and the field switch of the driving alternator. Increase the excitation of the alternator, keeping close watch on the current in the a-c. lines. If this current reaches 150 per cent normal before the converter starts, check over the wiring and report to the Head of Section. If the machine starts rotating in the wrong direction, reverse two of the leads on the primary side of the transformers. After starting, as soon as the alternating current drops to the minimum value, showing the machine is in synchronism, and the alternating volts are normal, close the field "break-up switch." If, after closing the shunt field switch, the brushes begin to spark, the residual magnetism left in the poles by the induced voltage at starting is of the wrong polarity.

Two methods can be used to correct this. First, reverse the field with respect to the armature by flashing with the field reversing switch. Second, reverse the residual polarity by opening the alternator field switches. Then close this circuit and bring the converter back into synchronism, repeating this operation if necessary until the field builds up in the right direction.

Before proceeding further read the current in each phase to make sure there is no unbalancing. These currents should not vary more than one per cent from the average; any greater variation due to wiring must be remedied at once.

After balance is obtained the no-load phase characteristic should be taken in a similar manner as for a synchronous motor, and holding the direct voltage constant. The machine may then be loaded and the full load phase characteristic similarly taken holding the direct voltage and current the same for each value of field current. (See Calculation Sheet 6.) At the point of minimum input the ratio of alternating to direct current should be as follows:

Three-phase, alternating and direct current practically the same.

Two-phase, alternating current equal to ¾ the direct current.

Six-phase, alternating current equal to ½ the direct current.

These operations having been completed, the full load heat run may be started after the brushes have been set for the best commutation. On the load run hold full load d-c. amperes and direct volts constant, with minimum input field current. When holding minimum input by means of wattmeters make sure that they are connected to the proper rings, otherwise they may show unity power-factor when in reality the actual amount being held is about 60 per cent. The load should be kept on at least one

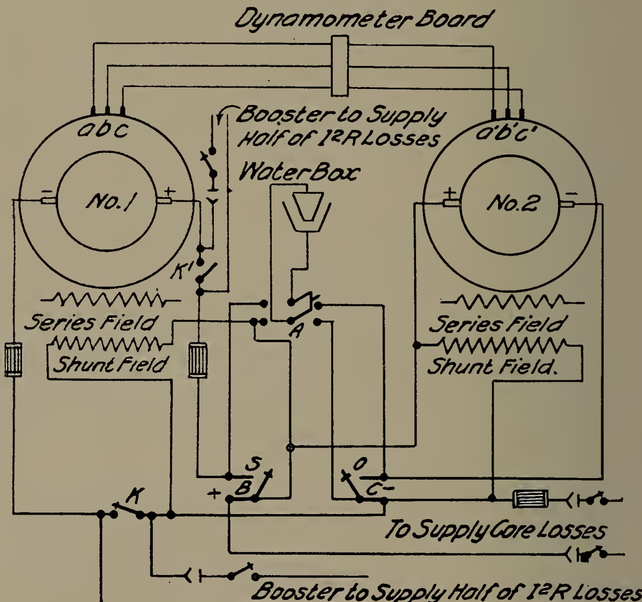

Fig. 92
CONNECTIONS FOR LOADING SYNCHRONOUS CONVERTERS WITHOUT THE USE OF A REGULATOR

hour after all temperatures are constant, and at the end of the run temperatures must be taken on all parts of the machine, and the resistance measured on the armature (from the a-c. end) and on all field circuits.

If an overload run is required an overload phase characteristic should be taken similarly to the full load. The direct voltage should be held constant at the normal rating and the amperes output constant at the required overload value. The field excitation should be varied through as near the same range used on the full load as possible. The heat run should then be applied for the specified time and care should be taken that the time does not run over the limit.

With Boosters in the D-C. Side (Circulating Current Method)

Fig. 92 shows the connections for two three-phase converters wired for a feed back heat run, without a potential regulator to control the load. The core losses and I^2R losses are supplied from the d-c. end. The diagram shows, also, the standard starting panel which should always be used when two converters are tested together.

To start the machine, choosing No. 1 for instance, close the shunt field switch and switches K and K^1 which short-circuit the armatures of the loss supply. Note that the shunt fields are wired across the core loss supply, which is wired to busses B and C of the starting panel, and that the series fields are left open. Throw switch A to the left and slowly reduce the resistance of the water box till it is practically short-circuited, when switch S may be closed. The blade of the water box should then be drawn out of the water and the switch A thrown to the right. Machine No. 2 is then started in a similar manner.

The strength of the field of each machine is then decreased until they both run at normal speed. (See cautions on page 203 regarding inverted converters.) Now connect a number of incandescent lamps in series, of which the rated voltage is equal to the sum of the machine voltage across rings aa', viz., across switches located on the dynamometer board. Two sets of lamps should be provided, one being connected across one of the switches while the other is used to step across each of the other switches in turn. Should one set show a rise and fall in voltage directly opposite to that of the other, the two phases are reversed, and must be corrected. When all phases show a simultaneous rise and fall, the machines may be phased together, bringing their speeds to the same value by changing the field on one of them. When the rise and fall of voltage shown by the lamps decreases to a period of 5 seconds or longer, close all the switches simultaneously, when the lamps are dark.

Never close a single switch on the a-c. end as this would make a short-circuit on the armature.

During the period of starting and phasing the machines together, the boosters should be short-circuited, with open fields. When the machines are synchronized the short-circuits are removed. Apply a weak field on the booster and watch the line ammeter on No. 1. The reading of this ammeter should reverse from that given on motor load if No. 1 is taking load as a converter. By reversing the booster field either machine can be made to run as a converter.

After balancing the current in each phase, the full load phase characteristic may be taken. The speed should be held constant by varying the field of the inverted converter, and the load held constant with the boosters while the shunt field of the converter is varied throughout its range and readings of current input carefully taken. Full load voltage ratio should then be taken after which the heat runs may be made.

A line ammeter-shunt must be used in each side of the d-c. circuits. The currents flowing through them must have equal values, otherwise one line has more resistance than the other, the unbalanced current returning through the a-c. ends of the machines. The currents in these lines can be balanced by decreasing the resistance of copper to the low reading line. The direct currents should be balanced before attempting to balance those in the a-c. side. Two boosters for supplying the I^2R losses are necessary to eliminate unbalancing.

In running this test there will be a slight difference in the direct voltages equal to the IR drop of the machines. The field of the inverted machine will be less than that required for minimum input.

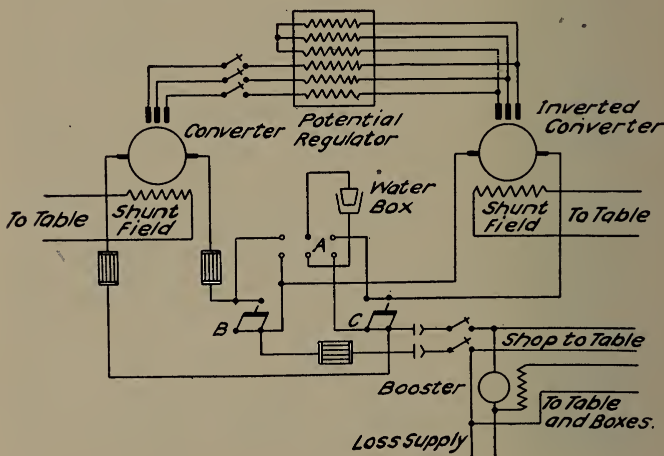

Fig. 93

CONNECTIONS FOR FEEDING BACK SYNCHRONOUS CONVERTERS WITH REGULATOR

This method of supplying the I^2R losses with boosters requires such large low voltage boosters that it is not often used except for small converters.

With a Regulator in the A-C. Side (Feeding Back Method)

Using D-C. Loss Supply

A second method of testing converters for actual load heat runs, is to use a voltage regulator in the a-c. side of the machines as shown in Figs. 93 and 94. The regulator is connected with its secondaries in series with the a-c. lines and its primaries excited from the inverted machine. It is always preferable to connect the regulator between the inverted converter and the dynamometer board so that the instruments of the converter will not read the losses in the regulator. The regulator takes the place of the booster used in the previous method, and is very satisfactory for supplying the I^2R losses.

Starting the machine, checking the phase rotation, phasing in, and the other matters already described are repeated with this method. Always see that the regulator is set at the neutral point before phasing in, otherwise load will be thrown on when the switches are closed. For the no-load phase characteristic the regulator should be disconnected.

Load is increased by turning the core of the regulator in the direction of boost, at the same time watching the ammeter

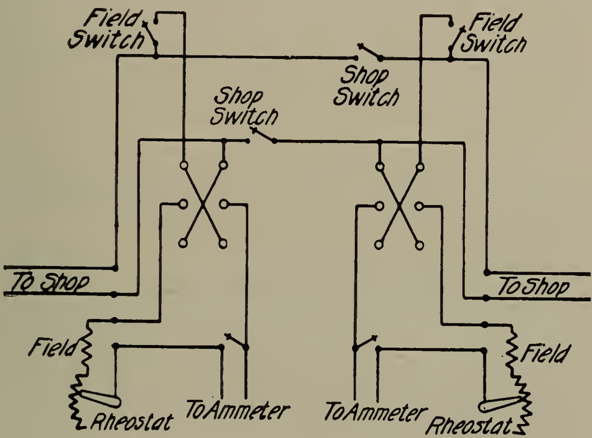

Fig. 94

TABLE CONNECTIONS FOR SYNCHRONOUS CONVERTER FEED BACK

of machine No. 1. If the reading reverses from motor load, then No. 1 is running as a converter. If No. 1 does not reverse, turn the regulator in the opposite direction. This shows that the regulator is wrongly connected in reference to its markings. There is no necessity, however, to change connections.

Using A-C. Loss Supply

If instead of supplying the losses from a d-c. source of power, we connect an alternator across the a-c. lines (between the inverted converter and the regulator to avoid reading the losses in the regulator) in the preceding method the losses can be supplied at the a-c. end. When the alternator is large enough to start the converters, the wiring on the d-c. end is greatly simplified. The starting panel is omitted, and the shunt fields are connected according to the print of connections for the machine. Load is obtained by means of the regulator as before and the test carried out as already described.

If the alternator is too small to start the machines, the latter may be started from the d-c. side as before, and phased together. The alternator is then synchronized on the pair. If only one machine can be started by the alternator, bring it up to speed, then open all its circuits, and let it run by its own momentum, and quickly start the second machine. Take off the excitation from the alternator field, and then close the switches on the first machine. Excite the alternator field, and bring both machines up to speed, together. After the machines are once started they can be brought up to speed without excessive current being required.

After the necessary heat runs have been taken and while the machine is still warm, the wiring should be removed and the high potential test applied. Hot drop on field spools, running light from the d-c. end, etc., should be taken as for other direct current machines.

SPECIAL TESTS

Special tests consist of d-c. and a-c. starting tests, core losses, saturation, impedance, voltage ratio at no load and full load. Voltage range curves at no load and full load will be taken on split pole machines.

Saturation and **impedance** are taken in the same manner as for d-c. and a-c. generators, previously described.

D-C. starting tests are taken with the machine running as a d-c. motor and wired to a d-c. machine of ample capacity to give satisfactory readings without an excessive fall in voltage. The main field of the converter should be excited at that current necessary for no load minimum input unless full field is specified. The current through the armature should be increased gradually until the armature begins to revolve and held constant at that value until the machine reaches synchronous speed. The elapsed time from start to synchronous speed should be recorded. This test should be repeated with higher values of armature current held and enough readings taken to plot a curve with amperes armature as ordinates against time as abscissæ so as to determine the current necessary to bring the converter to synchronous speed in one minute.

A-C. starting tests are taken in the same manner as for a synchronous motor.

The converter should be wired to an a-c. generator of sufficient capacity to start it without overloading. If transformers are needed, in order to get the correct voltage, they should be placed between the dynamometer board and the generator.

Converters at starting from the a-c. end are similar to a transformer. The armature corresponds to the primary, and the field, having a large number of turns, corresponds to the secondary. Hence the induced volts on the field may be very high (often 3000 or 4000 volts). In all cases, therefore, the field connection must be broken in two or more places to keep this voltage within safe limits. A potential transformer and voltmeter should be connected across one or two spools in series, for reading the induced volts field, and a note made on the record sheet as to the number of poles included in the reading.

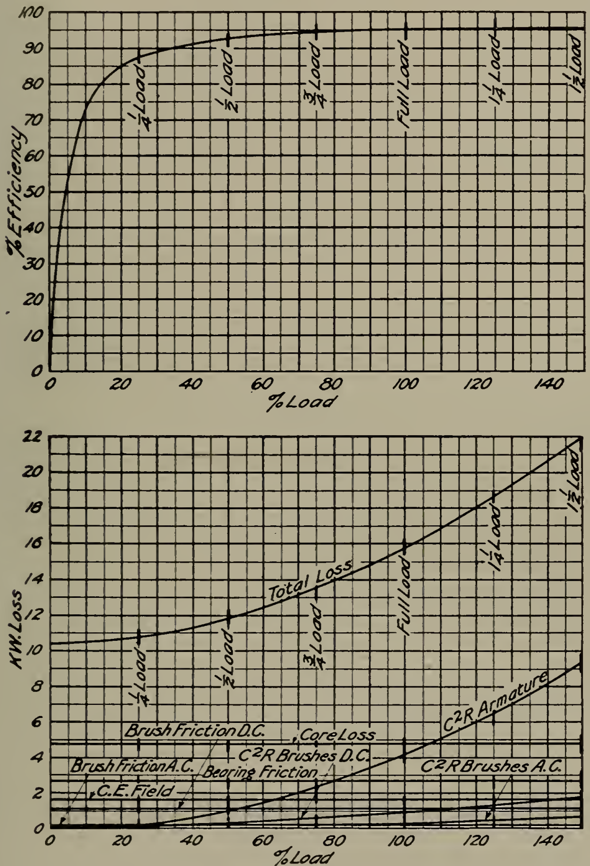

Fig. 95

EFFICIENCY AND LOSSES ON A 300 KW., 600 VOLT, 750 R.P.M., 25 CYCLE, 3-PHASE SYNCHRONOUS CONVERTER

Starting tests should be made from several different positions of the armature with respect to the field. A scale, corresponding to the distance between collector ring taps, should be laid off on the armature, divided into five equal parts. A point of reference is marked on the field, opposite to which the marked positions of the armature are placed for the successive starts. These positions should be numbered and a sketch showing the numbering be made on the Record Sheet.

Having brought point No. 1 opposite the reference point, the a-c. switches should be closed and a moderate field put on the alternator, sending about one-half normal full load current through the converter. Read volts and amperes in the various phases. As it will be impracticable to read all phases at once during the start, cut the ammeter into that phase which shows the highest current and the voltmeter across the phase which indicates the highest voltage, so as to get the maximum readings at the instant of starting. Increase the field of the generator until the armature begins to revolve, when volts and amperes input and induced volts on the field should be read. The voltage across the collector rings should then be held constant, until the converter reaches synchronism, the time required to reach this point from the start being noted.

There are several methods of determining whether the machine is in synchronism. One is, the induced volts field will fall to zero; another, the voltmeter across the armature will read a definite voltage, which would vary from a negative to a positive reading if the machine were below synchronism.

Readings should be taken on all phases, of volts and amperes after the machine has reached synchronism. The machine should then be shut down, the armature brought to position No. 2 and the test repeated. In this manner all five points should be taken. After these tests have been taken, the time required to bring converter to synchronism should be taken by throwing one-half voltage across the collector rings.

Core Losses are taken with the converter running as a generator and results recorded as given in previous chapters. A reading should be taken of the volts across the collector rings as a check on the no load ratio. Calculation Sheet 25 shows the results of a core loss taken by the motor core loss method.

STANDARD EFFICIENCY TEST is made by the method of losses. Page 435 and Calculation Sheet 13 shows the method used in calculating the efficiency of a converter. See Fig. 95.

COMPLETE TESTS consist of normal and overload heat runs and special tests.

Other tests which may be called for on synchronous converters are:

Compounding Test with Reactance

When a converter is required automatically to deliver a constant direct voltage, with a load subject to sudden changes, a compound wound machine is used with a definite reactance inserted between the converter and the line. Such reactances must be tested with the machines for which they are designed. A constant voltage is possible, since an alternating current passing through a reactance will increase the potential if leading, and decrease it if lagging. By adjusting the shunt field so that about 20 per cent lagging current flows at no load and the current at full load leads slightly, the strength of the series field can be adjusted so as to give the same voltage at no load and full load. A compound wound converter, running with reactance, must be compounded like a direct current generator. Unless other specific instructions are issued in reference to compounding, hold constant the voltage of the alternator by which the converter is driven. Adjust the shunt field to give the correct no-load voltage, then, without touching the field rheostats, put on full load and read the direct volts. If the machine over-compounds, the series field is too great, and gives too much leading current. In this case a shunt must be adjusted across the terminals of the series winding to shunt a portion of the current. On this compounding test, all readings are taken and adjustments made as on a direct current generator without touching the field rheostats after the no-load adjustment is made.

Pulsation Tests

Since the torque of a converter need only be great enough to overcome that due to its own losses, it is very sensitive to changes in line conditions, viz., excessive line drop or speed changes of the driving unit. Line drop alone will start a machine pulsating, in many cases. Once started the pulsation generally increases rapidly, till the machine falls out of step or flashes over. To prevent pulsation, copper or brass bridges are located between the poles, which act as a short-circuited secondary and oppose sudden changes of the input armature current. Converters of new design are tested for pulsation by inserting a resistance per phase, between them and the driving alternator. The drop through this resistance corresponds to the line drop which will probably occur in practice. Usually 15 per cent drop is used. If two machines are tested together each machine would have 15 per cent drop between it and the driving alternator or there would be 30 per cent between the two machines as shown in Fig. 96.

With the two machines running in synchronism self-excited and with the fields adjusted to give minimum input, observe the voltmeters on the d-c. end of the two machines. Any slight pulsation will be shown by these instruments at once. Hold the direct volts constant on one machine throughout the test. With one field held at minimum input value, reduce the field current in the other machine to about one-half minimum input value. If no pulsation is noted, take a full set of readings on both machines, then reduce the field current of the other machine to one-half minimum input value, and watch for pulsation on both machines which now take a heavy lagging current. Take a full set of readings under these conditions. Next adjust the field of the first machine again to the minimum input value, watch for pulsation and take readings. With this field held at minimum input, change the field of the other machine from its value at one-half minimum input to twice the minimum input value, observe and read. The other field is then brought up to twice normal value, readings are taken and the effect of the heavy leading current in each machine noted. Leaving one field over excited, weaken the other field so as to get half minimum input, look for pulsation and take a full set of readings. Next adjust both fields for minimum current and raise and lower one field about once a second between the extreme values used above and repeat this test for the other machine. If no pulsation develops with the high line drop under these extreme conditions the machines are satisfactory.

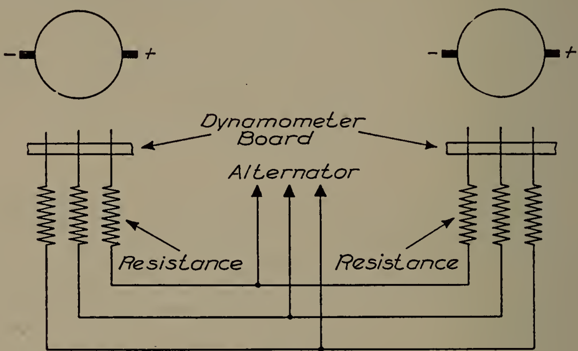

Fig. 96

CONNECTIONS FOR PULSATION TEST

Input-Output Efficiency Test

Input-output tests on small machines are made with the machine running as a converter, dead loaded on a water box. Larger machines are tested in pairs, one machine feeding back on the other with electrical loss supply. The machines are wired exactly in a similar manner to that used in a heat run (circulating current method) special attention being given the wiring to see that no unbalancing occurs in either the a-c. or the d-c. circuits. On the machine running as a converter, wattmeters are connected in the a-c. end, between the converter and the transformers and preparation made for reading d-c. armature and field current and volts. If current transformers are used with the wattmeters, duplicate transformers must be used in the other phases of the machine to prevent unbalancing caused by the resistance and inductance of the transformers. With the machine running in synchronism at rated speed with zero load, and all meters connected, hold constant the alternating volts impressed on the converter and take careful readings of all instruments. Then read the current and volts in each phase, as a check on the wiring and balancing of all phases. Also carefully check all instruments for stray fields. Any instruments so affected must be protected by iron shields or their location changed. With full load, repeat the test for stray fields, since any instrument affected will give misleading and erroneous results. With the no-load minimum input field current held constant, carefully read the a-c. input, as shown by the wattmeters, as a check on the no-load losses.

As efficiency is usually guaranteed at ¼, ½, ¾, 1, ¼ and 1½ load, careful readings must be taken at these loads. Each time the load is changed, the converter field excitation must be changed to the minimum input value for that load. This is shown when the sum of the wattmeter readings is exactly equal to the kv-a. input. To obtain this condition every time usually requires several trials and considerable time, so that an efficiency test made in this way is more expensive than when made by the separate loss method. The likelihood of error is also greater.

INVERTED CONVERTERS

The speed of a converter, running from the a-c. side, is determined by the line frequency. The same machine running as an inverted converter and delivering alternating current operates as a d-c. motor. Its speed depends upon the field excitation and load, and it will deliver a variable frequency, particularly if compound wound. When run inverted, a compound wound machine should have its series field almost, if not entirely, short-circuited when part of its load is inductive, since a lagging alternating current will weaken the field and increase the speed, sometimes causing a runaway. For this reason, care must always be taken when running a converter inverted, to see that sufficient field excitation has been obtained to prevent excessive speed, particularly when another machine is operated as a converter from the inverted machine.

SPLIT POLE CONVERTERS

The field poles of split pole converters consist of two or more separate and independent parts each equipped with its own field coil. The ratio of the converter is changed by varying the relative strengths of the main and auxiliary windings. The transformers should never be connected delta primary with diametral secondary because of the harmonic current that may flow if this connection be used. The testing instructions will include, besides the regular tests to be made, the volts to be held across the collector rings and the range through which the direct volts are to be varied by means of the auxiliary field.

All preliminary tests are taken as for standard converters and the following tests are modified according to instructions below.

Phase Characteristics

Phase characteristics should be taken under three different conditions of excitation.

NO-LOAD PHASE CHARACTERISTICS

(a) Hold the *direct* volts constant and vary the main field with the regulating and compensating fields unexcited.

(b) Hold the *alternating* volts specified in the testing instructions and with the main field only, find the main field current for minimum input. (This may check with [a].) Set the main field rheostat to give minimum input current as just determined and vary the compensating field while using the regulating field to maintain the direct volts constant at the lowest limit.

(c) Same as (b) except it is taken at the highest limit of direct volts.

NOTE.—In case there is no compensating winding take curves corresponding to (b) and (c) by holding the direct volts constant with the regulating field while varying the main field.

FULL LOAD PHASE CHARACTERISTICS

The full load phase characteristics should be taken in the same manner as the no load, except that in all cases the current in the d-c. end should be held at the value necessary to give the rated output of the machine at the voltage on which the kilowatt rating is based.

Voltage Range Curves

Voltage range curves are taken by holding the impressed volts constant and, with the main field rheostat set for minimum input current as found in (a) of the phase characteristics varying the current in the regulating field to obtain the specified range of direct voltage. Minimum input current must at all times be maintained by varying the compensating field.

NOTE.—In case there is no compensating winding two curves should be taken.

(1) Holding the main field rheostat constant. (2) Holding minimum input current by changing the main field rheostat.

Curves are plotted with direct volts line as ordinates and amperes regulating field as abscissæ.

Similar curves should be obtained for full load conditions.

Core Loss and Saturation

Two core loss tests are required to cover the various conditions of operation.

(1) Vary the direct volts by means of the main field only with the auxiliary field unexcited. This test is the same as for a standard machine.

(2) Holding the alternating volts constant at the value specified in the instructions and with the main field rheostats in the position determined from (1) for obtaining the specified alternating volts, vary the regulating and compensating windings to change the direct volts throughout the range. (It will be found necessary to vary the compensating winding in order to hold the specified alternating volts.) NOTE.—If there is no compensating winding, change the main field rheostat to hold the alternating volts constant.

Saturation curves should be taken under the same conditions as core loss.

Running Light Readings

Running light readings from the d-c. end should be taken under three different conditions.

(a) Holding the specified alternating voltage using the main field only, and allowing the direct volts to come what they will.

(b) Holding the minimum direct volts and the specified alternating volts by varying the regulating field, and varying the compensating field to obtain correct speed.

(c) Taken in the same manner as (b) except at the maximum direct volts.

Heating Tests

The heat runs should be made by holding the specified alternating voltage, varying the regulating field to obtain the desired direct voltage and adjusting the compensating winding to obtain minimum input. The main field rheostat should remain in the position found in obtaining the specified alternating voltage with normal current output and minimum current input when the compensating and regulating fields are unexcited. On those machines not equipped with compensating field, the main field must be varied to obtain minimum input.

COMMUTATING POLE CONVERTERS

The brushes of the commutating pole converter should be set on mechanical neutral for best commutation. This point is located by placing the armature bars, which are painted red, central with respect to a main pole, and then setting the brushes so that the center of the brush comes over the center of the red mark on the commutator as specified under "Commutating Pole Generators" in Chapter 7. It sometimes may be necessary to shift the brushes slightly forward to secure a falling voltage characteristic under load.

When adjusting the commutating field on a converter, in order to determine whether it has the proper field strength, run the machine at full load or as near this value as possible, and take the drop from the pigtail of one brush to various points on the commutator under the brush. If the drop is the same to all points under the brush the adjustment is correct, but if it is higher on the trailing side the commutating field is weak and if higher on the leading side, the field is too strong.

Most commutating pole machines have a brush raising device to lift all except two pilot brushes from the commutator during the period of starting from the a-c. end. This device should be carefully examined to see that it operates satisfactorily, that it does not bind, that it raises all the brushes (except the pilot brushes) well off the commutator and that it allows all the brushes to make proper contact on the commutator with plenty of allowance for the wear of brushes. The pilot brushes are for the purpose of getting field on the machine and correcting reversed polarity if necessary.

Converters with A-C. Boosters

Commutating pole converters which have an a-c. booster are equipped with an auxiliary shunt winding on the commutating poles. The strength of this field is controlled by means

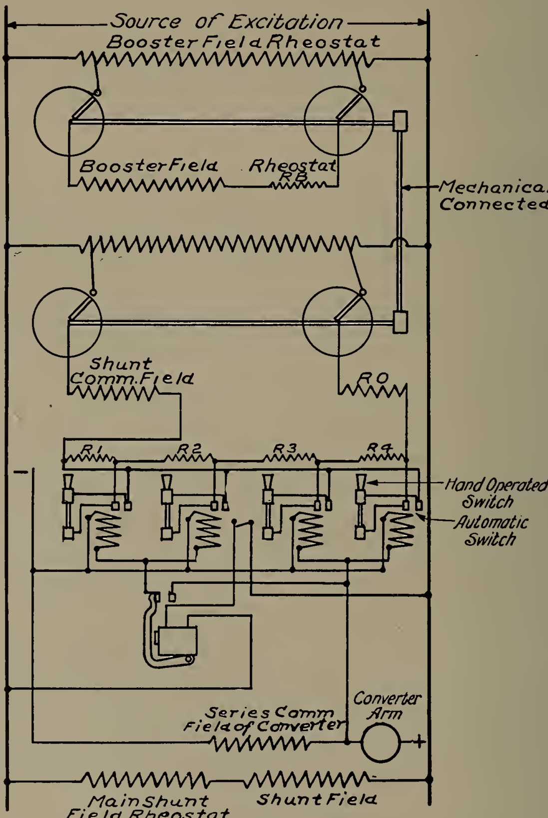

Fig. 97

CONNECTIONS OF A-C. BOOSTER FIELD AND AUXILIARY SHUNT COMMUTATING FIELD WITH CONTROL FOR SYNCHRONOUS CONVERTER HAVING COMMUTATING POLES AND A-C. BOOSTER

of a double-dial rheostat, which is mechanically connected and operated with the double-dial rheostat in the booster field, and an auxiliary resistance which is divided into steps that are controlled by contactors. These contactors are set to operate at various loads thus changing the resistance in the shunt commutating field according to the load on the converter. (See Fig. 97.) The double dial rheostat takes care of any change in commutating field strength made necessary because of a change of the direct voltage of the converter.

The contactor-controlled resistance is set for the maximum value of auxiliary field which will give good commutation at no load. The load is then increased to the maximum value which can be carried with good commutation at this field strength. The first contactor should be adjusted to close at this value (which will be about 40 per cent normal load) and the auxiliary field strength thus increased to the greatest value permissible without sparking. The load should then be increased to the maximum which will not cause sparking at this setting (which will be about 85 per cent normal load) and the second contactor adjusted to close at this point. The same operation should be repeated for the other two contactors which should be set to close at about 110 per cent and 130 per cent normal load.

The only *phase characteristics* which need be taken on this type of machine are those with the booster field unexcited and are the same as those described for standard converters.

The *voltage range curves* should be taken at no load and full load with the alternating volts held constant and are similar to those for split pole machines *without* compensating windings. The booster field is used in place of the regulating field.

Core loss and saturation curves should be taken.

(a) With the main field of the converter excited (booster not excited).

(b) With the booster field excited and the converter not excited.

The alternating and direct voltage of the converter should be read in each case.

Other tests should be taken as previously described.

MOTOR CONVERTERS

A motor converter consists of a standard synchronous converter and an induction motor. The induction motor has a wound rotor with taps brought out to a set of common rings that take the place of the collector rings for both motor and converter. The voltage of the induction motor rotor is the alternating voltage of the converter. The advantage of the motor converter is that high tension (up to 13,000 volts) may be applied on the stator of the induction motor, the rotor delivering low voltage to the converter. Hence the intervening bank of transformers always necessary with a synchronous converter are not required. No reduction of power-factor is caused by the induction motor, since unity power-factor may be maintained with the motor converter by proper adjustment of the field of the synchronous converter. Caution should be observed when when starting a motor converter to see that it does not exceed synchronous speed. This synchronous speed is always the synchronous speed of a machine having a number of poles equal to the sum of the number of poles on the synchronous converter and induction motor forming the motor-converter.

CHAPTER 12

INDUCTION MOTORS

The tests made on an Induction Motor either for Engineering information, or for checking guarantees may be divided as follows: Preliminary tests; commercial tests; heating tests; special tests; input-output tests.

Preliminary test consists of air gap, resistance measure, and inspection as contained in the instructions in Chapters 3 and 4 which should be carefully followed. Special measuring scales are used in taking the air gap of Induction Motors, as noted on page 83, Chapter 3. Great care should be used in taking both the stationary and revolving gap measurements. Ordinarily there should be as many points measured as there are openings in the end shield. On machines equipped with pedestal bearings at least eight equally spaced points should be taken.

Resistance measure is generally made between terminals. On some machines the separate phases are each brought out to a terminal block. Whenever the resistance is measured per phase it should be clearly indicated on the record sheet. Quarter-phase machines are usually measured between terminals 1-3 and 2-4. Detailed descriptions of the apparatus and methods used in resistance measurements are given in Chapter 2. When a motor is delivered to test it bears a tag on which the resistance between terminals as measured by the Armature Department is written. This value is generally accepted by the Testing Department and the machine need not be re-measured except when heat runs or special tests are to be made. All heat runs and special tests should be preceded by a resistance measurement taken when the machine is cold and a careful measurement by thermometer of the machine windings.

Commercial Tests

Commercial tests consist of preliminary tests, excitation readings, stationary impedance, and voltage ratio on Form M and Form P motors. The *excitation readings* consist of taking running light readings of volts and amperes with normal voltage impressed on the stator. The windings of phase wound rotors must be short circuited. Form L and Form P rotors should be short-circuited by means of the short-circuiting switch provided on the motor; Form M rotors should be short-circuited by connecting the brush-holders together with a short cable. The brushes should be sanded to a good fit to reduce the contact resistance as much as possible. In starting, the voltage should be applied gradually or in steps, the lowest being about one-quarter of the normal voltage. The majority of motors should start on one-fourth normal voltage with the rotor short-circuited. The voltage necessary to start must be recorded. The bearings must be watched carefully to detect any undue heating, especially in the case of high speed machines. End play must be tried out, both with and without voltage applied to the stator. A tachometer reading of speed should be taken and recorded to show that the motor is running at the correct speed for the frequency of the circuit used, and also as a rough check on the frequency of the driving alternator. After the motor has been run for several minutes to show up any defects the readings of volts and amperes should be made and recorded. Care should be taken to detect any unbalancing in the voltage or current in the different phases.

Stationary Impedance consists of taking readings of volts and amperes, at normal rated amperes, with the rotor short-circuited and blocked with the clamping device furnished for this purpose. On Form K motors, this value will be practically the same for any position of the rotor. On motors having phase wound rotors, it is necessary to vary the position of the rotor, with respect to the stator, in order to obtain the maximum and minimum effects. Normal amperes is first obtained with any convenient position of the rotor, and the corresponding voltage is held constant during the shifting of the rotor position. This voltage is generally found to be about one-fifth of the rated voltage of the motor, a fact which will serve to detect any gross error which might be made in testing. On Form L motors, a reading must also be taken and recorded with the resistance in. Close attention must be given to current and voltage balance on the different phases and much care must be used to avoid applying excessive currents and damaging the winding.

Voltage ratio readings must be taken and recorded on all Form M and Form P motors. This consists in applying normal voltage to the stator winding, and measuring the voltage between rings on the rotor winding, the rotor being open-circuited and held stationary. The primary exciting current must also be read and recorded.

HEATING TESTS

Heating tests generally taken on Induction Motors may be divided into *actual load runs* and *equivalent load runs.*

ACTUAL LOAD RUNS

The actual load runs may be sub-divided into normal load, overload, crane motor, and intermittent heat runs. They are usually made by belting or direct connecting the motor to a d-c. shop generator and holding normal voltage and the specified current. The instructions in Chapter 4 relating to thermometers should be followed carefully. Readings should be taken every half hour on normal load runs, and every fifteen minutes on overload and crane motor runs.

Crane motor heat runs are taken on motors designed for intermittent service and are generally made holding normal voltage and current for a half hour. In some cases the runs extend over a period of one hour. Readings should be taken every fifteen minutes.

Intermittent heat runs are usually made according to instructions from the Engineering Department.

The **Induction Generator method** is sometimes employed in making load runs on Induction Motors. Two similar induction motors are belted together and run in parallel from the same alternator which supplies the losses. See Fig. 98. In order to get full load in both machines, the diameter of the pulleys must differ by a percentage equal to double the full load per cent slip.

In starting, the switches A are closed and the motor allowed to come up to speed, until the speed of the motor running as a generator is above synchronism. The alternator field is opened momentarily, while the switches B are closed. The circuit in the alternator field is then closed again, and full load current flows through the two machines. No changes in

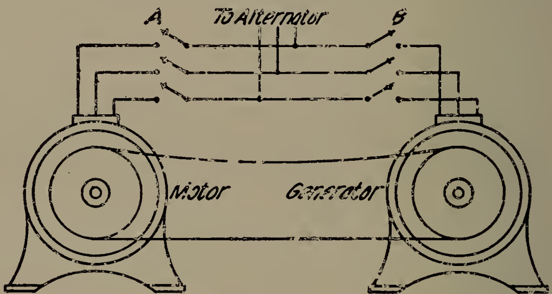

Fig. 98

INDUCTION GENERATOR METHOD OF FEEDING BACK

load can be made without changing the pulley ratio and it is absolutely necessary that this ratio be correct in order to obtain full load.

Several modifications of this method are possible. The shafts of the two machines may be direct connected or belted together and one winding of the machine to act as the induction generator be separately excited with either alternating or direct current and the other winding connected to water boxes. In this method the induction generator cannot be a Form K machine.

Another modification sometimes used is to wire the induction generator to the synchronous motor of a motor-generator set and load the set, the field of the synchronous motor being adjusted to supply the exciting current for the induction generator.

Slip readings should be taken during all heat runs as described on page 217.

EQUIVALENT LOAD RUNS

Equivalent load runs are generally made on large motors which it would be difficult to load on account of the large amount of power required. The heating due to iron losses is obtained by running the motor light at normal voltage until the temperatures of the various parts become constant, readings being taken and recorded as in actual load heat runs. The heating due to copper losses is obtained by running the motor under partial load at a voltage less than normal, and holding normal and overload currents. From the results obtained in these tests the temperatures which would be obtained under actual load conditions may be approximately determined.

SPECIAL TESTS

Special tests consist of excitation curves, impedance curves, slip curve, stationary torque test and starting tests. The excitation, impedance and slip curves are very important, since it is from these curves that the data are taken for the calculation of the characteristic curves of the induction motor. These curves are generally accompanied by torque tests and occasionally by starting tests.

Excitation Curves consist of a series of readings of volts, amperes and watts, taken at different voltages when the motor is running light, the frequency of the applied voltage remaining constant.

The motor should be so located that all conditions affecting its operation remain unchanged throughout the test. A solid foundation is necessary to prevent vibration at full speed. The driving alternator should be at least three-fourths of the kilowatt capacity of the motor. It should be driven by an endless belt or by direct connection to its driving motor to avoid pulsations in the instrument readings. The transformers and other apparatus must be connected so that the alternator is working under normal conditions, since satisfactory wattmeter readings cannot be obtained if the alternator is run too low on its saturation curve. Transformers when used must be well balanced and must not be forced beyond their voltage range. The alternator used should have a sine waveform.

The testing table must be adapted for wattmeters. If the voltage be too high for direct reading on the wattmeters and voltmeters, multipliers or potential transformers must be connected between the points measured and the instrument; similarly, if the current be too high for direct reading, current transformers must be used in the wattmeter and ammeter circuits. On motors of less than 20 h.p., the potential lines must be attached on the generator side of the testing table, since, if they are attached to the motor side of the table or to the motor terminals, the exciting current of the potential transformers passes through the wattmeters. Although this current is small, it may be quite an appreciable percentage of the exciting current of a small motor, and the error involved may cause an abrupt break in the curve whenever a potential transformer ratio is changed. In the case of large motors, the exciting current of the potential transformer is so small in comparison with that of the motor, that the incidental errors are negligible. When multipliers are used the above precautions may be disregarded since they are non-inductive. On large motors the potential leads should be connected to the motor terminals to eliminate the line drop in switches and cables leading from the table to the motor. The current leads to the wattmeters and ammeters should be twisted together throughout their length and should be free from sharp bends or loops. All connections must be bright and clean. The short-circuiting switches must always be closed when instruments are changed. On circuits of more than 500 volts all instruments must be discharged to eliminate static charge. Do not ground the secondary circuits of the potential transformers. The iron cases of oil-insulated potential transformers should be connected together and grounded. Each man should become thoroughly familiar with the characteristics and limitations of instruments and transformers as explained in detail in Chapter 2.

In starting up, the same precautions should be observed as in commercial tests. After preliminary inspection of wiring, bearings, etc., the line switches of the testing table should be closed. Always see that the wattmeter short-circuiting switches are closed in starting, or whenever a change is made in the generator field excitation. The exciter field switch should be closed, and the voltage brought up gradually until the motor starts and reaches normal speed. The motor should then be inspected to see that it is operating normally. The amperes and volts in the different phases should be read, and any unbalancing discovered and a few check readings made with a different set of instruments. The end play must be tried out, since defective end play may cause friction losses, which would render the excitation curves inaccurate. Small motors should be run about 1½ hours and larger ones at least 2½ hours, in order to obtain constant friction, before beginning the curves.

In taking an excitation curve on a quarter-phase motor both wattmeters read positive. However, in the case of a three-phase motor, one wattmeter reads negatively through the upper portion of the curve. It is, therefore, necessary to determine the algebraic signs of the readings of both wattmeters before beginning the curve. Adjust the circuit so that both wattmeters show a positive deflection on the scale, then open one of the phases in which a wattmeter current coil is connected and observe the other instrument. If the needle drops off the scale below zero, the instrument reads negatively. If the needle drops to some value above zero the reading is positive. This process must then be repeated for determining the sign of the other wattmeter.

In taking the data for the curves, the frequency of the alternator must be held constant. A value of about 125 per cent normal volts should be used for the first reading. Readings of volts, amperes, watts, and frequency must be made and recorded. The volts should then be decreased in steps to give 15 or 20 points on the curve, down to a value of 10 or 15 per cent normal volts. At this point the motor becomes unstable. As readings are taken on the descending curve, the instrument with the negative sign will read less than the positive reading instrument, and its readings fall off more rapidly, becoming less and less until zero is reached and its sign changes. When it becomes positive its current leads must be interchanged. The two most important points on the excitation curve are amperes and watts at normal voltage, and friction watts. These readings determine the core loss of the motor. Several readings only a few volts apart

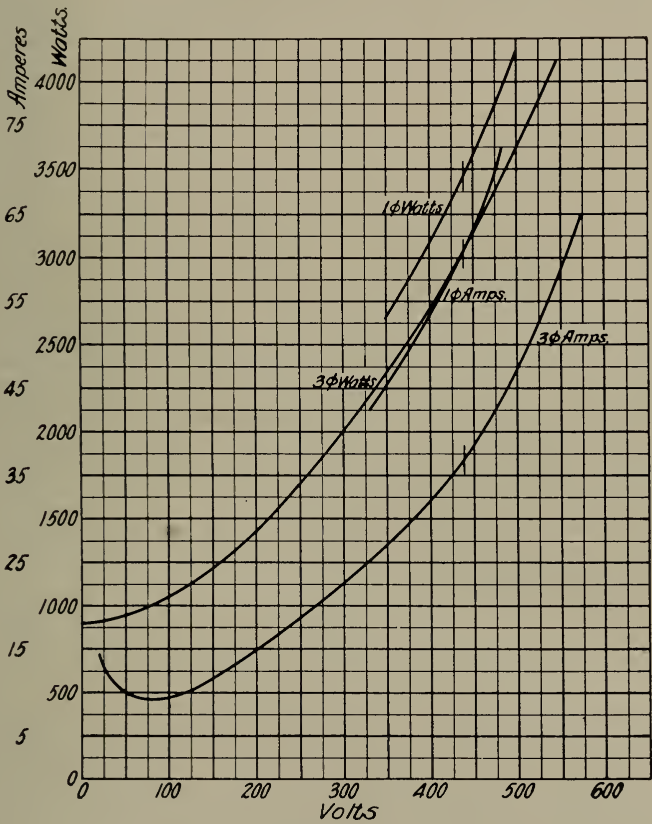

Fig. 99

EXCITATION CURVES ON A 100 H.P., 6 POLE, 500 R.P.M., 440 VOLT, FORM M, 3-PHASE INDUCTION MOTOR

should be taken on each side of normal voltage. The volts and amperes in the different phases should be read at normal volts, and at two or three other points in the curve as a check on the phase balance of the motor. These readings should be recorded.

As the lowest point on the curve is approached, a large number of readings should be taken, since it is from these readings that the friction watts of the motor are determined. In many cases hunting begins at low voltage. This causes the wattmeter needle to swing with a slow beat. Reliable readings can generally be obtained between beats but care must be used to avoid taking readings when the motor is accelerating or decelerating. Bad cases of hunting are not numerous.

As a check on the three-phase curve, single-phase readings of several points around normal volts should be taken on the two phases in which the wattmeters are connected. Volts, amperes and watts should be read as in the three-phase curve, A few check readings should also be made with a different set of instruments. Before shutting down, curves should be plotted using volts as abscissæ, and amperes and the algebraic sum of the wattmeter readings, as ordinates. The single-phase amperes are theoretically 1.73 times the three-phase or twice the quarter-phase amperes. Practically, however, the single-phase amperes have a value from 1.4 to 1.8 times the polyphase, for either three-phase or quarter-phase motors. The single-phase excitation watts generally come about 10 per cent higher than the polyphase on account of higher I^2R losses, the iron losses being practically the same whether the motor is running single-phase or polyphase. The temperature of the laminations should be recorded at the end of the test.

The calculation of the excitation curves is done in the Calculating Room. The instrument readings are corrected by means of the calibration curves furnished by the Calibrating Laboratory. The data are then worked up, and the curves plotted. The data of a calculated excitation test are shown on Calculation Sheet No. 16. Fig. 99 shows a typical set of excitation curves, plotted from this data.

Impedance Curves consist of a series of readings of volts, amperes and watts, taken at different values of current, when the rotor is blocked and short-circuited, the frequency of the applied voltage being constant. The test table arrangement is the same as that for the excitation curve.

The rotor of a squirrel cage (Form K) motor is a symmetrical bar winding; therefore, the impedance of the motor is practically the same for any position of the rotor relative to the stator. In Forms L, M, and P motors having phase-wound rotors the impedance varies with different positions of the rotor relative to the stator. It is therefore necessary to determine the rotor positions at which the impedance is maximum and minimum so that the rotor may be blocked on an average position for the impedance curves. For accomplishing this, a position curve is taken. Before taking the position and impedance curves, the rotor must be short-circuited. This is accomplished in Forms L and P motors by means of the short-circuiting switch and in the Form M motor either by a short cable connected directly to the collector rings, or by short-circuiting the brush-holders, using metallic brushes in order to reduce the contact resistance to a minimum.

Position Curve. In taking the position curve, an angular distance should be marked off on the end shield, equivalent to one-half of a pole pitch for quarter-phase motors, or two thirds of a pole pitch for three-phase motors. This space should then be pointed off into about ten equal parts. A pointer should be attached to the motor shaft or pulley so that its outer end will pass over the division marks. The pointer is first set on position No. 1 and the rotor blocked so that it cannot move from that position. The switches should then be closed

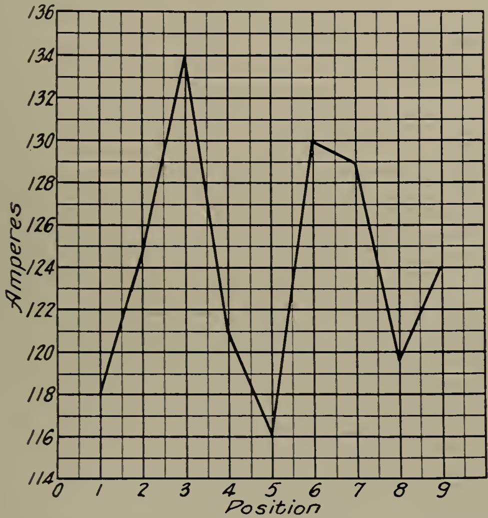

Fig. 100
POSITION CURVE ON A 100 H.P., 500 R.P.M., 25 CYCLE, 440 VOLT, FORM M, 3-PHASE INDUCTION MOTOR
(Test Taken at 63 Volts)

and the impressed voltage increased gradually, until a value of about normal amperes is obtained. Volts and amperes on all three phases should be read and recorded to make certain that there is no unbalancing on the different phases. Holding the same volts as in position No. 1 the rotor should be turned until the pointer is over position No. 2 where the amperes should again be read. This is repeated on each of the succeeding positions. A curve should then be plotted between position number as abscissæ, and amperes as ordinates (when this curve is plotted for Engineering Data, the ordinates used are the amperes at normal volts found by multiplying by the ratio $\left(\frac{\text{normal volts}}{\text{voltage used in test}}\right)$. The rotor is blocked for the Impedance Curve on the position which gives an average value of current. See Fig. 100 and Calculation Sheet 17.

Impedance Curve

Having blocked the rotor in any convenient position, in the case of a squirrel cage rotor, or on the average position as shown

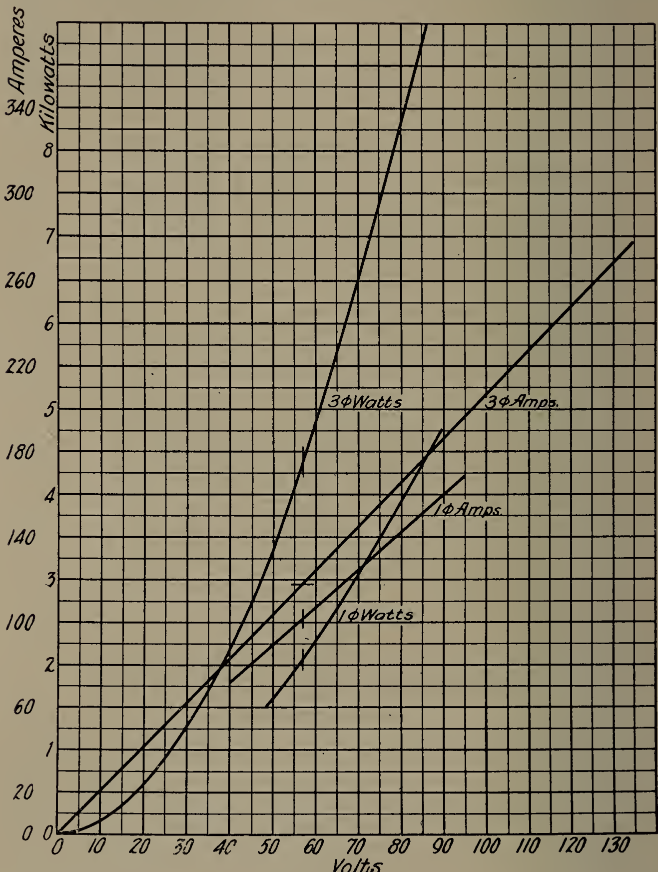

Fig. 101

IMPEDANCE CURVE ON A 100 H.P., 500 R.P.M., 25 CYCLE, 440 VOLT, FORM M, 3-PHASE INDUCTION MOTOR

by the position curve in the case of a phase-wound rotor, the impedance curve may now be taken. The readings of volts, amperes and watts should be taken beginning at the lower part of the curve, the current readings increasing in steps until a a value of 150 per cent normal amperes is reached. Up to this point about 12 or 15 readings should be taken, special care being used to get several good readings at and near normal amperes. Above the 150 per cent normal ampere point the wattmeter readings may be discontinued, the curve of volts and amperes alone being extended with several points, to a value of 300 per cent normal amperes. Great care must be used not to overheat the motor windings. A set of phase-balance readings should be taken at normal amperes. Single-phase check readings should be made on the two phases in which the wattmeters are connected, at a voltage equal to that necessary to obtain normal amperes on the three-phase curve. The single-phase impedance amperes should be $\frac{\sqrt{3}}{2}$ times the three-phase at the same voltage. The single-phase impedance watts should be ½ the three-phase at the same voltage. In taking the curve data, the current should not be held on the motor any longer than is necessary to secure a reading. After each reading the exciter switch should be opened until ready to take the next reading, thus keeping the temperature of the motor more nearly uniform. Final temperatures of the rotor conductors should be recorded.

Curves should be plotted using volts as abscissæ, with amperes and the algebraic sum of the watts as ordinates. The volt-ampere curve is a straight line, curving slightly upward on the higher values. Single-phase amperes are practically equal to the polyphase, in the case of quarter-phase motors; or about 86 per cent of the polyphase for three-phase motors. Single-phase watts should be about one-half of the polyphase, for either quarter-phase or three-phase motors.

The calculation of the impedance curves is done in the Calculating Room. The data of a calculated impedance test is shown on Calculation Sheet No. 19. Fig. 101 shows a typical set of impedance curves, plotted from the data given there.

Slip Curve. There are several methods employed by the Testing Department for measuring the slip of induction motors, among which the following are the more important: First, by means of a slip indicator; second, by means of an arc lamp and revolving disk; third, by means of a voltmeter; and fourth, by means of a revolution counter.

The method employing the slip indicator is the one most commonly used. The construction and operation of this instrument are described in detail in Chapter 2, page 27.

The arc light and revolving disk method is a good one but it requires more time to set up the apparatus than does the slip indicator method. A disk (see Fig. 102) having as many white and as many black sectors as there are poles on the motor, is attached to the shaft of the motor, so that it revolves with it. This disk is illuminated by an alternating current arc lamp which is operated from the same alternator as the motor. Assume a six pole 60 cycle motor running at the synchronous speed of 1200 r.p.m. or 20 revolutions per second. Then 20×6 or 120 black sectors pass a stationary point on the circumference of the disk, in one second. As the frequency is 60 cycles, the arc lamp will give 120 maximum illuminations per second. The black sectors would therefore appear to be stationary. Practically, the induction motor cannot run at synchronous speed, and the slip, at each maximum illumination will cause each black sector to lie a small angle behind that seen by the previous illumination. These successive differences in position appear as sectors rotating backwards, which can be followed by the eye. The difference between the actual speed and the synchronous speed of the motor can be counted.

Fig. 102

DISK FOR MEASURING SLIP OF SIX-POLE MOTOR

The voltmeter method affords a very accurate and convenient scheme for measuring the slip of motors having collector rings. The alternating voltage drop across the brushes is read by means of a low reading d-c. voltmeter. Every time the rotor slips an angular distance of two poles behind the synchronous revolving field of the stator, a complete voltage cycle is generated in the rotor winding. The d-c. voltmeter will be deflected in a positive direction every alternate half wave or once every cycle. Therefore, by counting the number of positive beats per minute of the voltmeter and dividing this value by one half the number of poles, the slip of the motor is obtained in revolutions per minute.

The method employing a revolution counter is generally used in the case of high speed machines where it is not possible to measure the slip by any of the methods above described. It consists in reading the number of revolutions of the rotor for a known interval of time by means of a revolution counter. The difference between the speed thus measured, and the synchronous speed, gives the slip of the motor in rev. per min. Several readings should be taken and averaged, when this method is employed.

In all of the foregoing methods for taking slip, it is very necessary that the load and impressed voltage on the motor, and the *frequency of the driving alternator, remain constant while the readings are taken and in each case the speed must be checked with a speed counter.*

Slip readings must always accompany heat runs. When special tests are made, a slip curve should always be taken. This curve must have readings at no load, and at 50, 75, 100

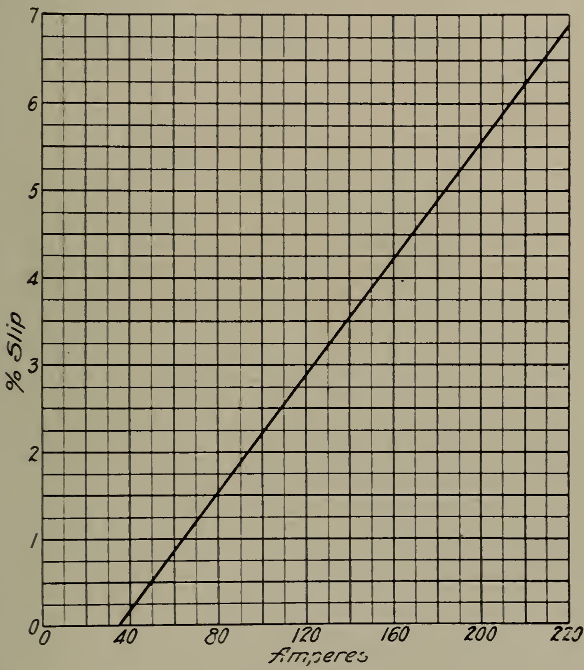

Fig. 103

SLIP CURVE ON A 100 H.P., 500 R.P.M., 25 CYCLE, 440 VOLT, FORM M, 3-PHASE INDUCTION MOTOR

and 125 per cent of normal load amperes. Sometimes it is not possible to hold normal voltage on the motor on account of the large amount of power necessary. In such cases the highest obtainable voltage should be held and the voltage and current should be reduced from normal in the same proportion. The motor should always be heated to its normal running temperature at the time the slip readings are taken. All readings of volts, amperes, and slip must be recorded. A typical calculation of a slip curve may be found on Calculation Sheet No. 18. Fig. 103 shows a slip curve plotted from the data given.

Stationary Torque Tests. Two methods are employed for measuring stationary torque, one in which a spring balance is used, the other in which a special torque indicator is used, each in connection with a lever arm attached to the shaft. The first method applies to motors having squirrel cage rotors, in which the torque is practically constant for varying positions of the rotor relative to the stator. The second method is used on motors having phase-wound rotors, in which the torque is not constant for all positions of the rotor.

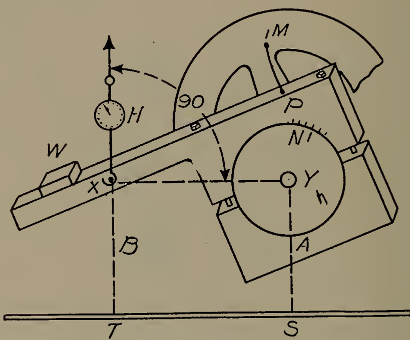

Fig. 104
MEASUREMENT OF TORQUE BY MEANS OF SPRING BALANCE

In the first method the lever is clamped to the pulley or shaft as shown in Fig. 104. The size and length of the lever depends on the rating of the motor, the lever and spring balance being chosen to give a maximum reading at about ⅔ of the capacity of the balance used. Torque at 1 ft. radius $= \frac{5250 \times \text{h.p.}}{\text{r.p.m.}}$ In estimating the length of lever needed, allowance should be made for at least 175 per cent of full load torque. The balance and length of lever L should be chosen to make $(W+F+T)$ (see below) equal to at least twice $(W+F)$. Let the point of attachment to the lever be at X. Then XY = the length of the lever arm. On the frame of the motor, a mark should be made at M, corresponding to the position of the pointer P, when the distances TX and SY are equal. If the weight of the lever is not sufficient to overcome the friction of the bearings and allow it to turn downward of its own weight, attach the additional weight, W. Open all line switches, thus doing away with any torque effect resulting from residual magnetism of the alternator field. By means of a suitable windlass, raise the lever slowly, pulling vertically on the spring balance H. As the pointer passes the mark M read the tension as indicated by the balance. Call this reading $(W+F)$, W being the force due to the weight of the lever and F

the force due to bearing friction of the motor. Raise the lever until the pointer is some distance beyond M, then lower it slowly allowing the force of gravity to pull it toward the floor. When the pointer passes the mark M, the spring balance should again be read. Call this reading $(W-F)$. The lever should be moved as steadily as possible, otherwise the tension indicated by the spring balance will fluctuate. Several readings should be taken as described above.

Now close the line switches and bring up the line current gradually to a value of 200 per cent normal amperes. In so doing, watch the motor carefully to see that it does not tend to turn in the wrong direction. Take readings in the same manner as that just described. Call the reading taken as the lever is raised $(W+F+T)$, and that taken as it is lowered $(W-F+T)$, T being the force due to the stationary torque of the motor. The readings should be recorded as follows:

Volts Amperes $(W+F)$ $(W-F)$ $(W+F+T)$ $(W-F+T)$ T. Solving for the value of T, and knowing the length of the lever arm in feet, L, the stationary torque is calculated from the formula

$$\text{Stationary Torque} = \left(\frac{\text{Normal volts}}{\text{Volts held}}\right)^2 \times L \times T$$

Care must be taken to see that the motor does not overheat. To get reliable readings the frequency of the alternator must be held constant. If any variation of $(W+F+T)$ and $W-F+T)$ should occur with change of rotor position, the maximum and minimum values should be recorded. As a check on the readings taken, the lever should be loosened and the rotor turned to a different position relative to the stator. Here the lever should be again clamped to the shaft or pulleys and readings of $(W+F+T)$ and $(W-F+T)$ taken. This should be repeated for several different positions. The temperature of the rotor conductors must be taken and recorded at the end of the test.

The second method of taking torque applies to Forms L, M and P motors having phase-wound rotors. The data is taken by mean of a special torque indicator described in detail in Chapter 2, page 29. The indicator must be fastened to the lever arm so that the rope pulls vertically upward on the instrument. The cord used should have no tendency to twist when decreasing in length. In taking the torque cards, the diagram need cover but one pole-phase, to represent a complete torque cycle of the motor. The purpose of the indicator is to show the minimum torque effect exerted by the motor.

On Form L motors two torque cards should be taken; one with the secondary starting resistance in, the other with it all cut out. A current of one-half normal amperes should be held for the reading with resistance in. Normal amperes should be held for the card taken with the resistance cut out. The motor should be carefully watched to see that the secondary resistance does not become too hot. Temperatures of the rotor must be recorded.

On Form M and Form P motors, torque cards are generally taken with different values of secondary resistance. Sometimes the secondary resistance is changed by changing the leads to the grids, and often by means of a controller. Whenever the test is made with a controller, a torque card should be taken for each controller position. The current held for these cards should be as near normal as the heating of the motor and grids will permit. The grids must not be allowed to become too hot, since this would lead to unreliable results, on account of the

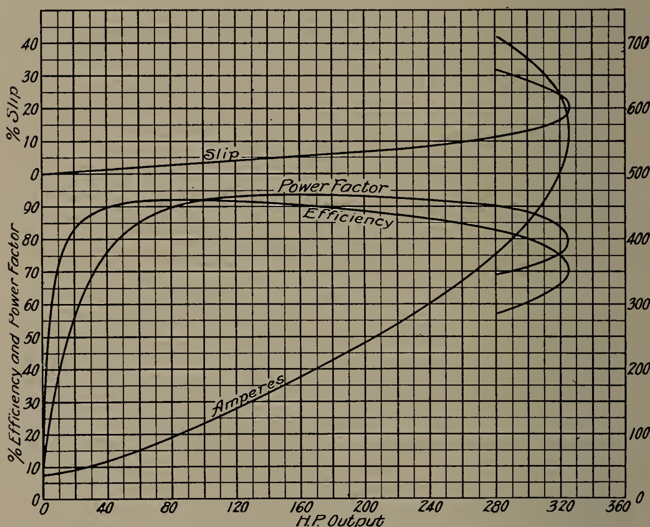

Fig. 105

CHARACTERISTIC CURVES OF A 100 H.P., 500 R.P.M., 25 CYCLE, 440 VOLT, FORM M, 3-PHASE INDUCTION MOTOR

rapid change in resistance with change of temperature. Temperatures of the rotor and grids should be recorded for each card taken. Calculation Sheet 22 shows the results of this test

Starting tests are closely associated with the torque tests just described. They are generally taken according to instructions given by the Engineering Department.

Characteristic curves of the Induction Motor are calculated from the data obtained from the special tests. The data of a calculation are shown on pages 439 to 445 and Calculation Sheets 20 and 21. The corresponding characteristic curves are given in Fig. 105.

The data used in the calculation are taken from the excitation curves (Fig. 99), the Impedance Curves (Fig. 101) and the slip curve (Fig. 103).

COMPLETE TESTS consist of normal and overload heat runs and special tests.

SPECIAL OVERLOAD HEAT RUN consists of bringing the machine to normal load temperatures, then applying 50% overload for two hours and recording temperatures, then applying 25% overload until constant temperatures are reached and recording temperatures.

LONG COMMERCIAL TEST consists of taking equivalent load heat runs, readings of excitation and stationary impedance.

GENERAL TESTS consist of taking excitation and impedance tests with wattmeters, single-phase, at points near normal voltage and normal current respectively.

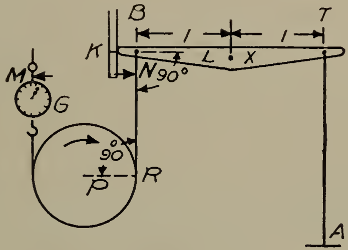

Fig. 106
DIAGRAM OF APPARATUS USED IN TAKING INPUT-OUTPUT BY THE STRING BRAKE METHOD

STANDARD EFFICIENCY AND POWER-FACTOR TESTS consist of calculating from general or special tests the efficiency and power-factor at any load.

INPUT-OUTPUT EFFICIENCY AND POWER-FACTOR TESTS consist of determining the efficiency and power-factor directly by the input-output method with wattmeters.

They can be made either by the "String Brake" or "Electrical Load" methods. Neither of these methods is particularly accurate nor are they recommended. In certain cases, however, these tests are made on Induction Motors.

String Brake Method

In Fig. 106 *L* is a lever or scale beam suspended at the point *X*. From *T* the small platform *A* is suspended, on which calibrated weights are placed. *P* is a *flat* faced pulley on the shaft of the motor running in the direction shown by the arrow, i.e., toward the lever *L*. One end of a small rope is attached at *B*, which is wound one or more times around the pulley. The other end is made fast to a spring balance *G*. A strip bearing a mark is located at *K* so that when the point of the lever *L* comes opposite to the mark, the lever is in a horizontal position at an angle of 90 degrees to the force exerted by the pulley.

Since the stress along a rope is transmitted through its center, adjust the brake until the points *M* and *N* are a distance apart equal to the diameter of the pulley plus the diameter of the rope, one-half the diameter of the rope being added to each side of the pulley. This adjustment must be carefully made and care taken to see that nothing moves to throw the brake out of line or proper adjustment. When ready, slip one turn of the rope off the pulley but leave it attached at *B* and *G*, then balance the lever until the pointer on the end comes to rest at the mark *K*. This balancing of *L* must be repeated each time the rope is changed.

The motor should be run light for at least one hour before the test proper is commenced, so that friction may become constant. Since speed is one of the important factors in the output of the motor it should be taken very carefully.

Running light readings should now be taken on the motor. The voltage impressed on the motor should be held constant as well as the impressed frequency. Attach a small weight to the spring balance to give enough tension on the spring for a reading on the balance of a quarter or half a pound. This "no load" scale reading must be recorded and subtracted from all subsequent readings taken.

Put a small weight on *A* and pull up on the spring balance *G* until the pointer on lever *L* reaches *K*. Then when the motor volts and speed of the generator are normal and all meters are steady, read and record volts, amperes, watts, weights on *A*, spring balance reading and speed given by the tachometer. A reading should also be taken of the slip. Add more weight to *A* and take another reading, continuing in this manner until the breakdown load of the motor is reached. For an induction motor the readings should be recorded in the following manner:

Volts	Amps.	+Watts	−Watts	Weight on *A*	Tension on balance	Slip	Speed of Motor

A rope of small diameter gives better results than a larger one, even though it may require more time to make the tests on account of having to renew it more frequently. On motors up to 20 h.p. a ¼ in. oiled hemp rope is best and a ½ in. rope can be used up to 50 h.p. The rope will last longer, usually, if doubled and two strands used in parallel. The rope turns around the pulley should all lie closely and evenly together on the face of the pulley. The tension read on the balance *G* will vary with the temperature of the rope and may differ widely with different loads.

The additional weight put on *A* each time should be such as to give from fifteen to twenty readings between no load and breakdown.

When the breakdown point has been reached and complete readings taken and recorded the diameter of the pulley should be carefully measured.

(Weight on A) − (tension on balance) − ("no load" reading on balance) = actual load in pounds = P.
(Normal speed) − (slip) = actual speed of motor.
R = (Radius of pulley in inches) + (½ diameter of rope.)
S = Speed in revolutions per minute.

$$\text{Power-factor} = \frac{\text{Watts}}{\text{Volts} \times \text{amps.}}$$

$$\text{Then H.P.} = \frac{2\pi R \times P \times S}{12 \times 33{,}000}$$

$$\text{Efficiency} = \frac{\text{H.P. output} \times 746}{\text{Watts input}}$$

When making any special test, the tester should see that the tests check among themselves before handing them in.

Efficiency by the "Electrical Load" Method

Consider Fig. 107; let M be the motor and L the load machine. This should be of about an equal capacity and be belted to

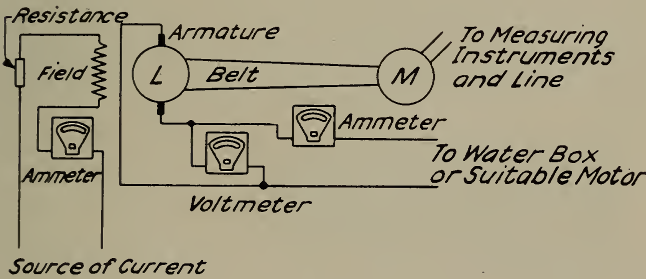

Fig. 107
CONNECTIONS FOR MEASURING INPUT-OUTPUT BY "ELECTRICAL LOAD"

the motor M. It should be a direct current machine, and must be separately excited from a suitable source of energy.

To take the efficiency test, connect M so that the total input can be obtained. Separately excite the field of L, connecting an ammeter and a variable resistance in circuit. Connect the armature of L to a water-box or a motor the load of which can be varied, placing an ammeter in the circuit and a voltmeter across the brush terminals. If the test involves a considerable range of speeds, run M over that range, and hold the field current of L constant, its value being such that the speeds or loads required for M can be obtained.

Having made the necessary connections, etc., keep the field current of L constant at its predetermined values. Vary the load on L by changing the water resistance or the load on the motor to which it is connected, to suit the testing conditions required on *M*. The efficiency of *M* may be required for a series of speeds or loads. Read the input and speed of *M*, and the volts and amperes of *L*, keeping the field of *L* constant and noting its value. The "counter torque" must now be obtained to complete the calculations.

To obtain this, disconnect *M*, connect *L* to a source of current which can be varied so as to give *L* different speeds, keeping *L* separately excited. Run *L* as a motor driving *M*, keeping the field current of *L* constant with the same value it had when *L* was used as a generator.

Vary the speed of *L* so that the speed of *M* can be varied slightly below its previous minimum speed to slightly above its maximum speed. Take a number of readings at varying speeds, reading volts and amperes input of *L* and speeds of *L* and *M*. If the electrical efficiency alone is desired (case A), sufficient readings have been taken. If the commercial efficiency is desired (Case B), take off the belt from *L*, and run it light as a motor. Vary its speed from slightly below to slightly above the speeds used before when running as a motor, and take a number of readings at different speeds, reading volts and amperes input and speed, separately exciting *L*, with the same current used in the two previous cases. The necessary readings are now complete for calculating the efficiency.

Case A

Let *Wm* be the total input of *M*.

Let *Wl* be the product of volts and amperes read for *L*.

Let *Fm* be *M's* friction, windage, etc.

Let *Fl* be *L's* friction, windage, etc.

Divide the belt friction equally between *L* and *M* including this in *Fm* and F*l*.

Let *R* be the hot resistance of *L's* armature, which must be measured.

Let *I* be the current in *L's* armature.

Then electrical efficiency $= \dfrac{Wl + I^2R + CT}{Wm}$ where *CT* is the mechanical losses in *L* and *M* and the belt loss.

Case B

Commercial efficiency $= \dfrac{Wl + I^2R + C'T'}{Wm}$ where $C'T'$ is the mechanical losses of *L* including belt loss.

In running the counter torque curves, the field of *L* must be held constant throughout, and readings must not be taken when accelerating.

HIGH POTENTIAL TESTS should be taken on all induction motors as called for in the Engineering Instructions.

CHAPTER 13

STEAM TURBINES

Since the horizontal type of turbine has almost entirely supplanted the vertical type, the following instructions and illustrations will refer principally to the horizontal machines. However, the work of operating and testing is practically the same for both types, except in certain features which will be dealt with separately, and the instructions may, in general, be considered as applying to both types.

Nomenclature

Due to the radical differences in construction of the steam turbine from that of any other prime mover, there are many parts more or less unfamiliar to the average engineer. To secure uniformity in the designation of parts, thus avoiding any uncertainty and unnecessary delay, Figs. 108 and 109 should be carefully studied until thoroughly familiar.

The number of stages of both vertical and horizontal machines is indicated by the following form letters.

No. of Stages	Vertical	Horizontal	No. of Stages	Vertical	Horizontal
1		A	7	M	P
2	B	C	8	Q	R
3	D	E	9	S	T
4	F	G	10	U	W
5	H	J	11		AA
6	K	L	12	BB	CC

Generators are indicated thus:

Type	Form
ATB Vertical	T
ATB Horizontal	HT
CC Horizontal	T

Tests

Tests on a steam turbine may be divided into two classes, *Commercial Tests* and *Special Tests.*

For *commercial tests* the turbine is assembled in Building No. 60, and is operated non-condensing at practically no load, and without regard to any definite steam pressure or superheat. The tests consist of dynamic balance, adjustment of operating and emergency governors, and the inspection of the

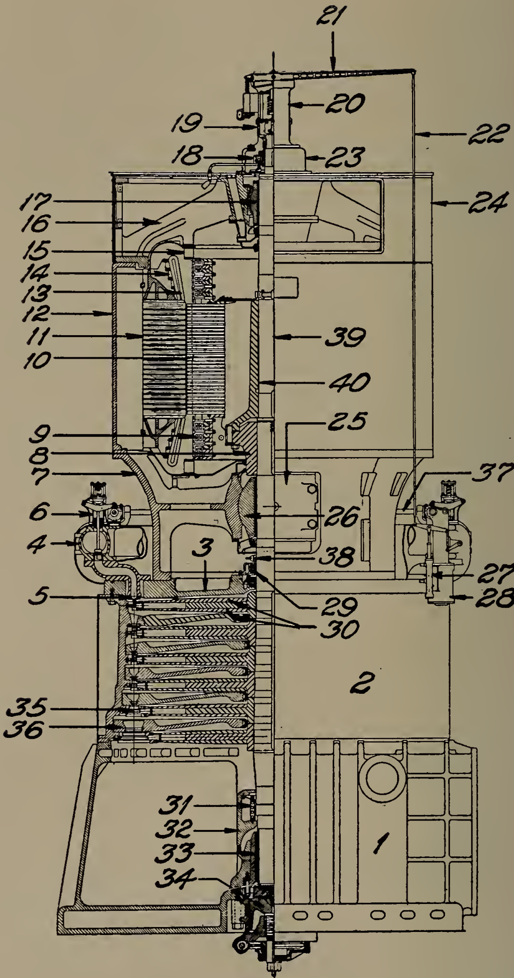

Fig. 108

VERTICAL TURBINE AND GENERATOR

PARTS OF VERTICAL CURTIS TURBINE AND GENERATOR (See Fig. 108)

1 Condenser base
2 Intermediate holder
3 Turbine head
4 Steam chest
5 First stage nozzle
6 Operating valve
7 Generator stool
8 Coupling
9 Ends of field coils
10 Field core
11 Armature core
12 Armature spider
13 Armature coils
14 Coil supporting rings
15 Ventilating fan
16 Top bearing bracket
17 Top bearing
18 Collector and brush-holder
19 Operating governor
20 Governor dome
21 Governor beam
21 Governor beam
22 Governor rod
23 Governor dome stool
24 Ventilating hood
25 Mid bearing cap
26 Mid bearing
27 Pilot valve chest
28 Hydraulic cylinder
29 Head end carbon packing rings
30 First stage wheel
31 Exhaust end carbon packing rings
32 Packing ring dome
33 Guide bearing
34 Step bearing
35 Intermediate buckets
36 Nozzle diaphragm
37 Cam shaft
38 Emergency governor
39 Shaft
40 Field spider

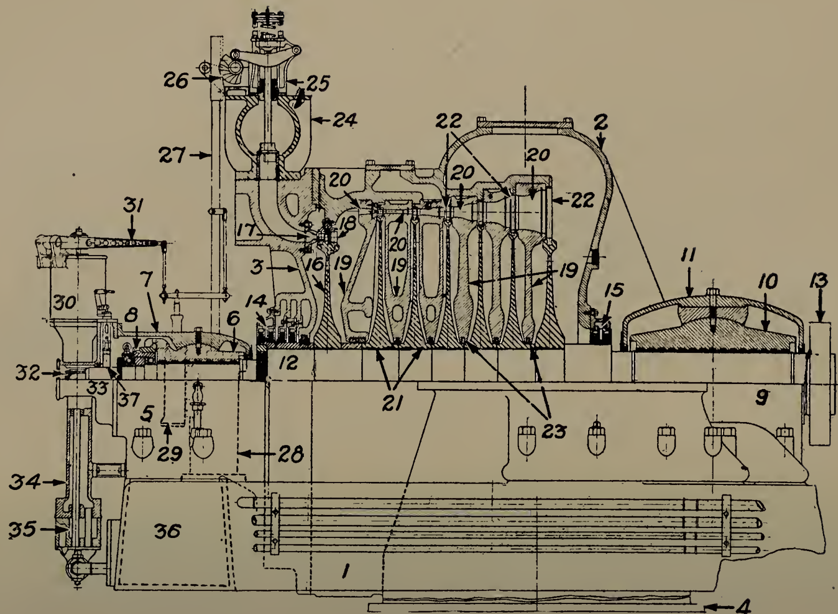

Fig. 109
HORIZONTAL CURTIS STEAM TURBINE

PARTS OF HORIZONTAL CURTIS STEAM TURBINE (See Fig. 109)

1 Turbine base
2 Top half turbine shell
3 Turbine head
4 Exhaust connection
5 Turbine end bearing standard
6 Top half turbine end bearing
7 Bearing cap
8 Thrust bearing
9 Middle bearing standard
10 Middle bearing
11 Bearing cap
12 Shaft
13 Coupling
14 Head end carbon packing
15 Exhaust end carbon packing
16 First stage wheel
17 First stage nozzle
18 First stage wheel bucket
19, **19** Nozzle diaphragms
20, **20** Nozzles
21 Wheels
22 Wheel buckets
23 Diaphragm packing
24 Steam chest
25 Controlling valves
26 Cams and cam shaft
27 Hydraulic piston rod
28 Hydraulic cylinder (shown dotted)
29 Pilot valve chest (shown dotted)
30 Governor dome
31 Governor beam
32 Spiral gears
33 Gear casing
34 Pump shaft casing
35 Gear pump
36 Oil tank (shown dotted)
37 Emergency governor

unit, complete with its generator, for proper assembly and satisfactory mechanical and electrical operation. All machines must be assembled complete in all details and pass inspection before leaving the factory.

Special Tests include in addition to commercial tests, steam consumption and efficiency tests. For this purpose machines are set up and run in Building No. 61, where provision is made for obtaining any desired steam pressure, superheat, and vacuum and for loading on water boxes.

Steam, Exhaust and Oil Piping

For the commercial tests in Building No. 60, steam is piped from the Power Station in Building No. 61 through two 12 inch mains. These mains enter Building No. 60 at the front of the building and are carried overhead to the testing section. One main runs along the test gallery and then enters a duct where it connects with the other main which has been brought down on posts nearer the side of the building. Through the duct the main is brought around to the front of the test floor. Taps are made to the main at each test stand. At the points where the steam mains enter the test, are located in each main electrically operated valves. The valves are provided with controlling switches located at easily accessible points about the test floor and gallery. These valves are for emergency use only. It must be remembered that they control the steam for all pressure pumps as well as steam for the turbines, hence must be used only as a last resort. All men should become familiar with their location and method of operation. Two main exhaust lines are provided. They run under the gallery and across the test floor at the upper end of the test. The upper main leads to the atmosphere, and also to the factory heating system. This main may be connected directly or through lateral sub-mains to any stand on the test floor.

The lower main leads to a 6700 sq. ft. Worthington condenser located in a pit under the gallery, and is available for use on about half of the test stands. Machines to be loaded are connected to this main, but through a header provided with valves by means of which the machine may also be connected to the atmospheric main. The exhaust headers are also provided with drains, and these may be connected with the condenser or the atmosphere as occasion demands.

There are four pressure oil lines. One line known as the "small accumulator" line, has connections at every stand on the test floor. The small accumulator is located in the small pump pit and maintains a pressure of about 125 lb. per sq. in. The object of the accumulator is to reduce the pulsation in the line due to the stroke of the pumps, and also to hold a small reserve of oil under pressure long enough to allow a change of pumps in case of a break down. This pressure line is used on the oiling system and the governor valve hydraulic mechanism of all vertical machines, and on the oiling system of horizontal machines not provided with an auxiliary steam pump until such time as they may be ready to have their gear pumps assembled.

The other three lines can be connected only to the testing stands on that section of the floor used for vertical machines. Of these lines, one is the "step" or "large accumulator" line, and supplies oil at a pressure of 1150 lb. per sq. in. for use on step bearings. The large accumulator is located in a separate pit with the step pumps, and is used for the same purpose as the small accumulator on the low pressure line.

The remaining two lines are known as the "variable pressure" lines and are not connected to an accumulator, but by means of adjustable relief valves may be operated at any pressure desired. They may be used on water pressure if necessary to supply a water step bearing. All oil is drained back into a common supply tank located in one of the pump pits. All steam piping is under the supervision of one man, not a test man, who will take care of the opening and closing of all steam valves, except the valve nearest the machines under test. This last valve, that is, the valve controlling a single machine, will be operated by the man in charge of the tests on the machine. The test man will be responsible for the exhaust valves.

The oil system, pumps and condensers are in charge of a pump man who will take care of all valves except those connecting directly with the machines under test.

Instruments

With the exception of electrical instruments, transformers, and thermometers, all instruments used on turbine test, such as gauges, tachometers, air-measuring devices, etc., are kept in the turbine test supply cupboards in charge of the pumpman. They are given out on receipt in the same way as instruments at the Instrument Rooms.

Special Instructions

In addition to instructions given in this book, there will be found further written instructions in a folder on the shelf near the door of the turbine test office. These written instructions take up some matters more in detail than would be desirable here, and also give special instructions which are subject to change at intervals. Hence this folder should be consulted frequently.

Preparing Machines for Test

When a machine is first delivered to the Testing Department the turbine only is assembled and made ready for wheel balance. Considering a horizontal machine, the first step is to test out the cooling coils in the bearings for water leaks. See Fig. 110.

Water should be turned on and the *oil* drains from the bearings watched for indications of water which might leak through inside the bearings.

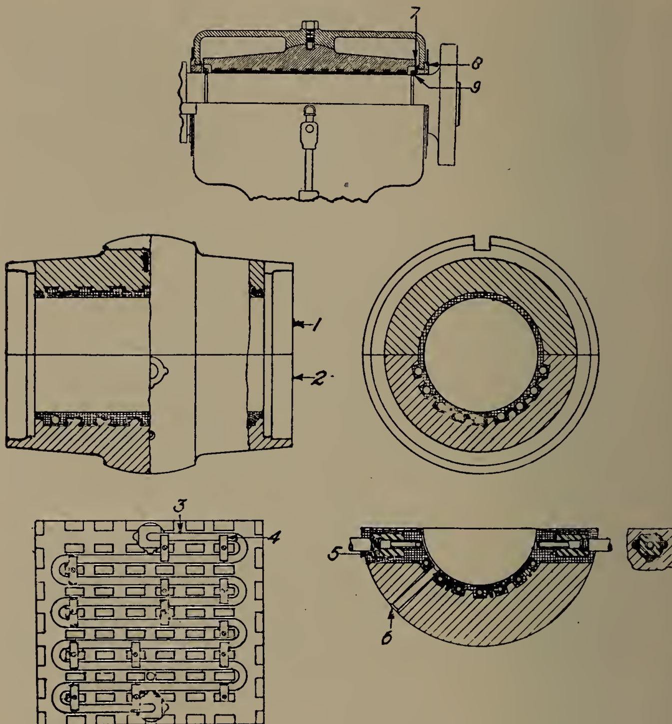

Fig. 110

BEARING (WATER COOLED, HORIZONTAL TURBINES)

1 Top half bearing
2 Bottom half bearing
3 Cooling coil
4 Retaining clip for (3)
5 Terminal block for (3)
6 Oil feed inlet
7 Oil guard for bearing shell
8 End packing ring for bearing standard
9 Oil deflector ring

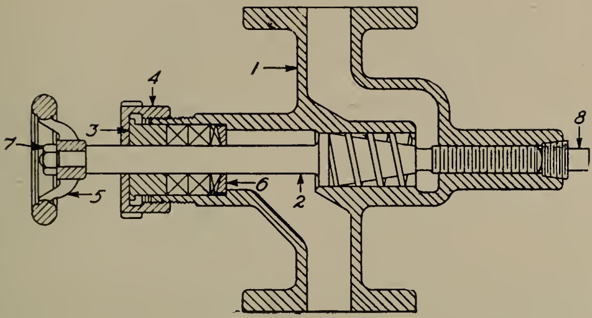

Fig. 111

ADJUSTABLE REDUCING BAFFLER FOR REGULATING BEARING PRESSURES (HORIZONTAL TURBINES)

1 Reducing baffler frame
2 Reducing baffler plug
3 Stuffing gland for (1)
4 Nut for (3)
5 Handwheel for (2)
6 Support for packing
7 Nut for (5)
8 Pipe plug for (1)

Any trace of water escaping into the oiling system should be reported at once, and corrected before proceeding further. If, however, there is no apparent leakage, the oil tank may be filled, or oil turned on from the low pressure test system. It is only on such machines as are not equipped with an auxiliary steam pump that the department oil system is used, and then only during balance work. The auxiliary steam pump, when used, must be provided with a lubricator which must be in operation whenever the pump is working.

With pressure on the oiling system, look over the machine for leaks in the piping, and if all right, set the pressure at 15 to 20 pounds by means of the adjustable baffler shown in Fig. 111.

Before turning steam into a machine each bearing must be inspected for oil flow. It is not enough to inspect the pressure gauge only, as one bearing may have its flow entirely cut off and still the gauge would read properly. The proper amount of cooling water to be used on the bearings is better ascertained after the machine has been run at normal speed a short time. The quantity, which is adjustable at each bearing, should be such that the water is lukewarm as it leaves the bearing. Using a larger quantity is wasteful, and unnecessary.

The oiling system of the vertical machine differs from that of the horizontal machine in several respects. Oil pressure is always supplied from the shop system, and the flow to each

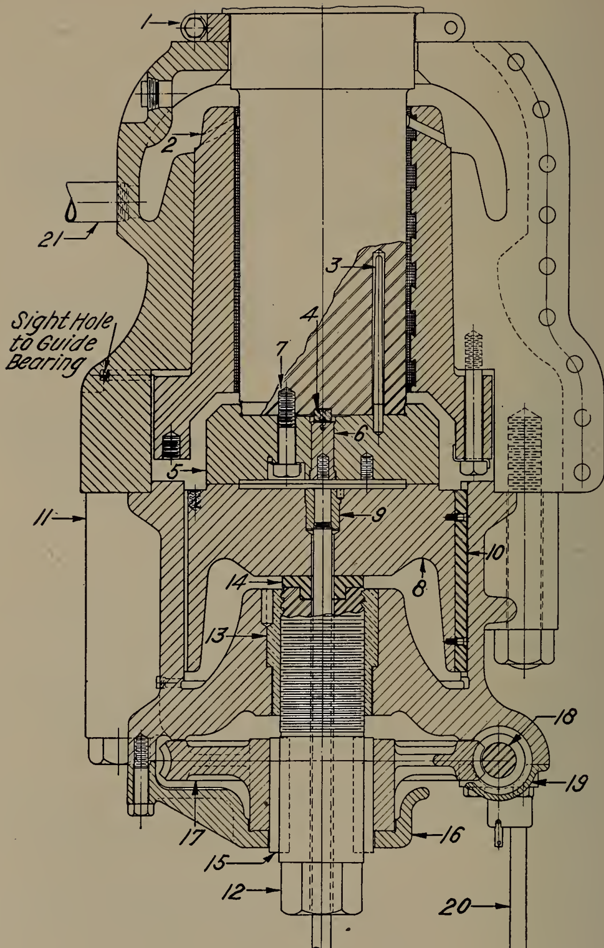

Fig. 112
STEP BEARING

DETAILS OF STEP BEARING (Fig. 112)

1 Collar for supporting rotor when removing bearing
2 Step guide bearing with holding bolts and keepers
3 Guide pin
4 Key for driving (5), with screws
5 Revolving step plate
6 Plug for (5)
7 Bolts and keepers for fastening (5) to shaft
8 Stationary step plate
9 Bushing and pin for (8)
10 Key for driving (8), with screws
11 Step bearing head with bolts
12 Adjusting screw
13 Threaded bushing and pin for step bearing head
14 Hardened steel cap for (12)
15 Key for driving (17) by (12)
16 Supporting bracket for (17), with bolts
17 Worm wheel for adjusting device
18 Worm and worm shaft for adjusting device
19 Bearing cap for (18) and (11)
20 Ratchet handle for adjusting device
21 Drain for step bearing

bearing is regulated by individual bafflers. Fig. 113 shows the type of step baffler used in test. This is the old style of baffler, and is not a part of the permanent equipment of the machine. The new type will be shown later. The top and middle bearings are supplied from a manifold, and the flow regulated

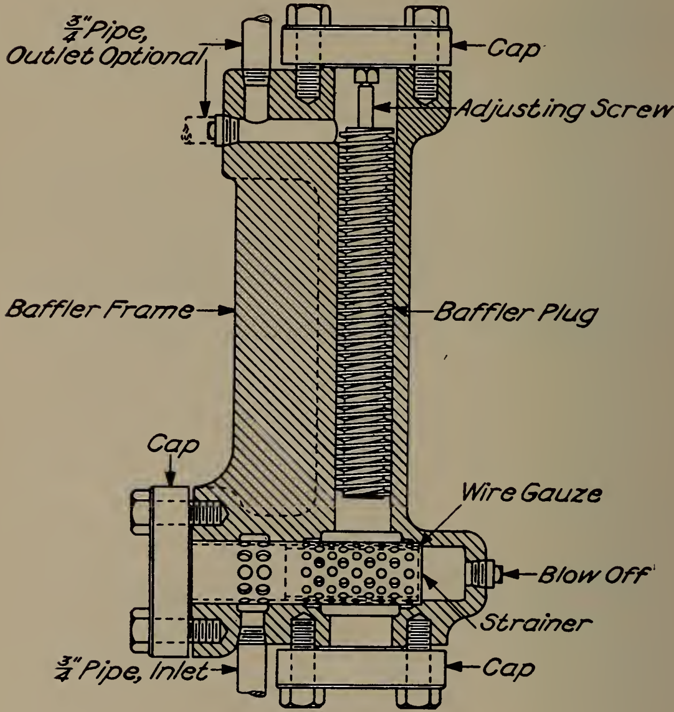

Fig. 113
STEP BEARING BAFFLER (OLD TYPE)

by bafflers similar to those used on horizontal machines. These bearings are not water cooled. The step bearing (see Fig. 112) is piped from the large accumulator line and special care must be used in handling this high pressure. It should be remembered that the valve stem on the hydraulic valve used in all high pressure lines is free to turn entirely out of the body of the valve. These valves should be opened six turns only. If opened further than this the result may be disastrous.

LUBRICATION OF VERTICAL TURBINES

Rating		Stages	Speed	Gallons of Oil per Minute				Lb. per Sq. In.			
Kw.	Kw. Max.			Step Bearing	Guide Bearing	Hydraulic Cylinder	Total	Step	Baffler Drop	Pump	Gear and Guides
500		2	1800	2	1	1.5	4.5	180	45	225	
500		4	1800	3	0.75		3.75	160	290	450	
	750	2	1800	3	1.5	2.5	7	290	60	350	120
800		4	1500	4	1.5	2.5	8	230	65	295	
1000		4	1500	4	1.5	2.5	8	250	65	315	
1000		4	1200	4	1.5	2.5	8	240	65	305	
	1500	4	1500	4	1.75	2.25	8	320	65	385	120
	1500	4	1800	4	1.75	2.25	8	320	65	385	
1500		4	900	4.5	1.5		6	475	425	900	
2000		4	750	9	2	5	16	450	90	540	
2250		4	900	9	2	5	16	400	90	490	
	2500	4	900	4.5	1.5		6	525	425	950	
3000		4	720	12	2.5	6.5	21	560	100	660	
	3500	4	750	9	2	5	16	625	100	725	
	3750	4	900	9	2	5	16	525	100	625	120
5000		5	750	15	3	7	25	800	150	950	
5000		4–5	500	8	3	5	16	550	120	670	
8000		5	750	18	3	9	30	880	150	1030	
	5000	4	750	12	3	6	21	825	120	945	120
	9000	5	750	15	4	8	27	900	150	1050	
	14000	5	750	18	4	10	32	900	150	1050	
	15000	6	750	20	4	12	36	850	150	1000	120
	20000	6	750	25	4	14	43	950	150	1100	120

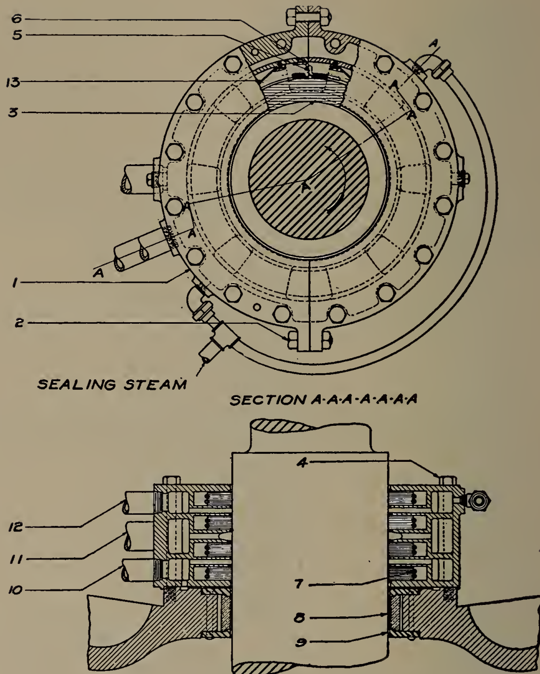

Fig. 114

CARBON PACKING (FLOATING RING TYPE)

1 Carbon packing casing (half)
2 Clamp bolt for (1)
3 Carbon ring segment
4 Retaining bolts for casing
5 Stop for carbon rings
6 Bracket for (5)
6 Garter spring
8 Alloy packing ring
9 Retaining ring
10 Drain to 2nd stage shell
11 Drain to 3rd stage shell
12 Drain to atmosphere
13 Supporting spring

In turning oil on the step bearing proceed as follows:

Open the valve until the step is raised and note the gauge pressure. Then close the valve, allowing the step blocks to come together again. Now open the valve very slowly, and watch the gauge. Hold the pressure between 90 and 95 per cent of that required to raise the step, and watch for oil leakage at the drain from the step. At this pressure the step will not be raised, and if the blocks are parallel the leakage between them will be practically nothing. However, if the blocks are not quite parallel there will be an opening on one side which will allow a considerable flow of oil.

Having ascertained that the step blocks are all right the valve should then be opened to give about a quarter of the required flow, and the step bearing and pipes allowed to become warm. This must be done since the oil will not drain away from the step rapidly enough to prevent flooding when cold. The oil in the supply tank is kept at a temperature of 45 to 51 deg. cent. and a short time should be sufficient to warm up the bearing and drains. The valve may then be opened the full six turns.

A table of the flow and probable pressures for various machine capacities is given on page 239.

This table is calculated for machines that are completely assembled.

It is usually necessary to readjust the baffler between the periods of adjusting wheel and field balance.

Oil leaks in the step bearing should be carefully watched for, and remedied before starting the machine.

Carbon Packing Rings

The carbon packing rings (see Fig. 114) should have enough steam to lubricate, and to seal in case vacuum is used. Too much steam is injurious. The right amount will be indicated by the escape of a little vapor from the drain leading from the carbon ring casing. This drain should always be left open. It sometimes happens that, through insufficient steam lubrication or other cause, the carbon rings tend to grip the shaft, become very noisy and throw the machine into vibration. When this occurs, which is more often on horizontal than on vertical types, a very thin solution of graphite and water should be introduced into the carbon casing. One or two applications will effectually remove the trouble. The graphite must never be mixed with oil, nor made into a thick solution with water, as it then becomes gummy, and causes the rings to stick in the casing and hold away from the shaft. When this happens the rings cannot seal.

Trip Rigging

Before starting a machine, try the trip rigging on the emergency throttle valve to see that it will trip the valve easily See Fig. 115.

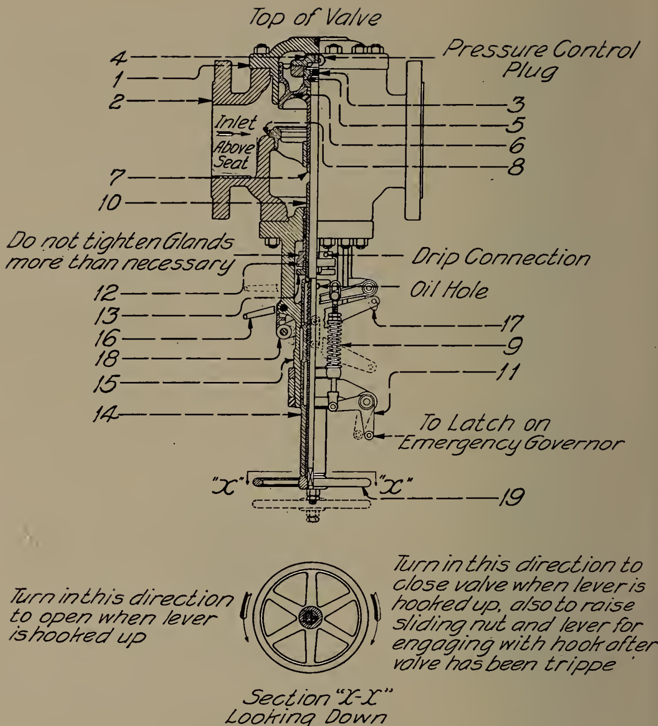

Fig. 115

THROTTLE VALVE AND EMERGENCY GOVERNOR TRIP RIGGING

1 Valve bonnet
2 Valve body
3 By-pass nut
4 By-pass valve cover
5 By-pass valve
6 Valve spool
7 Valve stem
8 Valve seat
9 Trip spring
10 Valve stem bushing
11 Trip bell crank
12 Large gland
13 Small gland
14 Sliding nut
15 Yoke
16 Trip handle
17 Trip hook
18 Lever for sliding nut
19 Handwheel

Wheel Balance

Before the main valve is opened to admit steam into the line to the emergency throttle, the exhaust valve should be opened. This will obviate any danger of excessive steam pressure on the turbine shell should the throttle valve leak.

Cold machines, in being started, should have enough steam given them to start them revolving at once. Otherwise the steam may distort the wheels, due to local heating. As soon as a machine starts to revolve, place one end of a wrench or bar against the intermediate holder, and rest the ear against the other end, and listen for rubbing. If the wheels seem to be running clear, bring the speed up to about 50 rev. per min., and then shut steam off completely. Listen for rubbing as before and at the same time notice whether the speed diminishes rapidly or not. The time that a machine should run before stopping varies greatly with the size and type, hence it is left largely to the judgment of the man in charge of the machine as to whether it is operating as it should. It is not necessary to let the machine come to a stop to see if it is running freely, as any marked diminution of speed can be noticed in a minute or two. Heat the machine up thoroughly before bringing it to normal speed by allowing it to run at about one fourth normal speed for fifteen to thirty minutes, depending on the size. When well heated, bring to normal speed (if the balance permits) and note the balance, or amount of vibration, on the bearings and on the intermediate holder. If the balance is good enough at normal speed it should then be tried at 110 per cent normal speed. Balance at 110 per cent speed should be as good, or nearly as good as at normal.

Some machines are in good balance when they come to test, but more often they have to be balanced dynamically. Before beginning wheel balance, the method of numbering the balance weight holes should be understood. It is impracticable to mark the wheel alongside the holes themselves, as the steam would soon efface the marking, so the following method is used:

On horizontal machines, holes for introducing balance weights into the wheels are provided in the turbine head and in the exhaust chamber. The wheels are revolved until a hole in the wheel is in line with the hole in the exhaust chamber. This is considered hole No. 1. A definite point of reference is made on the middle bearing in line with this hole, and a mark made on the coupling also in line. This locates hole No. 1 and should be permanently indicated by a prick punch mark on the coupling. The wheels are now slowly revolved and the location of each balance weight hole is marked on the coupling with chalk or whiting. Beginning with No. 1 the holes are numbered, always in the direction of rotation.

In vertical machines the holes are numbered in a slightly different manner. The coupling is not assembled during wheel balance, so a key-way is selected to locate hole No. 1, this key-way being indicated by a prick punch mark. The balance weight hole in the wheel nearest in line with the key-way is brought under the hole in the turbine head and No. 1 marked on the bearing under the key-way. Revolve the wheels slowly and mark under the key-way on the bearing the location of each hole. Numbering on the bearing must be against rotation in order that the numbering on the wheels themselves may be in the direction of rotation.

All turbines revolve counter clockwise facing the steam inlet end.

Before beginning work on balance, the shaft should be painted with whiting, at both ends when accessible. When the machine is up to speed or at as high a speed as the vibration will permit mark the shaft lightly with a pencil. The pencil line will appear heavier in one place which is generally opposite or nearly opposite the side that requires additional weight. Place a weight in the side indicated, in either the first or last stage wheel, depending on which showed the greater amount of unbalancing as indicated by the pencil mark. Use a fair sized weight, e.g., one two inches long. Bring the machine up to as high a speed as the balance will permit and note the balance of all parts. Then move the weight one-quarter way around the wheel and try the balance again. Proceed thus until both first and last wheels have been tried. Then continue trials in the holes in which the best balance was noted, using larger or smaller weights as may seem necessary. No rigid rule can be set down for the size and use of weights in balancing. It is a matter which must be left entirely to the judgment of the test man.

A balance record similar to that given on page 245 should be kept, and on this an accurate record of weights used and the per cent balance should be noted.

From this record it is evident that weights in hole No. 7 gave the best results in "quartering," hence it was then only necessary to try slight variations and changes in the neighborhood of hole No. 7 to obtain a perfect balance.

A number of things may influence the balance of wheels at the start which are not due to an actual unbalancing of the wheels themselves.

(1) The carbon packing rings may be gripping the shaft. This has already been discussed, and the proper remedy explained.

(2) The diaphragm packing rings may be rubbing on the shaft or wheel hubs. That surface of the packing ring that bears against the shaft consists of a series of V-shaped grooves. When there are indications of rubbing at this point, the turbine should be run continuously at a speed at which there is a slight vibration. This will in a short time wear a clearance between the rings and shaft and remove the source of trouble. This method should be followed in all cases in which a turbine vibrates at low speeds, and for which no other cause can be found.

(3) The wheels may be rubbing at the circumference. When this is the case it should be reported at once, and an investigation made.

(4) There may be water in the turbine. See that all drains are free. If, when opened, neither water nor steam escapes, it

	Balance Hole Numbers												Per Cent Balance		
	1	2	3	4	5	6	7	8	9	10	11	12	Turbine Bearing	Intrmdt. Holder	Middle Bearing
O	*no weights*												*93*	*95*	*94*
I															
O	*2″*												*90*	*94*	*93*
I															
O				*2″*									*92*	*95*	*93*
I															
O							*2″*						*97*	*97*	*95*
I															
O										*2″*			*93*	*95*	*94*
I															
O													*93*	*94*	*93*
I				*2″*											
O													*95*	*97*	*96*
I							*2″*								
O													*92*	*95*	*92*
I										*2″*					
O							*2″*						*98*	*99*	*98*
I							*2″*								
O								*2″*					*99*	*100*	*98*
I							*2″*								
O								*2″*					*100*	*100*	*100*
I						*1″*	*2″*								

"O" Indicates the outside, or first stage wheel.
"I" Indicates the last stage wheel.
Note—Italics indicate pencil notations by the one doing the balancing.

is evident there is a stoppage somewhere, and all valves and piping should be carefully examined.

CAUTION. Do not run wheels with loose weights. Be sure that all weights are tight, and that none project so far on either side of the wheel as to strike any stationary parts.

Field Balance

The method employed in balancing the field is practically identical with that used in balancing the wheels. In this case the numbers may be painted directly alongside each balance weight screw hole, beginning at the field leads and numbering in the direction of rotation. When the field leads are brought out on opposite sides of the shaft, hole No. 1 should be indicated by a prick punch mark.

On a later type of field the balance weight screw holes are replaced by a dove-tail groove in which are carried the heads of the bolts securing the weights. It will be necessary on this type to divide the groove into a number of equal sections, or "locations" which should be numbered as are the screw holes on the older type of field. *Twenty-four* is the most convenient number of "locations" to use.

On the older type of field the balance should be obtained by the use of one weight only in each end of the field. If this is impossible and more than one weight is necessary the weights must be concentrated, not scattered or counter-balancing each other.

On the later type with the groove, the procedure is somewhat different. Here the balance weights are always used in pairs, i.e., a pair of weights in *each* end of the field. The weights of any one pair must always be equal in size and similar in shape and each weight must be secured by at least two bolts. When a balance is finally obtained the size of the weights of a pair should have been so selected that the weights are located approximately 60 deg. to 90 deg. apart. This method of balancing allows of a very wide range of adjustment. By bringing the weights together or moving them further apart along the groove any effective value from zero to a maximum may be obtained, and the resultant value may be placed in any position desired. If the weights have been selected as directed there will be ample latitude for further adjustment should it become necessary at any time.

In all field balance work the shaft should be painted with whiting at each end of the field, and indications of the direction and amount of unbalancing made as described under the head of "Wheel balance." These indications should be used as a guide in the location of weights throughout all balance work, but the knowledge of how to do this must be gained by experience as the significance varies with every machine.

CAUTIONS

1. Balance weights must fit tightly, all bolts be in place and drawn up tightly.

2. Weights must fit firmly for their full length against the *outer* side of the slot.

3. No balance weight should be used whose thickness is more than twice the depth of the balance weight slot.

4. Weights should *never* be superimposed.

In loading machines for shutting down, *do not* load them single-phase.

The foregoing instructions on the balancing of alternator fields will also apply, in a general way, to the balancing of direct current armatures. The weights used in direct current armatures are of different shapes, and are secured in various ways, but the method employed in obtaining a balance is the same as that used in balancing turbine fields and revolving fields.

Before beginning balance work on any generator, all wiring should be completed and cold resistance measurements taken.

One condition to be watched in all balance work is the number of operating valves that are held open. Only just so many valves as are necessary to bring the machine up to speed should be used. If a greater number of valves is opened a greater amount of steam is required to do the same work. This is wasteful, and in the case of large machines the steam pressure in the mains may be so reduced by the excessive flow as to let the step-accumulator down, causing considerable damage if not stopped at once. This rule in regard to the number of valves opened should, in fact, be observed in the starting of machines at all times, especially those of larger sizes. The only case in which it cannot apply is in the testing of operating governors to be described later.

Too much importance cannot be attached to the maintenance of steam pressure. Low steam pressure may, through the loss of pressure in the step-accumulator oil system as just referred to, damage the wheels of a vertical turbine to such an extent as to require an entirely new set of wheels.

Governor Tests

EMERGENCY GOVERNORS

After the wheels are balanced and before the field is assembled, the emergency governor should be adjusted and tested. Thereafter it should be tripped at least once every twenty-four hours, and a record made in a folder provided for this purpose. Emergency governors are known as Type E. There are two forms now used. Form D, the eccentric ring type (Fig. 116) is used on all machines of 2000 rev. per min. and under, and Form E, the plunger type (Fig. 117) used on the higher speed machines.

The Form D governor is shown in Fig. 116 in its normal concentric position before operating. In operating, the ring (1) moves out eccentrically against the spring (13) coming in contact with the trip finger (9) (Fig. 118) thereby releasing the emergency throttle valve. The adjusting nut (8) (Fig. 116) over the spring screws on to the spindle (4). The thread is right-handed, so that by turning the nut to the right more tension is

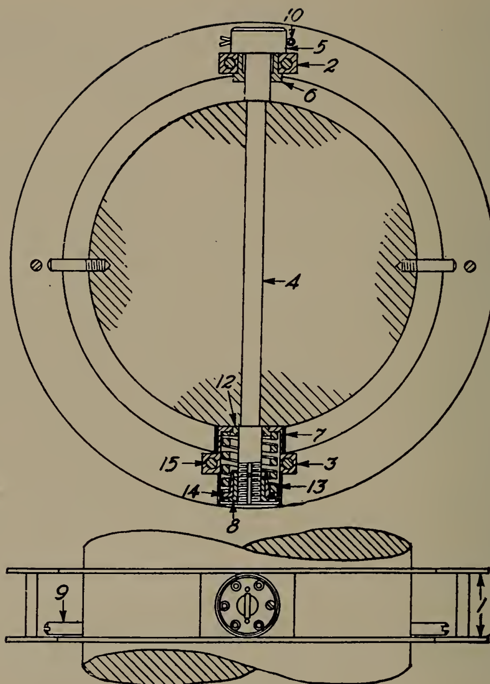

Fig. 116

EMERGENCY GOVERNOR (FORM D), (DOUBLE RING TYPE, HORIZONTAL TURBINES)

1 Emergency governor ring
2 Emergency governor guide block
3 Emergency governor spring box
4 Emergency governor spindle
5 Emergency governor stop
6 Bushing for (2)
7 Collar for (3)
8 Adjusting nut for (4)
9 Guide pin for (1)
10 Cotter pin for (5)
12 Bushing for (3)
13 Emergency governor spring
14 Support for (13)
15 Rivet for (1), (2) and (3)

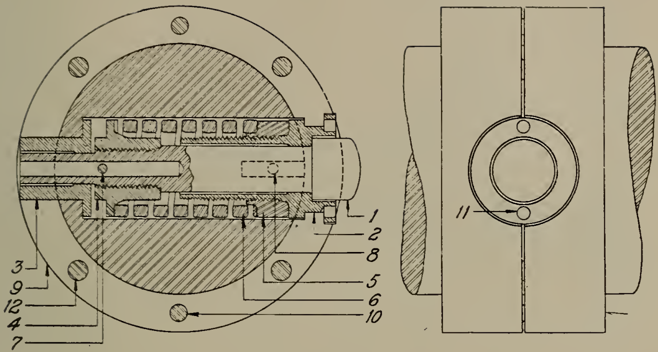

Fig. 117

EMERGENCY GOVERNOR, PLUNGER TYPE (FORM E)

1 Governor plunger
2 Tension adjusting bushing
3 Guide bushing
4 Retaining nut for spring
5 Adjusting nut for spring
6 Governor spring
7 Cotter pin for retaining nut
8 Pin for adjusting nut
9 Clamping collar for governor
10 Dowel pin for clamping collar
11 Holes for spanner wrench
12 Cap screw for clamping ring

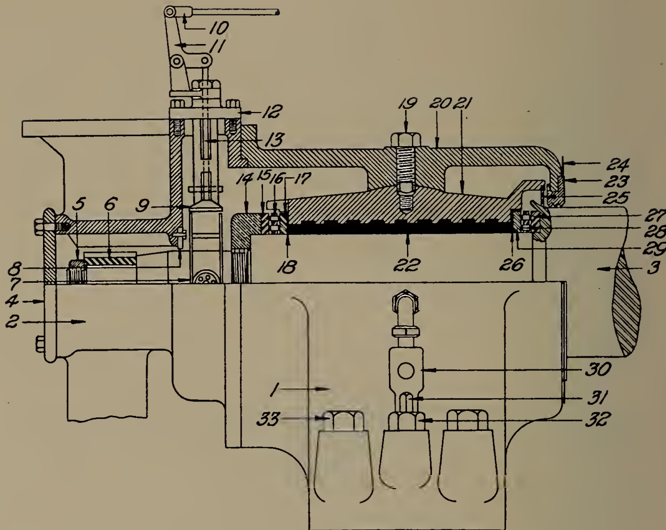

Fig. 118

EMERGENCY GOVERNOR AND THRUST BEARING

1 Pillow block or standard
2 Gear casing
3 Shaft
4 Gauge board
5 Lock nut for gears
6 Spiral gear
7 Emergency governor
8 Deflector
9 Emergency governor trip finger
10 Emergency governor connecting rod to throttle valve
11 Emergency governor rigging bell crank
12 Cover plate
13 Emergency trip finger rod
14 Thrust nut
15 Revolving plate, front thrust
16 Roller cage, front thrust
17 Stationary plate, front thrust
18 Adjusting shims, front thrust
19 Bearing cap bolt
20 Bearing cap
21 Bearing
22 Babbitt lining
23 Bearing packing ring
24 Air deflector
25 Oil guard
26 Adjusting shims, back thrust
27 Revolving plate, back thrust
28 Roller cage, back thrust
29 Stationary plate, back thrust
30 Water drain sight cup
31 Bearing standard dowel pin
32 Dowel pin nut
33 Bearing standard bolt

given to the spring and the speed at which the governor operates is increased. The nut (8) is held in position by a lock-screw, which goes through one of the holes in the nut and screws into a stationary plate below. This screw must always be replaced after it has been removed to make an adjustment of the governor.

The Form E governor is shown in Fig. 117. Here, instead of an eccentric ring, we have a plunger (1) to strike the trip-finger. The entire mechanism is contained in a bored out section of the shaft, and held in place by the two clamping rings (9,9). The adjusting nut (5) over the spring, does not turn, but is moved in or out by turning the bushing (2). Since the nut has a right-hand thread, turning the bushing to the left forces the nut in, puts more tension on the spring, and increases the speed at which the governor will operate. The bushing (2) is held in position and prevented from turning by the clamp rings (9), hence these rings must be loosened before any effort is made to move the bushing. The rings are clamped by four cap screws in the holes (12).

All emergency governors must be adjusted to trip at 10 per cent above the normal speed of the machine, with an allowable variation of ½ per cent either high or low. The speed at which they return to their normal position must be, on the Form D, between 90 per cent and 100 per cent of normal speed, and on the Form E, between 100 and 101 per cent. After the proper adjustment has been obtained, the governor must be tripped five or six times in succession, and the operation of all parts of the trip rigging noted. There should be no lag to any of the parts, and the valve should close quickly. Any defect must be reported at once.

Fig. 118 shows the assembly of a Form D governor and the arrangement of the trip rigging.

This illustration also gives a good idea of the arrangement of the thrust bearing and adjusting shims of the roller type of thrust.

Fig. 119 shows the arrangement of a later type of thrust bearing known as the "Block" type. This is the type of thrust also shown in the illustration of a general turbine assembly, Fig. 109. A third arrangement of a thrust bearing, known as the "Ring" type is shown in Fig. 120. The Ring type and the Block type thrusts are interchangeable. Either may be assembled in the outer housing (9) Fig. 119.

OPERATING GOVERNOR

The operating or main governor is known as Type M governor, Form C, and is shown in Fig. 121.

On vertical machines the governor is set directly on the top of the main shaft, see Fig. 108, but on horizontal machines it is driven from an auxiliary shaft connected to the main shaft by a worm and gear. See Fig. 122 and Fig. 123. This auxiliary shaft also drives the gear oil pump. After the gear pump is assembled and operative the steam driven oil pump should not be used except when starting and stopping the machine.

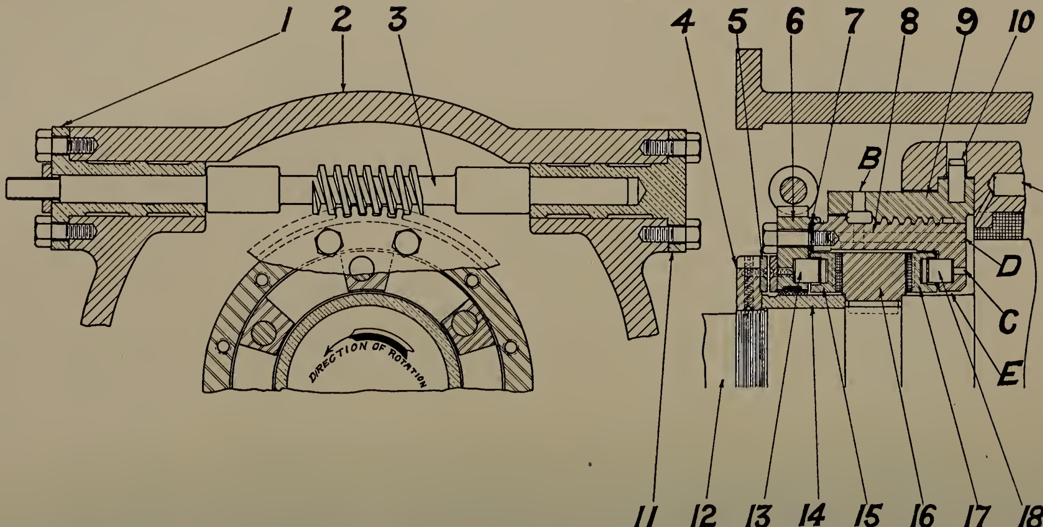

Fig. 119
BLOCK TYPE THRUST BEARING

DETAILS OF BLOCK TYPE THRUST BEARING (Fig. 119)

1 Worm shaft bearing—open end (with bolts)
2 Turbine bearing shell
3 Worm and shaft (one piece)
4 Shaft nut—forming an emergency thrust with parts 5.
5 Wearing shoes—one stationary and one revolving (with screws)
6 Gear—with bolts
7 Shims
8 Inner housing for thrust bearing
9 Outer housing for thrust bearing
10 Dowel
11 Worm shaft bearing—closed end (with bolts)
12 Main shaft of turbine
13 Bearing pins for 15
14 Sleeve for shaft
15 One set babbitt faced bearing blocks (outer) with hardened convex bearing disks
16 Thrust collar with key
17 One set babbitt faced bearing blocks (inner) with hardened convex bearing disks
18 Bearing pins for 17.

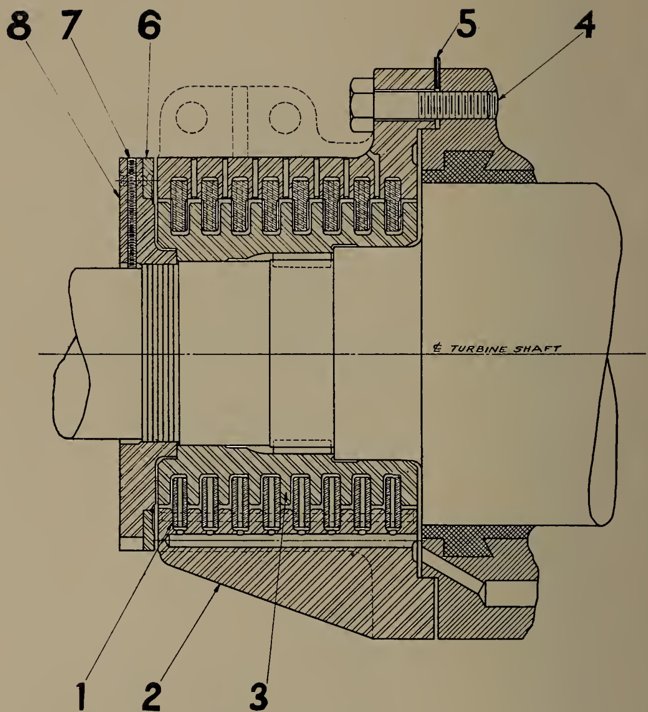

Fig. 120

RING TYPE THRUST BEARING

1 Alloy thrust rings
2 Thrust bearing shell
3 Thrust bearing
4 Bolts
5 Shims for adjusting clearance of wearing shoe
6 Wearing shoe
7 Set screw for shaft nut
8 Shaft nut

Before beginning governor tests the machine should be run for a short time with the governor holding speed to ascertain that all parts of the governor and hydraulic rigging function properly, that there is no sticking in any part, and that there is no hunting in the governor itself. Any defects noted should be reported at once and the necessary corrections made before proceeding with the governor test.

OPERATING GOVERNOR TEST

Fasten a pointer on the machine in some convenient place where it will be near the piston or connecting rod (No. 14, Fig. 122). Paint the section of rod opposite the pointer with a coat of whiting. Move the pilot valve by hand, opening all the operating valves. As the last valve opens so that the roller 12 (Fig. 124) just rises over the point of the cam (14) make a mark on the whiting opposite the pointer. Then lower the pilot valve stem so that the valves close, and as the last valve is just closed make a second mark on the whiting opposite the pointer. The foregoing refers to high pressure machines only. Machines designed to operate on both high and low pressure steam are provided with a low pressure butterfly valve, Fig. 125, whose operation precedes that of the high pressure valves. Hence the two marks must include the total travel of the piston rod (2), necessary to operate both the high pressure valves and the butterfly valve.

The first mark is located as described above. The second mark is made when the piston or connecting rod (2), Fig. 125, has, by means of the cam (8) and connecting rod (10) brought the butterfly valve to the "closed position" as indicated by dotted lines. The length of the connecting rod (10) should be so adjusted as to give a compression on the spring (5) of from $\frac{1}{32}$ to $\frac{1}{16}$ in. Having located the two limit marks, divide the intervening space into five equal parts, thus obtaining six marks. In order to bring the speed above the point at which the governor would normally hold the speed, and so make each mark on the scale pass the pointer, it is necessary to block open one or more valves. Before any valves are blocked open, and with the governor holding speed, check the tachometer. This is done preferably by holding the speeder on the end of the governor spindle (8), Fig. 121, rather than on the end of the main shaft. Take a two minute reading. The proper governor speed may be determined from the ratio of the worm and gear. The tachometer, which is always belted, should be provided with a pulley of such diameter as to give a reading well up on the scale.

All is now ready for the actual governor tests and adjustments. Speed readings should be taken as the marks on the scale pass the pointer, first as the machine is brought above normal speed, and again as it falls below normal.

The first readings are taken with the synchronizing spring (27), Fig. 121, set in mid-position; that is, with the plug (26) Fig. 121, set at the mid-position of its travel. All adjustments

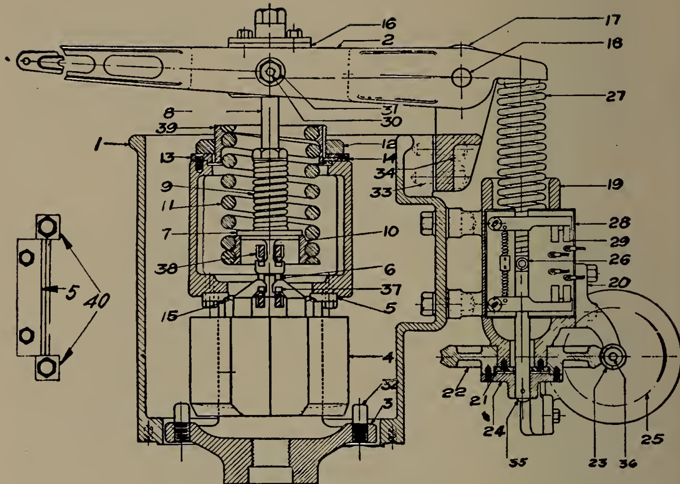

Fig. 121

OPERATING GOVERNOR

1 Governor dome
2 Governor lever
3 Governor bracket
4 Weights
5 Fulcrum block for (15)
6 Links
7 Yoke for (6)
8 Spindle or connection rod
9 Spring for universal joint
10 Lower spring plug
11 Main spring
12 Adjusting nut for (11)
13 Adjusting plate
14 Key for (13)
15 Knife edge for (4)
16 Transmission roller bearing
17 Lever bracket
18 Roller bearing for lever
19 Bracket for synchronizing gear
20 Bracket for worm gear
21 Thrust plate for (19)
22 Worm wheel
23 Worm
24 Supporting plate for worm wheel
25 Handwheel
26 Plug for synchronizing spring
27 Synchronizing spring
28 Limit switch base
29 Limit switch details
30 Trunnion for lever
31 Nut for (30)
32 Stop for weight
33 Studs for lever bracket
34 Nuts for (33)
35 Lead screw for (26)
36 Shaft for worm
37 Knife edge bearing block for (4) and (7)
38 Knife edge for (6)
39 Upper spring plug
40 Stop blocks

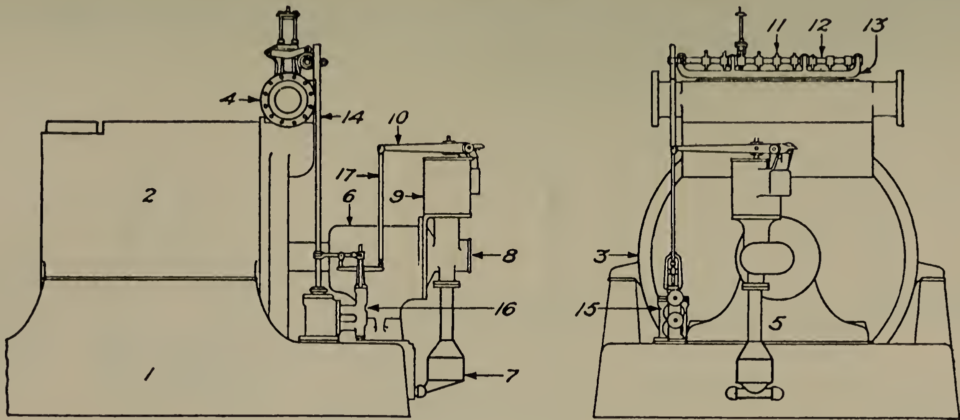

Fig. 122

ARRANGEMENT OF HYDRAULIC OPERATING MECHANISM

1	Turbine base	7	Gear oil pump	13	Cam shaft bracket
2	Turbine casing; top half	8	Gear casing	14	Piston rod
3	Turbine head	9	Governor dome	15	Hydraulic cylinder
4	Valve casing	10	Governor beam	16	Pilot valve chest
5	Standard for turbine end bearing	11	Cam	17	Governor rod
6	Cap for turbine end bearing	12	Cam shaft		

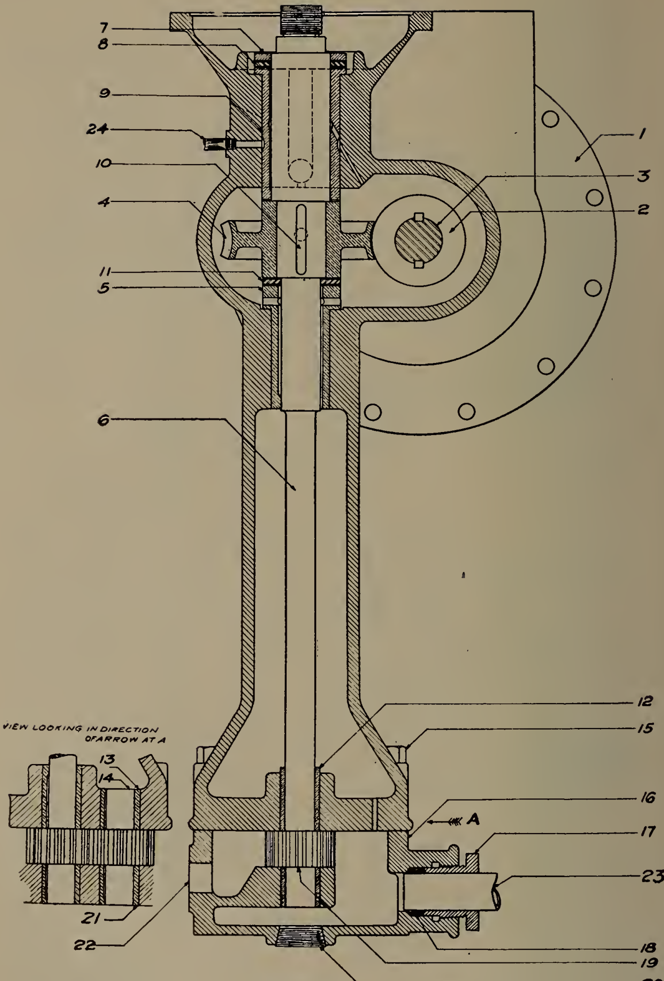

Fig. 123

GEAR PUMP AND CASING (OUTSIDE TYPE PUMP)

(See page 259)

PARTS OF GEAR PUMP AND CASING (Outside Type Pump)
(See Fig. 123)

1 Gear casing
2 Spiral gear driver
3 Turbine shaft and keys
4 Spiral gear driven
5 Lower bushing (governor end)
6 Governor and pump shaft
7 Bronze thrust plate for governor
8 Steel thrust plate for governor
9 Upper bushing (governor end)
10 Keys for (4) and (6)
11 Steel thrust plate for spiral gear
12 Upper bushing for (6) pump end
13 Upper bushing for (14) pump end
14 Idler shaft for pump gear
15 Bolt for (1) and (16)
16 Pump casing
17 Stuffing gland for pump suction
18 Stuffing box packing
19 Pump gear
20 Plug in bottom of casing
21 Bottom bushings for (6) and (14) pump end
22 Pump discharge
23 Pump suction

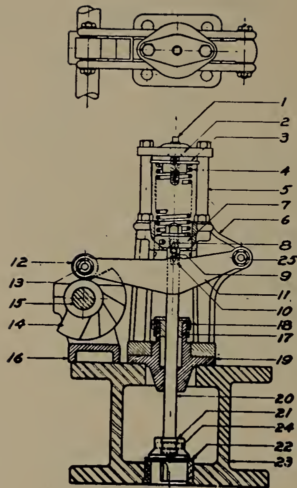

Fig. 124

HIGH PRESSURE CONTROLLING VALVE

1 Adjusting screw for valve spring
2 Supporting plate for (1)
3 Spring supporting plate (adjustable)
4 Controlling valve spring
5 Stud for spring supporting plate, with nut
6 Frame for controlling valve, with bolts
7 Guide plate for valve stem
8 Upper cup for (7)
9 Thrust pin
10 Lower cup for (11)
11 Controlling valve lever
12 Cam roller for lever
13 Spindle for cam roller with nut
14 Cam with key
15 Cam shaft
16 Cam shaft bracket with bearing cups and bolts
17 Gland for packing
18 Nut for stuffing box
19 Guide plate and stuffing box for valve stem
20 Valve stem
21 Valve (wing type)
22 Valve seat
23 Valve casing
24 Pin for (20 and (21)

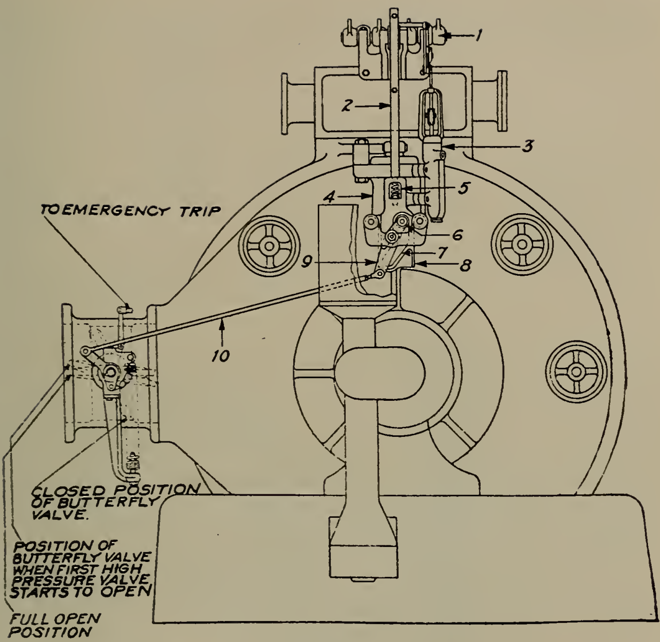

Fig. 125

ARRANGEMENT OF HYDRAULIC GEAR ON MIXED PRESSURE TURBINE

1 Cam shaft for high pressure valves
2 Piston rod
3 Pilot valve chest
4 Hydraulic cylinder
5 Spring
6 Cam roller
7 Slot for cam roller (6)
8 Cam plate
9 Cam lever
10 Connecting rod for butterfly valve

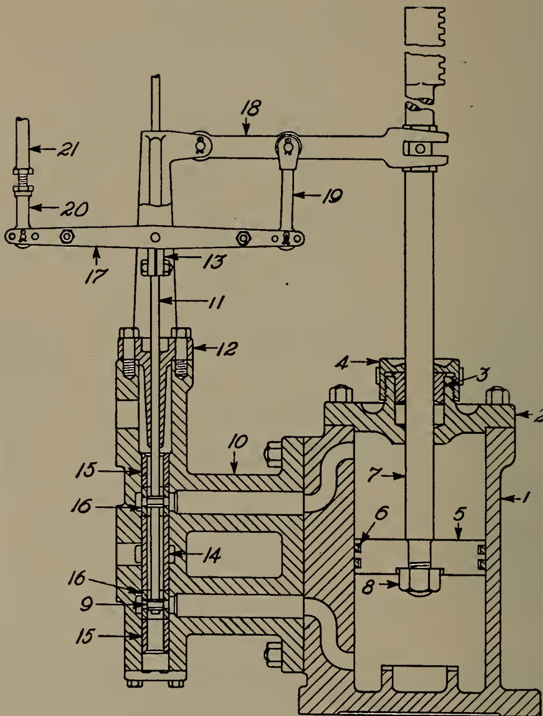

Fig. 126

HYDRAULIC OPERATING CYLINDER AND PILOT VALVE (HORIZONTAL TURBINES)

1 Hydraulic cylinder
2 Cylinder head
3 Stuffing gland for (2)
4 Nut for stuffing box
5 Piston
6 Piston ring
7 Piston rod
8 Piston rod nut
9 Pilot valve
10 Pilot valve chest
11 Pilot valve stem
12 Pilot valve stem guide
13 Pilot valve pivot clamp
14 Pilot valve middle bushing
15 Pilot valve end bushing
16 Pilot valve seat bushing (hardened steel)
17 Floating lever
18 Differential lever
19 Link for (18)
20 Rod end—adjustable
21 Connection to governor lever

of the governor must be made with the spring in this position. On a properly adjusted governor a set of readings similar to the following is obtained.

Marks	1	2	3	4	5	6
Accelerating	1728	1740	1748	1757	1770	1790
Decelerating	1725	1736	1743	1752	1767	1786
Lag	3	4	5	.5	3	4

Tachometer reading = 1750
Speed of machine = 1800

The requirements to be met are as follows:

(1) Normal speed must be between readings No. 3 and No. 4.

(2) The total regulation, that is, the difference between reading No. 6 accelerating and reading No. 1 decelerating, must be between 3.6 and 4.0 per cent of normal speed.

(3) The "lag" is the difference in the readings accelerating and decelerating for the same mark on the rod and must not exceed an average of 0.4, or a maximum for any one reading of 0.5 per cent of normal speed. If the speed or regulation of the governor is not correct, it can be adjusted by varying the tension on the main governor spring (11), Fig. 121, or by changing weights in the pockets of the governor weights (4), Fig. 121.

Increasing the tension on the main spring will raise the speed and decrease the regulation. Decreasing the tension lowers the speed and increases the regulation.

Increasing the weight in the pockets of the governor weights lowers the speed without appreciably affecting the regulation.

If the lag is excessive take a set of readings on the governor rod (17), Fig. 122, with the rod disconnected from the pilot valve. This will indicate whether the excess lag is in the governor or in the hydraulic rigging. See Fig. 126. In either case the lag should be corrected before proceeding. After the governor has been properly adjusted, take three sets of readings using the scale or marks laid out on the piston rod, the synchronizing spring being in mid-position. Then take two sets of readings on each of the two limit positions of the synchronizing spring: "Spring all in" (maximum compression) and "spring all out" (minimum compression).

Bafflers

The step bearing baffler, Fig. 127, is furnished with all vertical machines, having replaced the old style baffler (Fig. 113), now used only as a part of the permanent testing equipment.

The baffler frame is first tested for sand holes and porous places in the casting. It is carefully painted over the entire surface with whiting, filled with oil, and kept under a pressure of 2500 lb. per sq. in. for 24 hours. If at the end of this time

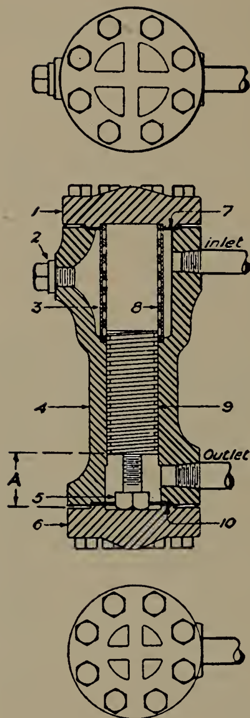

Fig. 127

STEP BEARING BAFFLER (ADJUSTABLE)

1 Head (inlet end)
2 Plug for blowoff
3 Strainer (gauze mesh)
4 Baffler frame
5 Adjusting screw
6 Head (outlet end)
7 Washer (inlet end)
8 Strainer frame
9 Baffler screw
10 Washer (outlet end)

there is no indication of oil anywhere on the whiting, the baffler is completely assembled with strainer and plug.

The plug or screw (9), Fig. 127, has a thread with a tapering depth of groove which allows of a wide range of adjustment. The deepest grooves should be assembled at the discharge end. The following table shows the approximate flows for given pressure drops across the baffler and various adjustments of the adjusting screw (5), Fig. 127. The temperature of the oil is 50 deg. cent.

FLOW IN GALLONS PER MINUTE

Length of "A" / Drop lb. per sq. in.	2 In.	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.
50	1.0	2.2	3.1	4.4	6.0	8.0	12.5
75	1.5	2.9	4.2	5.4	7.6	10.7	16.8
100	1.9	3.4	5.0	6.5	9.0	12.7	20.5
125	2.2	3.9	5.5	7.4	10.1	14.5	24.0
150	2.4	4.4	6.3	8.4	11.2	15.6	27.5

"A" is the distance between the end of the plug and the baffler head. See Fig. 127.

Stage Valves

In most of our multi-stage vertical turbines, valves are provided which open additional second stage nozzles at times of overload.

The usual arrangement of this valve is shown in Fig. 128. The pipe (16) connects with the first overload valve on the operating valve casing. When the operating valve is opened steam is admitted to the upper side of the piston (14) and the stage valve (2) is forced open against the spring (5). This valve should open quickly and positively, and should close in the same way.

The only test made on the assembled stage valve is to open and close the controlling valve a few times, and note that the stage valve acts properly and operates without sticking. Also the travel of the stem or indicator rod (8) should be measured.

A modification of this valve carries the spring outside of the casing, but the operation is essentially the same.

GENERATORS

Sectional views of vertical and horizontal turbo-generators are shown in Figs. 129 and 130.

The scheme of ventilation of the turbine generator is radically different from that of other types of generators. Referring to Fig. 129, air is drawn in through an opening in the side of the hood (9), forced by the fans (21), through the air gap and out through the ducts in the armature laminations (1) to the

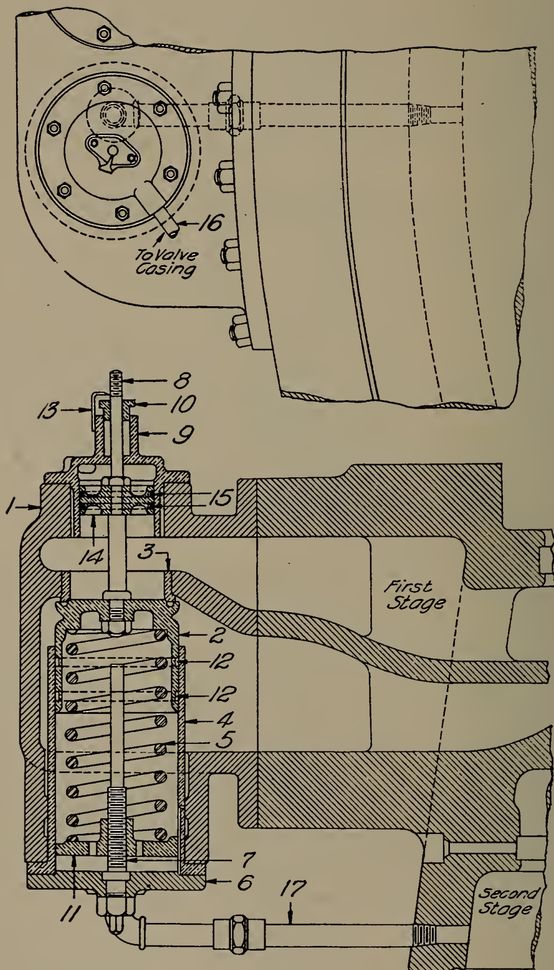

Fig. 128
STAGE VALVE (See page 267)

PARTS OF STAGE VALVE. (See Fig. 128)

1 Casing for stage valve
2 Valve and piston
3 Valve seat
4 Cylinder lining
5 Spring
6 Cylinder head
7 Adjusting screw
8 Indicator rod
9 Balance-cylinder head and stuffing-box
10 Gland for stuffing-box
11 Spring seat
12 }
12 } Rings for piston
13 Indicator
14 Balance piston
15 Packing ring for balance piston
16 Admission from overload operating valve
17 Drain for valve

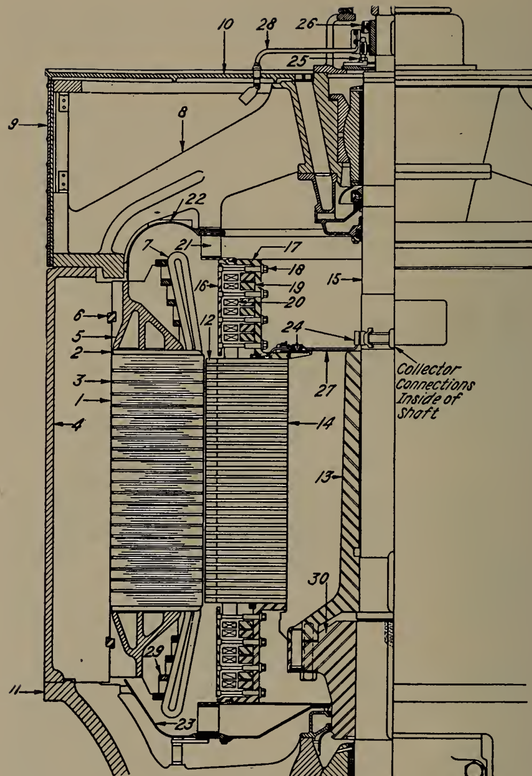

Fig. 129

VERTICAL GENERATOR SECTION

1 Armature punching section
2 Armature punching space block (outside)
3 Armature punching space block (inside)
4 Armature spider
5 Armature flange (top or lower)
6 Armature key
7 Armature coil
8 Bearing bracket (upper)
9 Ventilating hood
10 Floor plates
11 Generator base and middle bearing bracket
12 Pole piece revolving
13 Revolving field spider
14 Field spider rings
15 Shaft
16 Field coil support
17 End flange
18 Field coil retaining bolts
19 Retaining rings
20 Field coil
21 Fan
22 Air deflector (upper)
23 Air deflector (lower)
24 Collector lead supports
25 Brush-holder studs
26 Collector
27 Field lead
28 Brush-holder lead
29 Binding bands
30 Coupling

space between the laminations and the armature shell (4) and thence downward to be discharged through openings in the generator base (11).

The ventilation scheme on the horizontal generator, Fig. 130, is similar to that on the vertical, except that air is drawn in from below at both ends. The air is forced by the fans through the air gap and out through the laminations, and may be discharged at either the top or bottom of the armature as the customer may require.

On small machines of 1000 kw. and less, the fans are usually omitted from the field. On machines in test, where a bottom discharge is called for, the opening at the bottom of the armature is temporarily blocked off, and the air taken from the top. Otherwise, a more or less elaborate arrangement of air ducts would be necessary to prevent the hot discharged air from being drawn in and circulated through the armature over and over again.

Generator Tests

ALTERNATORS

Generator tests comprise the lesser part of the work on turbine sets. On standard machines, and those for stock, the only tests usually required are saturation and synchronous impedance curves, phase rotation, current leakage from shaft to pillow block, field and armature measurements, and high potential tests. These tests are invariably made on every machine.

In addition to the above, heat runs, either open circuit and short circuit, or a "zero power-factor" run may occasionally be called for. Other tests much less frequently made are ventilation tests, motor core loss, phase characteristic, armature impedance with rotor removed, open-delta heat runs, zero-excitation heat runs and full load heat runs.

As all the above mentioned tests except ventilation tests and "zero-excitation runs" have been dealt with elsewhere in this book no further mention is necessary except such details as may need special attention due to slightly different conditions that may be found on turbine generators.

Before beginning generator tests all pipe joints, and joints about the gear casing, pump and bearings where there is a possibility of oil leakage, should be carefully painted with whiting so that any leaks existing may be located during the progress of generator tests.

The limits to which saturation and synchronous impedance curves are to be run, and the values of voltage and current held on open- and short-circuit heat runs are varied from time to time under instructions from the turbine generator Engineers, hence, the book of "Special Instructions" previously referred to should be consulted for this data.

Cold Measurements

Under the head of "field balance" reference was made to taking cold measurements on the generator. This should be

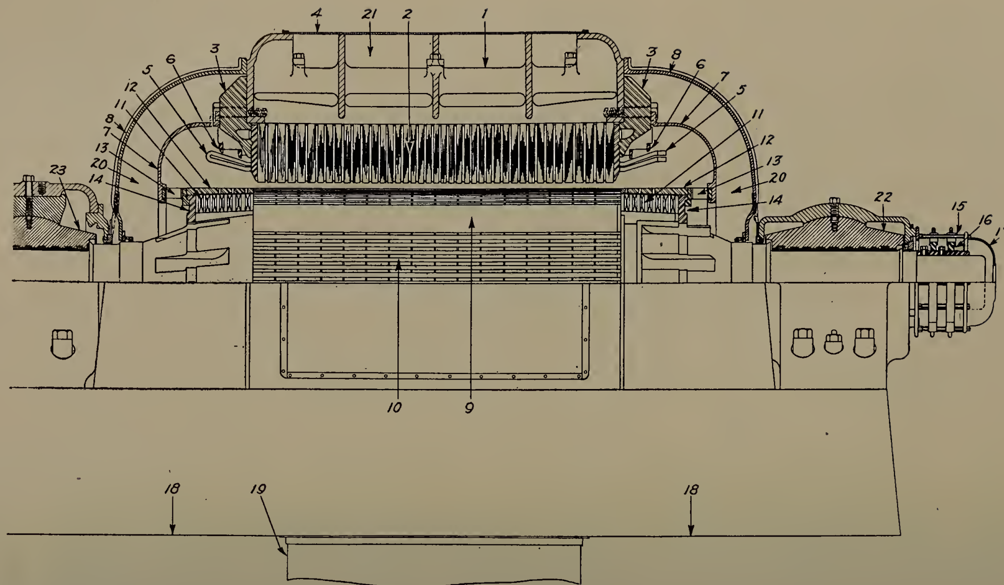

Fig. 130

HORIZONTAL GENERATOR SECTION (See page 271)

PARTS OF HORIZONTAL GENERATOR (See Fig. 130)

1 Armature frame
2 Armature laminations
3 Armature lamination clamp rings
4 Armature lagging
5 Armature coils
6 Armature coil supporting rings
7 Armature shields (inner)
8 Armature shields (outer)
9 Field core
10 Field winding slots
11 Field coils
12 Field coil retaining rings
13 Fans
14 Balance weight grooves
15 Brush-holders
16 Collector rings
17 Shaft guard
18 Air inlets
19 Air outlet
20 Air space, ingoing air
21 Air space, outgoing air
22 Generator end bearing
23 Middle bearing

done invariably before the field has been run. In addition to galvanometer measurements of the armature and field, the field is also measured by the voltmeter-ammeter method, as a basis for the field temperature measurements to be made and recorded with each half-hourly reading during the heat runs. When an armature is equipped with temperature coils these must be measured at the same time the other measurements are taken, both before and during heat runs. The information obtained from temperature coil measurements is the most important of any obtained from heat runs on a turbine generator, for it is by this means only that the actual internal temperatures of the armature can be learned. Hence, it is of the utmost importance that an absolutely accurate record of the cold *resistance* and *temperature* of these coils be made.

Shutting Down After Heat Runs

Whenever possible an alternator should be so wired that it may be quickly shut down after a heat run by loading it on water-boxes. The load must be three- or quarter-phase, as the case may be, *never* single-phase, and should be reduced as the machine slows down in order not to increase the heating due to decrease in ventilation.

In some instances it is impracticable to load on water-boxes, and when such is the case the Head of the test, or an assistant, should be consulted as to the best method to be used in shutting down.

Direct current machines should always be arranged for separate excitation for shutting down rapidly, and always provided with a water-box load, even when the tests and heat runs are being made by the "feeding-back" method.

Running Turbine Sets as Motors

When a turbine set is "motored" for a zero power-factor heat run, or any other test, special attention should be given to heating in the turbine. The friction of the air on the buckets will raise the temperature of the wheels to a degree far above the temperature of steam, and will cause serious trouble. To obviate this, the exhaust should be left open and a slight amount of steam passed through the turbine. This will hold the temperature down to a safe value. It is also necessary to keep steam turned on the carbon packing rings to prevent their cutting and scoring the shaft.

"Zero Excitation" Heat Run

A certain amount of heating on a turbine-generator is caused by the friction of the air which is forced through it at a high velocity. To determine this heating a heat run is occasionally made with no excitation on the field. Two hours are usually required to bring temperatures constant, the field being measured at intervals in the usual manner, but with a very small current in order to prevent heating from this cause. The current should be on only long enough for a quick reading. At the end of this run the armature and field should both be measured and final temperatures by thermometers taken as on any other heat run.

Ventilation Tests

When ventilation tests are to be made, a special pipe for this purpose is erected on top of the armature. There are two sizes of pipes in use at the present time, one, of 30 in. diameter for use on smaller machines, and another of 40 in. diameter for the large machines, both rising about 12 feet above the generator. Reducing cones may be fitted to the upper end for varying the diameter of the outlet, and a butterfly valve is sometimes inserted between the lower end of the pipe and the armature opening, for varying the volume of air from a maximum to zero. The manometer used in measuring volume is connected either to an impact tube located in the center of the plane of the outlet opening, or to a special plug inserted radially in the air pipe near the top, but below the base of the cone.

On machines of 1000 kw. and less, readings are taken with the impact tube only. Above 1000 kw. both methods are used. Simultaneously with every manometer reading, readings of the pressure inside the inner shields of the armature (see Fig. 130) are taken at each end of the armature, a U-tube being used for this purpose. The pressure in the shields is also taken occasionally with the opening in the armature entirely closed, that is, with no air circulating through the generator.

Testing Record Sheets

There are certain items and questions on turbine generator sheets which do not appear on sheets for other forms of generators, hence, these sheets should be carefully looked over and these items noted. It is important that they be checked carefully and that questions be answered in every case.

DIRECT CURRENT MACHINES

The only tests made on direct current machines are saturation, shunt adjustments and heat runs.

Compound is always adjusted for a rise in speed of 2 per cent from full load to no load. As steam conditions in the Testing Department are not the same as those under which a machine is to operate when permanently installed, the governor cannot be relied on to give the proper 2 per cent regulation, hence, it is necessary to vary the speed as required by means of weights on the governor arm.

DEFECTS

After tests are completed, the entire machine, both turbine and generator, should receive a thorough inspection for any defects which may not have been previously corrected during the tests.

All defects, large and small, should be carefully noted and recorded on regular "defect sheets," special attention being given to steam leaks and oil leaks, and oil throwing at bearings, If any doubt exists as to whether or not some particular condition is to be regarded as a defect, enter the item on the sheet as though it were a defect, and if on investigation it is found not to be, it can easily be marked off.

STEAM CONSUMPTION TESTS

These tests are conducted in order to check guarantees made to customers or to obtain engineering information on new or experimental machines.

In either case it is essential that accurate and thoroughly reliable data be obtained, and to this end every man concerned with the test must be held responsible for his individual part of the work.

Assembly of Machines

While the machine is being assembled the following record should be made:

The number of the Drawing List.

What combination is assembled in the turbine.

Changes made since previous test.

Any special features of construction.

During the assembly of the turbine, all necessary drilling and piping for gauges and thermometer wells should be done and a calibrated orifice should be placed in the feed pipes to the carbon packing rings in order that the amount of steam necessary to seal the rings can be determined. Before the steam piping is assembled a very accurate measurement of the pipe diameter should be taken at the point where the nozzle plug for the steam flow meter is to be installed.

If a water-brake is to be used for load, it is absolutely necessary that the brake hang free on the knife edges for a very little friction will give very erratic results in the scale reading.

Preparation for Test

The electric meters to be used in the test should be newly calibrated. Where exceptionally accurate results are desired, it is well to calibrate the meter transformers although as a general rule their calibration changes very little. In case a water-brake is used, the scale should be adjusted, using the standard weights furnished for that purpose.

It is sometimes very difficult to obtain the required amount of vacuum when the turbine is first started. Therefore, after the turbine is assembled and before starting the test, the machine should be run under load to determine if the required vacuum can be obtained. In case this is impossible, it is necessary to find the air leaks and stop them up. Large leaks can be found by holding a lighted torch near the crack, the air current drawing the flame in with it. Leaks can sometimes be found by applying soapsuds to the leaky joint. Leaks that cannot be closed by tightening the bolts should be subjected to a few inches of vacuum and the leading joints then painted with thick black japan. A serious leak may be closed by caulking with lead or solder and afterward painting with japan.

Readings Taken During Test

The following readings should be taken during test:
Pressures (or vacuum),
Temperatures,
Flow,
Load.

Pressure

The pressures to be read are:
Steam pipe (above throttle and strainer),
1st valve bowl,
Operating valve bowl,
Shell pressures of all stages (when called for),
Exhaust chamber (near exhaust opening),
Carbon packing steam.

The steam pressure is read outside of the emergency throttle valve and strainer, and is held constant during the test by throttling down the steam, at boiler pressure, with a specially equipped valve. The man holding this pressure should at once notify the man in charge of the test if the pressure cannot be held constant.

The bowl pressure is taken on the steam passage between each of the controlling valves and the 1st stage nozzle. The bowls are numbered in the order of their opening, the first one to open being No. 1. The pressure on this bowl is read as well as the pressure on the bowl on which the governor throttles, both readings being recorded every two minutes. Knowing the area of the nozzles open, the theoretical steam flow can be calculated and used to check the flow recorded.

Stage shell pressures are read on each stage just below the wheel and above the diaphragm for the next stage. The first stage should be equipped with both a siphon and a quill, to read either pressure or vacuum. If there are more than four stages the second stage may need a similar equipment but the lower stages only need a quill. The 1st stage pressure is read at two minute and the lower stages at four or six minute intervals.

The quill for the exhaust pressure should be tapped into the connection between the turbine and condenser close to the exhaust opening of the turbine.

Gauges are used to read all pressures above atmosphere, and they should always be calibrated with a dead weight tester, both before and after test. Before shutting down, except in case of an emergency, all gauges should be shut off to prevent being subjected to a vacuum. If this occurs, the needle may be drawn back against the stop pin so forcibly as to alter the calibration. The calibration may also be changed by sudden jars or by heating. To prevent the latter, all gauge piping must be equipped with a siphon, which is kept cool by applying wet waste. If a gauge is allowed to heat up, the solder in the Bourdon spring will melt and ruin the gauge.

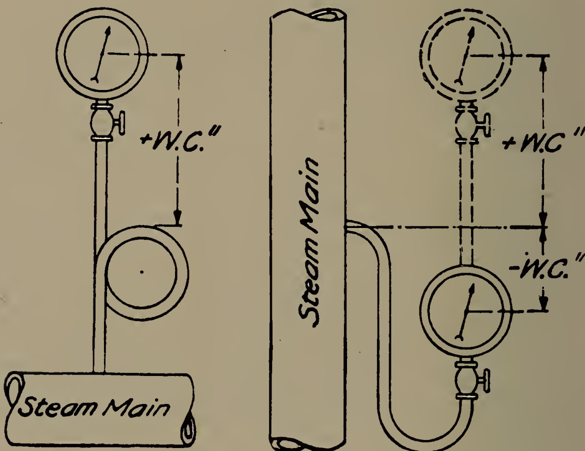

Fig. 131
WATER COLUMNS ON GAUGES

The water column on the gauges should be measured and entered on the testing Record Sheet with the number of the gauge. The water column is measured from the top of the siphon coil to the center of the gauge and recorded as + or − WC in inches. (See Fig. 131.)

U-tubes are used to read all vacuum and pressures of a few inches. These consist of a thick glass tube with ⅛ in. bore bent in the shape of a U, and mounted in a wooden case carrying a brass scale. (See Fig. 132.) The scale is graduated in inches with a zero at the center and numbered each way to read at least 16 in. The tube is then filled with mercury. The U-tube is connected up through a heavy rubber tube. The glass tube should be clean and free from water and the connections should be free from air leaks. These may be detected by turning the cock off, leading to the vacuum being measured, and noting if any perceptible fall of the column occurs. Both columns should be read and added together. Never read one and multiply by two. When the U-tube is disconnected both columns should stand at the same level. When reading vacuum the U-tube may be left connected to the machine, but it should be disconnected after each pressure reading, or the tube will gradually fill with water.

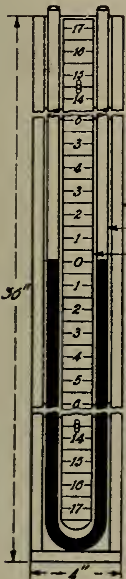

Fig. 132
U-TUBE

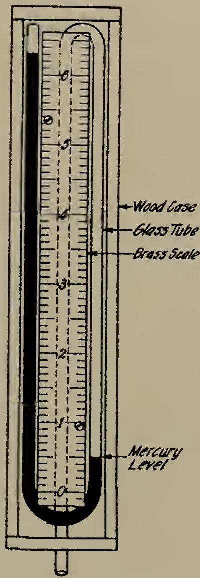

Fig. 133
ABSOLUTE PRESSURE GAUGE

Absolute pressure gauges are used only on the high vacuum of the exhaust, to check the U-tube. These are made of a thin glass tube bent in the shape of a U with one end longer than the other. The longer end is bent over and brought down below the bottom of the U. (See Fig. 133.) The short leg of the U and a couple of inches of the other leg is completely filled with mercury, which is then boiled out and the top sealed. The whole tube is then mounted in a wooden case carrying a brass scale graduated in inches. The lower end is connected to the vacuum to be measured by a heavy rubber tube. Normally the difference in the heights of the two columns will be six to eight inches, but with a high vacuum on the lower end they will tend to equalize. The upper column has an absolute vacuum on it so that the difference in the height of the two columns represents the difference between the vacuum being read and an absolute vacuum, or the *absolute back pressure*. The sum of the readings on the absolute gauge and the U-tube should check the barometer reading within less than 0.1 in.

The mercury in the end open to the atmosphere slowly oxidizes and when this takes place the absolute gauge will record a smaller back pressure than is actually present. The gauge should be placed above the opening into the vacuum space and the rubber tube kept free from loops or water may lodge in it and be carried over on the top of the mercury when the vacuum is broken. If this occurs, the gauge must be sent to the laboratory and cleaned and refilled. The gauge must always be kept in a vertical position and never laid down or carried horizontally, or air will get into the sealed end. Turn on to vacuum very slowly and never take it off suddenly, or the mercury may break the sealed end.

Temperatures

The temperatures to be read are:
Steam pipe (near pressure gauge),
All stage shells (when called for),
Air (near U-tubes and absolute gauges).

The temperature of the initial steam is read as nearly as possible to the pressure gauge, the thermometer-well being placed diametrically in the steam pipe. Steam is available at any pressure up to 200 lb. gauge, and of varying quality. For running tests, which require high pressure and low superheat, it is sometimes necessary to inject a spray of water into the steam. This is done at a considerable distance from the turbine in order to get a good mixture of water and steam. When dry steam is specified, it is best to hold about 15 deg. superheat; for, if a lower superheat be held, the temperature may drop to the saturation point where the condition of the steam cannot be determined without a calorimeter.

When the test is finished, always shut off injection water to avoid filling the steam pipe with water, as this would cause a water hammer when steam is again turned on.

In cases where it is necessary to read the temperature in the various stages, the thermometer wells should be located near the gauge and in the path of the steam; special precautions being taken so that the revolving part of the turbine will not strike the thermometer well.

The temperature of the air near all U-tubes and absolute gauges is taken in order to correct the length of the mercury column to the same temperature as that at which the barometer reading is read.

The man reading temperatures should fill the thermometer wells with mercury and be sure that there are no broken mercury columns in the thermometers in use. A thermometer should be placed as low in the well as possible with the readings to be taken, but do not have the mercury column below the point of immersion as vaporization of the mercury in the thermometer may take place.

Flow

There are two methods in common use of measuring the quantity of steam to be consumed: The first is to weigh the water after the steam has been condensed in a surface condenser. The second is to measure the steam flow by means of a steam flow meter.

The first method is the one most commonly used in the Testing Department, although in nearly all cases a flow meter is installed and readings recorded.

Flow Tanks

After the steam has been condensed in the surface condenser it is pumped from the hot well to the flow tanks where it is weighed. These tanks should be of sufficient capacity to hold the amount of steam condensed during six minutes. They are mounted one above the other. Both outlet pipes should be equipped with quick closing valves which shut perfectly tight. The upper tank is used as a reservoir, when taking weights on the lower, which is mounted on a pair of platform scales.

To measure the amount of condensed steam, proceed as follows: Close the upper tank outlet valve on an even six minutes. Then close the lower tank outlet and balance the scale. This reading is called "tare." The upper valve is then opened, and closed after exactly six minutes have elapsed from the first closing. After closing, the scale is again balanced, and this reading is called "gross." The difference between the "gross" and "tare" is the "net" reading which when multiplied by 10 gives the flow per hour. After taking the "gross" reading, the lower valve is opened and the water allowed to run to waste. The valve is then closed and the "tare" again taken. This cycle is repeated as long as the test continues, care being taken to close the upper valve at exactly each six minute interval. If the flow is extremely rapid, readings may be taken at four or even three minute intervals. Slight variations will occur due to irregular pump or condenser action, but the average of a number of readings will give accurate results with constant conditions. At least five readings should be obtained for each load, or operating condition.

Before taking any readings, the scales should be carefully inspected to see that the platform and the scale beam move freely. The scales should be calibrated frequently. This can be done by balancing the scales and then adding a 50 lb. standard weight. These should be placed on each of the four corners of the platform. The scales should be thoroughly overhauled occasionally and all knife edges kept sharp. When not in use the weight should be taken off the knife edges, by throwing the lever to the off position.

Load

There are two methods of obtaining load; one with an electric generator, and the other by the use of a water brake.

When an electric generator is used, the load is measured by means of wattmeters; ammeter and voltmeter readings being taken as a check.

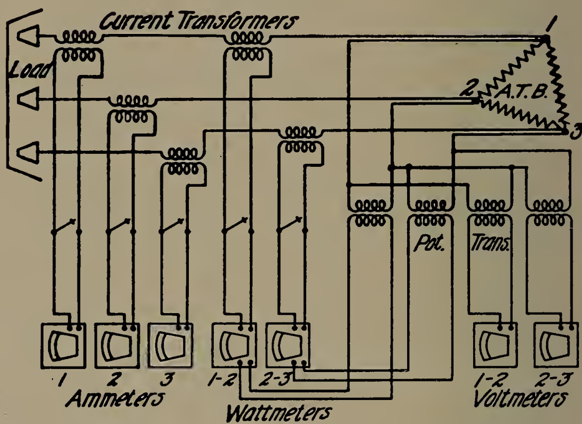

Fig. 134

WIRING CONNECTIONS FOR LOAD TEST

The meters required for reading the load on three-phase a-c. generators are: Two wattmeters, three a-c. ammeters, two a-c. voltmeters, one d-c. ammeter, and one d-c. voltmeter. Each a-c. instrument is provided with a separate potential or current transformer of sufficient ratio to bring the reading well within the scale of the meter. Five current and four potential transformers are required. (See Fig. 134.)

One side of the current transformer secondary is grounded and each circuit is provided with a single-throw, single-pole, short-circuiting switch, which must be used when the meter is disconnected. The volts, amperes and watts are read, using a separate transformer, to check the correctness of the load and the power-factor, which should be greater than 0.99; otherwise, the test cannot be accepted. The meters and transformers should be calibrated frequently, and a copy of the calibrations kept at hand for calibrating the load. A record of the number and date of calibration of each meter and the number, ratio, and date of calibration of each transformer should be entered on each sheet of every test.

The man reading the wattmeters is responsible for the load, and, assisted by the man reading the ammeters, must keep the phases as nearly balanced as possible. Average readings are taken at two-minute intervals; all readings being taken as nearly simultaneously as conditions permit. The man reading the voltmeters must hold the voltage constant by varying the field, when the governor is operating, and must read and record volts field and amperes field at four-minute intervals.

Quarter-phase generators require one less current transformer and one less a-c. ammeter. On d-c. generators, two sets of milli-voltmeters with shunts and two voltmeters are used to check the load. Considerable trouble is often experienced in getting shunts that will check within 1 per cent after they have been heated.

In cases where a water-brake is used, the same precautions concerning the care of the scales for the steam flow tanks apply to the water-brake scales. The knife-edges on the brake shell should bear properly and the brake shell turn without friction. Readings should be taken only when the scales remain balanced for an appreciable length of time and when the speed is exactly right. Care should be exercised to make sure that water is continually flowing through the brake in order to prevent excessive heating. The flow of water on each side of the brake disk should be very nearly equal; otherwise, the brake may vibrate severely, making it impossible to obtain accurate readings.

The following formula is used to calculate the kw. output:

Let R = Length of brake arm in inches.
P = The load on scales in pounds.
S = Speed in revolutions per minute.

$$\text{Then h.p. output} = \frac{2\pi RSP}{12 \times 33{,}000}$$

$$\text{Kw. output} = \frac{\text{h.p. output} \times 746}{1000}$$

Tests

The tests generally required are "load curve" and "no load flow with field excited" and vacuum and speed curves at various loads. The following may also be required: Bowl pressure curve, superheat curve, and shell pressure curve.

The readings to be taken and the time intervals are as follows for all tests:

Pipe pressure	2 minutes
Valve casing	2 "
1st bowl	2 "
Throttling bowl	2 "
Superheat	2 "
1st stage shell	2 or 4 minutes
2nd " "	4 or 6 "
3rd " "	4 or 6 "
Additional shells	4 or 6 "
Exhaust-vac. and abs.	2 minutes
Packing steam exhaust and head if used	6 to 10 minutes
Temperature of all U-tubes	10 minutes
Flow (water rate)	6 "
A-c. watts, A-c. amperes, A-c. volts	2 "
Field amperes and volts	4 "
D-c. amperes, D-c. volts	2 "

In taking a *load curve* (water rate with load) with the governor operating, the initial pressure, superheat and vacuum are held constant, and at least three, and preferably five, loads are used. These may be half-load, full-load, and 50 per cent overload, together with the quarter-load and 25 per cent overload.

"*No-load flow*" is taken by running the machine under normal steam conditions, holding normal voltage on the generator.

A vacuum curve may be run with or without the governor. When the governor operates, the initial pressure, superheat and load are held constant and the vacuum varied. For a short vacuum curve four or five points are taken at pressures varying 1 in. If it is desired to carry the test to atmospheric pressure, two or three of the higher vacuum readings are taken close together and the pressure differences then gradually increased to five or six inches at atmosphere. The same readings are taken as on the load curve.

In running a *vacuum curve* without the governor, a number of valves are blocked open to give approximately the desired load at 28 in. vacuum. The speed is held constant by varying the load and readings taken on the table, only when the speed, initial pressure, superheat and vacuum are correct. They are then taken at 1 minute intervals. All other readings are the same. The field amperes are held at the constant value, which gives normal voltage at normal speed. The water flow will be constant at the different vacuums so that the vacuum can be changed as soon as a sufficient number of steady readings on the table are obtained. Usually not more than four points are taken, at 1 in. pressure differences.

This test and the speed curve are the two most difficult water rate tests to make. Every man must work together, or the speed will continually vary and no results be obtained. The load should be varied in small increments and sufficient time allowed for a corresponding change in speed. The field amperes should be held absolutely constant as but a small change in excitation produces a large change in the load, especially on high voltage machines.

On a *speed curve*, the conditions are similar to that in a vacuum curve without governor and the same precautions apply. The speed is varied by varying the load, and field amperes are held constant to give normal voltage at normal speed. If, however, at the higher speeds the voltage is too high either for the safety of the windings or for the meters, the excitation may be reduced sufficiently to enable readings to be taken.

Maximum load non-condensing may be taken from a point on the normal load vacuum curve by a separate test. Occasionally back pressure curves above atmosphere are required.

If the turbine has no atmospheric exhaust openings the back pressure test can be obtained only by throttling down the air pump until atmospheric pressure is obtained at the exhaust opening of the turbine. This produces a high temperature in the condenser and is likely to cause leaks.

If, as is usual, the machine has atmospheric exhaust openings, they can be piped to the condenser through a gate valve, the condenser exhaust being blanked off. With this arrangement any desired back pressure may be held on the turbine, while the condenser is working under a high vacuum. The condenser is kept cool and there is no danger of damaging it or the air pump. The readings are the same as for the load curve. The load should be gradually increased until the last valve is practically wide open. If too much load is applied, the speed will fall off when the last valve is wide open.

A bowl pressure curve is generally taken at full load, with the governor operating. The range of initial pressures should be as large as possible, in order to neutralize the effect of throttling on any of the valves. All readings are taken in the same manner as for a load curve.

A superheat curve is generally taken at two points, though more may be taken, one at low and the other at high superheat. The conditions and readings are the same as for the load curve. with which it may often be combined to advantage.

A shell pressure curve is taken on those turbines that are equipped with stage valves, or with a movable diaphragm between stages.

This can generally be combined with the load curve. The group of nozzles controlled by the stage valve should always be wide open or closed tightly. They should never be throttled, as this will invariably increase the water rate.

Arrangement of Apparatus

In order to conduct the tests outlined on the previous pages, the Testing Section in Building No. 61 is equipped with apparatus especially arranged for this work.

Steam Controlling Equipment

There are four stands equipped with connections to the condensers and with a suitable switchboard for controlling the generator load. The condensers and their auxiliary apparatus are located under the switchboards in such a manner that they are readily accessible for repairs. The cooling water pump is located at the end of the Test Floor, the piping being so arranged that it can supply cooling water to one or both condensers at the same time. There are two hot-well pumps and the piping is so arranged that either or both pumps can be connected to either of the condensers. Each pump has a separate discharge line to the weigh-tanks. The air pumps are located as close to the condensers as possible.

The condensers are equipped with relief valves set to operate at slightly above atmospheric pressure. These valves should be inspected frequently to make sure that they are in operating condition, for it is a very dangerous practice to allow the pressure on the condensers to become excessive.

Electrical Equipment

Each of the four stands have switchboards so arranged that any of the stands can be connected to the water-boxes and to the exciters through a plug board. The switchboards are so connected that the instruments and transformers can be installed without any changes in the permanent winding. The exciters, two in number, are turbine driven sets, the fields of both being excited from the 125 volt shop circuit. Located directly back of the Testing Section office are the water-boxes used for obtaining load. The blades are remotely controlled, the controls being wired to the plug-boards so that they can be connected to any of the four stand switchboards.

Auxiliary Pumps

Injection water pumps for controlling the superheat, the step-bearing oil pumps, oil tanks, and other auxiliary apparatus are also located near the testing stands. When running a vertical machine it is well to detail a man to watch the step-bearing pump as there is no accumulator in the oiling system.

Caution

Although there is a regular attendant, whose duty it is to operate the pumps, exciters, etc., the man running a machine should know at all times what apparatus is in use and should be certain that the water, vacuum, and oil pumps are running before starting the turbine. When a turbine has been shut down for any length of time, the attendant should be notified so that he can shut down the auxiliary apparatus or make other changes that are necessary. In general all instructions applying to commercial testing of turbines apply and should be adhered to when taking steam consumption tests.

CHAPTER 14

MARINE ENGINE SETS

The Marine Engine Sets consist of vertical type double acting steam engines direct connected to multipolar generators. (See Fig. 136.)

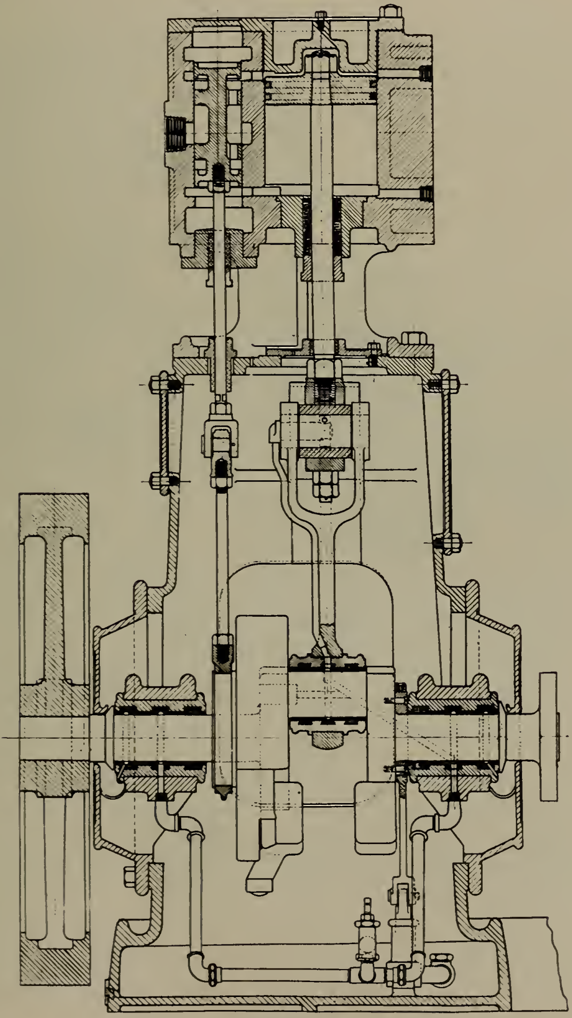

Fig. 135
MARINE ENGINE

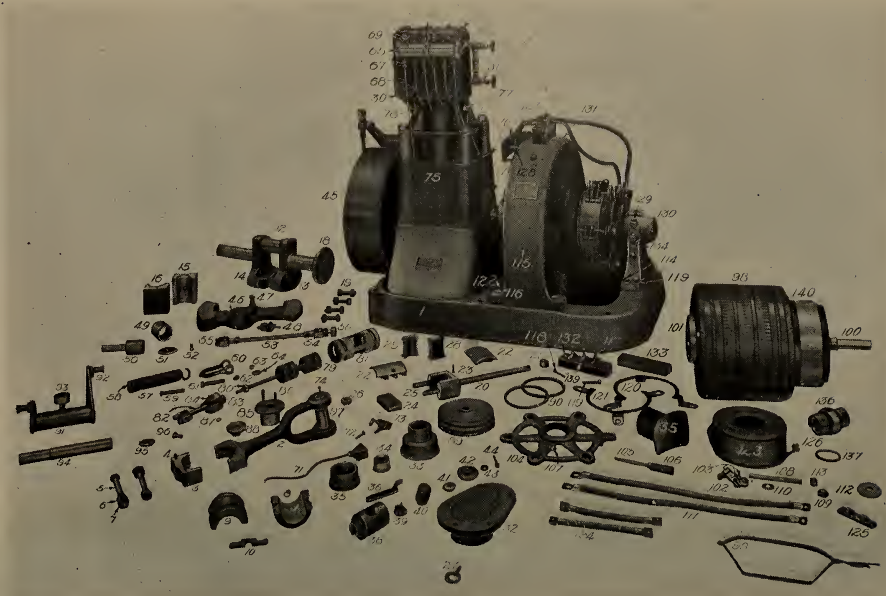

Fig. 136
PARTS OF MARINE ENGINE SET (See page 287)

PARTS OF MARINE ENGINE SET (See Fig. 136)

1 Base
2 Connecting rod with wrist pin
3 Cap
4 Cap set screw
5 Bolts
6 Nuts
7 Cotter pins
8 Crank pin brasses (top half)
9 Crank pin brasses (bottom half)
10 Liners
11 Column bolts and nuts
12 Crankshaft
13 Counterbalance (right)
14 Counterbalance (left)
15 Crankshaft bearing (top half)
16 Crankshaft bearing (bottom half)
17 Cap
18 Half coupling
19 Bolts and nuts
20 Crosshead and piston rod
21 Nut for piston rod
22 Shoes
23 Screws
24 Cap
25 Bolts
26 Nuts
27 Eye bolt
28 Wrist pin brasses (top half)
29 Wrist pin brasses (bottom half)
30 Cylinder
31 Drain valves
32 Head (top)
33 Head (bottom)
34 Gland
35 Brass nut
36 Spanner wrench
37 Studs and nuts
38 Relief valve casing
39 Relief valve
40 Relief valve spring
41 Relief valve cap
42 Relief valve cover
43 Relief valve lock nut
44 Relief valve adjusting screw
45 Governor pulley
46 Weight
47 Eccentric pin
48 Grease cup (automatic)
49 Bushing
50 Bearing pin
51 Cap
52 Securing screw
53 Governor connecting rod
54 Brasses (top)
55 Brasses (bottom)
56 Grease cup
57 Governor spring
58 Screwed plug
59 Adjusting screw
60 Shackle
61 Shackle bolt
62 Shackle nut
63 Shackle bushings
64 Shackle washers
65 Oil tank
66 End glass with washer
67 Sight feed glass
68 Distribution pipes
69 Filling plug
70 Bracket with screw
71 Oil cup and pipe for crank pin bearing
72 Oil cup securing screws for above
73 Oil cup with pipe for wrist pin bearing
74 Oil cup securing screws for above
75 Oil shield (front)
76 Oil shield (back)
77 Oil shield (generator side)
78 Oil shield (pulley side)
79 Piston valve
80 Stem with nuts
81 Bushing
82 Link
83 Link saddle
84 Link saddle pin
85 Valve stem stuff-box
86 Studs
87 Nuts
88 Gland
89 Piston
90 Rings
91 Rocker arm
92 Pins
93 Grease cup
94 Shaft
95 Cap
96 Securing screw
97 Wrist pin
98 Armature
99 Coil
100 Shaft
101 Half coupling
102 Brush-holder
103 Spring
104 Yoke
105 Binding spindle
106 Handle
107 Studs and nuts
108 Stud
109 Nuts
110 Washers
111 Cables
112 Insulating washers
113 Insulating bushings
114 Bolt for pillow block
115 Bolt for pole piece
116 Bolt for magnet frame foot
117 Bolt for cable terminals
118 Bolt and washer for connection board
119 Dowel pin for pillow block
120 Bus ring (large offset)
121 Bus ring (small offset)
122 Dowel pin for mag. frame
123 Field coil
124 Series field cables
125 Shunt field terminal board
126 Washers, bolts and nuts for series coil
127 German silver shunt for series field
128 Support
129 Top bolt for O.B.B. cap
130 Gauge glass for O.B.B.
131 Magnet frame
132 Connection board
133 Support
134 Pillow block
135 Pole piece
136 Self-oiling sleeve
137 Rings for self-oiling sleeve
138 Soft rubber washers
139 Cable terminals
140 Commutator

ENGINE

Single cylinder engines are used with generators from 2½ to 60 kw. capacity, and vertical tandem compound engines with machines from 25 to 75 kw. capacity. The engines are standard commercial machines. See Fig. 135.

Steam Pressures

The ratings of the standard single cylinder engines are based on the steam pressures given in the following table and those designed for 80 lb. steam pressure can be operated at pressures up to 125 lb. either condensing or non-condensing. If higher boiler pressures are used a suitable reducing valve must be placed in the steam line to give the desired pressure. For steam pressures of less than 80 lb., single cylinder engines are fitted with large cylinders, to operate at pressures ranging from 35 to 60 lb. The tandem compound engines are designed to operate economically at 125 lb. condensing or 140 lb. non-condensing.

Unless otherwise advised by Engineering instructions, all engines must be tested at the pressures given in the tables on pages 289 to 292 inclusive. These tables are a complete list of all types of engines manufactured.

Lubrication

Two systems of lubrication are used, gravity and forced.

In the gravity system all the main bearings of the engine are lubricated from an oil reservoir attached to the engine (refer to Fig. 136); each bearing being provided with an adjustable sight feed for regulating the flow of oil. The waste oil collects in a bedplate reservoir, from which it can be drained, filtered and used over again. The bearings of the governor and valve gear are lubricated by compression grease cups.

In the forced system the lubricant is passed under pressure to the various parts of the engines. The base of the engine forms an oil tank to which is attached a small plunger pump driven by an eccentric on the shaft. The oil is forced through grooves in the main bearings, drilled holes in the shaft connecting these grooves with the crank pin. The oil is also forced to the wrist pin through the pipe on the side of the connecting rod.

The passages in the crosshead pass the oil from the wrist pin to the guides. After passing through the bearings the oil is collected in the base, where it settles and is used over again. The bearing caps must be set up tight and the main bearing liners must be close to the shaft; otherwise too much oil leakage will occur before reaching the last bearing. To prevent the entrance of foreign matter a strainer is attached to the suction valve of the pump. When the crank chamber is inspected, no waste, dirt or other matter must be allowed to enter and mix with the oil. When cleaning the oil chamber, canvas and not waste should be used, since the latter clogs the strainer.

Only mineral oil should be used for lubricating. Since the oil passes through the bearings repeatedly, it gradually loses its lubricating properties, becoming thick and gritty. It should,

SINGLE VERTICAL CYLINDER ENGINE SETS, GRAVITY LUBRICATION TYPE

Classification	Dimensions in Inches				Volts Full Load	Amp. Full Load	Steam Pressure Lb.
	Dia. Cylinder	Stroke	Dia. Steam Pipe	Dia. Exhaust Pipe			
MP 4– 2½–700	3½	3	¾	1	110	23	80
MP 4– 3 –700	3½	3	¾	1	110	27	100
MP 4– 4 -600	4½	4	1	1¼	110	36	80
MP 4– 5 –600	4½	4	1	1¼	110	45	100
MP 4– 7 –550	5	4½	1¼	1½	110	64	80
MP 4– 8½–550	5	4½	1¼	1½	110	77	100
MP 6–10 –450	6½	5	1½	2	110	91	80
MP 6–12½–450	6½	5	1½	2	110	114	100
MP 6–15 –400	8	6	2	2½	110	136	80
MP 6–17½–400	8	6	2	2½	110	160	100
MP 6–20 –360	9	7	2½	3	125	160	80
MP 6–25 –360	9	7	2½	3	125	200	100
MP 6–30 –305	11	8	3	3½	125	240	80
MP 6–35 –305	11	8	3	3½	125	280	100
MP 6–40 –305	11	8	3	3½	125	320	125

Generators can be wound for 110, 125 or 250 volts.

SINGLE VERTICAL CYLINDER ENGINE SETS, FORCED LUBRICATION TYPE

Classification	Dimensions in Inches				Volts Full Load	Amp. Full Load	Steam Pressure Lb.
	Dia. Cylinder	Stroke	Dia. Steam Pipe	Dia. Exhaust Pipe			
MP 4 –7 –550	5	4½	1¼	1½	110	64	80
MP 4– 8½–550	5	4½	1¼	1½	110	77	100
MP 6–10 –475	6½	5	1½	2	110	91	80
MP 6–12½–475	6½	5	1½	2	110	114	100
MP 6–15 –425	8	6	2	2½	110	136	80
MP 6–15 –425	6	6	2	2½	110	136	150
MP 6–17½–425	8	6	2	2½	110	160	100
MP 6–17½–425	6	6	2	2½	110	160	175
MP 6–20 –400	9	7	2½	3	125	160	80
MP 6–25 –400	9	7	2½	3	125	200	100
MP 8–30 –315	11	8	3	3½	125	240	80
MP 8–35 –315	11	8	3	3½	125	280	100
MP 6–40 –315	11	8	3	3½	125	320	125
MP 8–50 –280	12	11	3½	4	125	400	100
MP 6–60 –280	12	11	3½	4	125	480	125

Generators can be wound for 110, 125 or 250 volts.

DIRECT CONNECTED SETS WITH TANDEM COMPOUND ENGINES, FORCED LUBRICATION

Classification	DIMENSIONS IN INCHES				Volts Full Load	Amperes Full Load	Steam Pressure Lb.	Vacuum Inches
	Dia. H.P. and L.P. Cylinders	Stroke	Dia. Steam Pipe	Dia. Exhaust Pipe				
MP 6–25–450	6½–10½	5	2	3	125	200	140	
MP 6–35–400	7½–12½	6	2	3½	125	280	140	
MP 6–50–400	9½–15	6	2½	4	125	400	140	
MP 6–75–310	10½–18	8	3	5	125	600	140	

DIRECT CONNECTED SETS WITH CROSS-COMPOUND ENGINES, U. S. NAVY TYPE, FORCED LUBRICATION

MP 6– *8–550	5	4½	1¼	1½	125	64	100	25
MP 6– 16–450	5½– 9	6	1½	3	125	128	100	25
MP 8– 24–400	6½–10½	7	2	3½	125	192	100	25
MP 8– 32–400	7½–12	8	2½	4	125	256	100	25
MP 8– 50–400	7½–14	8	3	5	125	400	150	25
MP 8–100–350	10 –18	10	3½	6	125	800	150	25

* The engine of this set is of the single cylinder type.

DIRECT CONNECTED SETS WITH SPECIAL CYLINDERS FOR LOW STEAM PRESSURES

Classification	Dimensions in Inches: Dia. Cylinder	Dimensions in Inches: Stroke	Dimensions in Inches: Dia. Steam Pipe	Dimensions in Inches: Dia. Exhaust Pipe	Volts Full Load	Amperes Full Load	Steam Pressure Lb.	Method of Lubrication
MP 4– 7–550	7	4½	2	2½	110	64	50	Gravity
MP 4– 7–550	9	4½	2	2½	110	64	35	Gravity
MP 6–10–450	7½	5	2	2½	110	91	60	Gravity
MP 6–10–450	9	5	2	2½	110	91	50	Gravity
MP 6–15–400	10	6	2½	3	110	136	50	Gravity
MP 6–15–400	12½	6	2½	3	110	136	35	Gravity
MP 6–20–360	11	7	3	3½	125	160	50	Gravity
MP 6–20–360	13	7	3	4	125	160	35	Gravity
MP 8–30–315	16	8	3	4	125	240	35	Forced
MP 8–35–315	16	8	3	4	125	280	45	Forced
MP 6–40–315	16	8	3	4	125	320	50	Forced
MP 8–50–280	17½	11	4½	6	125	400	50	Forced
MP 6–60–280	17½	11	4½	6	125	480	60	Forced

DIRECT CONNECTED ALTERNATING CURRENT SETS, FORCED SYSTEM OF LUBRICATION

Classification	Dimensions in Inches				Volts	Steam Pressure Lb.
	Dia. Cylinders	Stroke	Dia. Steam Pipe	Dia. Exhaust Pipe		
ATB-24-25-300	11	8	3	3½	2300	80
ATB-24-35-300	11	8	3	3½	2300	100
ATB-24-50-300	12	11	3½	4	2300	100
ATB-24-75-300	12	11	3½	4	2300	150

Sets wound for 240, 480, 600 or 1150 volts can be furnished if required.
Single-phase rating of above generators is 70 per cent of three-phase rating.
Sets are furnished with or without direct connected exciters.

therefore, be occasionally run through a filter and mixed with new oil. The number of filterings required depends upon the oil as well as the length of time the engine operates.

The oil should stand about ¾ in. above the suction and discharge valves, and no water should be allowed to mix with it. An oil pressure of about 15 lb. should be maintained by regulating the adjusting screw of the relief valve.

Valves

In all single cylinder engines, the plain plug piston valve is employed without any expanding rings. These valves take steam through the inner edges, and exhaust past the outer edges. (On tandem compound engines the low pressure valves take steam through the outer edges and exhaust past the inner edges.) The travel of the valve is controlled by the automatic governor; varying the cut-off from ¾ to zero, depending upon the load. Great care is used in grinding and fitting these valves to their chambers, to obtain economical and satisfactory operation. The fit of these parts is most important.

Starting the Engines

Before steam is admitted to the cylinder see that the valve moves freely by turning the governor wheel by hand. As the expansion of the valve is much more rapid than the cylinder, the cylinder should be allowed to warm up before full pressure is applied. By allowing the set to come to full speed gradually, no trouble will be experienced due to the valve "seizing." The engineer in charge of the section always prepares the engines for test, including the adjustment of valves, governors, packing, taking of indicator diagrams, care of indicators, piping, condensers and apparatus for weighing water when water consumption tests are made.

Tests

Unless otherwise advised by the Engineering Notice covering the particular requisition and engine, all single cylinder commercial engines are tested for the following only:

(1) Speed Regulation.
(2) Steam Consumption.

(1) The steam and back pressures and electrical load are held constant. Then the speed variation is tested by suddenly putting on or throwing off load when the conditions are constant. The total variation between full and no load should not exceed 3½ per cent. A speed regulation of 3 per cent is usually obtained and at this value the stability of the governing mechanism is satisfactory. When adjustments are being made for speed regulation, duplicate readings on the generator must be obtained, and the voltage must be carefully noted to see if it is affected by fluctuation in engine speed. If any voltage fluctuation occurs, it must be reported to the engineer and the proper correction made. With the engine exhaust connected to the condenser, the load must also be thrown on and off and

the speed noted, especially at no load, to see that the valve completely shuts off steam and that the engine does not "run away" or "race."

(2) The performance of every engine must lie within the limits given in the tables furnished the Testing Department regarding steam consumption. The method of weighing the condensed steam is exactly the same as employed on the turbine test. The piping in the testing stand and valves is arranged so that the exhaust steam from the engine can be passed either to atmosphere or through a condenser. If the steam consumption is excessive, the piston should be examined to see that the rings are free in the grooves and that they have a good and even bearing against the cylinder wall. If the rings are in good condition the valve is probably too small in diameter and allows steam to blow directly into the exhaust. In bad cases there will generally be a considerable variation in speed as the governor can not control the speed, with leaky valves.

Poor steam economy is generally due to the above causes, but lack of lubrication in the steam spaces, excessive friction in the stuffing boxes and bearings, or poor valve setting will increase the amount of steam used.

Operation

During the operation of the set in test the following points should be carefully noted:

(1) Balance of governor pulley.

(2) Concentricity of crank shaft with armature coupling and commutator.

(3) Absence of oil and grease throwing.

(4) Operation of engine with reference to quiet running.

(5) Proper alignment of all parts, especially the crank and wrist pin boxes, and central position of piston with reference to the cylinder; clearance of oil deflector of armature shaft from outboard bearing.

(6) Oil leakage around ends and at unions of Multiple Oiler, and points where supply pipes pass through column on gravity lubrication engines; that the oil drips from supply pipes into proper oil cups and channels, and in engines employing the forced system of lubrication, the quiet operation of oil pump check valves, and of the relief valves and pressure gauge in the system.

(7) The operation and "hang" of throttle valve and alignment of handwheel in reference to the valve stem in engines having the valve bolted to the cylinder.

(8) Absence of leakage in cylinder casting, due to porous metal or other causes.

(9) Fit of oil shields.

(10) Tightness and adjustment of cylinder relief valves. These should be allowed to open at the proper pressure, then tighten the set screw in casing about one turn.

(11) Vibration.

(12) General appearance of entire set.

Governor

The governor used in connection with the gravity lubrication type of engines is shown in Fig. 137, and is simpler than the various flywheel governors using shifting eccentrics. It consists of a heavy flywheel *A*, keyed to the shaft, and carrying the governor weight *B*, pivoted at *C*, and containing the eccentric *D*, which operates the valve.

The governor connecting rod transmits motion from the governor to the valve, and is connected to eccentric pin *D*. The length of the valve stroke, therefore, depends upon the

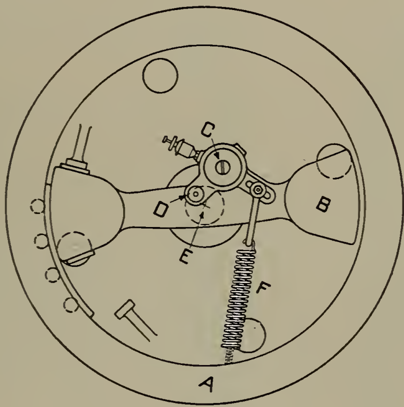

Fig. 137
GOVERNOR

distance of *D* from the center *E*. The amount of steam admitted to the cylinder varies directly as the distance between the center of *D* and *E*.

If the engine speed increases, then the weight *B* is moved by centrifugal force toward the perimeter *A*, decreasing the distance of *D* from the center *E* and reducing the amount of steam admitted to the cylinder. If the speed of the engine becomes excessive, the distance of *B* from *E* is reduced to the minimum and the steam is entirely cut off.

The motion of the fly weight *B* is opposed by the spring *F*, which is attached to the pulley and fly weight. By increasing or decreasing the tension of the spring, the speed may be raised or lowered. The same effect will be produced by moving the spring in the slot of the weight, moving it away from the fulcrum increases the speed, and vice versa.

Unstable regulation is due to too close an adjustment of speed, and may be avoided by moving the spring attachment away from the fulcrum. A leaking valve or insufficient lubrication of the fly weight fulcrum will also produce the same effect. If the lubrication is not sufficient the governor should be taken apart and cleaned. Only the best of soft grease should be used in the cup, and the governor should occasionally be taken apart and cleaned to obtain the best results. The governors of some of the forced lubrication engines are enclosed by the engine column and the bearing pin and eccentric are lubricated by oil under pressure from the oiling system.

Indicator Diagrams

When indicator diagrams are required, a stud is screwed into the wrist pin of the connecting rod for driving the motion, connecting through a link to a lever pivoted to the bracket on the engine column. The motion for the indicator is taken from a cord pin on this lever.

The indicator is a delicate instrument, and must be handled with care and kept in good order. The piston springs should be frequently calibrated. Before attaching the indicator to an engine, blow steam freely through the pipes and three-way cock to remove any particles of dust or grit that may have accumulated in them. After being used, the indicator should be carefully wiped and oiled. If any grit or other obstruction gets into the cylinder of the indicator the diagrams will give wrong results. This trouble is easily detected and should be remedied at once by taking out the piston, detaching it and cleaning with oil and replacing. The piston must move perfectly freely in its cylinder. To test this, take out the piston and spring, detach the latter and replace the piston and piston rod in their operating position, then, holding the indicator in an upright position, raise the pencil arm to its highest point and let it drop. It should freely descend to its lowest point.

Before taking diagrams, steam should be admitted to the indicator, and the cylinder allowed to become thoroughly heated. Indicator springs are made in different sizes of steel wire, to adapt them to different steam pressures. Springs are usually made to the following scales: 8, 12, 16, 20, 30, 40, 60, 80 and 100 pounds per inch travel of the indicator pencil. This scale is stamped on the spring. The spring used for indicating an engine depends upon the maximum steam pressure used; a spring should be chosen to give a diagram with maximum height not exceeding 1¾ in. The diagram should not exceed 2½ in. to 3 in. in length. The less the vertical and horizontal motions are, the slower will be the movement of the paper cylinder with a correspondingly more delicate pencil tracing. The proper spring required may be found as follows: Divide the boiler pressure, expressed in pounds, by the desired height of the diagram, expressed in inches, and the result will be the spring required. For instance, with a boiler pressure of 140 lb. gauge and a diagram height of 1¾ in. then $140 \div 1\frac{3}{4} = 80$, is the number of the spring required.

If too weak an indicator spring is used it will vibrate inside the indicator cylinder at admission and cause a wavy line on the card, hence the strength of the spring should be chosen with due regard to this point. The indicator cord should have sufficient tension on it to prevent any whipping action occurring at the extreme point of the stroke. Hence sufficient tension must be given to the rotary spring in the indicator to prevent this-

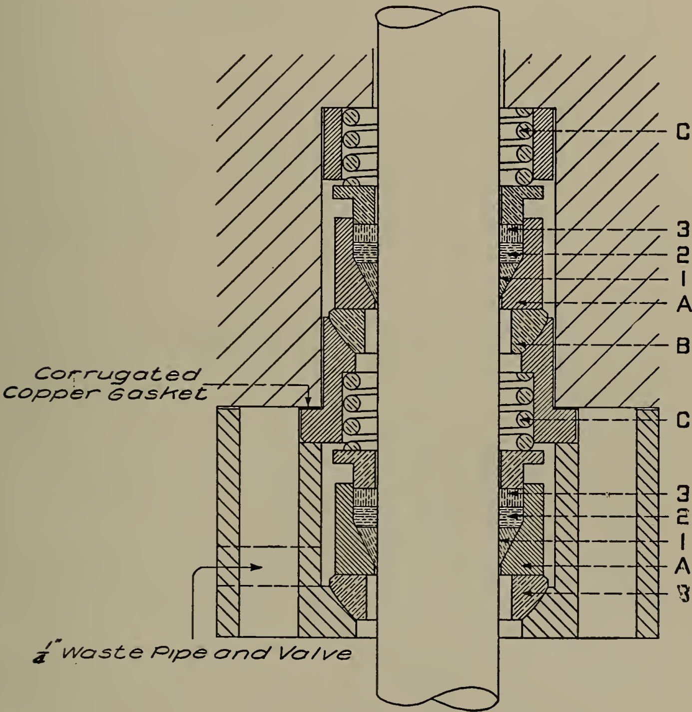

Fig. 138

PISTON ROD PACKING

action. If the tension on this spring is not sufficient, the length of the indicator cards will vary; the higher the speed of the engine the greater will the variation be.

The pressure of the pencil upon the paper can be adjusted by screwing the handle in and out. The line should not be heavy as this will cause unnecessary friction. After the diagram has been taken, close the cock and take the atmospheric line; then disconnect the cord to avoid excessive wear on the drum.

The following notes should be made on the card and any other data which it is proper to add:

Date	Time
Requisition No.	Dia. of Rod
Kw. Capacity	Cylinder
Card No.	Boiler Pressure
Stroke	Exhaust Pressure
Clearance	Revolutions per min.
Scale of Spring	Volts
Engine No.	Amperes
Cylinder No.	Pounds of water per kw-hr.
Dia. of Cylinder	

A trifle more lead at the crank end of the valve should be given at no load, as at ¾ or full load the average pressure on either side of the piston will be found to be practically equal, due to the angularity of the connecting rod. Various adjustments will be necessary to obtain the best diagram and operation of the engine.

Packing

In all single cylinder engines, up to and including the 30 kw. size, the Garlock Spiral Packing is used in both piston rod and valve stem stuffing boxes, and in the valve stem stuffing boxes of all engines, the leakage being taken up by tightening the brass nut on the box.

In the piston rod stuffing boxes of the tandem-compound, cross-compound and of the single cylinder 50 kw. engine, United States Metallic Packing is used. Fig. 138 shows the "Double" type which is commonly used, but in some machines the "Single Junior" packing is employed. The general construction of the two packings is similar.

The packings consist of vibrating cups *A* and *A*, receiving the packing rings 1, 2 and 3. These rings are in halves and, in assembling the packing, the joints should be broken. The vibrating cups rest upon rings *B* and *B*, which have a spherical bearing, so that the packing will follow the rod in any position. The steam pressure forces the packing down in the cups and against the piston rod, thereby preventing steam leakage. The coil springs *C* and *C* assist this pressure, at the same time holding the packing in place and preventing the rings from following the rod at the moment of reversing. If the packing has been taken out for examination, the ground surfaces should be cleaned and freed from grit before reassembling. The box holding the packing is drilled and tapped for a ⅛ in. waste pipe and fitted with a globe valve which should always be open.

General Instructions

An engine unit should not be considered mechanically nor electrically perfect, until the tests have so proved. Testers should familiarize themselves with every detail of design and operation, thereby helping toward the production of the most reliable piece of apparatus. After the inspection in the Engine and Testing Department the unit is dismantled and thoroughly overhauled, touched up and re-inspected, preparatory to final shipment.

GENERATOR

The tests taken on the generator are duplicates of those described in preceding chapters. All standard d-c. generators are given only compounding tests and adjustment of shunts. On standard a-c. generators saturation and synchronous impedance are taken.

If core losses are called for they are taken as previously described, the generator being either disconnected from its engine and assembled in shop bearings or the connecting rod, etc., of the engine is dismantled and a driving belt slipped over the engine flywheel.

CHAPTER 15

GENERAL ELECTRIC TEST TRACKS

As the work on the General Electric Test Tracks is almost entirely experimental a large number of the tests require special instructions. The following rules, however, have been issued relative to the operation of trains on these tracks, as well as instructions for obtaining data, in testing apparatus.

No test should be started nor should changes be made in any test without instructions from the office of the Supervisor of Test Tracks.

All data should be recorded upon special record sheets and supplementary column sheets, or upon the special form sheets provided for that test.

All data sheets should contain the name of the man in charge of the test, and date of test, while all supplementary column sheets should also contain in the upper right hand corner the number of the record sheet to which they belong.

ELECTRIC LOCOMOTIVES

Special form sheets are printed for testing locomotives, which should be carefully filled out. The procedure of testing is as follows:

1st. Inspect motors, contactor compartments, rheostat compartments, controllers, etc., for loose material, scrap wire, etc. Examine all bearings to see that they are properly lubricated, including motors, air compressors, dynamotors and all operating parts.

2nd. Ring out wiring to see that all connections are according to the wiring diagram. Inspect the wiring to see that all terminals are properly soldered and secured with lock washers; also that all parts of both the main and auxiliary circuits are properly insulated and that all wiring is so secured as to prevent the insulation being cut by chafing.

3rd. Take clearance measurements to see that the locomotive conforms to the clearance diagram.

4th. See that the current collecting devices are in proper condition and satisfactory for operation.

Where third rail shoes are used this should include the pressure on the rail in the running position as well as the measurements showing the position of the shoe with respect to the third rail.

On trolley poles and bases it should include the pressure of the wheel on the wire at some given angle of the trolley pole. This can be taken with a small spring balance attached to the trolley rope. It is well to note what this pressure is, both going up and coming down, to insure that the base does not have an undue amount of friction.

On pantograph trolleys the pressures of the pans, or rollers, against the wire should be taken as on trolley poles and wheels. Where rollers are employed as collecting devices it should be carefully noted whether the rollers are free to revolve and whether they are in every way satisfactory to operate.

5th. Connect to the power circuit and try out the lighting circuit, including headlights. Pump up the air pressure and try out the air brakes, adjust all valves, gauges, etc., according to the air brake diagram and inspect all air piping for leaks.

6th. Check with the wiring diagram the contactors that are closed, both forward and reversed on each notch of one controller and if there are two controllers check in one direction of the second controller. For some typical connections see DS prints No. 15466, 28765, 28234, 29302, 39188. These prints are on file in the Testing Section office.

7th. Determine the rotation of the motors, each motor or pair of motors separately and with all motors cut in. This should be done in both directions on each combination.

8th. Measure the resistance of each step of the starting resistance to see that it agrees with the specification. This should be done by applying the air brakes so that the locomotive does not move and having an ammeter wired in the motor circuit. Put the controller on the first point with the main switch closed so that the current will pass through the motor circuit. Simultaneous readings should be taken of the current flowing and the voltage drop across the various steps of resistances. The voltmeter leads should be applied at the contactors, or controller fingers to which the resistances are attached in order to make an additional check on the wiring. Care should be taken not to keep the current on longer than is absolutely necessary to take each reading so as to avoid an increase in resistance due to heating.

9th. Where a blower is used for forced ventilation of the motors the distribution of air to the different motors should be taken, holding constant the voltage of the trolley and reading volts line, amperes input to the blower motor, speed of the blower motor and the air pressure at some given point on the motor so that the volume of air going through the motor can be obtained by comparing these results with the result of tests previously made on the test stand. Before starting this test an inspection should be made to make sure that all motor covers are on, air outlets from the motors open and that the air inlet and outlet of the blower are free from any obstruction.

10th. Run for tests on bearings and note the operation of all auxiliary parts. This test should be started at slow speed and the speed increased as soon as the temperature of the bearings will permit, to the maximum speed at which the locomotive is to be run and continued at this speed for several miles, or until the bearings and all operating parts are in satisfactory operating condition.

11th. Make a wheel slipping test by bringing the controller up, point by point, until the wheels slip and read volts line and amperes to the motor on each step of the controller. This test should be made in both directions with and without sand and with all the various combinations of motor cutout switches.

It is necessary to take readings on each point, beginning with the first, only once for each combination and after this the controller should be immediately brought to the point next below the one at which the wheels slip and readings taken at this point and continued as before until the wheels slip again. The controller should be thrown off as soon as the wheels start to slip so as to damage the track as little as possible. The wheels should not be allowed to slip more than once in the same spot otherwise a false indication of tractive coefficient might be obtained.

12th. Remove all grounds and take insulation and high potential test. These should include all the wiring and all parts of the electrical equipment.

Mounting Motors on Trucks

Before mounting motors on trucks, the following measurements should be taken: Compare bore of gears with size of axle for gears; compare bore of axle liners with size of axle for liners; compare the distance between wheel hubs with the length of the motor; axle liner flanges and gear hub; compare the distance between the center of axle and suspension bar face on truck with the distance between the axle box centers and face of motor under nose suspension.

After these dimensions have been checked, and the motors have been found to fit on the truck, the key for the gear should be fitted in the key-way and the gear put on, care being taken to get the right side of the gear next to the hub of the wheel, and to see that all lock washers and cotter pins are in place. The motor should then be hoisted by the two lugs opposite the axle bearings with a two hook chain, and the motor placed on the axle without axle linings. The motor can then be lowered in place, by allowing it to revolve around the axle until the nose suspension rests on the suspension bar. The chains can then be hooked in the two lugs nearest the axle bearings and raised enough to allow the axle linings to be put in place. The axle caps, gear cover and strap fastening the motor to the suspension bar can then be put on and the installation is complete.

Before the motors are put into service or the car run as a trailer, the motor bearings and gears should be properly lubricated.

Trolley Bases

Test sheets should contain the following data:

Number and size of spring (outside diameter, free length, number of turns and size of wire). Position of tension adjusting screw during test. Length of pole from pivot to center of trolley wheel. Style of harp and wheel. Length and tension of springs with pole, in horizontal and 45 degree positions.

Pull Curve

This curve is taken by measuring the vertical pull in pounds at the center of the trolley wheel for different heights of the wheel.

The "height" of the wheel is the vertical distance of the center of the trolley wheel above its position when the pole is horizontal. (For pantograph trolleys the height is the distance of the top of the pan above its position when locked.) In taking this test a rope should be fastened about the wheel and readings of pounds pull taken, both going up and coming down.

Service Heat Runs on Motors

These heat runs are made on motors under as nearly as possible the same conditions as will obtain in service. By making a number of heat runs under various conditions data is obtained from which the thermal characteristics of the motor are determined. These curves show the relation between the ratio of distribution of losses (ratio between watts loss in field and in armature) to the degree (Centigrade) rise per watt loss for the armature and for the field.

The instructions for the test include the following points:

(a) Weight of train.

(b) Line voltage to be held.

(c) Accelerating current required.

(d) Schedule (includes length of run, time power is on, time of coasting, time of braking, and time of lay-over).

The following readings must be taken before starting the test: Resistance of field, total and partial resistance of armature.

In order to facilitate the measurement of armature resistance during the run, resistance readings are taken between commutator bars nearer to each other than the distance between brushes. These bars should be marked or the resistance taken with a templet, in order that all measurements can be made between the same points or including the same number of bars. The ratio between the partial resistance to the total resistance is a constant from which the total resistance can be calculated.

The following must also be taken during the test:

Air temperature, velocity and direction of wind, readings during test (taken every hour), field resistance, partial resistance of armatures of alternate motors, temperature by thermometer of field spools and frame, and air temperatures.

During the run a record is kept of the schedule, direction of wind, weather conditions and all points of any interest in connection with the runs.

Records of the line voltage and amperes motor are taken with graphic recording meters for a couple of runs in each direction during the hour.

When the temperatures of the motors have become constant, the test is stopped. Besides the regular hourly readings the following temperatures are taken: Armature core surface, and conductors; commutator; field spools; frame.

These readings should be taken indoors in order to avoid all draughts.

Train Friction

Train friction curves show the relation between the train or car friction expressed in pounds per ton and speed in miles per hour.

There are two methods by which car friction may be obtained, coasting tests and free running.

Friction from Coasting Curves

The test should be made on a straight and preferably level track. The car is accelerated to a speed slightly greater than the highest speed called for on the friction curve and allowed to coast. Speed should be measured with a speed recording instrument. Runs should be made in both directions.

From the rate of retardation at any point the retarding force is calculated which represents the total car friction at that speed.

The weight of the car plus the flywheel effect of the revolving parts is the weight that tends to keep the car moving. When geared motors are used, a test should be made to obtain the rate at which the armature will slow down due to the friction of its own bearings in order that it may be known whether the flywheel effect of the armature will be sufficient to overcome the friction of its own bearings and furnish power to assist in keeping the car moving, or whether the car will have to furnish power to keep the armature revolving. The type of motor and the gear ratio should be given, together with any information that can be obtained, regarding the type of car, arrangements of wheels, wheel base of truck, etc.; if possible a photograph, or a sketch showing the cross section of the car, or locomotive should be included.

Friction by Free Running

With the car running at constant speed, readings of speed, volts line and amperes should be taken, preferably with graphic recording meters. The input to the motors, minus their electrical losses, gives the power absorbed in friction at a given speed.

It is very difficult to get accurate results by this method on account of the difficulty of keeping the car speed absolutely constant.

The test sheets should contain the following data:

Weight of car or train.

Diameter of wheels and speed of car. The number, rating and serial numbers of motors, and gear ratio, must be given.

Operating Rules

Each man, when starting work on the Test Tracks, is given a copy of the "Operating Rules." These must be carefully learned and implicitly followed at all times.

CHAPTER 16

BLOWERS

Commercial Tests consist of the operation of the blower for such a length of time as is necessary to demonstrate that no electrical or mechanical faults exist. In case the motor is of sufficient power to drive the fans with unrestricted inlet and outlet it is so tested, but in most cases the motor is provided for a certain specified pressure and volume delivered from the fans and will not operate the fan with unrestricted inlet and outlet without overloading the motor. In such cases the load on the motor can be limited by partially obstructing the inlet to the fan by means of a blower or other restriction so that the motor will not be subjected to an excessive load.

Standard Heat Run consists of the operation of the machine with air delivery restricted for a specified time or until constant temperatures of the motor are reached. This restriction may be for the purpose of bringing the load on the motor to a specified amount or may be a restriction to give the required air delivery for which the fan is to be supplied.

Minimum Speed Heat Run consists of a heat run at full field with unrestricted inlet and outlet for a specified time or until constant temperatures are reached.

Maximum Air Delivery Heat Run consists of operating the blower at full speed with the inlet and outlet unrestricted for a specified time or until constant temperatures of the motor are reached.

Endurance Run consists of running the machine for 48 hours with the specified restriction of blower inlet and outlet.

In case of ventilating fans for the Government, this consists of a 40 hr. run in addition to the 8 hr. "Normal Air Delivery Heat Run."

General Tests consist of the following:

(a) Running the machine with air delivery restricted for a specified time, or until constant temperatures of the motor are reached.

(b) 48 hr. endurance run (40 hr. in addition to the normal air delivery heat run).

(c) Heat run at full field with unrestricted inlet and outlet for a specified time, or until constant temperatures are reached.

(d) Air measurements to determine the delivery of the blower.

Special Tests consist of general tests on the blower to obtain air delivery under different conditions of opening and under different speeds.

Complete Tests consist of the following:

(a) Running the machine with air delivery restricted for a specified time, or until constant temperatures of the motor are reached.

(b) 48 hr. endurance run.

(c) Heat run at full field with unrestricted inlet and outlet for a specified time, or until constant temperatures are reached.

(d) Tests on the blower to obtain air delivery under different conditions of opening and under different speeds.

1. DOUBLE PITOT TUBE OR GOVERNMENT METHOD

This test is made in accordance with Government specifications issued by the Navy Department under the cognizance of the Bureau of Construction and Repair.

For making air tests in accordance with this method using double Pitot tubes, a testing pipe preferably of galvanized iron having the same shape and size as the outlet of the fan and a length equal to twenty times the diameter of the pipe, if round, or twenty times the average of the width and depth, if rectangular, should be connected to the fan outlet. This pipe should be smooth and carefully fitted to the fan in order to avoid any unnecessary obstruction to the free passage of the air.

It is sometimes inconvenient to use a pipe of exactly the same shape as the fan outlet, and in many cases it would be permissible to use a pipe of nearly the same area connected to the fan outlet by an adapter gradually changing from the size of the outlet to the size of the pipe.

The double Pitot tubes should be supported in the middle of the test pipe half way between the two ends and should be parallel to the sides of the pipe and pointing toward the fan. All connections between the Pitot tube and the Manometer or U-tube should be carefully made to avoid any possible leakage, as a very small leakage in the connections of these rubber tubes might seriously affect the reading of the manometer.

In making the measurements the exact area of the pipe where the Pitot tube is located should be carefully measured allowing for curvature of the sides of the pipe which sometimes takes place when the pipe is made of thin material and the pressure in the pipe is considerable. When the area of this pipe differs from the area of the outlet of the fan, the results should be corrected accordingly, as the air velocity will be greater in a smaller pipe and the static pressure less, but the total impact pressure will not be affected except by the increased friction of the smaller pipe.

A suitable damper or door should be placed at the end of the testing pipe so that the size of the opening may be adjusted to obtain the proper pressure and volume. Care should be taken to run the fan at rated speed as nearly as possible, but where this is impracticable, correction may be made for small variations in speed by correcting the volume in proportion to the speed and the pressure in proportion to the *square* of the speed.

The most accurate results are obtained by using a nest of Pitot tubes connected to floating manometers which consist of metal cans floating in water, divided into as many air tight compartments as there are Pitot tubes; but it is more convenient to use a single tube in the middle of the pipe, in which case, according to the U.S. Navy rules, the velocity determined by the Pitot tube should be divided by 1.10 to obtain the assumed average velocity through the whole pipe.

In calculating the horse power the total impact pressure is used without any reduction, although to be strictly consistent the velocity head due to the average velocity of the pipe added to the static pressure should be used.

When the blower is provided with a straight inlet a considerable loss is occasioned by *vena contracta* which will not take place when the inlet piping is finally installed on the fan. If the fan were tested with nothing added to the inlet, the efficiency shown by the test would be too low and it is desirable to put a short cone or bell on the inlet of the blower in making the efficiency test unless the fan is built with a cone inlet.

Use of Air Table

When conducting a fan test the temperature of the air in the testing room should be taken by two Fahrenheit thermometers, placed near the fan. One should hang free in the air, and the other, with its bulb wrapped in thin cloth, should be suspended over a small receptacle filled with water so that the cloth will be saturated. The temperature of the water must be the maximum that it will naturally attain in the room, Corrected barometer reading must also be recorded on the test sheet.

The method of finding the weight of air from the air tables mentioned in the specifications, is as follows: On the page containing the dry bulb reading as recorded on the test sheet, note the barometer reading corresponding to the first three figures of the corrected barometer reading recorded on the test sheet. In the column under the dry bulb temperature and opposite the barometer reading, the corresponding weight of saturated air is given. The weight of air found in the table must then be corrected to correspond with the corrected barometer reading found in test. This correction will be found in the second line from the top of the page. Correction must also be made for the difference between the wet and dry bulb temperatures by adding to the weight of air already obtained the number in the third sub-division of the column under the dry bulb temperature which corresponds to the difference between the wet and dry bulb reading. This reading will be found in the second sub-division of the column.

Example

Given barometer reading 30.15 in.
Dry bulb reading 67° F.
Wet bulb reading 59° F.

Under the column showing the dry bulb temperature of 67° and opposite the barometer reading of 30.1, the weight of air is given as 0.07517. The addition for each 0.01 of an inch of barometer is given as 2.6 in the second line from the top of the page. Multiply this by 5, i.e., by the excess of the corrected barometer reading over that selected in the table; the result is 13, which must be added to the weight of air previously found.

The wet bulb depression is the difference between 67° and 59°, or 8°. The number opposite 8 is 23. This must also be added, making the total weight of air 0.07553. All pressure readings should be corrected for standard air (see page 309) by multiplying the actual pressure obtained by the ratio of the weight of standard air to the weight of air at the time of test. The readings of horse power input to the fan should also be multiplied by this ratio.

Pressure and Horse Power Curves by Double Tube Method

A pressure curve may be taken by the double tube method as follows:

The opening at the outer end of the discharge pipe should be closed and pressure and power readings taken. Under this condition the static and impact pressures should be exactly the same since no air passes through the fan. Readings should then be taken by increasing the opening by suitable increments from closed to wide open, measuring the opening each time. The speed of the fan should be held constant throughout the test. The air readings and electrical input readings should be taken simultaneously.

It will be noted that in a test which is made with a pipe on the discharge side of the fan, the reading of the impact tube is always greater than the static reading. If the pipe is on the suction side the readings will be negative and the greater numerical value will be given by the static side of the tube. This should be considered as the value for impact pressure of the fan. The smaller value is given by the impact tube and should be treated as static pressure when considering the capacity of the fan.

If readings are taken by means of a U-tube, the reading of both sides of the tube should be given on the test sheet. The test sheet should always specify whether the readings were taken by the U-tube or by a manometer. If by a manometer, the manometer constant should be recorded and must always be used in working up the test.

CALCULATION OF FAN TESTS BY THE DOUBLE TUBE METHOD

A fan test of this kind should be recorded in the following form of the standard column paper provided for this purpose. The same abbreviations should always be used to avoid confusion.

TYPE OF FAN.........SERIAL NUMBER.........DATE.........

Motor Rating................

Double Tube Test, Taken at —— R.P.M.

No.	h_1	h_2	h_3	h_f	V	Q	h_1+h_f	h_2+h_f	Air H.P.	Fan H.P.	Eff.
1											
2											
3											
4											

Wet Bulb......................°F. Barometer..............................in.
Dry Bulb......................°F. Wt. of Air..............................lb.
Effective area of Pipe = ...Sq. Ft.

The first column gives the number of the reading.

The second and third show the impact and static readings taken from the test sheet and corrected for standard air.

The fourth column shows the velocity head or the difference between h_1 and h_2.

The fifth column is friction which must be calculated from the velocity head by the formula $H=\frac{a+b}{ab}\times 0.00016\ lv^2$. $h_f=\frac{H}{69.73}$ where h_f equals friction loss in inches of water, l is the length of pipe in feet between the fan and the Pitot tube.

a = length of long side of pipe in feet.

b = length of short side of pipe in feet.

v = average velocity in feet per second.

The friction loss should be added to both the static and impact readings before the curves are plotted, but it does not affect the volume.

The sixth column showing the air velocity at the center of the pipe may be obtained from the curves shown on prints C-4487-A, B, C, and D. It may also be obtained from the formula $V=1097\sqrt{\frac{h_3}{w}}$

Where w = weight of air per cu. ft. in pounds.

This gives the velocity at the center of the tube. For the average velocity use 91 per cent of this value or use the same formula with a constant of 997 instead of 1097.

The volume must be given in the seventh column. It is obtained by multiplying the average velocities given in column six by the area of the pipe.

The horse power in the air can be calculated from the formulæ

$$\text{Air h.p.} = \frac{P\times Q}{33000} \text{ or } \frac{p\times Q}{3667} \text{ or } \frac{h\times Q}{6345}$$

The horse power input to the fan is the horse power output of the motor.

Unless instructions are issued to the contrary, all fan tests for Government work should be plotted with pounds per sq. ft., horse power input to fan, and efficiency as ordinates; and volume in cu. ft. per minute as abscissæ. Both static and impact pressure should be plotted.

The tester should carefully date and sign each test sheet, and should include sufficient data to distinguish all sheets used on the same test. For instance, electrical readings are usually placed on one sheet and fan pressure readings on another, therefore, each of these sheets should state the name and number of the fan, the rating of the motor, the speed at which the test was taken and the method used. The Calculating Room must see that this data is placed on the Calculation Sheet.

The sheet on which the curves are plotted should give the name, type and number of fan, rating of the motor, speed at which the test was taken, and the method employed. Curves should always be plotted across the width of the sheet.

2. CONE METHOD OF TEST

The following method of conducting a fan test is used only when a short convenient method is required for purposes of comparison. In this method of test an adapter is used, where it is necessary, to change the fan outlet from rectangular to circular, a cone being placed on the circular end. This cone is made up of sections about two feet in length, the sides of which slope about two inches to the foot. Readings are taken by a single Pitot tube, the open end of which is held flush with the opening in the outer end of the cone and pointed against the stream of air. Pressure is registered as before, by a manometer or U-tube. The readings are taken, one at the top, one at the bottom, and one at each side of the cone at a distance from the edge of the pipe of about 1/6 of the diameter of the opening. A reading is also taken in the center of the cone opening. The average of these five readings represents the impact pressure produced by the fan, and is taken as the velocity head. The velocity may be obtained from the curve or from the formula given for the double tube test.

The static pressure may be obtained as follows: Divide the volume of each opening by the area of the fan opening, which gives the outlet velocity V_1. The corresponding velocity head can then be obtained from the curve. The velocity head subtracted from the impact pressure gives the static pressure. The static pressure should be plotted as well as the impact pressure.

These tests should be plotted with pressures in inches of water, h.p. inputs to the fan, and efficiencies, as ordinates; and volumes as abscissæ.

The following form should be used for tabulating the results of calculations:

TYPE OF FAN..........SERIAL NUMBER..........DATE..........

Motor Rating.................

Cone Test Taken at —— R.P.M.

No.	h_1	V	A_e	Q	V_1	h_3	h_2	Air H.P.	Fan H.P.	Eff.
1										
2										
3										

Wet Bulb.....................°F. Barometer..........................in.

Dry Bulb.....................°F. Wt. of Air..........................lb.

After the curves are plotted, the efficiency, as given by the calculations, should be checked, with the efficiency obtained from the curves. This will correct any discrepancy between the efficiencies as obtained from the curve and as calculated.

3. THE BOX METHOD

The box method of testing fans is as follows:

The fan is arranged to discharge directly into a large box which has a sufficient capacity to reduce the air velocity to a minimum. An opening is made in the side of the box at right angles to the opening into which the fan discharges, and cones are attached similar to those used in the cone test. Readings are taken by the same method and readings should also be taken of the box pressure by a U-tube connected to a pipe inserted through a hole in the side of the box. The end of the pipe should be flush with the inside of the box to avoid eddy currents. The pressure shown by this pipe will be somewhat higher than that registered at the end of the cone, and both pressures should be corrected for standard air and plotted on the final curve sheet.

The volume must be calculated as in the cone test, but the pressure obtained in the box is taken as the static pressure produced by the fan, since the velocity head is lost in the box. To obtain the impact pressure the volume obtained should be divided by the area of the opening of the fan, and the corresponding velocity head taken from the curve. This velocity head should be added to the static pressure shown by the cone readings. For transformer ventilation it is customary to calculate the pressure in ounces, measured at the cone opening.

The following form should be used in tabulating the calculations:

TYPE OF FAN..........SERIAL NUMBER..........DATE..........

Motor Rating..................

Box Test Taken at —— R.P.M.

No.	h_2	p	V	A_e	Q	V_1	h_3	h_1	Air H.P.	Fan H.P.	Eff.
1											
2											
3											
4											

Wet Bulb........................°F. Barometer..........................in.
Dry Bulb........................°F. Wt. of Air..........................lb.

Fan h.p. should be calculated from the static pressure and the efficiency obtained will be the static efficiency.

FORMULÆ FOR BLOWER TESTS

h_1 = Impact head in inches of water.
h_2 = Static head in inches of water.
h_3 = Velocity head in inches of water $= h_1 - h_2$.
h = Total head in inches of water $= h_1 + h_f$
w = Weight of air in test in pounds per cu. ft.

B = Barometer reading.
h_f = Head lost in friction in the pipe from the Pitot tube to the fan, in inches of water.
H_f = Head lost in friction in the pipe from the Pitot tube to the fan, in feet of air.
H_3 = Velocity head of the air in feet of air.
a = Length of long side of pipe in feet.
b = Length of short side of pipe in feet.
f = Coefficient of friction = 0.00008 for ordinary piping.

This value should be used in determining the friction loss between the fan and Pitot tube, but for determining the amount of pressure required to overcome the resistance of air piping, it is usually safer to use a coefficient of 0.00010.

l = Length of pipe in feet from Pitot tube to fan.
v = Mean velocity of air in ft. per sec.
V = Velocity of air in ft. per min.
Q = Volume of air in cu. ft. per min.
P = Pressure of air in lb. per sq. ft.
p = Pressure of air in ounces per sq. in. $= \frac{P \times 16}{144} = \frac{P}{9}$.
A = Area of pipe in sq. ft.
A_e = Effective area of pipe in sq. ft. $= A \times K$
K = Constant for effective area of pipe = 0.94 for the Cone Method.
Eff = Efficiency.
w = Weight of air in test in pounds per cu. ft.

Weight of 1 cu. ft. of air at 30 in. Bar; 70 deg. F and 70 per cent humidity = 0.07465 lb.

This is taken as *standard air.*

Weight of water = 62.36 lb. per cu. ft. at 62 deg. F.

Weight of a column of water 1 ft. sq. and 1 in. high $= \frac{62.36}{12}$ = 5.2 lb. at 62 deg. F.

Weight of a column of standard air 1 ft. sq. and 1 ft. high = 0.07465 lb.

Weight of a column of any other air 1 ft. sq. and 1 ft. high $= w$.

Neglecting humidity $w = \frac{0.07465 \times B \times 530}{30 \times (460 + t^0)}$ for Fahr.

Neglecting humidity $w = \frac{0.07465 \times B \times 294}{30 \times (273 + t^0)}$ for Cent.

Therefore, to change from *feet of air* to *inches of water* divide by $\frac{5.2}{0.07465} = 69.73$ for standard air.

or divide by $\frac{5.2}{w}$ for any other air.

$$h_f = \frac{H_f}{\frac{5.2}{w}}$$

$$H_f = \frac{a+b}{ab} \times 2\, f\, l\, v^2$$

For round or square pipe $H_f = 4\, f \frac{l}{d} v^2$

where d = diameter in feet.

$$v = \sqrt{2\, gH_3} = 8.02\sqrt{H_3} = 8.02\sqrt{\frac{5.2\, h_3}{w}} = 18.28\sqrt{\frac{h_3}{w}}$$

$$V = 60\, v = 60\sqrt{2\, gH_3} = 481.2\sqrt{H_3}$$

$= 1097\sqrt{\frac{h_3}{w}}$ at the center of the pipe.

$= 4015\sqrt{h_3}$ for standard air.

$P = 9\, p$

$= 5.2 \times h$

Therefore $9\, p = 5.2 \times h$

$$p = \frac{h}{1.732} = 0.577\, h$$

$$Q = V \times A_c = V \times KA$$

$$= 1097\sqrt{\frac{h_3}{w}} \times KA \quad \left.\begin{array}{l} = 3654.0\, A\sqrt{h_3}, \text{ using av. vel.} \\ = 3774.0\, A\sqrt{h_3} \text{ for } K = 0.94 \end{array}\right\} \text{for std. air}$$

For a given opening, pressure varies as the square of the speed of the blower. Volume varies as the square root of the pressure, hence, directly as the speed,

Air h.p. varies as the cube of the speed.

$$\text{Eff.} = \frac{\text{Air h.p.}}{\text{Fan h.p.}}$$

CHAPTER 17

AIR COMPRESSORS

Wearing in Running

The air compressor should be run unloaded, that is, not having the delivery end of the compressor connected to the tank until the friction has reached a constant value.

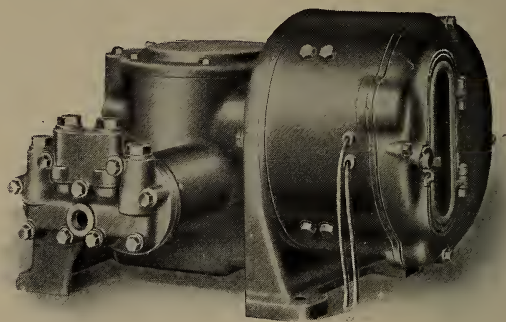

Fig. 139
AIR COMPRESSOR

Commercial Test

Resistance measurement should be made. The compressor (see Fig. 139) should be run light and the voltage, current and speed noted and recorded. The friction value should be checked with that given in the Standing Instructions (S. I.) 7884 and if it is excessive the defect must be remedied before the test is continued.

A full load run should be made for a half hour or an hour as specified by the Standing Instructions during which three successive capacity tests should be made in the following manner: The compressor should be connected to tank No. 1, see Fig. 140. The gauge pressure in tank No. 1 should be brought to 90 lb. or other standard working pressure as specified and the air then led into tank No. 2 at such a rate that the specified working pressure is maintained on tank No. 1. Note should be made of these items; the time from the opening of the valve between tank No. 1 and tank No. 2 until the gauge of tank No. 2 shows that working pressure has been reached; the total armature revolutions (on the testing record this should be reduced to compressor revolutions); the current required; the temperature of the air in tank No. 2 and the temperatures on the compressor cylinders.

The high potential test should be made at the end of the run with the motor hot. The oil leakage indicated by the glass gauge should be noted and also the air leakage of the compressor valves after the end of the test.

All compressors should be carefully observed for unnecessary noise or vibration in operation due to gears, connecting rods, valves or unbalanced armature. They should be observed for air leaks due to porous cylinder heads and defective gaskets and valve plugs; for oil leaks due to defective crank chamber gaskets or porous castings, for oil leaks entering the inner end of the motor frame from the compressor frame, and for vapor escaping from the crank chamber vent. If defects are found they must be reported at once.

Complete Tests

Complete tests consist of special tests, special heat runs, starting tests, and oil leakage tests.

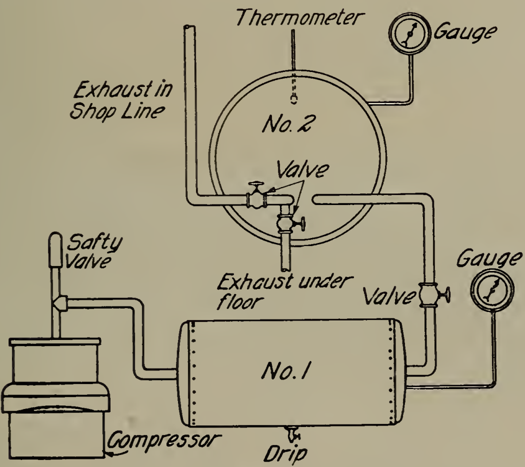

Fig. 140

TANK CONNECTIONS FOR AIR COMPRESSOR TEST

Special Tests

A speed curve should be taken in the operating direction of the compressor only, at 600 volts unless otherwise specified, on compressor loads in which the tank pressure varies from zero to 140 lb. During this test, or by making an independent test, the capacities of the compressor should be taken while pumping against pressures varying from zero to 140 lb. From these tests one curve should be plotted of tank pressure and compressor speed against amperes as abscissae. Another should be plotted of watthours per cu. ft. of free air and cu. ft. per minute of free air against tank pressure.

The field of the motor should now be separately excited, the gears removed and the friction and motor core loss test taken.

The armature should be run on a voltage which will give a speed corresponding to the speed curve and the field should be separately excited with the same current values as used when the speed curve was taken. A curve is then plotted of watts against rev. per. min. showing the friction and core loss combined.

The preceding results should be consolidated into a curve showing the speed, torque and efficiency of the motor at the pinion.

Special Heat Runs

These consist of several heat runs made with the compressor operating at different time cycles and different pressures. Usually three successive tests should be made at the rated working pressure, 90 lb. or otherwise as specified.

No. 1. 5 min. on and 5 min. off repeated to the end of the test.

No. 2. 7 min. on and 3 min. off repeated to the end of the test.

No. 3. Continuously.

Heat runs at other pressures and cycles of time operation should be made as specified for the given machine.

The machine should be allowed to stand idle not less than eight hours between each test and in each case the test should be continued until either the temperatures of the armature and field become constant or until the temperature rise amounts to 125 deg. cent. by resistance measurement. The commutator door and all covers should be kept closed during the test and unless otherwise specified, the machine should operate at 600 volts and pump against 90 lb. gauge pressure. Temperatures and resistances should be taken at regular intervals throughout the run, and final temperatures and resistances at the end.

From the results of the test, curves should be drawn on one sheet, of the temperature rise by thermometer of the field coil against time as abscissæ. Over these, curves of temperature rise by resistance measurement should be drawn.

On another sheet a similar set of curves should be made for the armature.

On the third sheet should be plotted a series of curves of thermometer rise at the end of each hour against the percentage of operating time.

In connection with run No. 3 the compressor capacity should be taken as nearly cold as possible and at frequent intervals throughout the test. Temperatures should be taken every five minutes on the cylinder and exhaust chamber. The temperature rise of the cylinder and exhaust chambers, watthours per cu. ft. of free air, and cu. ft. of free air per minute should be plotted against time. The volume and temperature of the air in the measuring tank must be known to determine the watthours per cu. ft. A curve should be plotted showing the relation of capacity to cylinder temperature.

Starting Tests

The starting tests for direct current air compressors should consist of tests made at various reduced voltages making note of the current, voltage and rev. per min. of the motor expressed on the testing record as r.p.m. of the compressor. The manner of starting of the compressor should be observed and noted, that is, whether it starts properly from rest or whether it hesitates and starts with an irregular rotation of the motor, or finally whether it fails to start at all.

In taking starting tests for alternating current motors special attention should be paid to the equipment serving the motors with current; that is, it should be sufficiently large so that the momentary conditions existing when the compressor is starting from rest against full load pressure do not cause any material drop in voltage. These tests should be repeated step by step at various voltages to determine the conditions under which the compressor starts irregularly, and finally fails to start.

Oil Leakage Tests

These tests commonly consist of a 20 hour half time cycle of compressor operation under the control of the governor. An oil separator is installed between the compressor and the tank for the purpose of taking these tests. After the completion of the run the separator and tank should be allowed to stand at least an hour to allow the oil to collect at the draw off valves. It should then be drawn off, measured and the quantity noted, both separately as collected from the separator and the tank and the total quantity. Any water found in the graduated glass with which the measurement is made should be deducted.

CHAPTER 18

VOLTAGE REGULATORS

General Principle of Operation

Voltage regulators are used to control the voltage of a circuit within narrow limits by rapidly opening and closing a shunt circuit connected across the field rheostat of the exciting circuit of the generator. Those for use for a-c. generators are known as Type TA, and those for use on d-c. circuits are Type TD.

TYPE TA REGULATORS

TYPE TA FORM A2

These regulators operate by rapidly opening and closing a shunt circuit connected across the exciter field rheostat. Actual electrical connections vary, but a schematic diagram is shown in Fig. 141.

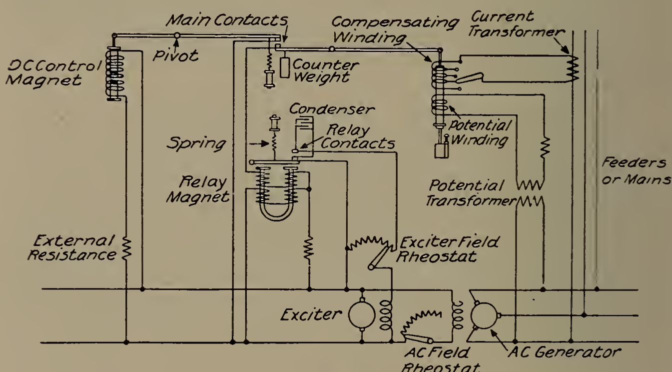

Fig. 141

ELEMENTARY DIAGRAM OF TA, FORM A REGULATOR

The regulator has a d-c. control magnet, an a-c. control magnet and a relay. The d-c. control magnet is connected to the exciter busbars and has a fixed stop core in the bottom and a movable core in the top which is attached to a pivoted lever having at the opposite end a flexible contact pulled downward by four spiral springs. The a-c. control magnet has a potential winding and also an adjustable compensating winding connected through a current transformer to the principal feeder. This compensating winding raises the voltage of the a-c. busbars as the load increases, and thus compensates for line drop. The a-c. control magnet has a movable core and a lever and contacts similar to those of the d-c. control magnet, and the two combined produce the "floating main contacts." The relay coil has a differential winding and a pivoted armature controlling the contacts which open and close a shunt circuit across the exciter field rheostat. One of the differential windings is permanently connected across the exciter busbars and tends to keep the contacts open; the other is connected to the exciter busbars through the floating main contacts, and when the latter are closed, neutralizes the effect of the first winding and allows the relay contacts to short-circuit the exciter field rheostat. Condensers are connected across the contacts to prevent arcing and possible injury.

CYCLE OF OPERATION

The circuit shunting the exciter field rheostat through the relay contacts is opened by means of a single-pole switch at the bottom of the regulator panel and the rheostat turned in until the alternating voltage is reduced 65 per cent below normal.

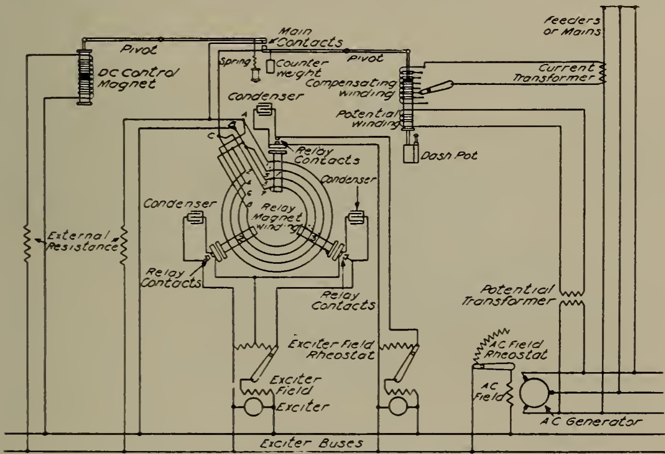

Fig. 142
ELEMENTARY DIAGRAM OF TYPE TA, FORM F3 REGULATOR CONNECTIONS

This weakens both of the control magnets and the floating main contacts are closed. This closes the relay circuit and demagnetizes the relay magnet, releasing the relay armature, and the spring closes the relay contacts. The single-pole switch is then closed and as the exciter field rheostat is short-circuited the exciter voltage will at once rise and bring up the voltage of the alternator. This will strengthen the alternating current and direct current control magnets and at the voltage for which the counterweight has been adjusted the main contacts will open. The relay magnet will then attract its armature and by opening the shunt circuit at the relay contacts will throw the full resistance into the exciter field circuit tending to lower the exciter and alternator voltage. The main contacts will then again be closed, the exciter field rheostat short-circuited through the relay contacts and the cycle repeated. This operation is continued at a high rate of vibration due to the sensitiveness of the control magnets and maintains a steady exciter voltage.

TYPE TA FORM F

The TA Form F Regulator has several relays according to the size and number of exciters used. The principle of operation is the same as for the Form A2. An elementary diagram is given in Fig. 142.

TYPE TD REGULATORS

The Type TD Regulator consists essentially of a main control magnet with two independent windings, and a series wound relay magnet. The elementary connections are shown in Fig. 143.

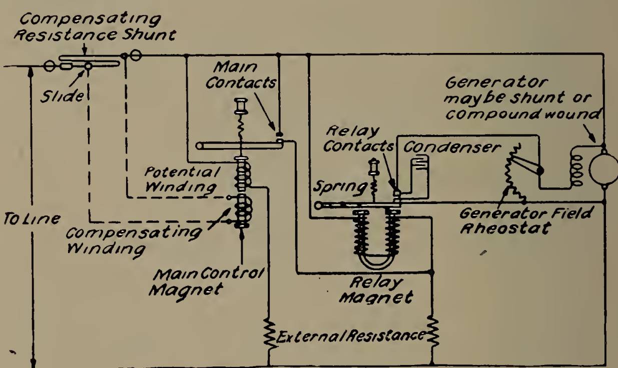

Fig. 143

DIAGRAM SHOWING ELEMENTARY CONNECTIONS OF TYPE TD REGULATOR

The potential winding of the main control magnet is connected across the generator terminals, and the compensating winding across a shunt in one of the load mains, and opposes the action of the potential winding, so that as the load increases a higher potential at the generator is necessary to overcome the line drop. The control magnet has an adjustable stop core at the bottom with a movable core above. The movable core is attached to a lever operating the main contacts, the pull of the magnet being opposed by a spiral spring which tends to keep the main contacts closed.

The armature of the relay magnet operates the contacts that open and close the shunt circuit across the field rheostat. The relay magnet winding is permanently connected, through resistance, to the busbars, and this winding is short-circuited by the main contacts of the control magnet. When the main contacts are open the relay contacts are open.

CYCLE OF OPERATION

The shunt circuit across the generator field rheostat is first opened by means of a switch on the base of the regulator and the rheostat turned to a point that will reduce the generator voltage 35 per cent below normal. The main control magnet is at once weakened and allows the spring to pull out the movable core until the main contacts are closed. This short circuits the relay winding, which demagnetizes the relay magnet core. The relay spring then lifts the armature and closes the relay contacts. The switch in the shunt circuit across the generator field rheostat is now closed, practically short-circuiting the field rheostat, and the generator voltage at once rises. As soon as it reaches the point for which the regulator has been adjusted the main control magnet causes its movable core to open the main contacts, which in turn open the relay contacts across the rheostat. The rheostat is thus connected in the field circuit, the voltage at once falls off, the main contacts are closed, the relay armature is released and the shunt circuit across the rheostat again completed. The voltage then starts to rise and this cycle of operation is continued at a high rate of vibration maintaining a steady voltage at the busbars.

TYPE TD FORM G

The Form G Regulator is designed to control the voltage of generators of small capacity, and is provided with both potential and compensating winding on the main control magnet. It may be connected to several small compound wound machines operating in parallel. It is then used on only one of the generators at a time, the others being allowed to "trail" by means of their compound winding and equalizers.

TYPE TD FORM R

The Form R Regulator operates as the Form G, but contains two, three or four separate relays, and is designed to control the voltage of two or more generators operating in parallel.

TYPE TD FORM L

The Form L Regulator is designed for use with two or more separately excited d-c. generators and operates the same as the Type TA, Form A2 regulator described above.

ADJUSTMENT

Before setting any voltage regulator upon the testing table the following defects should be looked for: Improper stamping of name plate, wrong stamping of resistance box, loose coils, loose magnet frames, loose or inclined dashpot, bent switches and studs, wrong a-c. cores. Check the air gap on the relay, the friction of the relay armature, alignment of the relay contacts, relay numbering, loose screws, and loose terminals. See that different kinds of nuts and washers are not used on the same stud, that compensating switches on the a-c. regulators are not stamped for the wrong direction. Care should be taken to see that the regulator hangs true after it is installed, as any variation may cause trouble in operation. Each regulator should be wired according to its print and no testing should be done if the terminals are stamped incorrectly or if connectors are on the wrong studs. The internal connections on the regulator should be inspected for loose joints, improper connections, or poorly soldered terminals. After the regulator has been wired properly the cores should be made to hang in the center of the magnet spools and the levers should not fit too loosely nor too tightly.

HIGH POTENTIAL

High potential should be applied to all parts of the regulator to ground and between coils. The potential between coils should not be instantaneously applied nor must the circuit be suddenly broken but the high potential terminals should be placed on the coil under test and the voltage gradually raised on the alternator to the desired amount and then reduced in the same manner until zero voltage is reached before removing the high potential leads.

RESISTANCE MEASUREMENTS

All relay coils, d-c. magnets, a-c. magnets and resistance boxes should have their resistance measurements carefully taken and the variations should not exceed those specified in the Engineering Brief which will be found in the files of the Testing Section.

HEAT RUNS

Heat runs are made on all regulators to determine the maximum heating on the different coils and the external resistance. The run on the a-c. regulator is made at 115 volts, and at normal rated voltage on the d-c. coil. The run on the d-c. regulator is made at the standard rated voltage, the value of which will be found on the name plate of each regulator. The length of run in each case is three hours.

ADJUSTMENT OF RELAY CONTACTS

The manner of adjusting the relay contacts is the same on all regulators. Press the armature firmly against its stop stud and set the contacts, one directly over the other and $\frac{1}{32}$ in. apart.

TYPE TA FORM A2 REGULATOR

This type of regulator is built for the following standard voltages:

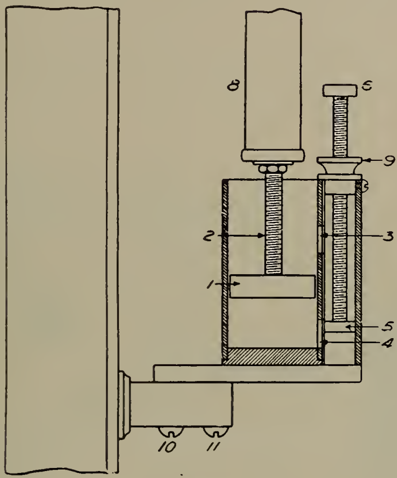

Fig. 144

DASHPOT FOR TYPES TA-60 AND TA-125, FORM A2 VOLTAGE REGULATOR FOR GENERATORS

Type	Form	Exciter Volts	Range of Exciter Volts	A-C. Volts
TA-60	A2	60	33/67	100 to 125
TA-90	A2	90	50/100	100 to 125
TA-125	A2	125	70/140	100 to 125
TA-250	A2	250	140/280	100 to 125
TA-550	A2	550	308/616	100 to 125

ADJUSTMENT OF DASHPOT

The dashpot is shown in section in Fig. 144. The piston fits closely, but should move freely, as friction will result in unstable voltage. The piston (1) is attached to the lower end of the alternating current magnet core stem (2) and its normal position is about midway between the two port holes (3) and (4). Piston

(5) may be raised by turning thumbscrew (6). This results in closing port hole (4) thus retarding the movement of piston (1). When the port hole is entirely closed and the dashpot full of oil, the piston moves very slowly. The dashpot should never be filled with anything but light dynamo oil. This can best be done as follows:

Remove screws (10) and (11), give the dashpot a quarter turn, then it can readily be taken off. See that it is free from all dirt, then fill it to within about ⅜ in. of the top, replace it and securely tighten screws (10) and (11); the oil should then stand

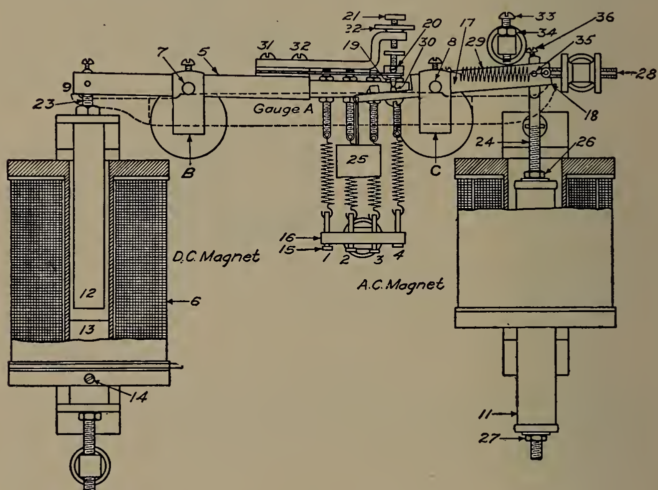

Fig. 145
MAIN CONTROL MAGNETS AND LEVERS FOR TYPES TA-60 AND TA-125 FORM A2 VOLTAGE REGULATORS FOR GENERATORS

about ⅛ in. from the top of the cup. By raising and lowering core (8) by hand and at the same time varying the height of thumbscrew (6), the position of piston (5) can be readily determined, as a slight change in the height of piston (5), when at the position shown varies greatly the free action of core (8). The dashpot should be adjusted until core (8) moves with very little retarding. The retarding effect of the dashpot necessarily depends entirely upon the time constants of the exciters and generators but ordinarily the piston should move freely.

ADJUSTMENT OF SPRINGS NOS. 1, 2, 3 AND 4 FOR TA-125 REGULATORS

Before adjusting lever (5) Fig. 145, core (11) should be raised to its highest position and blocked, thus bringing main contact

(30) to its lowest position, to prevent contact being made between (19) and (30) while lever (5) is being adjusted. This is necessary since if contacts (19) and (30) were to come together, the proper adjustment of lever (5) could not be made. Springs (1), (2) and (3) should be loosened to their extent or taken out while spring (4) is being adjusted. A gauge for use in adjusting lever (5) is always furnished with the regulator. To adjust spring (4) first see that the voltage on the exciter to which the direct current control magnet (6) is connected, is maintained at 65 volts. Then by taking the gauge between the thumb and index finger at "A" place it firmly against the brackets "B" and "C" and against the under side of pivot sockets (7) and (8) as illustrated. Then adjust spring (4) by means of the small nut at the top of its adjusting screw, until the under side of lever (5) comes even with the top of the gauge at (9). After this adjustment has been made, the exciter voltage should be increased to 122, and at exactly this point spring (4) should be overpowered by the magnet, and the cores (12) and (13) will come together. Should it require more or less voltage to overpower the spring and bring these cores together, core (13) should be either raised or lowered, and spring (4) readjusted until the under side of lever (5) comes to the gauge as before. The adjustment of spring (4), lever (5), and core (13) must be repeated several times to insure correctness as this adjustment is of the utmost importance. After the proper adjustment has been obtained, the lock nut beneath the lever on spring (4) should be securely tightened after which the exciter voltage should again be varied over its range, and the adjustments checked. Then screw (14), which holds stop core (13) in position, should be securely tightened. This screw should, however, be kept well tightened while the adjustments are being made. After these adjustments have been made, spring (1) should be adjusted by raising the exciter voltage to 90, and at exactly this point this spring should begin to come under tension, and the small head (15) on the spring stem will be brought in contact with the spring support (16). After this adjustment has been carefully made, the lock nut below the lever on spring (1) should be securely tightened and the adjustment of spring (1) checked to see if it is correct. Then spring (2) should be adjusted by increasing the exciter voltage to 115, when it will come into action as does spring (1). After adjusting this spring, the lock nut beneath the lever on spring (2) should also be securely tightened and the adjustment checked. Spring (3) should then be adjusted by raising the exciter voltage to 138, at which point this spring will come into action as did springs (1) and (2). Following this adjustment, the lock nut underneath the lever on spring (3) should be securely tightened and the adjustment of spring (3) checked.

Springs for Standard Regulators are adjusted as in the following table:

TYPE TA-60 VOLTAGE REGULATORS

Spring No. 4 adjusted with gauge at 31 volts.
Spring No. 1 adjusted to pick up at 43 volts.
Spring No. 2 adjusted to pick up at 55 volts.
Spring No. 3 adjusted to pick up at 66 volts.

TYPE TA-90 VOLTAGE REGULATORS

Spring No. 4 adjusted with gauge at 47 volts.
Spring No. 1 adjusted to pick up at 65 volts.
Spring No. 2 adjusted to pick up at 83 volts.
Spring No. 3 adjusted to pick up at 99 volts.

TYPE TA-125 VOLTAGE REGULATORS

Spring No. 4 adjusted with gauge at 65 volts.
Spring No. 1 adjusted to pick up at 90 volts.
Spring No. 2 adjusted to pick up at 115 volts.
Spring No. 3 adjusted to pick up at 138 volts.

TYPE TA-250 VOLTAGE REGULATORS

Spring No. 4 adjusted with gauge at 130 volts.
Spring No. 1 adjusted to pick up at 180 volts.
Spring No. 2 adjusted to pick up at 230 volts.
Spring No. 3 adjusted to pick up at 275 volts.

TYPE TA-550 VOLTAGE REGULATORS

Spring No. 4 adjusted with gauge at 286 volts.
Spring No. 1 adjusted to pick up at 396 volts.
Spring No. 2 adjusted to pick up at 506 volts.
Spring No. 3 adjusted to pick up at 607 volts.

ADJUSTMENT OF THE FLOATING MAIN CONTACTS

Main contacts (19) and (30) are specially constructed, and no contacts other than those supplied by the General Electric Company should be used. Care should be taken in grinding them not to cut away any more of the metal than is necessary.

For the proper adjustment of these points, maintain 65 volts on the exciter and with levers (5) and (17) in position according to gauge, the contacts should be set squarely one above the other after which screws (31) and (32) should be securely tightened.

With levers (5) and (17) in this position, the upper contact (19) should be raised or lowered until it will just touch contact (30), after which the set screw (20) should be securely tightened. Screw (21) should be adjusted to within $\frac{1}{32}$ in. of screw (19) and lock nut (22) securely tightened. With lever (17) still in its proper position, screw (33) should be adjusted to within $\frac{3}{32}$ in. of lever (17) and nut (34) securely tightened.

The screw (33) is for the purpose of limiting the excessive upward travel of lever (17); and immediately back of this screw, passing through the same post is a threaded stud extending down and bent at right angles to extend underneath lever (17). This stud should be so adjusted as to limit the downward travel of lever (17) at 20 per cent above normal exciter voltage or 150 volts on a 125 volt exciter.

ADJUSTMENT OF THE A-C. MAGNET CORE

If the alternator voltage varies through the range of exciter voltage as specified, it would indicate an improper adjustment of the a-c. magnet core (11) and to correct this, proceed in the following manner:

The exciter voltage should be varied from 70 to 140 volts by means of the a-c. generator field rheostat, and if the alternating voltage rises or falls, core (11) should be raised or lowered on stem (24) until at a point that will give neither rise nor fall in the alternating voltage on varying the exciter voltage from 70 to 140. If the alternating voltage falls on increasing the exciter voltage from 70 to 140, core (11) should be lowered or vice versa. After this adjustment has been determined, lock nuts (26) and (27) should be securely tightened, and the previous adjustment checked.

The values given for the adjustment of the a-c. magnet core (11) of 70 volts to 140 volts are for 125 volt regulators and exciters. Other standard regulator and exciter voltages are as follows:

Minimum Excitation Voltage	Normal Standard Exciter Voltage	Maximum Exciter Voltage
33	60	67
50	90	100
70	125	140
140	250	280
308	550	616

For the proper adjustment of core (11) see also "Error in Voltage" under the heading "Locating Trouble" on page 332.

ADJUSTMENT OF RELAY

A complete side view showing the connections of the relay, etc., is shown in Fig. 146. As this relay is differentially wound with two windings on each spool, there are four leads extending from the side of each magnet spool. The two outer terminals represent one winding and the other corresponding two inner leads are connected to the other winding. These leads are connected to binding posts A, B and C as follows:

(3) and (5) to "A."
(2), (4), (6) and (8) to "B."
(1) and (7) to "C."

No two of the various holes in the three binding posts are at the same distance from the panel, and each lead from the spools is brought out opposite the binding post hole in which it should be inserted, thus rendering the connections very simple. Inasmuch as the relays are differentially wound, they will work to some extent whether the windings are in service or not. Therefore, if the relays operate unsatisfactorily they should be tested to ascertain whether the coils are all working properly. Should trouble be experienced which is apparently due to improper connection of the relay magnets or a possible open circuit, the

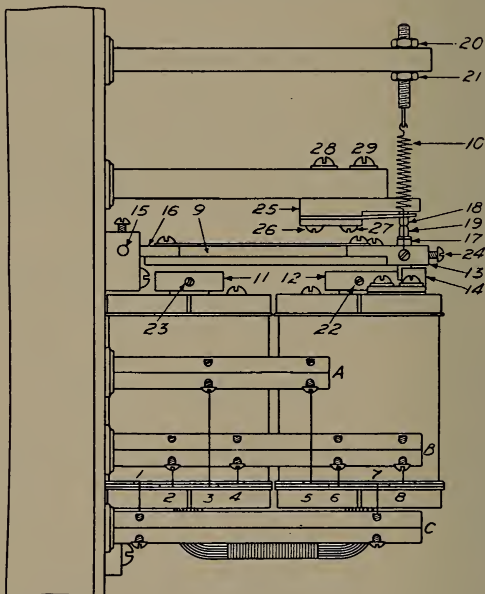

Fig. 146

RELAY FOR TYPES TA-60 AND TA-125 FORM A2 VOLTAGE REGULATOR FOR GENERATORS

fault may be easily located by ringing out the different coils with a magneto or other circuit-testing device; when this is done all leads should be disconnected from their respective binding posts. It is also important to ascertain that all the leads are properly connected to posts (A), (B) and (C) and that the set screws holding them are securely tightened. See that the expanded core tips (11) and (12) are flush with the ends of the wire cores; then securely tighten set screws (22) and (23).

Pivot holder (16) should be adjusted on the pivot until contact stud (17) clears stop stud (14) by $\frac{1}{16}$ in. The set screws holding the pivot sockets should be tightly secured, leaving no end play in the pivots.

With contact holder (13) resting upon stop stud (14), core tips (11) and (12) should be only $\frac{1}{32}$ in. from armature (9). This distance is very important and should be measured by gauge. After these have been adjusted the four set screws on the opposite side of the spools holding the iron cores in position should be securely tightened.

Setting of Relay Adjusting Springs

With the relay contacts (18) and (19), Fig. 146, properly adjusted (see adjustment of relay contacts, page 322) and insulating material placed between the floating main contacts (19) and (30), Fig. 145, the relay armature should be so adjusted by means of spring (10), Fig. 146, that with 45 volts on the exciter, the contact (19) just floats midway between the upper relay contact (18) and the stop stud (14).

After the movable relay contact which is attached to the armature has been adjusted in accordance with the above instructions, the lock nut (21) should be securely tightened.

The above value of 45 volts applies to 125 volt exciters and for the other standard voltages this adjustment figure is directly proportional, as is indicated by the following table:

Exciter Volts	Values for Relay Spring Adjustments
60	22
90	32
125	45
250	90
550	197

CONNECTIONS FOR LINE DROP COMPENSATION

The compensation may be accomplished by a single current transformer which has its secondary connected to an adjustable compensating winding on the a-c. control magnet as shown in the standard diagrams. This transformer is preferably connected to the main feeders and care should be taken that it be inserted in one of the mains to which the potential transformer is connected; for with three-phase as well as with two-phase currents, if the current transformer is not connected to one of the same leads with the potential transformer it is obvious that at unity power-factor the current in the potential winding will be displaced by an angle of 90 deg. from that in the current winding; therefore, no compensating effect whatever will be obtained, although in cases where the power-factor is below unity there would be a slight compensation due to the lagging current.

In all cases, the current transformer should be placed beyond the point where any load is taken off at the station, such as motor load, constant current transformers, etc., as the draught of current through the current transformer for such loads would increase the busbar voltage as though the load were out on the line, which would be undesirable. A current transformer that will give 3½ amperes secondary will compensate for about 15 per cent line drop.

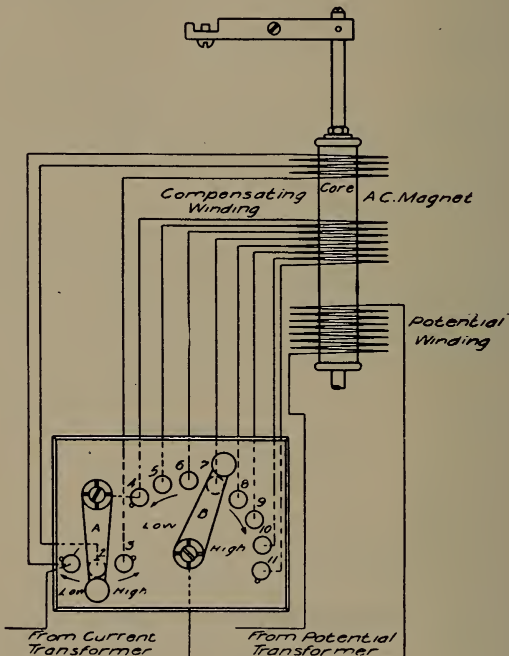

Fig. 147

CONNECTIONS OF POTENTIAL AND COMPENSATING WINDING OF TYPES TA-60 AND TA-125 FORM A2 VOLTAGE REGULATORS FOR GENERATORS

The compensating winding (see Fig. 147) consists of three layers of wire, the two inner layers of which are connected as follows: The terminals of the first winding are connected to buttons (1) and (2) while the second winding is connected to buttons (2) and (3). The third layer is divided into sections of (5) turns each, which have taps brought out to buttons (4) to (11) inclusive. Over these buttons, levers (A) and (B) are arranged to swing.

In order to increase the busbar voltage the current in these windings should oppose the current in the potential winding.

Therefore, if it is found that with a load on the generator and the levers (A) and (B) swung to the right, the busbar voltage falls, it would indicate that the current in the compensating windings is assisting the current in the potential windings in which case the leads from the secondary of the current transformer to the regulator should be reversed.

LOCATING TROUBLE

Should the regulator fail to build up the voltage

(1) See that the reversing switches at the bottom of the regulator base are thrown to the extreme position either up or down.

(2) See if the single pole switches at the bottom of the regulator base are closed on the proper exciters.

(3) Look for improper connections.

Should the voltage fall

Examine the rheostat shunt circuit connections to see if they are not so connected as to short-circuit the exciter field instead of its field rheostat.

Fluctuating Voltage

If, after placing the regulator in service the potential fluctuates to the extent of several volts, proceed as follows:

First—See that screw (21), Fig. 145, is properly adjusted as contact between screws (19) and (21) will cause unsteady voltage to the extent of from 5 to 10 volts on the secondary. (See "Adjustment of Main Contacts," page 326.)

Second—See if contact screw (19) is loose. If so it should be properly adjusted and set screw (20) securely tightened.

Third—Observe both levers (5) and (17) at the points where the core stems (23) and (24) are attached, to see that there is no friction at these points.

Fourth—The regulator should not be subjected to excessive vibration such as might be the case when it is mounted on iron brackets. Should such vibration exist, some rigid support should be provided to overcome it.

Fifth—The dashpot should be carefully inspected to see that it is actually full of oil within ⅛ in. of the top.

Sixth—The dashpot should be examined to see that it is securely attached to the supporting posts.

Seventh—The dashpot may be adjusted for too free a movement. This adjustment should be made as free as possible without causing "pumping" of the voltage at no load. (See "Adjustment of Dashpot," page 323.)

Eighth—Examine cores (11) and (12) to see that they do not touch the inside of the magnet spools.

Ninth—Carefully inspect all wiring, looking for such mistakes as using the same lead for binding posts (1) and (14) (on standard diagrams filed in the section), flat spots on the exciter commutators, loose brushes, or any other poor contacts that might cause an unsteady voltage.

Tenth—Observe pin (35), Fig. 145, to see that it does not make contact with spring (29), and that set screw (36) is securely tightened.

Error in Voltage

If there is an error in voltage from no load to full load without the compensating winding in circuit, it must be due to improper adjustment of the alternating current magnet core.

If after the core has become steady in going from no load to full load, the main alternating voltage has fallen off, it would indicate that the a-c. magnet core should be lowered slightly until the voltage is the same at full load as at no load. If on the other hand, the main alternating voltage is too high, it would indicate that the a-c. core should be raised slightly to overcome the error.

With ordinary exciters, if the a-c. magnet core is adjusted while the lever is in a horizontal position so that the core extends from the bottom of the spool to the end of the cap 1⅞ in. there is usually no error from no load to full load on the a-c. generators or with the exciter voltage varied from 70 to 140 volts. (For further adjustments see "Adjustment of the A-C. Magnet Core.")

If this adjustment is checked and found correct, the error may be caused by friction in the core stems on the magnet levers.

Error Due to Compensating Winding

If there is an error in voltage when using the compensating winding, such as too high voltage at no load and corresponding low voltage at full load at the center of distribution, thus requiring daily adjustment of levers (A) and (B) (see Fig. 147), it would indicate that the ratio of levers (A) and (B) is incorrect and that they should be swung further to the right and the alternating voltage lowered by means of counterweight (25) and spring (29). See Fig. 145. After the setting of these levers is once obtained, they should require no further adjustment, as it is evident that they will automatically compensate for voltage at all loads. (See "Connections for Line Drop Compensation," page 329.)

Arcing at the Relay Contacts

If there is excessive arcing at the relay contacts:

First—Check the connections of the rheostat shunt circuit to binding posts (7), (8), (12), (13) and (14) on standard diagrams to see that they are properly made, and that the rheostat only is being short-circuited. Also see that *separate* leads are run from the exciter busses to binding posts (1) and (14) on the regulator.

Second—The connections of the condensers should be checked.

CONDENSERS

The condensers furnished with the regulator should be connected in multiple if more than one is required, and connected to binding posts (6) and (11) (on standard diagrams). The number of condensers required should, roughly speaking, be one section for each 15 kw. or fraction thereof for exciters having laminated poles, and for each 22 kw. for exciters having solid poles.

TA FORM "L" REGULATORS

The Form L voltage regulator is the same as the A2 with the exception that it is for mounting directly upon the switchboard panel while the Form A2 regulator is mounted upon its own base. The instructions given for the Form A2 also apply for the Form L.

TA FORM "F" REGULATORS

The Type TA Form F regulators have the following standard voltages.

Type	Form	Exciter Volts	Range of Exciter Volts	Alternating Voltage
TA-90	F	90	50/100	100 to 125
TA-125	F	125	70/140	100 to 125
TA-250	F	250	140/280	100 to 125

ADJUSTMENT OF DASHPOT

See instructions under Form A2 regulators.

ADJUSTMENT OF LEVERS AND SPRINGS

Levers

First—See that the center of the slot in which core stems (23) and (24), Fig. 148, are attached to the levers, is $1\frac{9}{32}$ inch from the marble base. After the levers and pivots have been set to give this distance, see that the set screws securing the levers to the pivots, and those holding the pivot sockets, are securely tightened. The pivots should be adjusted until they have but a slight amount of end play. Be sure that the core stems (23) and (24) do not bind in the slots in the levers; they should always have sufficient clearance to prevent binding, as friction at this point would be a serious defect.

Springs

Before adjusting lever (5) core (11) should be raised to its highest position and blocked by some means, thus bringing main contact (30) to its lowest possible position, to prevent contact being made between contacts (19) and (30) while adjusting lever (5). Springs (1), (2) and (3) should be loosened to their full extent, or taken out while spring (4) is being adjusted.

To adjust spring (4), first see that the voltage on the exciter, to which the direct current control magnet (6) is connected, is maintained at 60, assuming that a 125 volt regulator is being adjusted. Then adjust spring (4) by means of the small nut at the top of its adjusting screw, until the under side of lever (5) comes even with the white mark on gauge (37). After this adjustment has been made the exciter voltage should be increased to 112 and at exactly this point, spring (4) should be overpowered by the magnet, and the cores (12) and (13) will come together. Should it require more or less voltage to overpower

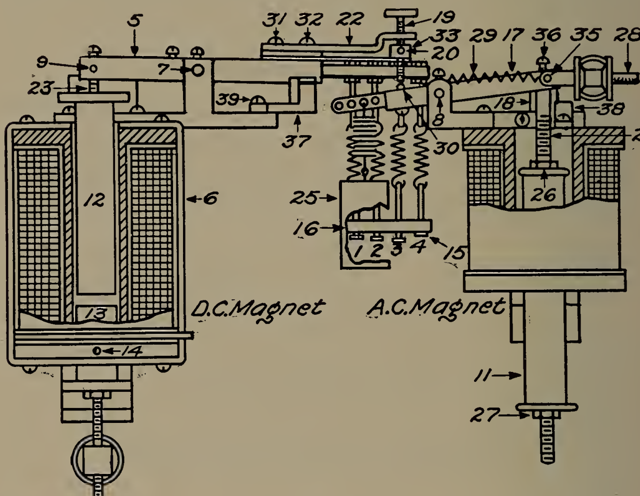

Fig. 148

TYPE TA, FORM F VOLTAGE REGULATOR MAIN CONTROL MAGNETS AND LEVERS

the spring and bring these cores together, core (13) should be either raised or lowered, and spring (4) readjusted until the under side of lever (5) comes to the gauge as before. The adjustment of spring (4), lever (5) and core (13) must be repeated several times to insure their being correct, as they are of the utmost importance. After the proper adjustment has been obtained, the lock nut beneath the lever on spring (4) should be securely tightened, after which the exciter voltage should be varied over its range again, and the adjustments checked. Then screw (14) which holds the stop core (13) in position, should be securely tightened. This screw should, however, be kept well tightened while the above adjustments are being made. Spring (1) should be adjusted by raising the exciter voltage to 80 and at exactly this point this spring should begin to come under tension, and the small head (15) on the spring stem will be brought in contact with the spring support (16). After this adjustment has been carefully made the lock nut below the lever on spring (1) should be securely tightened and the adjustment of spring (1) checked to see if it is correct. Then spring (2) should be adjusted by increasing the exciter voltage to 110, when it will come into action as does spring (1). After adjusting this spring, the lock nut beneath the lever on spring (2) should also be securely tightened and the adjustment checked. Spring (3) should then be adjusted by raising the exciter voltage to 123 at which point this spring will come into action as did springs (1) and (2). Following this adjustment the lock nut underneath the lever on spring (3) should be securely tightened and the adjustment of spring (3) checked. The values of the different adjustment voltages in accordance with the standard exciter voltages for which the regulators are designed are tabulated as follows:

TYPE TA-60 VOLTAGE REGULATORS

Spring No. 4 adjusted to gauge mark at 29 volts.
Spring No. 1 adjusted to pick up at 38 volts.
Spring No. 2 adjusted to pick up at 53 volts.
Spring No. 3 adjusted to pick up at 59 volts.

TYPE TA-90 VOLTAGE REGULATORS

Spring No. 4 adjusted to gauge mark at 43 volts.
Spring No. 1 adjusted to pick up at 58 volts.
Spring No. 2 adjusted to pick up at 79 volts.
Spring No. 3 adjusted to pick up at 89 volts.

TYPE TA-125 VOLTAGE REGULATORS

Spring No. 4 adjusted to gauge mark at 60 volts.
Spring No. 1 adjusted to pick up at 80 volts.
Spring No. 2 adjusted to pick up at 110 volts.
Spring No. 3 adjusted to pick up at 123 volts.

TYPE TA-250 VOLTAGE REGULATORS

Spring No. 4 adjusted to gauge mark at 120 volts.
Spring No. 1 adjusted to pick up at 160 volts.
Spring No. 2 adjusted to pick up at 220 volts.
Spring No. 3 adjusted to pick up at 246 volts.

TYPE TA-550 VOLTAGE REGULATORS

Spring No. 4 adjusted to gauge mark at 264 volts.
Spring No. 1 adjusted to pick up at 352 volts.
Spring No. 2 adjusted to pick up at 484 volts.
Spring No. 3 adjusted to pick up at 541 volts.

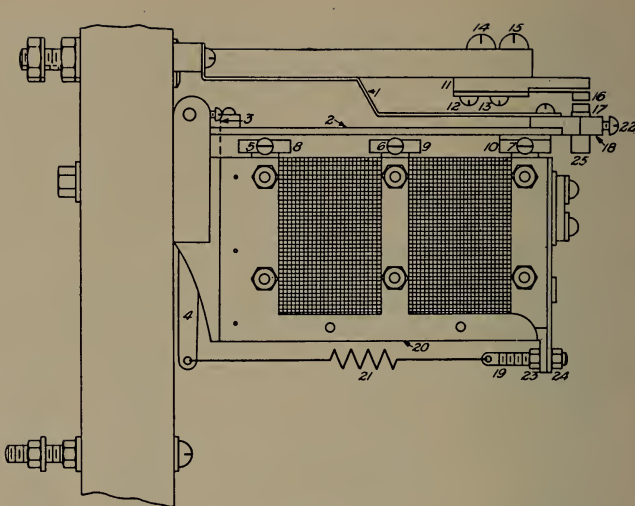

Fig. 149

SECTION OF RELAY MAGNET FOR TYPE TA FORM F VOLTAGE REGULATOR

1 Connection strip
2 Armature
3 Pivot bearing
4 Relay armature lever
5, 6, 7 } Set screws
8, 9, 10 } Expanded core tips
11 Stop stud for spring relay contacts
12, 13 } Set screws for spring contact
14, 15 } Adjustment screws for spring contact
16 Spring contact
17 Contact in armature head
18 Armature head
19 Relay spring for adjustment screw
20 Core plate
21 Adjustment spring
22 Set screw
23 Lock nut
24 Adjusting nut
25 Contact stud

ADJUSTMENT OF THE FLOATING MAIN CONTACTS

For the proper adjustment of the main contacts (19) and (30) swing block (37) underneath lever (5) and tighten screw (39) then swing block (38) underneath lever (17), and with levers (5) and (17) both resting upon blocks (37) and (38), first, see that contact screw (30) is securely tightened and that the contact screw (19) is centrally placed above contact screw (30), then securely tighten screws (31) and (32), after which contact screw (19) should be adjusted to just touch contact (30) and set-screw (20) securely tightened. Then blocks (37) and (38) should be swung out from under levers (5) and (17) so that engagement with them is impossible, and they should be securely tightened in this position.

ADJUSTMENT OF THE A-C. MAGNET CORE

If the alternating voltage varies through the regulator range of exciter voltage as specified, it indicates an improper adjustment of the alternating current magnet core and to correct this error, proceed as for the Form A2 regulator.

ADJUSTMENT OF RELAY

A complete sectional side view of the relay is shown in Fig. 149. As this relay is differentially wound with two windings in each coil, there are four leads extending from the side of each coil. These leads (not shown in Fig. 149) are connected to binding posts A, B and C (on the regulator base) in the following manner:

1 and 6 to "A."
2, 3, 5 and 8 to "B."
4 and 7 to "C."

The above leads are all provided with stamped metal tags, thus rendering their connection very simple, which should therefore obviate any possibility of a mistake. Inasmuch as the relays are differentially wound, they will work to some extent whether the windings are in service or not. Therefore, if the relays operate unsatisfactorily, they should be tested to ascertain whether the coils are all working properly. If trouble is experienced which is apparently due to improper connections of the relay magnets or a possible open circuit, the fault may be easily located by ringing out the different coils with a magneto or other circuit-testing device. Each coil is wound with two well insulated parallel conductors, therefore, when testing the coils care should be taken to see that there is no breakdown of insulation between the two windings. It is also important to ascertain that all leads are properly connected to posts A, B and C, and that the set screws holding them are securely tightened. See that the expanded core tips (8), (9) and (10) (Fig. 149) are flush with the ends of the cores; then securely tighten set screws (5), (6) and (7).

The pivot holder on the end of armature (2) should be adjusted on the pivot until armature (2) stands centrally over the core tips (8), (9) and (10). The set screws holding pivot and sockets should then be securely tightened, leaving no end play in the pivots.

With armature (2) resting upon stop cap (10), the core and tips (8) and (9) should be only 0.05 in. from armature (2). This distance is very important and should be measured by gauge.

Setting of Relay Adjusting Spring

With the relay contacts (16) and (17) properly adjusted (see "Adjustment of Relay Contacts") and insulating material placed between the floating main contacts (19) and (30) (Fig. 148) the relay armature should be so adjusted by means of spring (21) that with 45 volts on the exciter the armature (2) just floats midway between the upper relay contact (16) and the stop cap (10).

The above value of 45 volts applies to 125 volt exciters and for the other standard voltages this adjustment figure is directly proportional, as indicated by the table below:

Exciter Volts	Values for Relay Spring Adjustments
60	22
90	32
125	45
250	90
550	197

LOCATING TROUBLE

See instructions under the Form A2 regulators.

CONDENSERS

With each regulator there should be furnished one condenser section for each pair of relay contacts.

TA FORM K REGULATORS

There is the same difference between the Forms F and K as there is between the A2 and the L, that is, the Form F is mounted upon its own base while the Form K has the regulator parts mounted directly upon the switchboard panel. The same instructions given for the Form F also apply for the Form K.

TYPE TD FORM G VOLTAGE REGULATORS

ADJUSTMENT OF MAIN CONTROL MAGNET

Should the voltage be unstable or fluctuating, the adjustments of the main control magnet should be gone over as follows: With normal voltage on the generator, contacts (4) and (5) (Fig. 150) will be nearly closed and the lever (6) should be in a horizontal position. Then with an increase in voltage of 12 per cent, core (9) should jump back and strike core (10). Should this fail to occur at 12 per cent above normal voltage, core (10) should be turned in one direction or the other and spring (8) should be adjusted until the lever is again in a horizontal position. The voltage should then again be raised to 12 per cent above normal. The adjustment of these cores is very important and

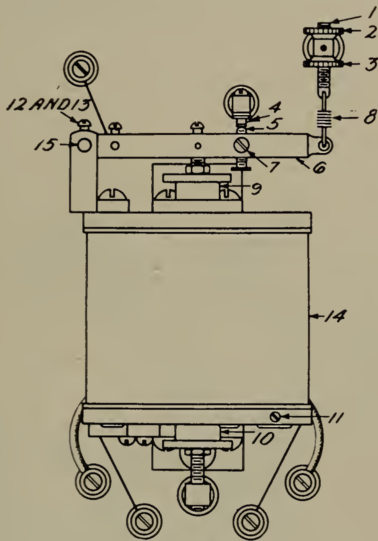

Fig. 150

MAIN CONTROL MAGNET FOR TYPE TD, FORMS G AND R VOLTAGE REGULATOR FOR DIRECT CURRENT GENERATORS

should be checked carefully. Make sure that pivots (15) are free and do not stick. A drop of oil on these pivots occasionally will prevent their rusting.

ADJUSTMENT OF RELAY MAGNET

The adjustment of the relay magnet is not the same on all TD regulators. A side view of the Forms S and G relay is shown in Fig. 151. The easiest way to adjust the relay contacts is to bring the voltage on 125 volt regulators to 88 volts or 30 per cent below normal. At this voltage the contacts should not open or close but should just come to a balance. If these contacts are open at this voltage lock nut (12) should be loosened and spring (10) should be tightened until the contacts merely come to a balance, then lock nut (12) should be securely tightened. In adjusting the relay magnet, before attempting to adjust the contacts the relay cores (3) and (4) should be $\frac{1}{16}$ in. from the armature with the armature resting on stop stud (6).

TYPE TD FORM S REGULATORS

The only difference between the Form G and the Form S regulator is that the latter has no compound winding. The adjustments are the same as for the Form G regulator.

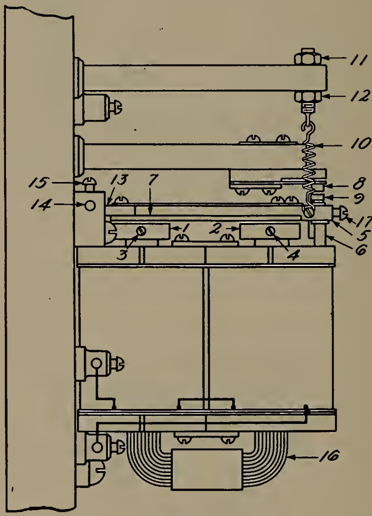

Fig. 151

RELAY MAGNET FOR TYPE TD, FORMS G AND S VOLTAGE REGULATOR FOR DIRECT CURRENT GENERATORS

TYPE TD FORM L REGULATORS

The Type TD Form L regulator is an exact duplicate of the Type TA Form A2 regulator with the exception that the TD Form L is intended for a direct current generator separately excited by an exciter, while the Form A2 is for an a-c. generator separately excited from an exciter and therefore the instructions for the TA-A2 apply for the TD Form L regulator.

TYPE TD FORM T REGULATORS

The TD Form T regulator is the same as the TD Form L with the exception that the former is intended for mounting directly upon the switchboard panel while the latter is mounted directly upon its own base. The instructions given for the TA Form A2 also apply for the TD Form T regulators.

TYPE TD FORM R REGULATORS

ADJUSTMENT OF MAIN CONTROL MAGNET

See instructions for Type TD Form G regulators.

ADJUSTMENT OF RELAY MAGNET

Fig. 152 shows the side view of the relay magnet of the Form R regulator. This relay is differentially wound with parallel conductors having four windings on the two coils. Two windings are connected permanently in multiple to the busbar through an external resistance. The second two windings which are connected in multiple are opened and closed by the main contacts.

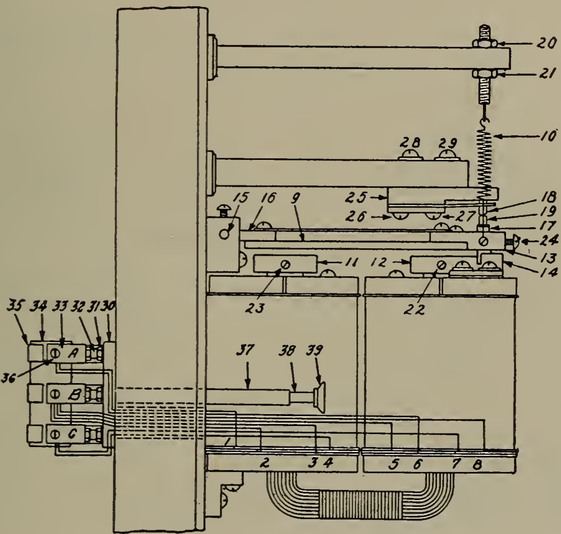

Fig. 152

RELAY FOR TYPE TD, FORM R VOLTAGE REGULATOR FOR DIRECT CURRENT GENERATORS

The adjustment of this relay is exactly the same as that given under the adjustment of relay for the Type TA Form A2 regulator with the exception of the spring setting. The tension of spring (10), Fig. 152, should be such that when the main contacts on the regulator are opened the relay armature (9) will just float midway between stop stud (14) and contact (18) with 88 volts impressed on the generator. This value, 88, is for the 125 volt regulator; for the 250 volt regulator this setting should be made at 176 volts.

The switch on the back of the relay is used for cutting out the relays which are not always in use and by opening this switch the main contacts have less work to do and consequently will last considerably longer.

TYPE TD FORM W SPEED REGULATOR

This regulator is intended to control the speed of d-c. motors and the adjusting spring (see Fig. 153) should be so adjusted

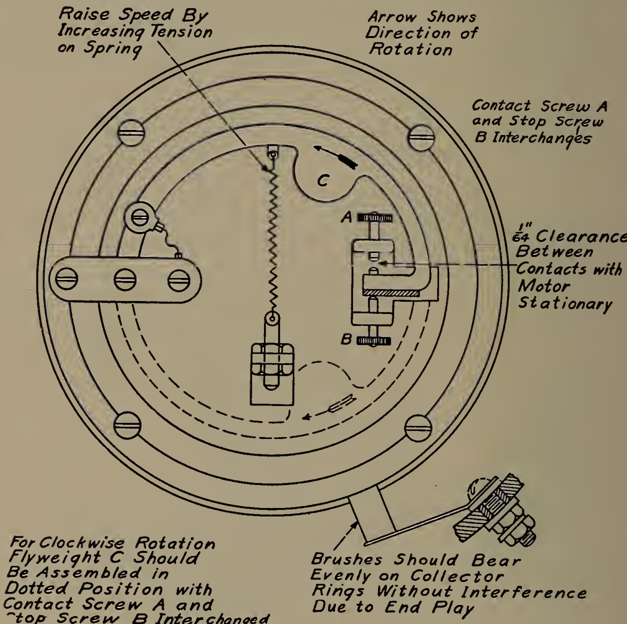

Fig. 153
ADJUSTMENT OF SPEED CONTROLLER FOR DIRECT CURRENT MOTORS

that the vibrating contacts just close at the desired speed. The regulating spring upon the back of this control device should be so adjusted that the contacts which this spring controls should open at about 15 to 20 per cent below normal speed.

The function of these contacts is to short-circuit the motor field rheostat in starting to prevent the motor starting with a weak field.

When relay magnets are furnished with this regulator their adjustment should be the same as that given under TD Form R regulators.

CHAPTER 19

INDUSTRIAL CONTROL APPARATUS

GENERAL

Under this heading are included resistances, field, starting and regulating rheostats, and controllers. The Testing Dept. is responsible for detecting all mechanical and electrical defects on apparatus which passes through the Department. A mechanical inspection should be given each piece of apparatus before the electrical test is begun. Particular care should be used in handling apparatus. Sliding contacts should move freely, contact brushes should make good contact on the segments and have a uniform pressure throughout the arc of movement. See that no loose bolts, nuts, terminals, or nameplates are passed. Where bead insulation is employed, the leads should be provided with a sufficient number of beads to prevent a short-circuit in case two leads should touch one another. Terminals should be spaced a sufficient distance apart to insure safety for the voltage employed and should be stamped according to the DS sketch or drawing list, as the case may be. No apparatus except supply parts should be sent out without a nameplate stamped with the drawing list or catalogue number and rating of the apparatus, which will be given on the Engineering Notice, drawing list, or DS sketch.

Owing to the fact that the resistance of materials is subject to considerable variation, a standard list of the allowances which are approved by the Engineering Dept. is posted in the Section. Devices whose resistance measures above or below these allowable percentages of variation from the specification should be rejected. All rheostats which have reversed, open, or short-circuited steps should be returned to the manufacturing department for repairs. The tester must assure himself, before approving any pieces of apparatus, that all circuits are wired according to the wiring diagrams.

After all tests are complete, the nameplate should be marked by the tester to indicate that the test is complete, and the wiring sketch should be securely fastened to the apparatus for delivery to the Shipping Dept.

Field Rheostats

All field rheostats should receive an insulation test, as given in the Engineering Brief, and the total resistance and the resistance of each step should be read and checked up with the specifications, which will be called for on the drawing list. Hand operated or chain operated rheostats should have the contact arm moved through the complete arc and should make full and even contact for the entire distance. Remote control rheostats are operated by a ratchet and pawl actuated by a solenoid. This should work satisfactorily on 80 per cent of the voltage for which it is designed and should not jam on 120 per cent. Motor-operated field rheostats should have a resist-tance in multiple with the motor armature and another in series with the motor. The value of both of these resistances is determined by the Testing Department and after adjustment to give the travel in a specified time on normal voltage they should be tried on 80 per cent voltage, and with the above adjustment must give satisfactory and positive operation.

Rheostats for Split Pole Synchronous Converters

These are for use in the auxiliary field of synchronous converters and should have a load test as follows: Connect a suitable resistance in the circuit marked "field" and in series with this connect an ammeter of proper capacity. Turn the contact arm to the neutral position and apply voltage to the line terminals. The ammeter should read correctly when the arm is turned in one direction and should read backward for the other direction. This point must be checked for all rheostats of this type.

Hand Operated, Starting and Regulating Rheostats

In addition to the regular mechanical inspection, the arm should be brought to the first point and released to see if it returns promptly to the "off" position. This should also be tried from the running position. Regulating rheostats should be tried for holding and releasing in each position of the arm.

All starting and regulating rheostats should be tried starting a motor several times and the release voltage noted. The arm must hold securely on half voltage. After this has been tried, full voltage should be applied. Then with the arm in the running position the line switch should be opened and the voltage at which the arm opens the circuit should be read. This must not exceed 35 per cent of the line voltage, but must operate before the motor has stopped. The retaining coil specification number should be checked and where an overload release is provided, the overload should be tripped and should release the arm immediately. The overload spool should afterwards be calibrated. See the drawing list for values. In the larger sizes which employ a contactor instead of a retaining magnet the contactor should be tested. (See instructions on "Contactor Testing" pages 345–6.)

Automatic Starters

These devices should receive a mechanical inspection; the contactor coil specification should be checked against the drawing list or Engineering Notice; all resistances should be measured and checked, and contactors tested (see instructions on "Contactor Testing" pages 345–6). Interlocks should be checked to see that they close in proper sequence with reference to the closing of the main contact tips of the contactor. All interlocks which are open should close, and those which are closed should open when the contactor closes.

All sliding levers which are attached to dashpots should be moved by hand to see if they move smoothly and easily. There should be no burred or pitted spots on the contact buttons or segments across which the contact arm moves. See also that the lever is properly retarded by its dashpot. Series contactors should be adjusted for the current values, as given in the Engineering Brief. Counter e.m.f. starters must be adjusted to pick up at the voltages specified, and after adjustment must be given an operating test with a motor of suitable rating.

Alternating Current Panels

Each panel should be given a test which represents the operating conditions as nearly as possible, and should be tried under different conditions, such as low voltage and high voltage. Where reversing features are provided, they should be tried thoroughly, and other special features should be given careful attention. For these tests the alternator should be held at normal voltage and frequency, except for the high and low voltage tests. Automatic compensator panels should have the taps on the compensator read at the motor terminals. The magnetizing current should also be read at normal voltage and frequency, as this will furnish an additional check on the compensator coil. The NR number of the coil is stamped on a small piece of fiber and is imbedded in the coil surface. This number should be checked against the rating of the panel. If dashpots are employed, they should be adjusted for time as specified on the drawing list or Engineering Notice. This adjustment should be such that a greater time limit cannot be obtained in case the customer attempts to make readjustments. If this is not done, a burned coil may be the result. After this adjustment, the dashpot should be operated several times and the time checked to see that the adjustment is constant. A rough check on the temperature of the coils should be made by feeling each one after the voltage has been applied for a considerable time.

Direct Current Panels

As with alternating current panels, the operating conditions should be approximated or equaled where possible. All overload, underload, field, and other relays should be calibrated and adjusted. Current limit relays should be adjusted and tried in all positions to see that they do not bind. Magnetic clutches should be adjusted by the factory and checked by the Testing Dept., and the operation on low voltage tried. Contactors should be adjusted (see below). The control circuits should be tried for normal operation, dashpots adjusted, and interlocks checked as given previously. All panels, after having the circuits and resistances checked, should be connected to the motor and given a complete operating test. High potential tests should be applied after all other tests are completed. The terminal stamping should be checked.

Contactors—Direct Current

Contactors should have the resistance of the coil measured and recorded, the "pick-up" and "wipe" current checked, also the amount of "wipe." If the wipe current is higher than the pick-up, this should be recorded separately. This current must not be greater than that specified in the Engineering Brief for the coil specification in use. Finger pressure, both initial and final, should be taken. The high potential test should be given after all other tests are completed and should be according to the Engineering Brief for both a-c. and d-c. contactors.

Contactors—Alternating Current

The resistance of the coils should be measured and recorded on the record of the panel. The coil specification, the "pick-up" and "wipe current," and the amount of wipe should be checked. Finger pressure, both initial and final, should be taken and the watts consumed by the contactor should be recorded and checked against the Engineering Brief. If an adjustable shading coil is used, it should be adjusted to give a watt value equal to, or lower than that specified in the Engineering Brief. The voltage and frequency should be held at normal for this test. The contactor must not hum at the minimum operating voltage given in the Engineering Brief, or at normal voltage. High potential tests should be applied after completion of the above test.

Where a series resistance is used with contactors as a holding resistance, the contactor must pick up and wipe on 80 per cent of line voltage and remain sealed on this voltage with the series resistance in the circuit. When the contactor is open and the series resistance is in the circuit, the contactor must not pick up on 120 per cent of the line voltage, even with considerable vibration. The above does not apply where a series resistance is used other than as a holding resistance.

Printing Press Controllers

Each resistance should be measured and recorded. The circuits should be checked up and the contactors tested (see instructions on contactor testing). On two-motor equipments, the resistance should be checked as above and the pilot motor connected up. The time for a complete movement of the arm should be obtained at normal voltage with the variable pilot motor armature shunt resistance both all in and all out. See that the tripping of the overload opens the "stop" circuit of the control and immediately stops the equipment. Try the "safe" and "run" features of the push button stations. The small motor reversing switch should open the large motor control circuit when the small motor is reversed. All interlocks should be checked. On current limit controllers the master dial switch should be connected up and care should be taken to see that proper sequence of contactors is obtained. Try the current limit interlocks to see that they do not bind. Adjust the field relays according to the Engineering Notice. Calibrate the overload relay and check the wiring. The dynamic brake contactor should wipe with the motor running at minimum speed.

High Potential Tests

All apparatus should receive a high potential test, as specified in the Engineering Brief. This varies with the class of apparatus.

Shipment

After the completion of the test, the name plates should be marked with the Testing Department's stamp and the wiring diagrams should be securely attached.

There are occasionally special cases in which the diagram is to be mailed, in such cases the Head of the Section should obtain written permission from the Engineering Dept. to ship the apparatus without diagrams, and should attach a card marked "No connection diagram necessary."

STARTING COMPENSATORS

Compensators for starting Form K induction motors, synchronous motors, and synchronous converters are built for voltages from 110 to 13,200 volts. The switching mechanism and connections constitute the chief difference between the various forms. Forms A and B have double-throw oil switches which are so connected that the fuses, or overload relays, as the case may be, are in the circuit only when the motor is thrown on the line. (See Figs. 154 to 159 inc.) The figures show the connections for the Forms A and B two-phase and three-phase compensators with the necessary overload and no-voltage relays. The tests required are ratio, magnetizing current, heat runs when specified, double potential and high potential. The no-voltage release coil should, in addition to the double potential and high potential tests, receive pick-up and releasing tests and have its resistance measured. The oil boxes should be removed and the switches carefully examined before making any tests.

On compensators above 550 volts the oil switch must not be used to break the magnetizing current unless the oil box is filled with oil as the switch will arc across and not open the circuit.

Complete tests on compensators consist of commercial tests, heat runs, impedance, and insulation tests.

Commercial tests consist of ratio of taps, exciting current at normal voltage and frequency, and insulation tests.

Insulation tests consist of applying high potential between the windings and ground for one minute, operating the compensator at double potential for one minute and also at one and one-half times normal potential for five minutes.

Ratio

Connect the line leads to the terminals on the testing stand. These terminals are connected in multiple by busbars at the back of the terminal board. Apply 100 volts to the lines; throw the switch on the compensator under test to the "starting" position, leaving all others in the "off" position. On the three-phase compensator read the voltage between the taps (the

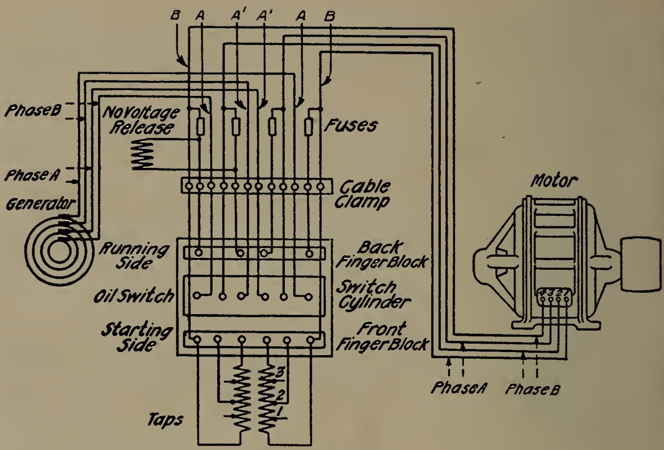

Fig. 154

CONNECTIONS OF QUARTER-PHASE, TYPE IQ, INDUCTION MOTOR AND TYPE NR, FORM A2 STARTING COMPENSATOR WITH NO-VOLTAGE RELEASE ONLY

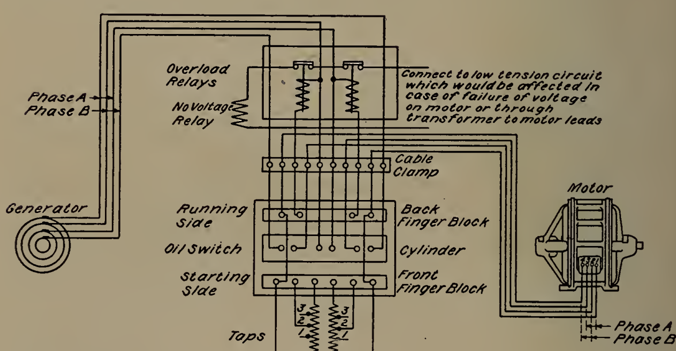

Fig. 155

CONNECTIONS OF QUARTER-PHASE HIGH VOLTAGE TYPE NR STARTING COMPENSATOR WITH NO-VOLTAGE AND OVERLOAD RELAY

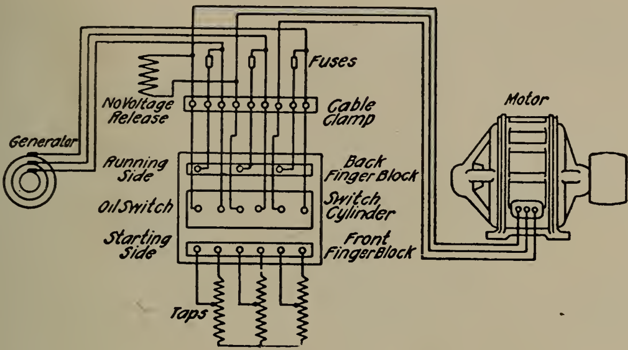

Fig. 156

CONNECTIONS OF THREE-PHASE, TYPE I, INDUCTION MOTOR AND TYPE NR, FORM A2 STARTING COMPENSATOR WITH NO-VOLTAGE RELEASE ONLY

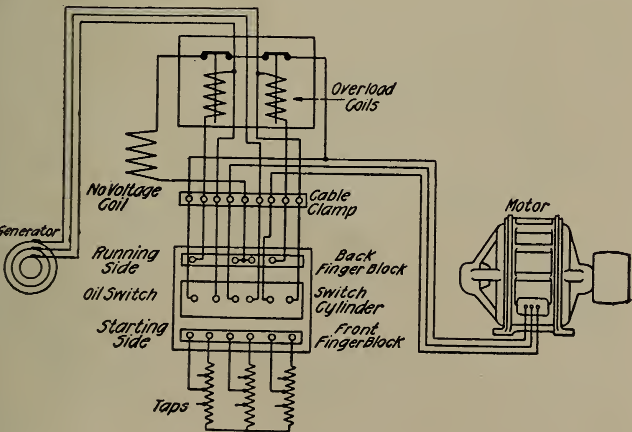

Fig. 157

CONNECTIONS OF THREE-PHASE TYPE I, INDUCTION MOTOR AND TYPE NR, FORM A3 STARTING COMPENSATOR, WITH NO-VOLTAGE AND OVERLOAD RELEASE

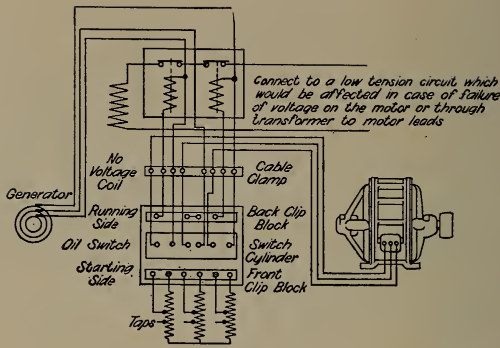

Fig. 158

CONNECTIONS OF CR HIGH VOLTAGE THREE-PHASE STARTING COMPENSATOR WITH NO-VOLTAGE AND OVERLOAD RELEASE

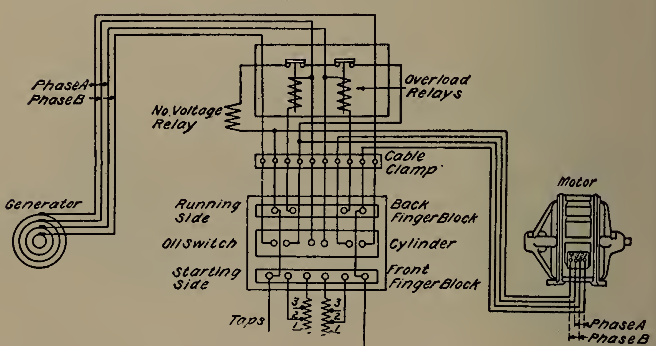

Fig. 159

CONNECTIONS OF QUARTER-PHASE, TYPE IQ, INDUCTION MOTOR AND TYPE NR, FORM A3 STARTING COMPENSATOR WITH NO-VOLTAGE AND OVERLOAD RELEASE lowest voltage tap is next to the core). Standard compensators for motors up to and including 17 h.p. have 50, 65, and 80 per cent taps; those for motors above 17 h.p. have 40, 58, 70 and 85 per cent taps. The ratios obtained should agree to within 3 per cent of the above.

In determining ratios see that both the primary and secondary instruments are on the same phase. In checking the ratio of quarter-phase compensators, join leads A' and A' (see Fig. 154), apply 100 volts to the lines A and A, and read the voltage on the taps between the motor leads B, B and each tap. These compensators are tested "open delta."

Magnetizing Current

Magnetizing current is measured at normal primary voltage and frequency. The alternator used should operate at normal voltage. The exciting current at normal voltage and frequency should, on 60 cycle compensators, not exceed 25 per cent, and, for 40 and 25 cycle compensators, it should not exceed 30 per cent of the full load current of the motor, assuming in the smaller sizes, the motor to operate at 75 per cent efficiency and in the larger sizes at 80 per cent.

On special compensators, covered by Engineering Notices, the magnetizing current should be taken at 20 per cent above normal potential as well as at normal. In making this test hold the voltage constant across one phase and read the current in all three legs, then hold the current constant in one leg and read the three-phase voltage, or instead of holding current in one leg, two voltmeters may be used, one to hold the voltage constant, and the other to read the three-phase voltage. Owing to the fact that these machines are used for starting duty only, a high current and magnetic density is employed. Therefore, a very small change in frequency or potential makes a considerable difference in the exciting current, and care must be exercised to see that the voltage and frequency are normal. Quarter-phase compensators are tested "open delta."

It will be noted that on three-phase compensators one leg will read slightly lower than the other two, which should be balanced. This is due to leakage caused by the high magnetic density and the close proximity of the iron case and supporting straps.

Heat Runs

Short-circuit the motor leads and apply sufficient voltage to the line leads to force the required current through the coils. This current should be held constant for one minute and the impedance volts read in each phase during this period and on each set of taps. The value of the current will be given in the standard Engineering Brief, or in Engineering Notices covering special cases. Thirty minutes should elapse between successive heat runs on the same compensator up to and including 200 h.p.; above this size one hour should be allowed. A thermometer should be placed on each coil and the temperatures watched until they attain a maximum after each run and this value should be recorded. Directly after the close of each run the tap leads should be changed to the next tap. Heat runs should always be started on the tap next to the core.

On large compensators it sometimes happens that there is not sufficient power available to make the heat run as called for. In this case upon permission from the Engineering Dept. the following alternative may be used:

Hold half the current called for, and hold it four times as long. This will give an equivalent heating.

After the completion of the heat run the taps should be taped up after placing the tap leads on the second set of taps. All compensators should be sent out with the tap leads on this tap.

Insulation Tests

The double potential and the high potential tests should be applied after all other tests are completed and the compensator is assembled with the taps taped up. The frequency should be high in order to keep the magnetizing current below the normal current for which the compensator is designed. In case the normal voltage of the compensator is so high that it is impossible to secure double potential, one set of taps may be connected to the line and voltage applied, which shall be double the voltage for which the tap is designed.

All compensators up to and including 550 volts normal rating should receive 2500 volts insulation tests from windings to core and frame for one minute; those from 550 to 4000 volts should receive 7500 volts; those for 4000 volts should receive 10,000 volts; those above 4000 volts, double normal potential. In applying the high potential tests all leads should be connected together.

CHAPTER 20

MINE AND INDUSTRIAL LOCOMOTIVES

MINING LOCOMOTIVES

Mining locomotives (LM type) are built for various gauges in sizes of 3 to 20 tons. With the exception of an occasional 3-motor, 6-wheel type they are all 2-motor, 4-wheel locomotives and are equipped with either 250 or 500 volt series wound, totally enclosed motors mounted directly on the axles and driving through double reduction gearing. The controllers are of the "R" type, which have a separate cylinder for forward and reverse in which is incorporated a commutating switch that permits starting the locomotive with motors either in series or in parallel.

Before being sent to the Locomotive Department the various parts of the equipment are tested separately; the motors being subjected to the standard test for railway motors and the controllers, circuit breaker, etc. being subjected to the regular tests in force in their respective departments. The test of the locomotive proper is, therefore, principally a bearing run, a check of the wiring connections and a general inspection to see that all parts operate properly, that clearances are sufficient and that the apparatus is properly located.

Unless otherwise specified, tests should be conducted as follows:

1. Anchor the locomotive securely on the testing stand that is provided in the Locomotive Section and operate it on all points of the controller, forward and reverse, both series and parallel, to assure that connections have been properly made.

Caution: As these are series motors running practically without load, power should be thrown off as quickly as possible when checking with the controller in the "parallel" position.

2. Make a bearing run of 15 minutes duration in each direction at full "series" position of the controller.

3. Measure and record the resistances of the several rheostat steps. A 20 per cent variation from the values given in the DS print is allowable.

4. Make a careful general inspection to see that the brakes, sand rigging, headlights and circuit breaker operate properly; that the wiring cables are clamped securely and that they do not interfere with the access to the motor bearings or other parts; see that the rheostat terminals have good clearances to "ground" on the locomotive frame and check up carefully all questions on the testing record.

Cable Reels

Many locomotives, particularly the 5 and 6 ton sizes are equipped with motor-driven cable reels. The purpose of the reel is to permit operation over those portions of the mine roads that are not provided with trolley wires. The reel rotates with its axis vertical and is driven by a four pole, series wound, vertical motor which is wired directly across the line in series with a permanent resistance to protect it from an injurious rush of current when the motor is stalled. The outer end of the cable is hooked over the trolley wire and as the locomotive moves forward the reel motor is overhauled and acts as a series generator, its counter torque producing sufficient tension in the cable to pay it out evenly. As soon as the locomotive starts back and slackens up on the cable, the motor action comes into play and winds up the cable; the action is analogous to that of a spring having infinite length.

Test as follows:

1. Measure and record the cold resistance of the armature, field and permanent rheostat.
2. Check the polarity.
3. Check for satisfactory operation by mounting the reel equipment on the shop locomotive that is provided for this purpose and run it out on the test track. At least five trials should be made running the full length of the cable. The reel should pick up and wind the cable compactly when the locomotive is running on the full series point of the controller.
4. When the reel equipment is mounted on its own locomotive, check the rotation (looking at the top of the reel) as follows: If the motorman's seat is on the left hand side of the locomotive the rotation should be counter-clockwise. If the seat is on the right hand side of the locomotive the rotation should be clockwise.

Winding Devices

For hauling cars out of mine slopes where the grade is too steep for locomotive operation some locomotives are equipped with winding devices. These consist of a vertical axis cable drum fitted with 400 to 600 ft. of flexible steel cable and driven by a series wound, totally enclosed motor.

Test as follows:

1. Give the drum and motor a 15 minute bearing run, holding them down to moderate speed by applying the band brake on the drum.
2. See that the brake and clutch levers operate readily and that the clutch engages properly.
3. With the clutch disengaged, see that the cable can be hauled out by hand easily. Use a spring balance and record the pull required; this must not exceed 45 lb.
4. Measure and record the resistance of the starting rheostat.

INDUSTRIAL LOCOMOTIVES

Industrial locomotives (LS type) are built for various gauges and in sizes from 3 to 25 tons. They are practically all of the single truck, 4-wheel, 2-motor type. The electrical equipment in general is the same as for the mine locomotives and they differ only in the mechanical arrangement of the frames. With the exception of the larger sizes (15 to 25 tons) the test should be conducted in the same manner as for the mining locomotives. Those of 15 tons and above are, as a rule, built for the standard gauge (56½ in.) and are equipped with cabs, air brakes and MCB couplers. Instead of using the testing stand in the Locomotive Section, these should be tested on the General Electric Company test tracks and the general instructions in force there will apply.

STORAGE BATTERY LOCOMOTIVES

Storage battery locomotives (C.S.B. and L.S.B. types) are at present built in various sizes, from 2½ to 8 tons. These as a rule will be single truck, 4 wheels, with either one or two motors, and for various gauges from 24 in. to 56½ in.

The equipment differs from the standard mine (L.M.), and industrial (L.S.) types, in having low voltage automobile type motors, driving the wheels by double reduction gearing in place of the regular 250-500 volt motors. The storage battery will usually consist of 44 "lead acid" cells or 70 to 80 Edison cells, all connected in series for an average discharge potential of 85 volts.

After the battery is in proper condition of charge as hereinafter described, the locomotive should be placed on the testing stand and test conducted in the same manner as before described for mining (L.M.) and industrial (L.S.) type, i.e., operate on all points of the controller forward and reverse to see that all connections are properly made, make 15 minute bearing runs in each direction; measure the resistance of the rheostat; and make a general mechanical inspection of brakes, sand rigging, headlights, wiring, etc.

When a locomotive has been delivered to test, each and every cell should be carefully inspected to see that the electrolyte is at the proper level. This level varies for the different types and makes. For the "Lead Acid" battery (distinguished by a rubber jar) the level of the liquid should be ½ in. above the plate, for the Edison (distinguished by metal jars) the level of the liquid should be ½ in. above the plates for the A-4 and A-6 types, and ⅛ in. for the A-8, A-10 and A-12 types.

Caution: Gas may be present in the cells. Do not use a match, candle or other open flame to inspect.

The lead cell batteries may be easily inspected by removing the cover or the soft rubber plug. For determining the height of liquid in Edison cells the method illustrated in Fig. 160 will be found convenient.

If the liquid is low, sufficient *pure distilled water* should be added; never use water suspected of containing the slightest impurities as very great damage to the battery may result.

After ascertaining if the liquid is at the proper height see that the several battery trays or crates are properly connected in series, as otherwise a portion of the battery might easily be ruined.

Since it is impossible here completely to describe the various methods of charging the several types of batteries, due to the fact that the several manufacturers recommend slightly different procedure, the following brief summary must suffice for the first charge while the battery is temporarily in our care: The battery should be placed on charge at the normal rate as given with the instructions that accompany each battery. For lead

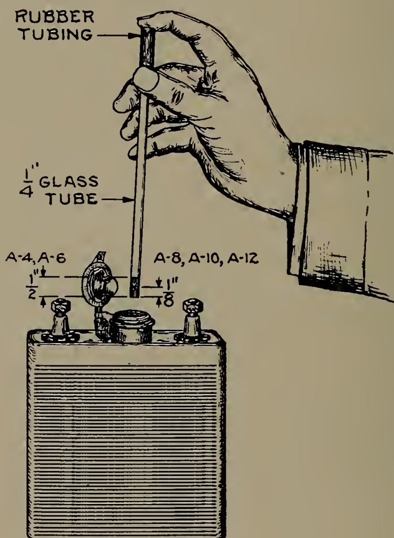

Fig. 160

QUICK METHOD OF DETERMINING PROPER LEVEL OF ELECTROLYTE ABOVE PLATES

batteries when the voltage has reached a value of 2.55 volts per cell (112 volts for 44 cells) the charging should be discontinued. For Edison batteries, charge at the normal rate as given on the name plate for 7 hours or until the voltage has reached a value corresponding to 1.85 volts per cell.

When all tests have been completed, the locomotive may be shipped without recharging, as the running light test will as a rule use but little of the battery charge.

Fig. 161 shows the proper method of connecting a battery to the line for charging.

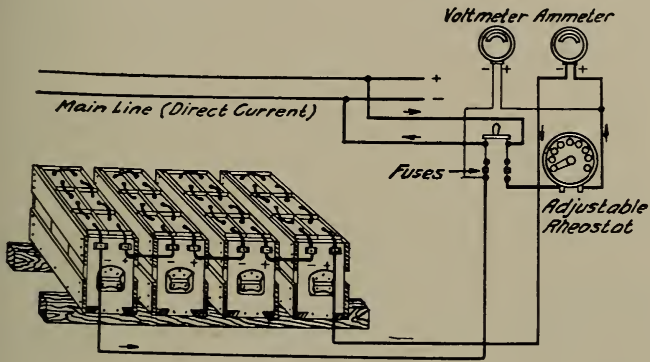

Fig. 161

DIAGRAM SHOWING GENERAL METHOD OF CHARGING BATTERIES

The trays are first connected in series, i.e., the negative of one tray to the positive of the adjoining tray. The current flows from the positive wire of the current supply, into the positive terminal of the first tray (in this case on the right); through the positive and out of the negative of each cell and each tray in turn and returns to the current supply from the negative of the last cell.

The voltmeter is connected inside the resistance or rheostat, to show the battery voltage only.

CHAPTER 21

PORCELAIN INSULATORS

Insulators are of two distinct types; link insulators and bushings.

The Link Insulators are those used for either strain or suspension work and have holes, called cableways, for fastening the cables.

Bushings comprise all other kinds of porcelain insulators which are cylindrical in form, and serve as conduits.

Inspection

Before testing, all insulators should be given a rigid inspection for mechanical defects, such as cracks, flaws, warping, chipping and non-uniformity in color of glaze.

Methods Used in Applying High Potential

In applying high potential to porcelain insulators, they are placed on a rack which holds twelve, and these are tested together.

In the larger type requiring a special test, it will be found advantageous to use two racks at once.

The Link Insulators have cableways on either side between which the potential is applied.

This can be done by using two spiral springs which can be pushed through the cableways and hooked upon themselves, thus making the insulator take the same position as it does in service.

In testing bushings, a pipe or spring is laid through the center of approximately the same size as the hole. A piece of metal foil or spring is then wound around the outside at the middle point. The potential test is then applied between the metal parts.

Routine Potential Tests on Insulators for Switchboard Department

Potential values, where called for, should be determined by the needle gap and striking distance curve C-845. (See Fig. 186.) This determination should be made under testing conditions with the insulators connected to the transformer. (The capacity currents taken by some insulators and the oscillating discharge passing over their surface sometimes seriously affect the transformation ratio.) Where arc-over values only are specified, the tester must see that the testing outfit and conditions will not facilitate arc-overs.

Insulators in production and not listed in Eng. Brief 10761A should be called to the attention of the Engineering Department.

Any insulators listed showing serious discrepancies from the results of specified tests, without defects being apparent, should be referred to the Engineering Department before proceeding further.

Tests are called for by letters having the following significance:

"*A*" Apply potential between central stud filling the insulator bore, and the foil band around the outside of insulator. Foil should be so located as to bring the maximum tax (stress) through that section of the insulator which is under maximum stress in service. If the outer surface is not completely glazed foil should be placed on the unglazed surface.

"*B*" Includes "Blind" Insulators. Apply potential between the stud and foil around the opposite end of insulator, the foil being located to give approximately service conditions.

"*C*" Apply potential between foil located inside and outside the insulator on the unglazed parts.

"*D*" Apply potential between spiral springs coiled in cableways.

"*A*," "*B*," "*C*" and "*D*" tests consist of a flash-over voltage applied instantaneously and a 90 per cent flash-over voltage applied for 30 seconds.

TUBES

Wet process porcelain tubes must be tested at 20,000 volts per each ⅛ in. thickness applied for 30 seconds between central stud and foil covering the outside completely except at ends where the foil is omitted to obtain the necessary striking distance.

CHAPTER 22

TRAIN CONTROL APPARATUS

Inspection and High Potential Tests

Before testing any apparatus, a careful inspection must be made for any mechanical defects. Any part of apparatus that will be subjected to a difference of potential must be given a high potential test, corresponding to that specified in the Engineering Briefs.

AIR BRAKE APPARATUS

This includes valves, governors, strainers, cylinders, and all other parts that make up the braking system of a car or train.

VALVES

Air valves are manufactured under the following type letters: A, S, VL, E, and TE.

The A and S are motorman's valves, different forms of which are used for straight air and emergency brake systems.

The VL is a pressure reducing valve used for automatic air brake systems, and reduces the main air reservoir pressure to a lower and constant pressure.

Type E includes all emergency valves. One of the most important is the Form E, used with automatic air brake systems in connection with the pilot valve located in the controller. It exhausts the train pipe whenever the pilot valve is opened, thus applying the brakes to the car or train.

Magnet valves are included under the Type TE. They are used for remote control. The Form B is used for operating pantograph trolleys.

Mechanical Inspection

Each valve is given a careful inspection to see that all the pipe connections have good threads. In the Types A and S, the fit of the handle should not be too loose. There should be only enough clearance to allow it to be easily removed. The handle should move over the different positions with comparative ease and be removable only in the lap position.

Air Valve Tests

Every casting, which will be subjected to air pressure in service, should be tested for porosity. This is done by immersing the casting under pressure in water. Where this cannot be done, cover the casting, under air pressure, with soap suds. Water must be used in every case to determine the amount of leakage, and all castings showing a continuous leakage must be rejected.

After assembly, each valve should be subjected to an air pressure and operated as near as possible at the service pressure. All parts should then be again tested for leaks by immersing in water or by covering the part with soap suds, while under pressure.

Valves with metal stem seats are provided with ground stems. The stem and hood are inspected before being assembled on the valve body.

GOVERNORS

Governors automatically keep the air pressure of the braking system within a certain range by opening and closing the compressor motor circuit.

Operating Test

Each governor is stamped with the type letters and numbers; the letters represent the style of the governor, and the numbers represent the capacity and range at which it will operate. The first number indicates the minimum opening pressure in pounds per square inch. The second number denotes the maximum opening pressure. The third denotes the variation in the opening and closing pressures. The tests are similar in all governors and consist of connecting them to a source of compressed air, the compressor motor circuit being wired through the governor tested. The governor should then be adjusted to open the circuit at the minimum opening pressure and close it as soon as the pressure is reduced by an amount equal to the given pressure range. It must then be tested for maximum opening pressure and should again close when the pressure is varied through the amount equal to the normal range.

All parts under pressure should be examined for leaks.

Type ME 65–100–10 Form A Governor

This governor is designed for use with a large compressor, the circuit of which is made or broken by a contactor or contactors controlled by the governor. The test is similar to that given above, except that the main circuit of the compressor is broken by the contactors controlled by the governor instead of by the governor direct.

STRAINERS

Strainers are used in air brake systems to catch scale and small particles that would interfere with the operation of any of the apparatus. They are tested with air pressure and examined for leaks.

CONTROLLERS

The R, K, C and T controllers comprise the principal types, All others are modifications of the above.

The R and K types make and break the main motor circuit within the controller.

The Type C controller makes and breaks a circuit which operates contactors that open and close the motor circuits. With a contactor box on each car and the control circuits connected in parallel, the motor circuits for a whole train can be controlled with one controller.

Type T is used with induction motors, generally being used to cut out resistance in the rotor circuit of Type M motors.

Inspection

The development of each cylinder and its fingers should be examined to see that they check with the DS diagram. The fingers should make good contact on the segments of the cylinder and in the order shown. Controllers having several auxiliary fingers in series should be tested to see that these fingers make and break contact simultaneously. All auxiliary release knobs should open the auxiliary contact fingers when released at any position of the handle. The main cylinder and reversing cylinder should interlock, so that the reversing handle cannot be thrown when the controller is in any but the "off" position. When the reversing handle is in the removable position, the main cylinder should be locked in the "off" position. All controllers should receive a careful inspection for mechanical defects. All cables passing through the frame of the controller should pass through an insulating bushing, except in the case of Type R controllers for mining locomotives.

There should be sufficient clearance between points at different potentials and between all current-carrying parts and frame.

Operating Test

All controllers should be connected and operated under service conditions as nearly as possible. Those controllers which operate the main motor circuit should be connected and operated with a motor or motors with the proper resistance in circuit, to check the wiring and the blow-outs on the different fingers. Carefully note whether the arc blows in the proper direction and ruptures satisfactorily when turning the controller to the "off" position. When the controller is not adapted to motors used in the testing department, the complete development and wiring of the controller should be carefully checked with the DS diagram. Those built to operate contactors should be connected to the latter and operated, noting the direction the arc blows as in other controllers. When turning the controller to the "on" position the auxiliary finger or fingers should make contact first, and should break last when turning to the "off" position, unless otherwise stated on the Engineering Brief for that particular type or form of controller.

Where a separate blow-out is used for the auxiliary fingers, it should be carefully tested. The auxiliary fingers, whether fitted with a blow-out coil or not, should break the total current of the controller in any position, when the auxiliary release knob is released.

Automatic and Semi-Automatic Controllers

Several types of the C controllers have their cylinders fitted with a spring and governor so that when the handle of the controller is turned to the "full on" position, the spring is wound up sufficiently to rotate the cylinder. The governor should be adjusted so that the cylinder will rotate in the specified time. The governor is fitted with a small magnet coil which should lock and hold the cylinder in any position when the specified current is passed through the coil.

Pilot Valves

Many C controllers are fitted with pilot valves operated by the auxiliary release knob. This pilot operates a valve for an emergency operation of the brakes. They should be connected to an emergency valve which should trip whenever the auxiliary release knob is released. The reversing handle should interlock with the valve in the "off" position, and should prevent tripping of the emergency valve. The valve should operate quickly without leakage when closed.

REVERSERS

Reversers used in Type M control are operated by solenoids energized through the reversing cylinder to the controller. The segments on the rocker arm are so arranged that a movement from one extreme position to the other changes connections and reverses the armature or field circuits of the motors.

Operating Test

The operating test consists of connecting the inductive resistance specified between the first and third fingers, one side of the shop to the third finger, with the other side connected alternately to the two solenoid coils. Under these conditions the reverser should operate quickly and throw completely over, without rebounding. It should be operated on the different voltages specified. The arc formed on the control fingers must be blown outward from the fingers and should rupture immediately. This should be noted. The coil resistances should be measured and should check within 10 per cent of that specified in the Engineering Briefs.

Spools for Supply Shipments

After the high potential test, the resistance of each spool should be measured and should check within 8 per cent either way, from that specified in the Engineering Briefs.

MS SWITCHES

MS switches are made up for the control of various car or train circuits, and are in most instances equipped with magnetic blowouts. Quick-break operation on some types is also employed.

Each switch should be examined for mechanical defects such as broken or loose parts. The switch should work freely and should not stick or bind in any position. It should make good contact when closed.

Switches designed to open the main current should be given a blow-out test, consisting of breaking a specified current in order to see that the arc is blown outward, and ruptures satisfactorily. All switches should be given a high potential test between parts of opposite polarity when a blade or blades are open.

CUT-OUTS

Cut-outs for train control service are used to cut out the control circuits of individual cars from the rest of the train, one cut-out being placed on each car.

Besides seeing that the fingers make good contact on the contact segments, all fuses should be "rung out" to see that they are in good condition.

CONNECTION BOXES

Connection boxes are used as splicing junctions where the wiring of the car is run through conduit. They consist of a metal box containing connection terminals to which wires may be easily connected or disconnected. They receive a high potential test only.

MU TRIPPING SWITCHES

These switches have a series coil through which the motor circuit is wired, and a small control switch through which the control circuit for the line contactors is wired.

The series coil operates an armature fitted with a calibrated spring similar to a circuit breaker, so that if an excess of current is taken by the motors, the armature trips out the control circuit switch, opening the contactors in the motor circuit. Examine the compound box to see that it is not cracked or broken, and that all flat headed screws are center punched other than the removable screws used in fastening the cables.

The control switch should work freely and make good contact when closed.

The switch should open when the lever is thrown to the "off" position.

All MU switches are calibrated for various tripping points. (See Engineering Briefs.) They are sent to the Test Dept. for calibration without the cover. The armature should be held in the operating position by means of a block of fiber or other non-magnetic substance, as though it rested against the cover. Marks are made to determine the relative positions of the cap of the calibrating springs for the different currents. The switches are then returned to the shop for stamping and assembly of cover, after which they are given a blow-out test, which consists of breaking a small inductive circuit with the switch to determine the direction of the blow-out.

A high potential test should be made between the series coil and the control switch, also between the switch blade and upper left-hand terminal when the switch is open.

CONTACTORS

Contactors are used for making and breaking the motor circuits on a car. They are operated by a solenoid which actuates a lever carrying one contact tip, the other tip is stationary, and fitted with a blow-out coil which helps to break the arc between the tips.

There are two distinct types of contactors: DB contactors which are used for direct current work, and DBA contactors which are used for alternating current work.

The DBA contactors have a laminated armature and an E- or U-shaped laminated field with copper shading coils in the face of the outside leg, to prevent humming when the contactor is closed.

An arbitrary number is assigned to each contactor, and form letters are used to indicate minor mechanical differences. A numeral follows the form letter to indicate the operating coil used, viz. DB-260-A-1.

Inspection

Each contactor should be examined carefully for mechanical defects, such as broken arc chutes, cotter pins, loose screws or bolts. Also note whether it bears the Mechanical Inspection Department's stamp. The contact tips when closed should make good contact over their full width. The copper shunt should be free from sharp kinks or bends and should not rub on any metal part having sharp or rough edges. All contactors must operate freely, and must not stick or bind in any position.

TYPE DB CONTACTOR

Commercial Tests

From the tables given in the Engineering Briefs, see that specification on the spool corresponds with the stamping on the name plate.

When hung in the proper position, the contactor should pick up and wipe contact at or below the current values given for the respective spools, care being taken that the contactor wipes full contact, as sometimes the pick up current is taken to be the same as that required for the wipe contact. To avoid this error, note that the first upward movement of the plunger only brings the contact tips together. This is called the pick up. The next movement wipes the contacts over one another, and also increases the pressure between them. The amount of this movement should equal or exceed that given in the Engineering Brief.

Measurement of Spring Pressure

Insert a strip of paper or cloth between the tips, and put enough current through the operating coil to close the contactor completely.

Hang a spring balance from the screw heads holding the tip on the finger, and note the pull required on the spring balance to loosen the paper between the tips.

Resistance Measurement of Spools

The resistance of each coil should be measured and be within 8 per cent above or below the specified resistance at 25 deg. cent.

TYPE DBA CONTACTOR

The pick up and wipe is similar to that in the DB contactors. As each DBA contactor, however, is connected directly across the line, it is tested for the operating voltage instead of the current. The voltage should be obtained by gradually raising the field on the alternator.

The magnetizing current is measured at the proper frequency, and should be taken with the armature fully closed.

The finger pressure should be taken as in the DB type. See that the contactor wipes on the same voltage at which it picks up. It should do so to protect the tips from freezing (welding together) due to insufficient contact area. The operating coil would also burn out, since with a-c. contactors the current is high until the contactor is closed. After the contactor has wiped, it should be perfectly noiseless.

SPECIAL TESTS

The test sheet should contain the following data:

Coil specification (No. of turns and size of wire). Cold resistance and temperature of coil at which the cold resistance is taken. Number of coils in series or multiple during test.

Finger Pressure

This test is made by holding the contact fingers at full wipe position, attaching a spring balance to the screw which holds the finger to the jaw by means of a small loop of wire. A pull is then exerted through the spring balance until the fingers separate sufficiently to allow a thin strip of paper, placed between them, to be drawn out. The pull as recorded by the spring balance is taken as the finger pressure. The pressure of each finger should be measured separately.

"Minimum Pick Up" and "Wipe"

A contactor is at "pick up" position, when the armature is raised so that the fingers just make contact. At "wipe" position the contactor is fully closed.

On a-c. contactors, two additional tests, *regulation of alternator*, and *chattering and drop-out voltage* are made in connection with the minimum pick up test.

Regulation of Alternator

With the armature blocked open, read the speed and voltage of the alternator both with and without the contactor in circuit. Repeat with the contactor blocked shut.

Chattering and Drop-Out Voltage

With the contactor picked up and fully wiped, note the minimum to which the voltage can be reduced before the contactor becomes noisy, and also note the voltage at which the contactor opens.

Saturation Curve

This curve is taken at different voltages reading amperes and watts, readings being made both with the contactor closed and opened, or at such air-gaps as special instructions may require.

Pull Curves on D-C. Contactors

This curve is taken by holding a constant current and reading the pounds pull for different air gaps. The curve is taken in either of the following ways:

First: By carefully adjusting the air gap, weighting down the plunger, and holding the amperes constant while weights are subtracted from the plunger until it picks up.

Second: By weighting down the plunger and holding the amperes constant, while the air gap is gradually decreased until the plunger picks up. The air gap is then measured. A variation of this curve is sometimes made by holding a constant air gap and varying the amperes and weights. In connection with the data for these curves, the length, diameter and weight on plunger should be given; the length of plunger being taken as the length from the butt end to the center of the hole in the lower end. The weight given in the table should be exclusive of the plunger and should be so stated on the Test Sheet.

Pull Curves on A-C. Contactors

The method of taking a pull curve on an a-c. contactor is more complex than on a d-c. contactor. In either case the pounds pull is dependent upon the ampere turns. In a d-c. contactor, however, the amperes at any voltage varies directly with the resistance of the coil and is independent of the plunger air gap, whereas in an a-c. contactor the amperes at any voltage does not vary with the resistance, but with the impedance. The reactance varies with the armature air gap. For this reason it is not desirable to hold the amperes constant. If, however, the voltage is held constant, an error will be caused due to the resistance of the coil being increased by heating.

In tests where great accuracy is required, this error can be eliminated and all contactors can be compared upon a common basis by the following method:

First: Measure the resistance of the coil cold.

Second: Holding the voltage constant at that value at which the pull curve is desired, take an ampere air gap curve; i.e., read amperes at various air gaps. This curve should be taken as rapidly as possible to avoid undue heating of the coil.

Third: Take a check reading of the resistance to see if the coil has been much heated. If the heating is slight, an average of the two readings should be taken as the resistance of the coil.

Fourth: The ampere air gap curve thus obtained should be corrected for a temperature of 25 deg. cent. and replotted.

Fifth: Take a pull curve as given by the first method for d-c. contactors, holding the amperes constant corresponding to the different air gaps as obtained from the corrected ampere-air gap curve.

In cases where the cold temperature of the coil happens to be within a few degrees of 25 deg. cent. the pull curve can be taken directly, holding the voltage at the value at which the curve is desired. Great care should be taken to prevent undue heating of the coil. The current must be on only for a sufficient time to obtain readings. At the completion of the test take another check reading of the resistance to determine the heating.

Work Curve

This curve is taken by measuring the pounds pull necessary to lift the plunger or armature at different air gaps, having the complete operating mechanism of the contactor and spring adjusted to give the finger pressure required.

Speed Curve

Speed curves are taken on contactors and relays to determine the time a contactor takes to close or to open.

For taking this curve, a special mechanism has been made which operates as follows: The contactor is set on a special stand and a mechanism is then fitted to the plunger of the contactor so that a pencil attachment operates along a vertical line. The pencil bears upon a sheet of sensitive paper which is secured to a cylindrical drum, revolving about a vertical axis. The drum is rotated by a small shunt motor operating at constant speed. Upon the periphery of the drum, contact fingers are fastened, which make and break the circuit through the contactor coil. The contactor is then operated through a number of cycles, and the mean curve is drawn. In this test the required voltage must be held across the coil without resistance in series, on account of the inductance of the circuit.

Heat Runs

This test is very similar to the heat runs made on other apparatus and consists in measuring the temperature of the coil or other part at frequent intervals, both by thermometer and resistance. It should be noted that, as the operating coils are well wrapped with twine or other binding, thermometers placed on the outside of the coils do not give a fair indication of the temperature of the interior of the coil. For this reason the temperature must be calculated from the rise of resistance. To get these readings as accurate as possible, care should be taken in measuring the cold resistance. All heat runs on coils should be made with coils assembled in the contactor frame, unless otherwise specified. All heat runs should be made holding the voltage constant.

Life Tests

Life tests on contactors are made generally to determine the effect of service on the wearing qualities of the various parts.

Before starting the test, the diameter of the hinge pins and hinge pin bearings, the maximum air gap, finger pressure, and all other parts of the contactor that will be affected by service, should be carefully measured. During the test a daily record should be kept of the number of operations, and of the operating failures of any of the parts. At the completion of the test, the parts measured at the beginning must be again measured to determine the amount of wear.

FUSE BOXES

Commercial Tests

Fuse boxes are made of fiber or compound, and are fitted with terminal blocks, in which ribbon fuses may be readily placed.

The principal test is high potential, for the value of which see Engineering Briefs.

Fuse Boxes with Magnetic Blowout

After the high potential test, a small fuse is placed across the terminal of these boxes. A current is then passed of sufficient capacity, and at sufficient voltage, to blow the fuse immediately. This is done to determine the direction of the blowout.

FUSES

The test sheet should contain the catalogue number, ampere rating and dimensions of the fuse, also the style of box or holder in which the tests were made.

Before starting the test, carefully inspect the fuses for defects, such as sharp bends, dents, burred holes, etc., discarding those that are not perfect, unless the test is being made to get an average curve on fuses from stock.

Test to Determine Rating

Connect a switch to the fuse box or holder, using a short-circuiting switch in multiple with both. If run off the shop circuit connect a water box in series. If run from the "booster," the current can be controlled from the booster field with a low resistance grid in series with the booster armature.

With the series switch open, and the short-circuiting switch closed, adjust the current to the desired value, and hold as near constant as possible. Then close the series switch quickly and open the short-circuiting switch, and note the time by a stop watch it takes before the fuse blows. Fuses are rated at one-half the current at which they blow in thirty seconds.

When a number of fuses are blown, the holder is likely to get very hot unless care is taken to cool it between tests. Thermometers should generally be placed on the fuse holder and the temperature kept below 75 deg. cent.

Time-Current Curve

To obtain time-current curves, fuses should be blown at current values which will blow the ribbons at periods varying from ten seconds to three minutes.

COUPLERS

In train-control work, couplers are used to make temporary connections for the bus line, and control circuits between the cars of a train. Two parts are included in the complete coupling; the socket coupler, Type DA, and plug coupler, Type DC, which fits into the socket coupler.

The contact terminals should be well fastened in the compound base, and the cover on the DA coupler should be held firmly closed by the spring.

Couplers without cables are simply given a high-potential test, from the frame to each terminal, and between each terminal and the adjacent terminal.

Sockets are placed at the ends of the car and cables run from them to the connection boxes in the car. When the socket is assembled with a cable, it is given the usual high potential test, and then each terminal is rung out with a lamp circuit to see that it is connected to the proper cable wire.

CONTACTOR BOXES

In the Type M or C control, instead of breaking the motor circuits in the controller, as is done in the K control, the controller operates a set of contactors assembled in a contactor box, which open and close the motor circuits. One contactor box is placed on each car, and the control circuits, besides being brought to the controllers of the car, are taken to couplers at either end of the car, from whence they can be connected by jumpers to other cars, and operated in multiple with them. The whole train is thus controlled from one controller. This control is manufactured either automatic or non-automatic.

In non-automatic equipments, the motorman has full control of the acceleration of the car. In the automatic equipments, however, he does not control the resistance (acceleration) points. The automatic feature can readily be connected. One end of the cable is left open which can be afterwards connected to the connection boxes. The different wires are designated by various colors. For the colors and numbers corresponding see the DS diagram.

Inspection

Each interlock should be carefully inspected to see that the rod is properly stamped, and that the disks agree with the Engineering Brief in regard to wipe and break.

The terminal board and the terminals on all wires should be clearly and properly stamped and all wiring neatly done. The interlock rods should clear the back frame of the box by at least ¼ in. The name plate on each contactor and on the contactor box itself should be checked.

Operation Test

Each contactor box is connected to a controller and reverser, and operated so as to test all the control circuits. The main or motor circuits are rung out according to the DS diagram.

The operating voltage for each set of equipments should be obtained from Engineering instructions. The contactors should pick up and fully wipe on the minimum voltage, in the order specified. See that the arc is promptly ruptured on the interlocks having magnetic blowouts.

Potential Relay

All automatic equipments having a potential relay should operate at a voltage higher than that at which the relay picks up.

JUMPERS

A jumper consists of two coupler plugs connected by a cable. It completes the circuits between cars.

After the high-potential test, jumpers are "rung out" to see that the correct connections exist between the plugs as called for on the Engineering Notice.

CIRCUIT BREAKERS

There are several types of railway circuit breakers, the DB and MR representing the present standard. Most of the forms are fitted with a brush contact, auxiliary to the breaking finger contact, the latter being protected from the arc when opening by the contact fingers, which always open last.

The MR circuit breaker is closed manually by throwing the handle to the "on" position and can be tripped by throwing the handle to the "off" position, which gives a quick break opening. It is also arranged to trip out automatically on overloads.

The DB circuit breakers are used for Type M control and are provided with solenoids for opening and closing. The coils are energized through a switch in the motorman's cab, the breakers themselves usually being under the car.

Inspection

All the cable terminal thimbles should be well fastened in the terminal blocks to prevent being lost in transportation. The arcing or secondary fingers should remain in contact when opening the circuit breaker, after the brush has opened contact by at least ¼ in. Both brushes and secondary fingers should make contact over their full width. All auxiliary switches on the circuit breaker should be examined to see that they make good contact at the proper time. The copper shunts should be free from kinks or sharp bends.

Calibration

Each circuit breaker is calibrated for three tripping points. It is first tested for low tripping point, then for high point and finally for the intermediate point. It is left at the latter point, and the check nut is then set. Marks must be made designating the relative position of the cap of the calibrating spring for the different currents.

Blow-Out Test

Each circuit breaker is given a blow-out test in order to determine the direction of the arc.

RELAYS

Railway relays can generally be classed under three heads: Current, potential and accelerating relays.

Current Relays

Current relays comprise all those which have their tripping coil in series with the circuit in which the current is to be controlled; the controlling circuits being wired through its disks or relays.

Potential Relays

Potential relays comprise all those having their operating coil shunt connected. These relays are used where a certain value of voltage is required for proper operation. Their function is either to cut out resistance in control circuits, thus permitting lower voltage operation, or to transfer, or change control circuits.

Accelerating Relays

Accelerating relays are used with automatic control, their function being automatically to advance control connections.

OPERATING TEST

The relay should be able to break the specified amount of current on the contact studs, and if provided with a blow-out the arc should blow in the proper direction.

The operating coil should operate the relay under the conditions specified in the Engineering instructions. The disks or arms should make good contact on the studs, and the wiring should be arranged in workmanlike fashion to prevent electrical or mechanical breakdowns in operation.

CHAPTER 23

PROJECTORS

Projectors are designed for operation from direct current circuits and it is necessary to provide motor-generator sets or mercury arc rectifiers where only alternating current supply is available.

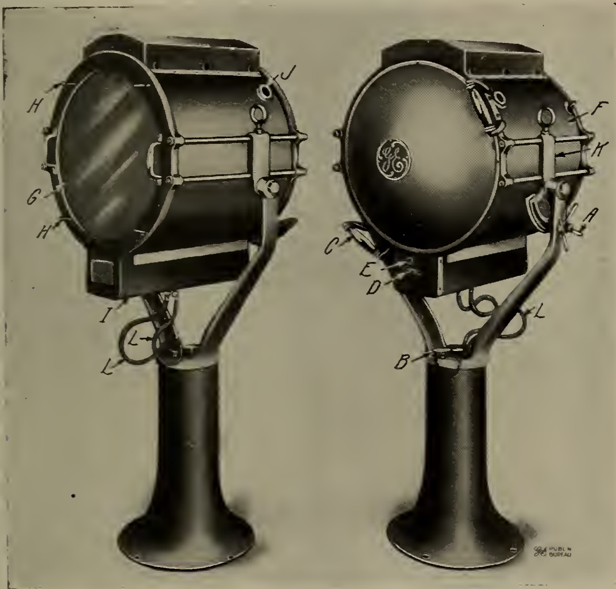

Fig. 162
HAND CONTROL PROJECTOR

The standard line of rheostats is designed with adjustments for line volts varying between 110 and 125 volts. When projectors are operated in series or when one projector is operated from a line of greater than 125 volts potential, it is necessary to provide automatic cutouts with resistances equal to the resistance of the arc under normal conditions and rheostat capacity sufficient to take up the difference between the sum of the arc voltages and the line voltage.

Inspection

All projectors are inspected before the final test to see that the drum is balanced, that no bolts, screws, nuts, or cotter pins are missing, and that the rating on the name plate is correct.

Types of Control

HAND—The hand control projector shown in Fig. 162 is controlled by handles on the rear of the drum and is provided with clamping devices for the horizontal and vertical planes.

Fig. 163
PILOT HOUSE CONTROL PROJECTOR

PILOT HOUSE—The pilot house control shown in Fig. 163 is operated from the inside of the pilot house by a controlling gear extending through the roof, the movement in both the horizontal and vertical planes being controlled by one handle.

ROPE CONTROL—The rope control projector shown in Fig. 164 is operated by means of cables connected to the controlling gear of the projector. As the movements in both the horizontal and vertical planes are controlled by a single handle the controlling gear may be placed in the pilot house, on the bridge, or at any other convenient place.

Electric Control—The electric control is of three types. First, the direct armature control in which the entire current for the motors is carried through the controller cable, the contacts in the controller being arranged to start, stop and reverse both the elevating and training motors, and so connected that the beam follows the movement of the controller handle. This control is employed in the 13 and 18 inch sizes.

Fig. 164
ROPE CONTROL PROJECTOR

Second, the rheostatic control in which the training and elevating motors are controlled from a distance through the controller cable, the controller being provided with resistances which give one or more speeds of training and elevating motors.

Third, the synchronous control in which only the current required by the pilot motors is carried through the controller cable, the controller operating the pilot motors which in turn control the elevating and training motors.

Adjustment

A great deal of testing and adjusting of the electric control is done during the construction of the operating mechanism. For the synchronous control projectors, the pilot motors are connected and tested for polarity in accordance with Fig. 165, after which they are returned to the assembler for final connection. The motor is then wired to a controller and if connected correctly the rotating field will take up 12 equidistant positions per revolution. After this test the pilot and training motors are assembled and wired, and thoroughly tested to insure the wiring being correct. When the projector is assembled the electric control is operated for some time to make sure that

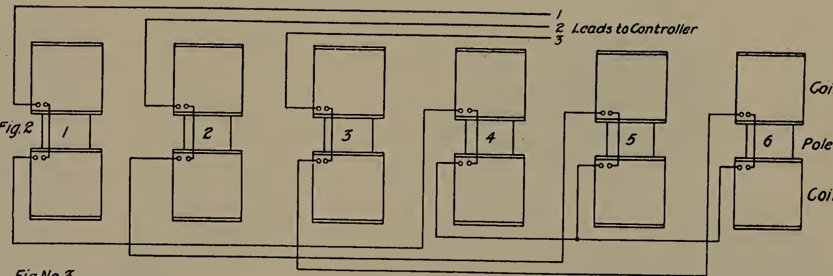

Fig. No. 3
Polarities and Position of Field for Pos. No. 1 Fig. 4

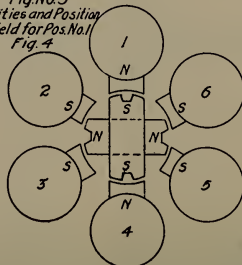

Fig. No. 1
Armature Coils No. 1

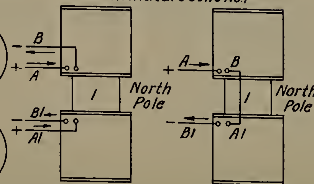

Fig. No. 1A   Fig. No. 1B

Test each Coil as indicated in Fig. No. 1A with compass. This gives North Armature pole with Current flowing as indicated by arrows. Connect Coils on each Pole as shown in Fig. No. 1B giving North Armature Pole with Current flowing as indicated.

Fig. 4

Position of Field	Polarity of Armature poles Nos.						Direction of Current through Leads Nos.		
	1	2	3	4	5	6	1	2	3
1	N	S	S	N	S	S	+	−	−
2	N	N	S	N	N	S	+	+	−
3	S	N	S	S	N	S	−	+	−
4	S	N	N	S	N	N	−	+	+
5	S	S	N	S	S	N	−	−	+
6	N	S	N	N	S	N	+	−	+
7	N	S	S	N	S	S	+	−	−
8	N	N	S	N	N	S	+	+	−
9	S	N	S	S	N	S	−	+	−
10	S	N	N	S	N	N	−	+	+
11	S	S	N	S	S	N	−	−	+
12	N	S	N	N	S	N	+	−	+

Fig. 165

CONNECTIONS OF PILOT MOTOR FOR TYPE EC PROJECTORS, FORM N the connections are correct and that there are no mechanical faults in the training and elevating mechanism. Lamps are wired, adjusted and operated at the proper current and arc voltage, care being taken that the gap at the circuit breaker in the feeding magnet circuit is of the proper length, also that the screws limiting the motion of the pawls are properly set after which the feeding magnet armature spring may be adjusted so that the lamp will operate at its rated arc voltage. At the end of this test the lock nuts should be tightened and a general inspection of the mechanism made to see that everything is properly secured.

With the lamp in position in the projector and in operation the position of the lamp should be adjusted by means of the

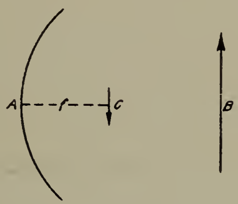

Fig. 166
MEASUREMENT OF FOCAL DISTANCE

focusing screw so that the beam will appear to be composed of parallel rays.

Mirrors

Referring to Fig. 166, the mirror *A* is held facing an object *B* approximately 100 feet from the mirror and a piece of ground glass or white card *C* is then moved backward and forward in the focus. When the focus is reached the image of the object is very distinct. The distance from the card to the center of the reflecting surface of the mirror is the focal length. Mirrors are tested for regularity of curvature and grinding by placing them in front of a large white screen on which horizontal black lines are drawn. The lens of the camera is placed back of the screen and through a hole in the center and the reflection of the right lines is photographed. Fig. 167 shows a mirror in which the curvature of the reflecting surface and the grinding is correct. Fig. 168 shows a mirror with irregularities in the reflecting surface which can be distinctly seen in the photographic test.

Rheostats

A rheostat or ballast is connected in series with the arc when it is operated from a constant potential circuit. The object of this resistance is to prevent fluctuations of the arc current.

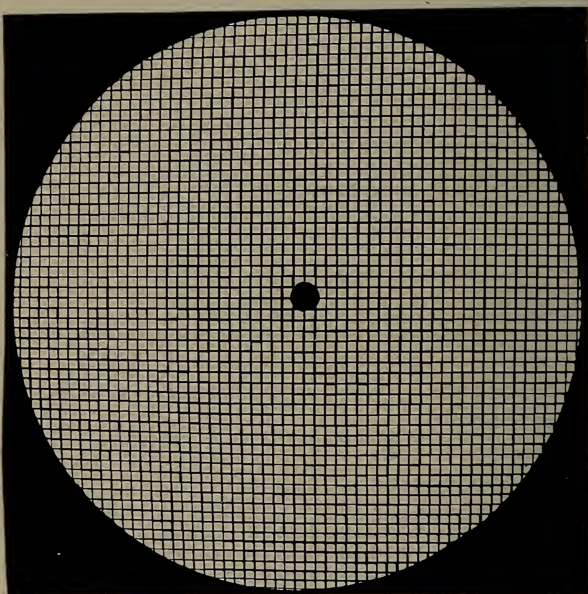

Fig. 167
SHOWING CORRECT CURVATURE OF MIRROR

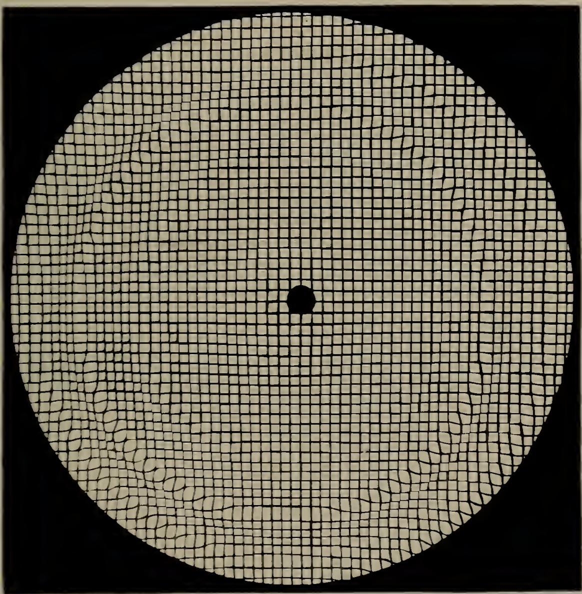

Fig. 168
SHOWING IRREGULARITIES IN CURVATURE

Carbons

One per cent of all projector carbons are tested. The points to be observed are as follows:

The kind of arc obtained, whether quiet or noisy, steady or wandering; the amount of refuse left in the lamp after the carbons have been consumed, and the amount which the carbons burn out of focus.

The table on page 381 gives the sizes of carbons, etc., for standard apparatus.

SIGNAL APPARATUS

Keyboards

Keyboards must be wired and every combination tried, care being taken to see that the proper lamps light and that the contact switch makes contact so that the lamps light simultaneously.

An insulation test is made at 500 volts. The cables are connected to the keyboard and every combination gone through to see that the connections are correct. The connections to the receptacles should be inspected to see that there are no loose ends of wire to short-circuit or ground the receptacle.

Trucklight Controllers

Trucklight controllers are wired and tested to see that the proper lamps light and that the pulsator works correctly.

Diving Lamps

Diving lamps are tested under water, as specified in the Government specifications for the apparatus, to see that leakage does not occur.

SIZES OF CARBONS FOR STANDARD PROJECTORS

Size	Ratings		Size of Carbons in Inches		Life in Hours
	Amperes	Arc Voltage	Positive	Negative	
9 in.	10	45	½ by 5½ cored	7/16 by 3½ solid	3½ to 4
13 in.	20	45	⅝ by 6 cored	½ by 4½ solid	3½ to 4
18 in.	35	45	13/16 by 8½ cored	⅝ by 5 solid	4 to 4½
24 in.	50	48	1 by 12 large core	¾ by 7 small core	5 to 6
30 in.	80	50	1⅛ by 12 large core	⅞ by 7 small core	5 to 6
36 in.	110	60	1¼ by 12 large core	1 by 7 small core	5½
60 in.	175	65	2 by 15 large core	1⅜ by 12 small core	5½

Instructions contained in the following chapter must be followed by all men while working in the Transformer Testing Department at Pittsfield.

CHAPTER 24

TRANSFORMER TESTS

CONSTANT POTENTIAL TRANSFORMERS

Tests

COMPLETE TESTS consist of commercial tests and of normal and overload heat runs.

COMMERCIAL TESTS consist of cold resistance, polarity, ratio and checking taps, impedance, core loss, exciting current and insulation tests. These are applied to all transformers, except for the resistance test which is often omitted on duplicate transformers of small capacity.

NORMAL LOAD HEAT RUN consists of operating the transformer at normal load until it shows constant temperature.

OVERLOAD HEAT RUN consists of operating the transformer until it has reached normal load temperature and then applying the required overload for the specified time.

EFFICIENCY is calculated from the core loss and the resistance at 25 deg. cent.

REGULATION is calculated from the impedance and the resistance at 25 deg. cent.

INSULATION TESTS are: (1) the high potential test, which consists of applying high voltage between windings and from windings to ground; (2) the induced voltage test, which consists of operating the transformer at considerably more than normal voltage for a short time.

Types of Transformers

For purposes of test, constant potential transformers may be conveniently divided into four classes, depending upon the method of cooling as follows:

Natural draft
Air blast
Oil immersed self cooled
Oil immersed water cooled.

Natural draft transformers have the core and coils exposed directly to the air, and depend entirely upon the natural circulation of the air for their cooling. They are built only in small sizes and low voltages, seldom over 25 kv-a. or 1000 volts.

Air blast transformers depend upon a forced circulation of air over the surface of core and coils to carry away the heat. They may be built for large capacities, but the voltage rarely exceeds 30,000 because of the difficulty of insulating them properly.

Self cooled oil immersed transformers have the core and coils immersed in a tank of oil. This tank is usually made of cast or sheet iron, and is quite often corrugated so as to increase the surface available for dissipating the heat generated in the core and coils. Sometimes external tubes or radiators through which the oil circulates are used for this same purpose.

Water cooled oil immersed transformers depend on the circulation of water through a coil of iron, brass or copper, placed in the top of the tank to carry away the heat from the oil. The tank, which is usually made of steel plate dissipates only a small portion of the heat. This type is used for the largest capacities and is suitable for any voltage.

The method of cooling affects principally the insulation test and the heat run, since oil immersed transformers depend on the oil for insulation, as well as for cooling. It is necessary that they be filled with oil of the proper quality when more than a small percentage of their normal voltage is applied to or induced in them. During the heat run, transformers must be filled with oil if they are of the oil immersed type, and must be subjected to the cooling conditions for which they are designed.

Order of Tests

The order of tests is to a great extent left to the discretion of the man making them. The cold resistance must be measured before the transformer has been heated up by any other tests, care being exercised to obtain the correct temperature of the windings. The heat run, high potential and induced voltage tests should be made last and in the order named, except that for transformers of 100 kv-a. or less the induced voltage may be placed before the high potential test.

Preparation for Tests

Information from the Engineering Department, regarding guarantees, rating, operating conditions, etc., is furnished to the testing department by means of test data cards, Engineering Notices, DS sketches, and specifications. On power transformers, which include all sizes of over 100 kv-a. the test records are prepared in advance by the calculators in the Testing Department so that it is not necessary for the man making the tests to refer to any instructions from the Engineering Department. The test record then shows the guarantees, the special requirements and sketches of windings. On standard lighting transformers full information is given on the test data card. On special transformers of small sizes the test data card is sometimes supplemented by an Engineering Notice and always by the DS sketch. Reference should be made to all these before starting the tests.

The transformers must be properly placed in position for test, especially if there is to be a heat run. Great care must be exercised to see that air blast transformers are properly supported above the pit, as otherwise they may fall and injure persons stationed under them. No opening should be left through which air can escape and influence the readings of the thermometers on the iron. Large transformers, especially those of self cooled types, should be so located as to allow free air circulation between units during the heat run. The distance between self cooled transformers of over 100 kv-a. capacity should be at least 2 ft. and if possible, a greater distance. Such transformers should always be placed not less than 12 in. from the walls of the testing pit. Idle units used in checking heat run temperatures should be located at least 4 ft. from the hot units or other sources of heat.

Cold Resistance

The cold resistance measurements are used for two purposes; first—for calculation of copper loss and consequently for efficiencies; and second—for the determination of the temperature rise of the windings.

The drop of potential method should be employed unless the rated current of the windings is less than 1 ampere, in which case the Wheatstone bridge may be used. The current used should not be more than 15 per cent of the rated current of the winding, as a larger value is liable to cause heating, making it impossible to obtain accurate values of the temperature of the windings. The voltmeter leads should be attached to the terminals of the transformer separately from the leads carrying the current, so as to avoid including the drop in voltage due to the temporary connections. In measuring cold resistance, a spot on which to hold the voltmeter leads should be cleaned with sandpaper.

Resistance of the full series winding should always be measured. In case the heat run is to be made on a tap or on a multiple connection the cold resistance of such connection should also be measured.

It is important that the temperature of the windings at the time the cold resistance is measured be determined accurately, especially where this resistance is to be used for the calculation of temperature rise. It is advisable therefore to take several readings of resistance and temperature at half hourly intervals, the thermometer being placed on or very near the coils.

The resistance of each winding at 25 deg cent. should be calculated and noted on the test sheet. The method of calculating the rise in temperature by increase of resistance is explained under the subject of heat runs on page 399.

Polarity

The polarity test gives the only means of readily determining the connections required for transformers in banks, for instance, several transformers in parallel. General Electric Company transformers always have the same polarity, except in some special cases where the customer requests that it be reversed. There are three methods of making the test, the most convenient one being used in each case.

(1) When a standard transformer of the same ratio as the one under test is available, the polarity and ratio tests may be combined.

The high voltage winding of the transformer under test should be connected in multiple with the high voltage winding of the standard transformer and the low voltage winding of the transformer under test should be connected in multiple with the low voltage winding of the standard transformer. One winding (usually the high voltage) should be excited while a voltmeter is placed between the two low voltage windings to indicate the difference in voltage. If there is no difference in voltage, the polarity and ratio are both correct. If there is a small difference the polarity is correct, but the ratio is not. If the difference in voltage is great the polarity is probably reversed. Further tests should be made to determine whether this is true.

(2) The polarity may be determined at the same time as the resistance by making use of direct current as follows:

With direct current passing through one winding, usually the high voltage, connect a high voltage voltmeter across the terminals so as to obtain a positive deflection. Then transfer the two voltmeter leads directly across the transformer, the lead from the right-hand high voltage being placed on the right-hand low voltage (facing the high voltage side), while the lead from the left-hand high voltage is placed on the left-hand low voltage terminal. Then break the current in the first winding, thus inducing momentarily a voltage in the other. If a positive kick of the voltmeter needle is produced the polarity is correct according to the standard General Electric Company practice. In case the polarity is indicated on the DS sketch by means of positive and negative signs, it should be checked in the manner explained above, except that the voltmeter lead resting on the high voltage terminal bearing a given sign (positive or negative) should be moved to the low voltage terminal bearing the same sign.

(3) If neither a standard transformer nor a source of direct current is available, the polarity may be determined by ratio as follows:

While facing the high voltage side connect the right-hand high voltage to the right-hand low voltage terminal. Excite the high voltage winding and read the voltage induced between the left-hand high voltage and the left-hand low voltage terminals. If this is greater than the voltage impressed on the high voltage winding the polarity is correct according to standard General Electric Company practice. In case the DS sketch indicates the polarity the test should be made in the same way, except that the positive high voltage terminal should be connected to the positive low voltage terminal and the voltage read between the two negatively marked terminals.

Determination of polarity on three-phase transformers requires much care. The accompanying diagrams allow a comparison to be made of the various standard connections.

Figs. 169 to 174 show standard connections for three-phase shell type transformers and Figs. 175 to 180 for three-phase core type transformers. It is understood that the leads are brought out as shown in these standard sketches, unless distinctly specified otherwise by the DS sketch or by special instructions. It is best to use direct current for such tests, each phase being checked separately.

In checking polarity of delta-delta, delta-Y, Y-Y or Y-delta connections, impress direct current from X to Y on the high

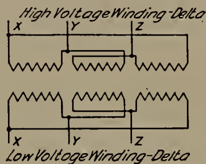

Fig. 169

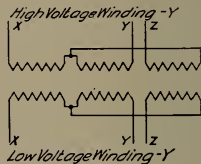

Fig. 170

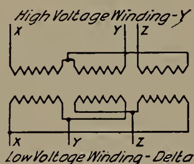

Fig. 171

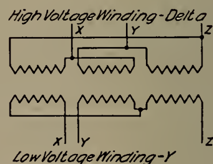

Fig. 172

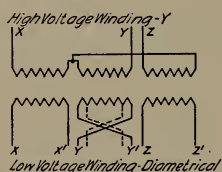

Fig. 173

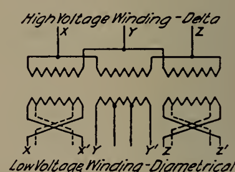

Fig. 174

Figs. 169 to 174

STANDARD THREE-PHASE CONNECTIONS, THREE-PHASE SHELL TYPE TRANSFORMER

NOTES.—In effect, high voltage and low voltage windings are wound in opposite directions.

Diagrams should be read facing low voltage side of transformer.

voltage, place the voltmeter across X to Y so as to obtain a positive deflection; then move the voltmeter lead on X high voltage over to X low voltage and the one on Y high voltage to Y low voltage. Break the circuit and note the deflection of the voltmeter. If it is positive the polarity is correct. The other two phases must then be checked in the same way.

In checking Y-diametrical connections (Figs. 173 and 179) excite X to Y for checking phase 1; also for phase 2. For phase

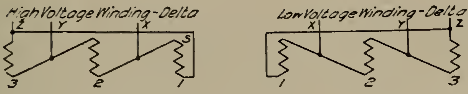

Fig. 175

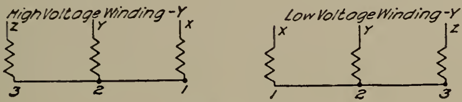

Fig. 176

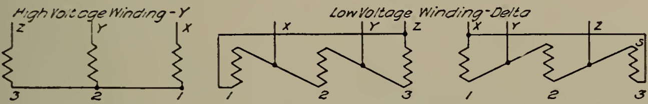

Fig. 177 Fig. 177a Fig. 177b

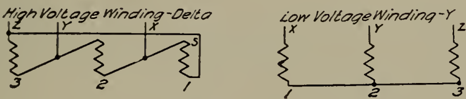

Fig. 178

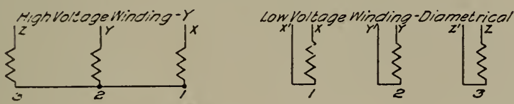

Fig. 179

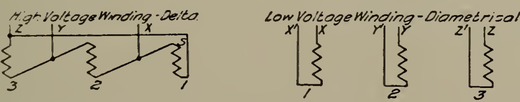

Fig. 180

Figs. 175 to 180

STANDARD THREE-PHASE CONNECTIONS, THREE-PHASE CORE TYPE TRANSFORMERS

Notes.—High voltage and low voltage winding wound in opposite directions.

Numbers 1, 2, 3 on diagrams refer to corresponding phases.

Fig. 177a is for transformers having high voltage winding 5300 volts or less.

Fig. 177b is for transformers having high voltage winding over 5300 volts.

1 transfer the lead from X high voltage to X low voltage and from Y high voltage to X' low voltage. For phase 2 transfer from Y high voltage to Y low voltage and from X high voltage to Y' low voltage. For phase 3 excite Z to X, then transfer from Z high voltage to Z low voltage and from X high voltage to Z' low voltage.

In shell type delta-diametrical (Fig. 174), proceed as follows: For the left-hand phase excite X to Y high voltage and transfer from Y high voltage to X low voltage, and from X high voltage to X' low voltage. For the middle phase excite X to Z and transfer from X high voltage to Y low voltage and from Z high voltage to Y' low voltage. For right-hand phase excite Y to Z, transfer from Z high voltage to Z low voltage and from Y to Z' low voltage.

For core type delta-diametrical (Fig. 180) proceed as follows: For phase 1, excite X to Z, transferring X high voltage to X low voltage and from Z high voltage to X' low voltage. For phase 2 excite X to Y, transfer from Y high voltage to Y low voltage and from X to Y' low voltage. For phase 3 excite Z to Y, transferring from Z high voltage to Z low voltage and from Y high voltage to Z' low voltage.

Phase Rotation

In addition to the polarity test it is necessary to check the phase rotation on all three-phase and six-phase transformers except on such as are run in parallel with one on which the test has already been made.

The phase rotation meter should be connected to the high voltage side of the transformer and a relatively small voltage applied. This voltage should be sufficient to cause rotation of the meter but should not exceed 550 volts. The direction of rotation should be noted. Then the leads from the meter should be transferred straight across the transformer to the low voltage terminals. The transformer should again be excited with voltage sufficient to cause the meter to rotate and the direction of rotation should be noted. When the direction is the same on the low voltage as on the high voltage side, the result should be marked on the test sheet as "Standard." When it is opposite on the two sides, attention should be called to that fact on the test sheet.

Six-phase transformers having double delta connections must have the rotation checked on each delta.

Transformers having diametrical connection with the middle points of each phase brought out should have these points joined after which phase rotation should be checked by selecting terminals which will give two Y-connections. In addition to the test with the meter these transformers should have the neutrals connected together while the six voltages are read between each pair of consecutively numbered leads. These should all be of equal value and also should be equal to the voltage from any one of them to the neutral point. When the neutral points are not brought out a temporary delta connection should be made for the phase rotation test.

Ratio

The ratio of a transformer is the ratio of voltage of the high voltage winding to the low voltage winding. The required voltages are given in the rating and are shown on the DS sketch. The ratio should be measured on at least one of each group of similar transformers and compared with the ratio shown by the DS sketch. The ratio of all other transformers in the group should be checked by running each in parallel with the one on which the ratio has been measured.

The transformer should be operated at normal frequency or higher and at normal voltage or lower during the ratio test. An exception to this rule is made for transformers having capacities of 500 watts or less and with exciting current of more than 10 per cent. These should be tested at normal voltage and frequency.

Where possible, it is best to make a ratio test by comparing the transformer with a standard of exactly the same ratio. The two should be connected in parallel on both sides and the high voltage winding excited while a voltmeter is used to read the difference in voltage between the two low voltage windings.

When the above method is not applicable, two voltmeters should be used, one to read the low and the other to read the high voltage, the latter being stepped down through a potential transformer when necessary. Where voltages and scales will permit, the instruments should be interchanged between readings so as to eliminate errors. It is best to take at least two sets of readings, calculating the ratio from each and considering the average as the correct value.

The parallel run should be made at normal frequency and normal voltage, the voltage being applied usually to the low voltage winding. A test for circulating current between the two high voltage windings should be made by closing and opening the circuit. If a spark is observed a further test should be made by measuring the amperes circulating through the high tension winding and by measuring the difference in voltage on open circuit. If no spark appears on the first test, it is best to make sure of the presence of voltage in the winding by touching the free high voltage terminal to the case (at reduced voltage). If the circulating current is more than 5 per cent of the rated current of the winding, attention should be called to the fact on the test sheet.

On three-phase transformers it is preferable to use single-phase power and to measure the ratio of each phase separately. This is not possible when the neutral point of a Y-connection is not brought out. In such cases three-phase power must be used.

On Y-diametrical transformers where the neutral point is not brought out, three-phase excitation must be used. Any inequality in the magnetizing characteristics of the three phases will result in distortion of the neutral, thereby causing unequal phase voltages. When such an inequality is found the diametric connection should be changed to a Y-connection and the phase voltages measured. If these are equal and of the proper value, i.e., $\sqrt{3}$ times the diametric voltage, the ratio may be considered as being correct. If the voltages are still unbalanced, however, the transformer should be returned to the Assembly Department so that the neutral point can be brought out. It should then be tested single-phase and if the phase ratios are correct the transformer may be passed. The Y-connection may be made from the diametrical by referring to the standard connection diagrams previously referred to under polarity test.

A variation of more than ½ of 1 per cent above or below the value shown on the DS sketch or connection label on standard lighting transformers should be called to the attention of the Engineering Department. On other transformers the allowable variation is 1 per cent.

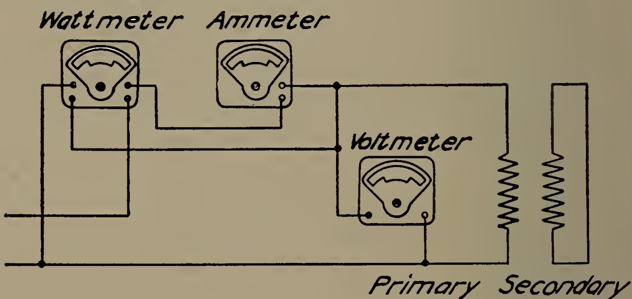

Fig. 181

CONNECTIONS FOR IMPEDANCE TEST

Checking Taps

Nearly all transformers are provided with taps in one or both windings, so that a slight change in ratio or a low voltage for starting may be obtained. These tap voltages should be checked to determine whether they agree in voltage and in position with the DS sketch. This test may be made either by means of the "two voltmeter method" or by running the transformer in parallel with a standard transformer or with one on which the test has already been made. When two voltmeters are used, it is best to apply a low voltage to the full winding, then read the voltage from the terminals to the first tap, then between successive taps of the same winding. Care should be taken in handling the voltmeter connected to the tap, because, although the voltage reading is low, the circuit to which it is connected may be several thousand volts above ground. If the opposite end of the circuit be grounded a severe shock may be obtained from the meter.

On windings having low voltage taps at the ends it is sometimes necessary to check their location by checking the polarity of each section of the winding. If the polarity of each is correct the taps are properly brought out.

Impedance

The impedance of a transformer is measured by short-circuiting one of the windings and impressing an alternating e.m.f. on the other windings and taking simultaneous readings of amperes, volts, watts, and frequency. The impedance of transformers should be carefully measured for the following reasons: Transformers operating in multiple divide the load inversely as their impedance voltages; i.e., the one having the higher impedance will take the smaller part of the load and vice versa. When transformers of different types are operated in multiple, the impedance of one transformer must sometimes be increased by putting a reactive coil in the secondary circuit, and adjusting until the desired impedance is obtained.

Impedance tests show whether a given arrangement of coils is satisfactory or not. If the arrangement is not satisfactory, excessive magnetic leakage will take place and high impedance voltage result. The impedance watts will also be high, due to excessive eddy current loss in the copper. Since regulation depends upon impedance to a great extent, a low impedance is very necessary for close regulation.

The impedance voltage of lighting transformers varies from about 1 to 4 per cent while that of power transformers is usually from about 4 to 8 per cent. Transformers for operating synchronous converters are often provided with magnetic shunts in order to obtain high impedance, that is from 12 to 20 per cent. The impedance watts do not as a rule exceed 1 to 1½ per cent of the total capacity of the transformer, although they are higher than the calculated I^2R on account of the eddy current losses in the copper.

The following method should be used in making the test: Place a thermometer on or very near the coil so as to obtain the exact temperature. Make a good short-circuit on one winding, using as short a cable as possible and one of ample cross section so that no appreciable losses will occur. Make the connections shown in Fig. 181. Adjust the current with the pressure circuits of the voltmeter and wattmeter open, then close the pressure circuits and take the reading of volts and watts. See Fig. 181. The watts should be corrected for the losses in the voltmeter, wattmeter and instrument transformers (if any are used).

In measuring the impedance of three-phase transformers, the two wattmeter method should be used, a single set of instruments being transferred from one phase to the other by switches. The current should be adjusted so that the average value in the three lines is equal to the normal rated current.

If the measured impedance watts exceed the calculated I^2R watts by more than 15 per cent, attention should be called to that fact on the test sheet.

Core Loss and Exciting Current

When the transformer is connected to a source of alternating e.m.f. a loss of energy takes place in the iron due to the cyclic reversals of the magnetic flux. This loss of energy is known as core loss. Its value depends on the wave form of the impressed voltage as well as upon the value of that voltage. A peaked wave gives lower losses and a flat wave gives higher losses than a true sine wave. The core loss energy should therefore preferably be taken from a sine wave alternator operated at about its normal excitation.

The core loss test is similar to the impedance test except that the voltage is applied to one winding, all others being open-circuited. It is usually preferable to apply voltage to the low voltage winding so as to avoid reading meters in high potential circuits. Care should be taken to see that the high tension cables are located so that no one can come in contact with them

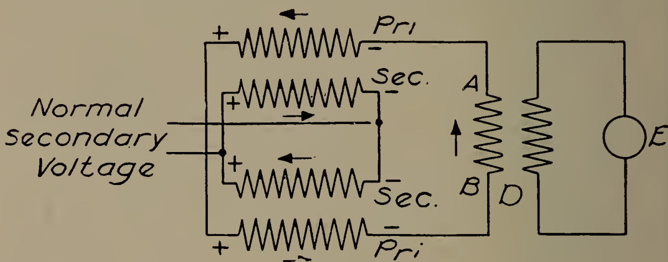

Fig. 182

CONNECTIONS FOR HEAT RUN

and so that there is no danger of a short-circuit. During the test it is best to have the windings connected according to some one of the connections shown on the DS sketch. It is particularly necessary to avoid leaving windings open at points where they would not be left open under operating conditions as it is sometimes possible to obtain excessive stresses between points of the same winding by leaving such connections open.

The connection of instruments in measuring core loss should be the same as in the impedance test and the reading should be taken in the same way. In measuring the loss of three-phase transformers it is advisable to take three entirely separate sets of readings by the two wattmeter method, each of the three lines being used in succession as the neutral. The average value of the three sets of readings should be recorded as the true core loss.

As alternators with perfect sine waves are very difficult to obtain, it is customary to correct the measured loss to a sine wave basis, by means of the core loss correction outfit. This outfit consists of a single winding on a small core, the sine wave loss of which has been carefully determined over a wide range of voltage. The outfit should be connected to the same source of power as the transformer under test, after which normal voltage should be applied to the latter. The loss in the standard core and the voltage across its terminals should be measured at the same time as that of the transformer under test. The sine wave loss of the standard core at the same voltage should then be determined from the calibration curve. The ratio of the measured loss of the standard core to the reading taken from the calibration curve should be used to reduce the measured loss of the transformer under test to a sine wave basis.

The exciting current may be corrected for wave shape by carrying the test a little further. After the core loss correction has been determined, the voltage should be raised until the measured loss is equal to the corrected loss. The exciting current read at this voltage is approximately the true sine wave value.

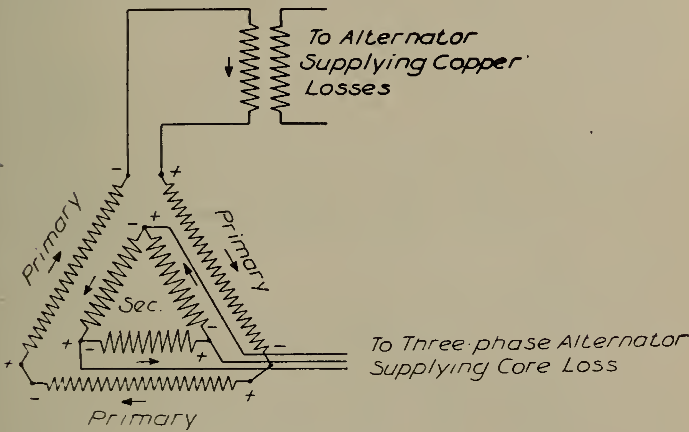

Fig. 183

CONNECTIONS FOR HEAT RUN

Heat Run

The heat test may be conducted in several ways, all of which are intended to approximate as nearly as possible the actual operating conditions. The run with actual load may be made by using lamps, water rheostats or choke coils, but as this is very expensive except for small devices, some form of motor-generator method is usually employed.

Fig. 182 shows the connections for testing two transformers by the motor-generator method. The secondaries of the two are connected in multiple and are then connected to an alternator which supplies the core loss and exciting current. The primaries are connected in series and opposing each other. If the transformers have the same ratio, the voltage from *A* to *B* will be zero.

The secondary of an auxiliary transformer *D* is connected in series with the primaries and an alternator *E* is used to supply the copper losses through this transformer D. The same method may be used for any even number of transformers, but it is not advisable to connect more than two high voltage units in this way, or more than six or eight units of any voltage. The arrows show the direction of the load currents.

Fig. 183 shows the connections for a heat run on three single-phase transformers. This method may also be used for one three-phase transformer when the windings can be connected in delta on each side. The three-phase alternator is used to

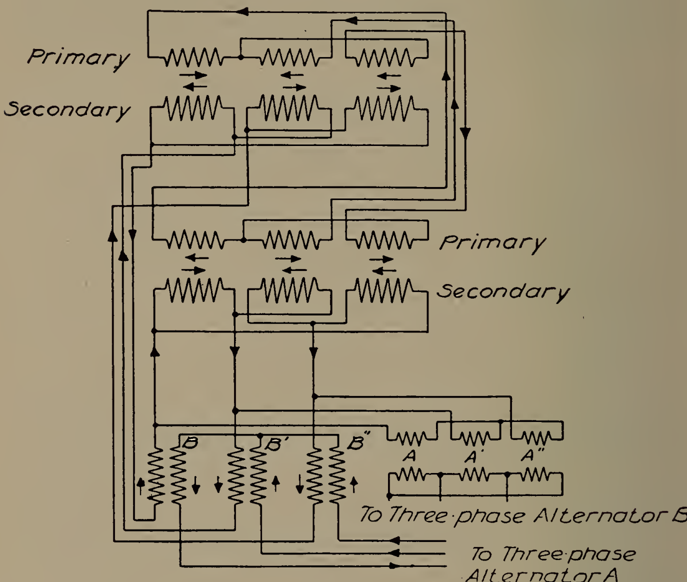

Fig. 184

CONNECTIONS FOR HEAT RUN, THREE-PHASE

supply the core loss and exciting current. One of the deltas is opened and sufficient single-phase voltage is impressed to cause full load current to flow. The current circulates within the deltas and is entirely independent of the three-phase voltage impressed by the core loss alternator.

Fig. 184 shows the connections for a heat run on two three-phase transformers in which three-phase current is used to supply the copper losses and three-phase voltage for the core loss. The auxiliary transformers A, A', A'' may or may not be used depending on whether the voltage of the alternator B supplying the core loss is of the proper value or not. Auxiliary transformers, B, B' and B'' are used as series transformers to supply the impedance voltage.

Fig. 185 shows connections for the heat run on two interchangeable single-phase units designed for operation on "T" connected two-phase–three-phase circuits. It is the common practice to make such units interchangeable, each having the 50 per cent and 86.6 per cent taps so that either may be used as the main or the teaser. In actual operation the one used as the main has a somewhat heavier load than the teaser. However, since either may be used as a main, the heat run should be made with the heavier load. The connections shown in Fig. 182 should not be used as with such a connection and with normal current in the winding for use on the two-phase circuit, the current in the three-phase side will be only 86.6 per cent of that

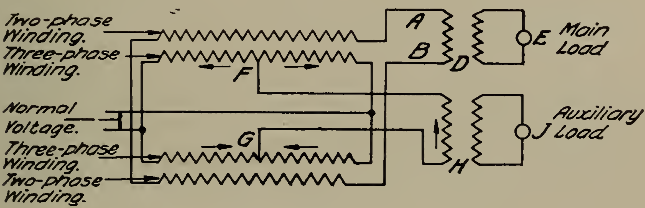

Fig. 185
CONNECTIONS FOR HEAT RUN ON SINGLE-PHASE UNITS FOR OPERATION ON T-CONNECTED TWO-PHASE-THREE-PHASE CIRCUITS

flowing under operating conditions. It is necessary to use connections shown in Fig. 185. The core loss is supplied in the regular manner and the normal current of the two-phase winding is supplied from alternator E through transformer D. An additional current is supplied from alternator J through transformer H to the middle points F and G of the two three-phase windings. Since F and G are the middle points, no voltage is induced between them by the core loss alternator, and furthermore, the current supplied by alternator J flowing in opposite directions in the two halves has no resultant effect upon the two-phase windings. The current from alternator J must be of such value as to produce a resultant current in the three-phase winding 15.5 per cent greater than that produced by alternator E alone. The frequency of alternator J must be different from that of alternator E so that the effect of the two currents in the three-phase winding will be equivalent to that obtained by adding them in quadrature.

The methods described above are the ones most commonly used, but it is often necessary to modify them so as to fit special conditions.

It will be noted that no provision has been made for making a heat run on a single transformer, except for such three-phase units as can be connected delta on each side. As a rule such units cannot be given a normal load run without the use of actual load. However, there are other methods which may be used in special cases. Sometimes, it is possible to use a set consisting of two alternators on the same shaft, the transformer being connected between the two and the load current being adjusted by varying the alternator fields. Another method is applicable in case each winding is divided into two equal parts. The run may then be made by paralleling each winding separately and supplying core loss to one side and forcing the load current through each winding separately. In addition to the above, there are some compromise runs which approximate the load condition. One method of making a compromise run is by supplying double the normal core loss over a short period and then supplying double copper loss for an equal length of time, this cycle of operation being repeated until constant temperature conditions are reached.

In connecting the transformers under test for the heat run, it is best to use the series connection of each winding, as this connection is preferable for resistance measurements. Care should be taken to see that the alternators and auxiliary transformers are of sufficient capacity to carry the normal load and the overload. In calculating the current necessary to supply the core losses, take the sum of the exciting currents of the transformers. To calculate the voltage required to supply the load current add together the impedance voltages of the transformers. Shop transformers should always be interposed between the loading alternator and the transformers under test, so as to avoid having high potentials on the switchboard and prevent breaking down the insulation of the alternator.

Thermometers should be placed on air blast transformers, so as to obtain the temperatures of the air at intake of blower, air from primary coils, air from secondary coils, air from core at top and bottom and temperature of core at top and bottom. In placing thermometers on three-phase units, each phase should have as many thermometers as are ordinarily used on a single-phase transformer. On water cooled transformers, the temperature of the ingoing water, outgoing water, top oil, top of tank near oil level and bottom of tank should be determined. On self cooled oil immersed units, the temperature of top oil, top of tank near oil level and bottom of tank should be determined. It is best to avoid changing the position of thermometers when taking readings. At the end of the run, especially in the case of air blast transformers, the thermometers on the core and coils should be carefully watched until the temperatures begin to fall. The maximum values should be recorded.

When three or more transformers are available for the heat run, it is advisable to use one of them as a base for determining temperature rise. The resistance and temperature of this transformer should be carefully measured in comparison with that of the other units before the heat run is started. During the run, it should be screened from the heat given out by the other units but should be subjected to the same cooling medium. That is, if it is an air blast unit, air should be forced through it; if a water cooled unit, water should be forced through its cooling coil; and if a self cooled type, it should be subjected to the same surrounding air conditions as the ones on the heat test. During the run, its temperature should be noted at the same time as that of the hot units, these values being used as base or reference temperatures. At the end of the run, the resistance of the hot and the "idle" units should be measured. The temperature rise is calculated from these final readings, a correction being made for any difference in the two initial resistances by multiplying the final resistance of the idle unit by the ratio of the initial resistance of the loaded unit to the idle unit. If an "idle" unit is not available, the reference temperatures should be as follows: On air blast transformers it should be the ingoing air; on water cooled units, the ingoing water temperature should be used, and on self cooled transformers, the surrounding air temperature should be considered as the base.

It is customary to overload self cooled transformers at the start of the heat run, so as to bring them up to operating temperature quickly. Air blast transformers are usually brought up to temperature on normal load, but without the use of the cooling agent. Water cooled units may be brought up on normal load, or slight overload without having water passing through the coils.

As soon as approximately normal operating temperatures have been reached, the load is reduced to normal and the water started on the water cooled units or the air on the air blast. On water cooled transformers, the temperature of ingoing water should be adjusted to be approximately the same value as the room temperature at the start of the run. This value, when once decided upon should, however, be held throughout the run. The quantity of water should be adjusted so as to give a rise of exactly 10 deg. cent. in passing through the transformers. On air blast transformers, the air should be adjusted to the required pressure and both dampers should be left wide open. The quantity of air should be measured at the start of the run, and the quantity of water each hour during the run.

The heat run should be continued until the rise of temperature is constant within one degree in three hours, this rise being determined by means of thermometers. The load should then be removed and resistances of hot and "idle" units measured. If the results do not seem to be consistent, the load should be replaced and the run continued until rises are again constant, after which a second set of resistance readings should be taken.

The rise by resistance is calculated as follows:

$$t_H = \frac{R_H - R_O}{0.0042\ R_O}$$

where R_H = hot resistance.

R_O = resistance at 0° cent.

t_H = hot temperature of winding.

The following variation of the formula is found to be serviceable for slide rule calculations:

$$\frac{R_H}{R_C}=\frac{238+t_H}{238+t_C}$$

where R_C = the cold resistance of the winding.

t_C = temperature corresponding to this cold resistance.

During the heat run the temperature of the hottest part of a transformer should not be allowed to exceed 100 deg. cent. unless specific instructions to the contrary have been received from the Engineering Department. Where terminals carrying more than 1000 amperes are used, the temperature of each should be measured at the end of the heat run.

High Potential

The application of a high potential to the insulation of a transformer is the *only* method of determining whether the dielectric strength is sufficient for continuous operation. Mechanical examination amounts to little and measurement of insulation resistance is equally valueless, since insulation may show high resistance when measured by voltmeter with low voltage, but offer comparatively little resistance to the passage of high tension current. The voltage of the insulation test depends upon the voltage for which the windings are designed, and upon the conditions under which the transformer is to operate. This voltage is always specified on the Standing Instructions or test data card. As a general rule, the voltage is double the operating voltage of the winding with a minimum test voltage of 10,000 for the high voltage and 4000 for the low voltage winding. The duration of the tests is always one minute, unless otherwise specified.

In testing from the high voltage winding to core or to low voltage winding, the low voltage winding should always be grounded to the core for the following reasons: In testing between one winding and the core, a potential stress is induced between the core and the other winding, which may be much greater than the stress to which the insulation is subjected under normal operation and greater, therefore, than it is designed to withstand. In testing between the high voltage winding and the core the induced potential between the low voltage winding and core may be several thousand volts, and the low voltage winding may thus be broken down by an insulation test applied to the high voltage winding under conditions which would not exist in normal operation. During the test all leads on the same winding must be connected together. If only one terminal of a winding is connected to the testing transformer, the strain may vary throughout the winding and at some point may even be greater than at the terminal at which the voltage is applied.

The charging current of a transformer varies with its size and design. This current may be measured by means of an ammeter placed in the low voltage circuit of the testing transformer. It will increase as the voltage applied to the insulation is increased. Inability to obtain the desired potential across the insulation may be due to large electrostatic capacity, or to the inability of the testing transformer to supply large capacity current at the voltage desired.

In making the insulation test, it is essential that the voltage be brought up gradually.

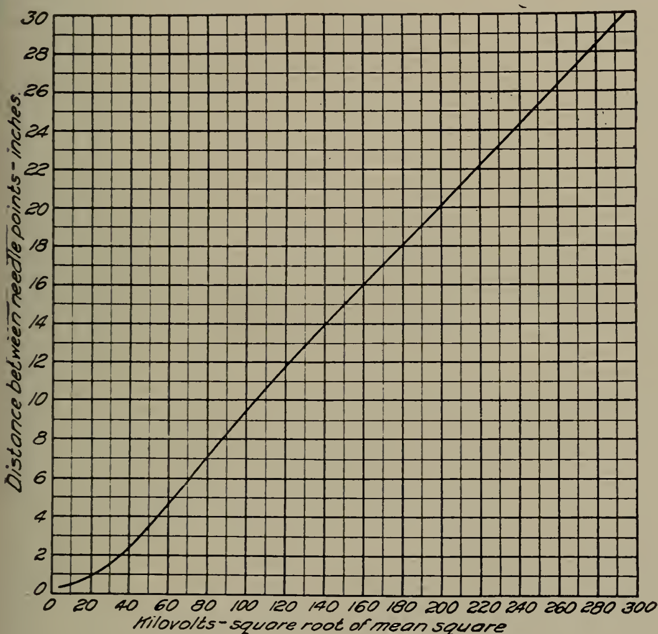

Fig. 186

SPARK GAP CURVE

The usual ways of controlling the voltage are as follows:

1st. By means of a resistance in series with the low voltage side of the testing transformer. Another resistance of such magnitude as to allow a flow of current at least five times the exciting current should be connected in multiple with the low voltage side, so as to maintain a smooth wave shape under all conditions.

2nd. By means of an induction regulator on the low voltage side of the testing transformer.

3rd. By variation of the strength of the generator field.

The first method is not well suited to very high potential tests on account of the large amount of resistance required. The second and third methods are, however, suitable for any voltage.

In applying the test voltage, it should be started at less than one quarter of the final value, should then be brought up during 30 seconds to the full value and after having been held the specified length of time should be reduced during about 15 seconds to less than one-quarter of its maximum value, after which the circuit may be opened.

The spark gap should be as near as possible to the transformer under test and on tests of more than 15,000 volts it should never be more than 20 feet away. Resistances should always be placed in series with this gap, but never between the testing transformer and the one under test. The value of the resistances placed in series with the gap should be such as to limit the current from ¼ to 2 amperes in case of a discharge across the gap. This will require from 4 ohms to ½ ohm per volt.

For tests of 10,000 volts or less, it is usually the practice to depend upon the ratio of the testing transformer in determining the voltage that is to measure the voltage on the low voltage side, a spark gap being placed across to the high voltage side and being set at 10 per cent above the required voltage as a safety valve. For tests from about 10,000 to 50,000 volts, the gap should be set in accordance with the curve of arcing distance shown. (See Fig. 186.) The voltage should be raised slowly until the gap breaks, at which time the voltmeter reading should be noted. The voltage should then be reduced to zero, and the spark gap setting increased to 10 per cent above its former value. The voltage should then be brought up until the voltmeter reads the same value, this voltage being held for the specified length of time. For tests above 50,000 volts, it is not advisable to cause the spark gap to break with the full voltage on the transformer under test. For such tests, therefore, the gap is first set for the desired voltage, while the transformer under test is entirely disconnected. The gap is then broken and the voltmeter reading noted. Then the gap is set for ¾ of the required voltage and the voltmeter reading obtained for the breaking of this gap. The transformer under test is then connected and the gap broken at the setting for ¾ voltage. The voltmeter reading obtained with this last setting is then multiplied by the ratio of the readings for full and for ¾ voltage with the transformer disconnected and this calculated voltage is held by voltmeter for the actual test, the spark gap being set at 15 per cent above this voltage during the test.

The presence of moisture in the coils and insulation lowers the dielectric strength to such an extent that it is general practice to dry carefully all high voltage transformers before they are filled with oil. The drying-out run should ordinarily be made on all transformers having test voltages above 100,000 volts, and upon any transformer having test above 15,000 volts if it has been standing in the factory for more than two or three weeks before test. The drying is ordinarily done by forcing a blast of air at about 80 deg. cent. through the transformer and this continued until the insulation resistance measured by the megger shows practically constant values.

Transformers having high potential test voltages above 13,200 volts are filled with oil for the test. Care should be taken to see that the oil itself is of sufficient dielectric strength. No oil having strength of less than 20,000 volts between half inch disks 0.2 in. apart, should be used during the high potential tests. When the test voltage is higher, the strength of the oil should be correspondingly greater. For tests above 100,000 volts, the oil should show a dielectric strength of at least 40,000 volts.

As the high potential test is made after the heat run, the oil has had an opportunity to free itself from air bubbles and to penetrate to every part of the transformer. In some cases, however, especially when the oil does not meet the requirements of dielectric strength, it is necessary to replace it before the high potential test. In such cases the transformer should be allowed to stand for some time before the test is applied. This period should be at least one hour for voltages of 50,000 and less, and at least 6 hours when the voltage is above 50,000.

Induced Voltage

Induced voltage is applied to transformers in order to test the insulation between turns and between sections of the windings. The usual value of this test is twice normal voltage induced for a period of one minute, followed by one and one-half times normal voltage for five minutes. Low voltage transformers (5000 volts or less), usually have three times normal voltage applied for one minute.

The source of power should have an approximate sine wave and a frequency such that the exciting current will not exceed 150 per cent of the rated load current of the excited winding. It is common practice to use a frequency of 200 cycles for 25 and 60 cycle transformers. The voltage may be controlled by any of the methods described for the high potential test. The voltage should be started at less than ¼ of the final value and should be brought up gradually to its full value. It should then be held for the specified length of time, after which it should be reduced slowly to less than ¼ of the full value before the circuit is opened.

During this test, windings designed for a voltage of over 1000 volts must be so arranged that all portions are connected together using one of the connections shown on the DS sketch. This precaution is necessary as otherwise excessive stresses might be induced between parts of the windings, which under normal operation would be subjected only to small voltages.

If the winding has a rated voltage of more than 20,000 volts, it is best to use the full series connection during this test. Three-phase transformers designed for Y-connection having voltage over 20,000 should ordinarily be connected for the highest Y-voltage during this test, although exception is made in the case of three-phase shell types for operation on Y-Y or Y-diametrical systems.

Failures in Test

When transformers fail between turns, between coils, between windings or from windings to other parts in such a manner that it becomes necessary to dismantle them, careful examination and tests should be made to determine whether failures in other parts have also occurred.

Transformers failing under high potential should be given an induced voltage test before they are dismantled. This test should be made in the manner specified for the regular induced voltage test.

Three-phase transformers failing in one phase should be given the full high potential test on the other two phases, one at a time, both windings of the two phases not under test being grounded. If the transformer is of shell type construction, induced voltage tests should also be made on each phase separately (whether or not they fail on high potential), with both of the other phases short-circuited.

Three-phase shell type transformers failing between turns or between coils so that dismantling is necessary, should have the broken phase short-circuited on both high and low voltage windings, after which further induced voltage tests should be made on the other two phases. Single-phase voltage should be impressed on each phase separately while the other phase is short-circuited.

Calculation of Efficiency

The efficiency of a transformer is the ratio of its net power output to its gross power input, the output being at non-inductive load. The efficiency is to be based on the maximum voltage and kv-a. rating, unless otherwise specified. It may be determined by either of two methods:

1. By the input-output method, or
2. By the loss method.

The first method which requires the measurement of the input and output on normal load is not accurate on account of the small difference between the input and output, and is very seldom practicable because of the difficulty of obtaining full load. The loss method is, therefore, used exclusively for commercial work.

The input includes the output together with the losses which are as follows:

1. The core loss which is determined by the core loss test.
2. The I^2R loss of the windings calculated from their resistances.

The core loss may be measured either on the high voltage winding or on the low voltage winding. Rated voltage and frequency should be used. If the generator does not have a sine wave, the loss should be corrected by means of the core loss correction outfit. The measurement of loss should be made at or near normal room temperature. The I^2R loss should be calculated from the measured resistance reduced to a room temperature of 25 deg. cent. unless otherwise specified. The rated current of each winding should be squared and multiplied by the resistance of that winding, the sum of these losses being added together to obtain the total I^2R loss. See Calculation Sheets 29 and 30.

The rated kv-a. of a transformer is to be considered the output and the losses are to be added to this value in order to obtain the input.

For auto-transformers the core loss should be measured in the same way as on a transformer, and the I^2R loss of each section of the winding should be calculated from the rated current and resistance at 25 deg. cent. The total loss should be added to the rated output to obtain the input. The rated kv-a. of the auto-transformer is not the same as the output, but the output is always specified by the Engineers.

Calculation of Regulation

In constant potential transformers the regulation is the ratio of the rise of secondary terminal voltage from full load to no load (at constant primary impressed terminal voltage) to the secondary full load voltage. Regulation may be determined by loading the transformer and observing the rise in secondary voltage when the load is thrown off. This method is not satisfactory on account of the expense of making the test, and the small difference between no load and full load secondary voltages. Much greater reliance can be placed on results calculated from separate measurements of reactance drop and resistance, than on actual measurements of regulation. For non-inductive load, we have the following formula:

$$\text{Per cent regulation} = \text{per cent } IR + \frac{(\text{per cent } IX)^2}{200}$$

where per cent IR = total resistance drop expressed in per cent of rated voltage.

Per cent IX = total reactance drop expressed in per cent of rated voltage.

For lagging currents, we have the following:

$$\text{Per cent regulation} = (\text{per cent } IR)\ P + (\text{per cent } IX)\ W + \frac{[(\text{per cent } IX)\ P - (\text{per cent } IR)\ W]^2}{200}$$

where per cent IR = total resistance drop due to load currents expressed in per cent of rated voltage.

per cent IX = total reactance drop due to load currents expressed in per cent of rated voltage.

P = power-factor ($\cos\theta$)

W = wattless factor ($\sin\theta$)

The following table gives the values of W, the wattless factor for various values of P, the power-factor:

P	W
1.00	0
0.95	0.312
0.90	0.436
0.85	0.526
0.80	0.60
0.75	0.66
0.70	0.714
0.60	0.80

The per cent IR is calculated from the rated current and the resistance at 25 deg. cent. It may be obtained conveniently by dividing the I^2R loss by ten times the rated kv-a. The per cent *IX* is calculated by taking the square of the per cent impedance volts, subtracting the square of the per cent IR and determining the square root. See Calculation Sheets 29 and 30.

In auto-transformers the per cent IR drop should be calculated in the same way as for a transformer, and may be conveniently obtained by dividing the I^2R loss in watts by ten times the equivalent transformer capacity in kv-a. The per-cent *IX* drop should be calculated from the per cent impedance in the same way as for a transformer. The auto transformer should be connected as a transformer during the impedance test. These values of per cent IR and the per cent *IX* should then be multiplied bythe ratio

$$\frac{\text{rated voltage (h.v. winding)} - \text{rated voltage (l.v. voltage winding)}}{\text{rated voltage (high voltage winding)}}$$

after which they should be used in the formulæ given above for transformers.

INDUCTION REGULATORS

SINGLE-PHASE INDUCTION REGULATORS

The IRS, or single-phase Induction Regulator, may be cooled by an air blast—it may be placed in a tank and be oil cooled—or it may be oil and water cooled. Regulators of this type are usually made for the control of single-phase lighting circuits. The primary winding is placed in slots on a movable core or armature, while the secondary winding is placed in slots on a stationary core. The regulator may be wound with any even number of coils.

The voltage induced in the secondary winding depends upon the relative position of the secondary with reference to the primary winding, the primary being in shunt and the secondary in series with the circuit to be controlled, the voltage of the circuit thus being increased or decreased accordingly. Single-phase, as well as polyphase regulators have a distributed winding for both primary and secondary, but the maximum pole face which can be covered by an active winding in a single-phase regulator so as to produce the best results, is approximately 60 per cent. In the neutral position the secondary winding, therefore, encloses an area on the primary core not enclosed by an active primary winding and the impedance would be extremely high if no windings were provided. The slots of the primary not used for an active winding are, therefore, filled with a short-circuited winding, so that in the neutral position of the regulator the current forced through the secondary induces a current through the short-circuited winding which reacts upon the primary and reduces the impedance.

Tests Required

The following tests are made on single-phase regulators:

Cold resistance.
Ratio.
Polarity.
Core loss.
Impedance.
Heat run.
High potential.
Induced voltage.
Noise tests.
Tests of auxiliaries.

These tests are usually made in the order mentioned above. The order may be changed, however, if desired. It is considered desirable to have the high potential and induced voltage tests made last and in the order named.

Cold Resistance

Cold resistance should be measured by the methods described for transformers, care being observed to obtain accurate measurements if the rise by resistance is to be calculated at the end of the heat run. The resistance measurements should be reduced to a room temperature of 25 deg. cent., and entered on the test sheet.

Ratio

The ratio should be taken with normal voltage on the primary, by reading the volts across the secondary with the armature in the limiting, maximum boosting, maximum lowering, and neutral positions. The feeder volts should be read in each position. The number of turns of the handwheel should be noted for each position, starting at a limiting position.

Polarity

Polarity should be checked against the DS sketch with the armature in the maximum boosting position. The regulator should boost the line voltage when the handwheel is revolving counter-clockwise.

Core Loss

On this type of regulator with the permanent short-circuit on the armature, the core loss must be taken from the primary winding. The power-factor will be low due to the air gap—hence, considerable care must be taken in making the test. The core loss watts and the exciting current should be measured at normal voltage and frequency with the armature in both the maximum boosting and the neutral position.

Impedance

Impedance is always measured on the secondary winding as it is impossible to force full load current through the primary winding in the neutral position. With the primary short-circuited, full load current should be forced through the secondary and the voltage recorded with the armature in the neutral position, maximum boosting position, and position of maximum impedance. The positions should be recorded by giving the number of turns of the handwheel from a limiting position.

Heat Run

The ordinary commercial regulators are given a short-circuited heat run without oil. One of the windings is short-circuited, and the rotor placed in the maximum boosting or maximum lowering position. Currents of sufficient magnitude to produce a temperature rise of from 50 to 60 deg. cent. in 20 minutes, are held in the secondary. The values of currents for standard regulators are specified by the Engineers.

In case a load run is required, the regulator is either connected as a transformer and placed on a non-inductive load, or in case two are available they are given a bucking run with the losses supplied from two sources of power. An idle unit is used as a basis for calculating temperature rises, if one is available.

Oil immersed regulators should be filled with oil to the gauge line at room temperature. Thermometers should be placed in the tank between the second and third ribs—one at the bottom and one 2 in. below the gauge line. One thermometer should be placed in the top oil, the bulb being immersed about 1½ in. Room temperature should be recorded at three or four positions around the regulator.

Normal voltage and frequency should be held on the primary, and normal current in the secondary. Thermometer readings should be taken at hourly intervals, and resistance readings every two hours, primary and secondary being measured alternately. The normal load run should be followed by a 125 per cent load for 2 hours, unless otherwise specified.

High Potential

High potential test is made in the same way as on a transformer. All leads must be connected to one or the other electrode of the high potential testing set. Standard 1100 to 2500 volt primary regulators are given a test of 7500 volts for one minute between windings, and from windings to frame.

Induced Voltage

The induced voltage test consists of the application of three times normal voltage for 10 seconds to the primary winding, followed by double normal voltage for 5 minutes. The frequency should be sufficiently high to keep the exciting current within the full load current of the regulator. The armature should be placed in the maximum boosting or maximum lowering position.

Noise Test

Every regulator must be carefully tested for noise with normal excitation, frequency and load, while the armature is moved through its complete range. When the noise exceeds the standard which will be set from time to time, the regulator should not be passed without the approval of the Engineering Department.

Tests of Auxiliary Apparatus

The motor and limit switch should be connected in accordance with the DS sketch, after which they should be operated throughout the entire range without load or excitation on the regulator. A record should be made of the minimum volts required to operate the motor, the amperes at normal voltage and the time required to operate it through the entire range. The tripping lugs should be adjusted during the test, so as to open the limit switch in such a way that the regulator will stop in the maximum boosting or maximum lowering position with allowance made for standard hunting. There must be sufficient allowance made to prevent the segment from coming against the stop pin when operating. When the tests have been completed the bearings should be drained, washed out with kerosene oil, and the oil plugs screwed in tight.

The brake shoes should be oiled, and the brake adjusted for hunting of approximately 1 per cent of the total range. The hunting should be recorded in turns of the hand wheel.

The relay switch should be supplied with normal voltage at normal frequency, and the amperes measured with the armature in the middle position and in the normal operating position. A record should also be made of the resistance, and the minimum volts required to operate. The minimum volts should not exceed 80 per cent of normal. The connections should be checked against the DS sketch. The stationary contacts should be adjusted so that there is ⅛ in. spring at the end of the face of the moving element when the armature is against the magnet coil. The stationary contacts must bottom in the holders which should be placed tight in the support. The switch should be given a double voltage test through the magnet winding for five minutes at approximately double frequency, with the magnet armature closed.

A high potential test of 1000 volts should be applied for one minute from windings to core, from contacts to frame, and between the contacts of the switches.

Special tests on motors will be called for by the Engineers when required. These include starting torque, impedance, heat run, minimum volts and amperes and watts with regulator loaded. The heat run is made by operating the regulator at no load, reversing at limits during one hour. Normal voltage and frequency should be applied to the motor. The brakes should be set so as to allow a hunting of about 1 per cent of the total range of the regulator, and should be oiled to maintain this hunting throughout the run. The room temperature, rise in bearings, windings, laminations, rotor, commutator, and brake pulley, should be measured by thermometer, and the rise of windings by resistance.

POLYPHASE INDUCTION REGULATORS

Induction regulators of the IRQ, IRT and IRH types are used principally with synchronous converters, but are well adapted to control polyphase transmission circuits. As in the IRS type, they may be either air blast, oil cooled, or oil and water cooled. The primary winding is connected in shunt and the secondary in series with the circuit. In the polyphase induction regulator, the voltage induced in each phase of the secondary is constant, but by varying the relative positions of the primary and secondary, the effective voltage of any phase of the secondary on its circuit is varied from maximum boost to zero, and to maximum lower.

Referring to Fig. 187 which represents graphically the voltage of the three phases of a three-phase or IRT regulator, *AAA* equals the line voltage or the e.m.f. impressed on the primary. This is shown by the large circle. Let *BA*, *BA* and *BA* equal the e.m.f. generated in the secondary coils and constant with the impressed e.m.f. This is shown by the three small circles on the circumference of the large circle. *BBB* shows the e.m.f. induced in the secondary coils directly in phase with the primary impressed e.m.f. This is the position of maximum boost. Positions *CCC* represent the neutral position, and *DDD* the maximum lower position. *EEE* represents a position between neutral and maximum lower.

By changing the position of the armature with respect to the field, the secondary voltage may be made to assume any phase relation with respect to the primary e.m.f.; it can be in series with it or directly opposed to it. This movement of the armature is obtained by means of a segment on the shaft which meshes with a worm on the small operating shaft. The regulator may be arranged for hand operation only, or can be motor-operated. Either a direct current or an induction motor may be used. The motor is controlled by a small double-pole double-throw switch, on the switchboard, to allow the voltage to be raised or lowered as desired.

To stop the regulator on reaching the limits of regulation when moving in either direction, a limiting switch is provided, which opens automatically. If properly connected, this automatic cut off, however, does not interfere with movement in the opposite direction, which can be obtained by the double-pole double-throw switch.

Tests Required

The following tests are required on all polyphase regulators:

Cold resistance.
Ratio.
Polarity.
Core loss.
Impedance.
Heat run.
High potential.
Induced voltage.
Noise test.

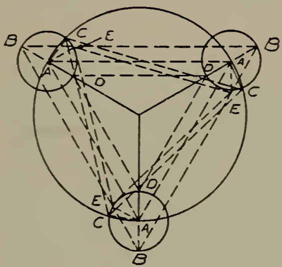

Fig. 187
REGULATOR DIAGRAM—THREE-PHASE

The order of tests is immaterial, except that it is best to have the induced voltage test follow the high potential test, both of them being made after the other tests have been completed. It is also advisable to check the connection with the DS sketch after the tests are made, particularly where permanent connections are made by the Assembly Dept. after tests.

Cold Resistance

The resistance in each phase should be measured and the values at 25 deg. cent. calculated and reported on the test sheet.

Ratio and Polarity

Two separate tests are required in order to obtain the ratio and polarity; (1) ratio of secondary to primary turns, and (2) boost and lower and polarity.

The ratio of turns must be checked by applying normal voltage at normal frequency to the primary and measuring the induced secondary voltages.

The primary and secondary should then be connected to a source of supply as shown on the DS sketch, normal voltage being applied at normal frequency. The feeder voltage of each phase should be measured with the armature in the extreme maximum boosting, neutral, maximum lowering and other intermediate positions. The position of the armature in each case should be recorded in turns of the handwheel from one extreme position. The direction of rotation of the handwheel for boosting should be recorded. Standard regulators are designed for counter-clockwise rotation to boost the voltage.

If the primary is incorrectly connected to the secondary, either an unbalancing of the feeder voltages will be noted, or with the feeder voltage balanced, the maximum boost, maximum lowering, etc., will be found at wrong positions of the armature. It is possible, although very improbable, that such unbalancing may be due to reversed secondary leads. In any event, the proper connection must be determined and the leads plainly marked so that the necessary changes can be made by the Assembly Department.

Core Loss

The readings of core loss should be taken on the primary side with normal voltage applied at normal frequency. As the core loss is not the same in all positions of the armature, the maximum and minimum should be found and the readings taken at these points. The position of the armature should be recorded in turns of the handwheel from one extreme position.

On IRH regulators having diametrical or double delta primary connections, it will be more convenient to make the test with three-phase single delta temporary connections. The connection used should be noted on the test record.

Impedance

The impedance is usually measured by short-circuiting the secondary and applying sufficient voltage to the primary winding to give full load current. As the impedance is not the same in all positions, the maximum and minimum readings should be obtained, and the position of the armature noted in each case. The impedance of an IRH regulator may be conveniently measured by connecting the primary, secondary, or both as three-phase.

Heat Run

It is customary to give standard regulators a compromise run with 150 per cent normal current and 125 per cent normal voltage for two hours, the proper cooling medium being used throughout. Hot resistances should be measured and the temperature rise calculated. Usually the secondary current is held at a specified value, but in case it is too large to measure it is considered satisfactory to hold the corresponding primary current calculated from ratio of turns.

The ultimate heat runs are usually made with two regulators connected according to the motor-generator method, with the primaries in parallel and the secondaries in series so connected that the primary fields will rotate in the same direction. Normal voltage is applied to the primary at the rated frequency. The armature of one regulator, called the generator, should be held in the maximum boosting position, while that of the other, the motor, should be adjusted until the proper secondary current is obtained. It is necessary to see that the currents in the primary and secondary windings are balanced, particularly when the secondary current is large. The primary current will not be the same in both regulators.

If the secondary current is too large to measure, the primary current of the one running as a generator should be calculated as follows: The theoretical primary current calculated from the ratio of turns should be added at an angle of 90 deg. to the magnetizing current measured at normal voltage.

Under such a test, the heating of the regulator running as a generator will be equivalent to that under normal load conditions, whereas the heating of the other will be somewhat higher.

Water cooled regulators should be run with the specified amount of water, which should be put in at about average room temperature, and the same temperature held throughout the run. Air-blast regulators should be furnished with air at the specified pressure. The quantity should be measured at the start of the run.

The temperatures should be observed at oil level on the outside of the tank, at the bottom of the tank; also the temperature of the top oil inside the tank. On air-blast regulators, the temperature at the top of the tank and at a number of places on the windings should be observed. Care should be taken to avoid obstructing the passage of air. In case there are likely to be hot spots in the windings or connections, thermometers should be placed on them. Resistance of one primary and one secondary phase should be taken alternately every hour, unless the secondary resistance is too large. In that event, the primary should be taken every hour. The resistance of each phase should be measured at the end of the run, and the rise of temperature calculated from the increase in resistance.

The proper number of single-phase regulators may be used instead of a polyphase regulator as the motor on a motor-generator run, provided they do not materially change the conditions of the polyphase unit under test. The heat run may also be made by putting dead load on the regulator, if necessary.

High Potential

The high potential test is usually made with the regulator hot. On standard 1100 or 2200 volt machines, 7500 volts is applied for one minute from primary to secondary and core, and from secondary to primary and core. On other regulators, the test voltage is specified. The same test voltage is applied between secondary phases and between primary phases if they can be separated. The test between phases should be made from phase 1 to phase 2, from phase 2 to phase 3, and from phase 1 to phase 3 independently—not from phases 1 and 2 to phase 3, etc. The phase not connected during test should be short-circuited on itself.

Induced Voltage

Triple normal voltage should be applied for 10 seconds to the primary winding, followed by double normal voltage for 5 minutes. The frequency should be sufficiently high to keep the magnetizing current within full load current limits.

The armature should preferably be placed in the maximum boosting position. If three-phase connections are used on an IRH regulator, care should be taken to see that the proper voltage is applied, viz. double volts per turn.

Noise Test

The noise test consists of operating the regulator with normal voltage and frequency, while the armature is rotated through all positions. If a short-circuited heat run is made, the armature should be moved over the full range during the run. If it is suspected that it may operate in a noisy manner under full load, a test should be made under as nearly full load conditions as can be obtained.

Tests of Auxiliary Apparatus

The operating motor and limiting switch should be connected in accordance with the DS sketch and normal voltage applied. The current and the time necessary to operate from maximum boost to maximum lowering position without load or excitation on the regulator should be noted. The minimum voltage required to operate the motor under such conditions should also be ascertained.

The brake magnet, which is always designed for the same voltage and frequency as the operating motor, should have normal frequency voltage applied, and the current measured with the armature up. The maximum volts required to operate this device should also be determined, and the cold resistance should be measured. If the minimum voltage is more than 80 per cent of normal, the brake should not be passed for shipment.

All auxiliary parts should be given a high potential test of 1000 volts for one minute from windings to frame and from active switch parts to iron supports.

BR REGULATORS

Modern central stations employ alternating current generators of large capacity, each generator usually supplying two or more districts through independent feeders. One feeder may serve a business district, while another from the same generator may feed a residential district. As the compounding required on any of the feeders depends on the amount of load carried by the feeder, and as the load peak occurs at different times in different feeders, a device to regulate the feeder voltages independently is necessary.

Type IRS may be used, but the automatic BR feeder regulator has been expressly designed for this work. Fig. 188 shows the circuits.

The automatic BR feeder regulators can change the line voltage quicker and with a smaller power consumption than other automatic types. The only moving part is a small and light switch arm. The friction of a number of small switch contacts constitutes the only turning resistance.

The moving part of the switch carries a series of fingers, the majority of which are always in contact. See Fig. 189. Each finger is connected to a corresponding stationary collector ring by a brush, and the collector ring is connected to the line through a preventive resistance. The resistances connecting the fingers to the line prevent excessive exchange currents as the fingers pass from contact to contact, and vary the line voltage uniformly. The regulator transformer is oil cooled.

Tests Required

The following tests are required:

Cold resistance.	Heat run.
Ratio	High potential.
Core loss.	Induced voltage.
Impedance.	Test of auxiliaries.

Cold Resistance

The cold resistance of the primary winding and of each half of the secondary winding should be measured exclusive of the preventive resistance. The resistance of each of the preventive resistances should be measured cold. The spring contacts should be insulated from the contact blocks by means of a thin sheet of fiber, and the resistance measured between the collector rings and the common connection.

Ratio

Ratio is taken at no load with full voltage on the primary, by reading the voltage across the secondary with the switch arm in maximum boosting and maximum lowering positions. The voltage should be read between the middle point of the secondary winding and each contact block. The polarity should also be checked against the standard sketches provided by the Engineering Department.

Core Loss

The magnetizing current and core loss readings should be taken at normal voltage and frequency with the switch contacts so arranged that each spring contact will cover one block only, or the contacts may be insulated from the blocks by means of a thin sheet of fiber. This arrangement is necessary as otherwise part of the secondary windings would be short-circuited through the preventive resistance and this loss would be included in the core loss reading.

Impedance

With the primary short-circuited and the switch arm in one extreme position, full load current should be forced through the secondary and the voltage and watts measured between the middle point of the secondary winding and the contact block covered by the spring contacts, after which the readings should be repeated with the switch arm in the extreme position. The same readings should be repeated with the drop and loss in the preventive resistances included.

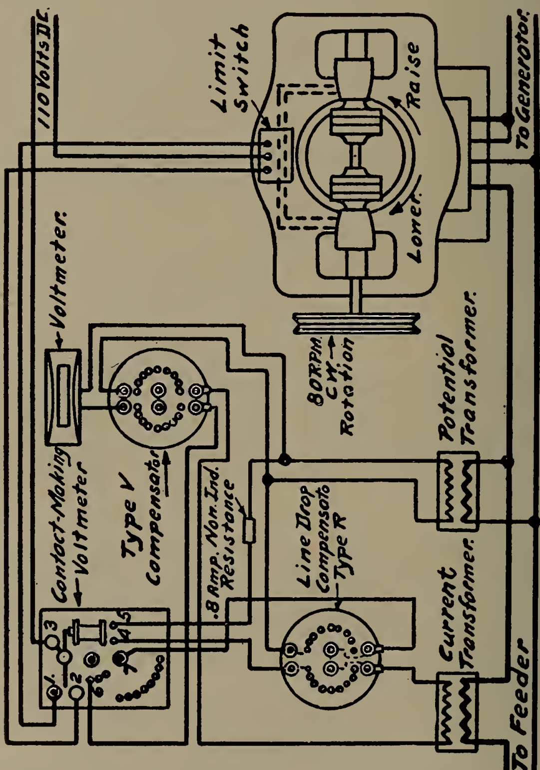

Fig. 188
CONNECTIONS OF BR FEEDER REGULATOR

Heat Run

The compromise heat run is made without oil, the primary being open-circuited and one-half of the secondary short-circuited, while current of sufficient magnitude is forced through the other half of the secondary to produce a rise of from 50 to 60 deg. cent. in 20 to 30 minutes. Resistance should be measured at the end of the run and the rise by resistance calculated. The two halves of the secondary should be measured separately so as not to include the preventive resistance.

The voltmeter leads should, therefore, be attached to the middle point of the two secondary coils and to the extreme contact blocks.

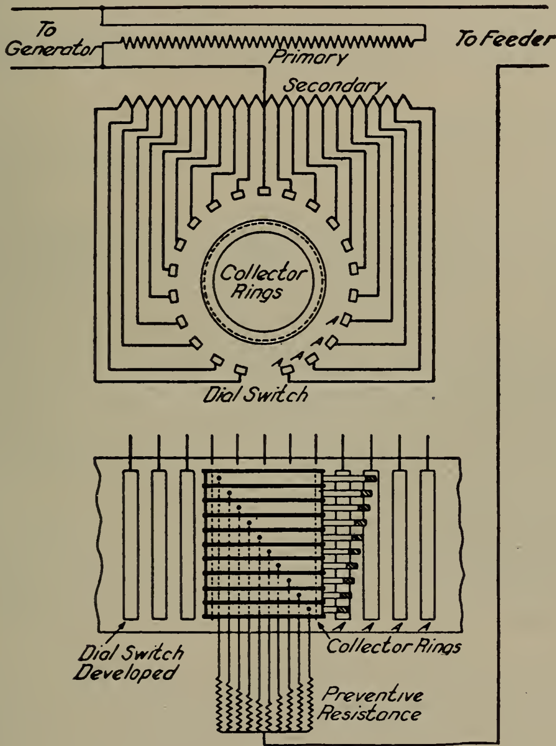

Fig. 189

BR REGULATOR

An ultimate heat run may be made by the motor-generator method if two regulators are available at the same time. If only one is in test, it may be pumped back on a suitably arranged bank of transformers or it may be loaded on a water rheostat. In the latter case, apply voltage to the primary, connecting the secondary to a water box, adjusting until full load current is obtained. The switch must be in one of the extreme positions.

High Potential

On 2200 volt regulators, a 7500 volt test for one minute should be applied from windings to ground. The test voltage will be specified on other regulators.

Induced Voltage

Three times normal voltage should be applied for one minute, followed by twice normal voltage for five minutes.

Tests of Auxiliaries

The motor should be tested to determine the minimum volts required to operate it, and the current consumed when operating at normal voltage.

The clutch coils should have tests to determine the resistance of each coil, minimum volts required to operate, and current consumed at normal voltage. With the motor and clutch coils connected to a line of rated voltage, the switch arm should be turned back and forth for one-half hour from one extreme position to the other. Operation should be watched closely and the time required for turning the switch arm from maximum boost to maximum lower should be measured.

High potential tests should be made before assembly with the transformer parts as follows:

A test of 1000 volts for one minute from clutch coils to frame, from active parts of limit switch to frame, from contact blocks to switch pot, from collector rings to support, from contact fingers to support, and between contact blocks.

A test of 500 volts for one minute between collector rings and also between contact fingers.

High potential test of 1000 volts should be applied for one minute between motor leads and frame, clutch coils and frame, and between active parts of limit switch and cover, when the final high potential test is made on the assembled regulator.

REACTANCES

At the present time reactances are built in several different types, the design depending principally upon the use to which the reactance is to be put. The largest sizes, called current limiting reactances, consist of a winding of bare copper cable on a cylindrical concrete core, the turns of this winding being insulated from each other by strips of wood, and the whole device being cooled by natural air circulation. Reactances of large size are also used in connection with the operation of synchronous converters, the design in this case being that of a polyphase unit wound on a laminated iron core and cooled by air blast or by oil circulation. The smaller reactances are used mostly in connection with the operation of mercury arc rectifiers. These are wound on iron cores and are cooled by natural circulation of the air.

Tests Required

The following tests are usually made on reactances:
Cold resistance.
Impedance.
Heat run.
High potential.
Double or triple voltage.

Where there are taps, it is necessary to check the tap ratio in the same way as on transformers.

Cold Resistance

No special instructions are needed for this other than those given for transformers.

Impedance

The impedance test consists of forcing normal current through the winding and reading the volts and watts. Care must be taken to have magnetic material removed at least 3 ft. from current limiting reactances during this test.

Heat Run

The heat run on current limiting reactances is made by forcing normal current at normal frequency through the windings and continuing the run until temperatures become constant. Spirit thermometers only should be used to measure temperature.

The heat run on reactances for use with mercury arc rectifiers usually consist of a 5-hour normal load run with a complete set of auxiliary apparatus connected to the mercury arc rectifier tube.

A stability test is usually made at the same time as the heat run on reactances for rectifiers. This test consists in the determination of the lowest value of direct current necessary to maintain the arc in the rectifier tube.

High Potential

The high potential test from windings to core is made according to the rules given for transformers. No special instructions are needed for reactances.

Double or Triple Voltage

This test is made in the same way as on transformers. The frequency is increased in order to keep the current within reasonable limits.

SERIES LIGHTING TRANSFORMERS

Series lighting transformers are used to insulate lamps from a high voltage series circuit. They range in capacity from 40 watts to 2000 watts and the standard ampere ratings are 4, 5.5, 6.6 and 7.5. As a rule, they are air cooled because the small capacity and low losses make it unnecessary to use oil as a cooling medium. The primary winding is connected in series with a series arc or series incandescent circuit so that under all conditions of load on the secondary, the primary carries the full current of the circuit. For satisfactory operation of the incandescent lamps connected to the secondary, it is desirable to obtain as near constant current in the secondary as possible.

The tests required are:

High potential.
Resistance.
Core loss and exciting current.
Open circuit voltage.
Impedance.
Regulation.
Heat run.
Induced voltage.

The high potential, resistance and impedance tests are made in the manner specified for constant potential transformers.

Core loss should be measured at normal primary voltage and at normal primary current, the secondary being open-circuited in each case. The normal voltage is calculated by dividing the rated kv-a. by the rated current.

The open-circuit voltage test is made by reading the voltage across the open-circuited secondary with normal current passing through the primary.

Regulation test is made by putting various loads on the secondary with rated current passing through the primary and measuring the secondary voltage corresponding to each load. Readings should be taken at ¼, ½, ¾ and full voltage. Incandescent lamps should be used for the load.

The heat run is made with incandescent lamp load.

The induced voltage test is made by applying three times normal voltage to the primary with the secondary open-circuited.

CHAPTER 25

CALCULATION SHEETS

The following calculations, which have been made with the slide rule, are intended to illustrate the method used in connection with testing work. Every effort is made to avoid error but this Company does not guarantee their correctness nor does it hold itself responsible for any errors or omissions in these sheets.

SATURATION ON A 500 KW., 600 V., 360 R.P.M., 60 CYCLE, 3-PHASE GENERATOR

Volts Arm.	Volts Field	Amp. Field	Speed R.P.M.
192	25	18.0	360
228	29	21.0	360
253	32	23.2	360
304	38	29.0	360
416	52	40.0	360
495	62	48.9	360
542	70	55.1	360
579	75	59.8	360
597 597 597	79	62.0	360
614	83	65.4	360
707	110	87.5	360
785	146	117.0	360
755	130	102.0	360
555	74	55.5	360
453	57	43.6	360
287	35	26.3	360
178	26	16.1	360

CALCULATION SHEET NO. 1

OPEN-CIRCUIT CORE LOSS ON A 500 KW., 600 V., 360 R.P.M., 60 CYCLE 3-PHASE GENERATOR

	Driving Motor							Generator				
	Volts Arm.	Amp. Arm.	Amp. Field	Speed R.P.M.	I.E. Input	I^2R	I.E. $-I^2R$	Core Loss	Volts Arm.	Volts Field	Amp. Field	Speed R.P.M.
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.2	62.0	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.0	85.0	2.5	500	9700	55	9645	1060	152	20.0	13.9	360
	114.2	90.0	2.5	500	10280	62	10218	1633	204	25.8	18.7	360
	114.3	95.5	2.5	500	10900	70	10830	2245	262	32.2	24.0	360
	114.5	103.0	2.5	500	11800	82	11718	3133	322	38.8	29.6	360
Friction	113.5	76.0	3.5	500	8630	45	8585	0	0	0	0	360
	114.5	112.0	2.5	500	12820	96	12724	4139	386	46.9	36.4	360
	114.6	126.0	2.5	500	14420	122	14298	5713	453	54.6	42.6	360
	115.0	145.0	2.5	500	16700	162	16538	7953	515	63.7	50.2	360
	115.4	160.0	2.5	500	18450	200	18250	9665	562	71.2	56.2	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	115.5	166.0	2.5	500	19200	212	18988	10403	570	74.0	58.0	360
	115.8	173.0	2.5	500	20000	230	19770	11185	594	78.0	61.0	360
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.5	62.0	360
	116.5	185.0	2.5	500	21580	263	21317	12732	624	84.6	65.7	360
	116.8	212.0	2.5	500	24800	345	24455	15870	684	100.5	78.4	360
	117.0	238.0	2.5	500	27850	435	27415	18830	721	117.5	90.9	360
	Motor	Runnin	g Light									
	113.0	15.4	2.5	500	1745	1.82	1738	6847	Frictio	n and	Winda	ge

Driving Motor MP–4–60–550–125 V. Res. Hot. =0.0077 Ohms.

CALCULATION SHEET NO. 2

SHORT-CIRCUIT CORE LOSS ON A 500 KW., 600 V., 360 R.P.M., 60 CYCLE 3-PHASE A-C. GENERATOR

	DRIVING MOTOR						GENERATOR					
	Volts Arm.	Amp. Arm.	Amp. Field	I.E. Input	I^2R	I.E. $-I^2R$	Core Loss + Gen. I^2R	I^2R	Core Loss	Amp. Arm.	Amp. Field	Speed R.P.M.
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
Friction	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.0	93.0	2.5	10600	66	10535	1950	1320	630	236	12.4	360
	113.8	94.0	2.5	10710	68	10640	2055	1680	375	266	14.0	360
	113.5	106.0	2.5	12050	86	11965	3380	2540	840	328	18.0	360
	114.2	115.0	2.5	13130	102	13030	4445	3440	1005	382	19.8	360
	115.0	125.0	2.5	14380	120	14260	5675	4130	1545	418	21.6	360
Friction	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.2	130.0	2.5	14850	130	14720	6135	4540	1595	438	22.6	360
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
	115.2	158.0	2.5	18200	192	18010	9425	6780	2645	536	27.6	360
	114.2	176.0	2.5	20100	238	19860	11275	8350	2925	594	30.6	360
	115	204.0	2.5	23450	320	23130	14545	10400	4145	662	34.0	360
	116	232.5	2.5	27000	415	26585	18000	12700	5300	732	37.5	360

Driving Motor MP–4–60–550–125 V. Res. Hot. =0.0077 Ohms. Generator Res. between lines including leads to table =0.0158 average of resistance before and after test.

CALCULATION SHEET NO. 3

CALCULATIONS OF DECELERATION CORE LOSS ON A 3000 KW., 2300 V., 10-POLE, 60 CYCLE, 3-PHASE GENERATOR

Moment of inertia is equal to $705{,}000 = Wr^2$.

The normal speed of the turbine being 720, S_1 is taken equal to 730 and S_2 equal to 710.

Consider curve taken with no field on the machine. (See Fig. 59.)

T_3 or time corresponding to $S_1 = 61.6$ seconds.

T_4 or time corresponding to $S_2 = 82.4$ seconds.

$T_4 - T_3 = 82.4 - 61.6 = 20.8.$

$$\text{Kw. loss } = \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{T_4 - T_3} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1 + S_2)\ (S_1 - S_2)}{T_4 - T_3}$$

$$= \frac{2308}{10^{10}} \times \frac{705000 \times 28800}{T_4 - T_3} = \frac{4700}{T_4 - T_3}$$

Substituting the value of $T_4 - T_3$ in the formula

$$\text{Kw. loss } = \frac{4700}{20.8} = 226 = \text{Friction and Windage}$$

For the curve taken with 77.4 amperes field current

$$T_2 - T_1 = 70.6 - 52.1 = 18.5$$

$$\text{Kw.} = \frac{4700}{18.5} = 254 = \text{Core loss} + \text{Friction} + \text{Windage.}$$

Curves taken with 103, 129 and 142 amperes field are calculated similarly, and together with that taken at 77.4 amperes field include the constant friction loss and core loss. The two losses can be separated.

Amp. Field Held	T_3 or T_1	T_4 or T_2	$T_4 - T_3$ or $T_2 - T_1$	S_1	S_2	$S_1^2 - S_2^2$	Friction	Core Loss and Friction	Core Loss	Volts from Saturation
0	61.6	82.4	20.8	730	710	28800	226	226	0	0
77.4	52.1	70.6	18.5	730	710	28800	226	254	28	1570
103	48.2	66.1	17.9	730	710	28800	226	266	40	1990
129	44.4	60.5	16.1	730	710	28800	226	292	66	2350
142	42.8	58.2	15.4	730	710	28800	226	306	80	2500

From the saturation curve the volts armature corresponding to the various field currents used can be obtained and a core loss curve plotted between volts armature as abscissæ and core loss as ordinates.

S_1 and S_2 are usually assumed at 2 per cent above and 2 per cent below normal speed.

CALCULATION SHEET NO. 4

FIELD COMPOUNDING ON A 150 KW., 250 V., 6-POLE, 225 R.P.M., D-C. GENERATOR

6 BARS BRUSH SHIFT

Volts Arm.	Amp. Arm.	Volts Field	Amp. Field	R.P.M.
250	0	226	10.8	225
250	150	240	11.65	225
250	300	270	12.90	225
250	450	300	14.3	225
250	600	334	15.9	225
250	750	370	17.6	225

CALCULATION SHEET NO. 5

PHASE CHARACTERISTICS ON A 300 KW., 600 V., 750 R.P.M., 25 CYCLE 3-PHASE SYNCHRONOUS CONVERTER

NO LOAD					FULL LOAD 500 AMPS. D-C.				
Volts D-C.	Volts A-C.	Amp. A-C.	Amp. Field	Volts Field	Volts D-C.	Volts A-C.	Amp. A-C.	Amp. Field	Volts Field
600	378	315	0.75	91	600	384	601	1.05	125
600	377	255	1.25	150	600	383.5	570	1.25	150
600	376	210	1.50	180	600	381	543	1.50	180
600	375	156	1.75	210	600	380	520	2.00	240
600	374	120	2.00	240	600	379	512	2.25	270
600	373	85	2.20	265	600	378	507	2.50	300
600	373	65	2.30	275	600	378	505	2.65	320
600	372	41	2.40	290	600	378	510	2.75	330
600	371	23	2.50	300	600	376	525	3.00	360
600	370	14	2.55	305	600	375	547	3.50	420
600	370	17	2.60	315	600	374	585	4.00	485
600	369	21	2.65	320	600	373	627	4.50	540
600	369	35	2.75	332	600	370	685	5.00	600
600	369	75	3.00	360					
600	368	116	3.25	395					
600	367	170	3.50	420					
600	366	205	3.75	450					

CALCULATION SHEET NO. 6

SYNCHRONOUS IMPEDANCE ON A 500 KW., 600 V., 20-POLE, 60 CYCLE, 3-PHASE GENERATOR

Amp. Arm.	Volts Field	Amp. Field	Speed R.P.M.
224	15.0	11.9	360
260	17.8	13.7	360
300	20.6	15.8	360
352	23.8	18.3	360
398	26.9	20.7	360
474	31.5	24.5	360
480 480 480	32.2	24.8	360
518	34.8	26.7	360
557	37.5	28.2	360
704	47.0	36.1	360
796	52.8	40.6	360
896	59.5	45.7	360
1000	66.5	51.1	360

CALCULATION SHEET NO. 7

INPUT-OUTPUT OF A 100 H.P., 600 V. RAILWAY MOTOR

Motor	Volts	600	600	600	600	600
	Amps.	60.5	94	134	178	249
	R.P.M.	1216	935	790	700	610
	Watts Input	36300	56400	80400	106800	149200
	I^2R {Arm. + Brushes + Exc. Fld. + Comm. Field}	935	2260	4590	8100	15800
	(A) = Watts − (I^2R)	35365	54140	75810	98700	133400
	(A) − (Core Loss + Fric.) = Output	29382	48180	69410	90755	123150
	Efficiency	80.9	85.4	86.4	85	82.5
Generator	Volts	602	592	580	551	522
	Amps.	38.5	70	105.5	142.5	203
	Watts	23150	41400	61150	79400	106000
	I^2R {Arm. + Brush + Comm. Field}	248	820	1860	3410	6900
	(B) Watts + I^2R	23398	42220	63010	82810	112900
	(A − B) ÷ 2 = Core Loss + Friction (1 Mach.)	5983	5960	6400	7945	10250

Resistance		Motor	Generator
	Armature	0.1082	0.1015
	Exciting Field	0.0792	—
	Comm. Field	0.0522	0.0492
	Brush Contact	0.0170	0.0170
	Total	0.2566	0.1677

CALCULATION SHEET NO. 8

SPEED, TRACTIVE EFFORT AND EFFICIENCY OF A 100 H.P. 600 V. RAILWAY MOTOR

INPUT		I^2R %	Core Loss %	Gear + Friction %	Efficiency %	Miles per Hour on 33 In. Wheels Gear Ratio 3.35	Tractive Effort
Volts	Amp.						
600	40	1.7	5.3	30.0	63.0	45.0	170
600	60	2.5	4.1	14.0	79.4	35.4	407
600	80	3.3	3.4	9.0	84.3	29.6	687
600	100	4.2	3.0	7.5	85.3	26.2	984
600	120	5.0	2.6	6.5	85.9	23.8	1310
600	140	5.9	2.3	5.7	86.1	22.5	1615
600	160	6.7	2.1	5.0	86.2	21.3	1960
600	200	8.4	1.8	5.0	84.8	19.5	2630
600	240	10.0	1.5	5.0	83.5	18.1	3350
600	280	11.7	1.3	5.0	82.0	17.2	4040

Resistances at	75° cent.
Armature	0.107 ohm
Exciting Field	0.076 "
Commutating Field	0.050 "
Brush Contact	0.017 "
Total	0.250 "

CALCULATION SHEET NO. 9

PHASE CHARACTERISTICS OF A 187 KV-A., 2300 V., 10-POLE, 720 R.P.M., 3-PHASE SYNCHRONOUS MOTOR

Volt Arm.	Amp. Arm.	Volts Field	Amp. Field	Cycles
NO LOAD PHASE CHARACTERISTIC				
2300	63	15	5.5	60
2300	50.76	24	10.2	60
2300	33.12	34.5	15.6	60
2300	18.6	44	19.5	60
2300	8.44	54	23	60
2300	1.44	58	26	60
2300	9.72	66	30	60
2300	19.56	73	33	60
2300	25.8	82	36.5	60
2300	32.52	85	39	60
2300	45	99	43.5	60
FULL LOAD PHASE CHARACTERISTIC				
2300	74.4	26.5	11.5	60
2300	69	31	13.5	60
2300	57.6	37	16.5	60
2300	48.3	46	21.5	60
2300	46.5	60	28	60
2300	46.5	62	28.5	60
2300	49.5	71	33	60
2300	52.8	79	37	60
2300	58.5	89	41.5	60
2300	66.6	100	46	60
2300	71.4	106	48.5	60
125 PER CENT LOAD PHASE CHARACTERISTIC				
2300	85.8	30.5	13.2	60
2300	68.4	42.5	19.3	60
2300	60	53.5	24.8	60
2300	58.5	62	28.7	60
2300	57.9	63.5	29.5	60
2300	59.4	71	32.8	60
3300	61.8	79	36.4	60
2300	65.55	87	40.3	60
2300	71.4	100	45.6	60

CALCULATION SHEET NO. 10

CALCULATING EFFICIENCY

Standard efficiency test is made by the method of losses and calculations, therefore should be made according to the following:

D-c. Generator

Consider a compound wound commutating pole generator and

Let V_L = Volts line.

I_L = Amperes line $= I_8 + I_9 = I_{10} + I_{11}$.

I_6 = Amperes shunt field.

I_4 = Amperes armature $= I_L - I_6$.

I_8 = Amperes series field $= I_L \frac{R_9}{(R_8+R_9)}$.

I_9 = Amperes series field shunt $= I_L - I_8$.

I_{10} = Amperes commutating field $= I_L \frac{R_{11}}{(R_{11}+R_{10})}$.

I_{11} = Amperes commutating field shunt $= I_L - I_{10}$.

R_5 = Brush contact resistance.

R_6 = Hot resistance of shunt field.

R_4 = " " " armature.

R_8 = " " " series field.

R_9 = " " " series field shunt.

R_{10} = " " " commutating field.

R_{11} = " " " " " shunt.

Then the total IR drop $= I_4 R_4 + I_4 R_5 + I_8 R_8 + I_{10} R_{10}$.

Let W_1 = Core loss watts taken from the core loss curve corresponding to $V_L + IR$ for each load.

W_2 = Watts brush friction from core loss test.

If the value taken from test appears inconsistent, calculate W_2 by the formula:

$$W_2 = \frac{F \times N \times B \times L \times \mu \times 746}{33000} \quad \text{where}$$

F = Circumference of commutator in feet

N = R.p.m.

B = Number of brushes

L = Lb. pressure per brush

μ = Coefficient of brush friction for the particular type of brush used.

In the case of engine-driven machines or those which are furnished without base, shaft or bearings, the bearing friction is omitted from the total losses, and is charged against the prime mover.

In nearly every case it is preferable to use the calculated brush friction instead of that obtained from test. During a short test, the commutator and brush contact surface cannot get into as good condition as is obtained after a long period of commercial operation. Consequently, the brush friction test does not represent the conditions that will exist after the machine has been in operation for some time. The coefficient of friction determines the value of brush friction, which in turn is deter-

EFFICIENCY AND LOSSES OF A 100 KW., 525/575 V., COMPOUND WOUND, 6-POLE, 275 R.P.M., D-C. GENERATOR.

% Load	0	25	50	75	100	125	150
Volts Line	525	537.5	550	562.5	575	575	
Amps. Line	0	43.5	87	130.5	174	217.5	
Amps. Shunt Field	3.10	3.18	3.25	3.32	3.4	3.4	
Amps. Armature	3.1	46.7	90.3	133.8	177.4	220.9	
Amps. Series Field	0	29.2	58.4	87.6	116.8	146	
Amps. Series G.S.S.	0	14.3	28.6	42.9	57.2	71.5	
IR Drop	0.417	0.628	12.15	18.0	23.9	29.7	
E+IR	525.4	543.8	562.2	580.5	598.9	604.7	
Core Loss	1042	1124	1205	1295	1395	1425	
Brush Friction	314	314	314	314	314	314	
Bearing Friction							
I^2R Armature		213	797	1750	3080	4770	
I^2R Brushes		36	117	222	331	445	
I^2R Shunt Field, I^2R Rheostat	1630	1710	1790	1870	1950	1950	
I^2R Series Field	0	33	131	296	523	820	
I^2R G.S.S.	0	16	64	144	257	403	
Total Losses	2986	3.446	4418	5891	7850	10127	
Kw. Output	0	23.4	47.8	73.4	100	125	
Kw. Input	2.99	26.85	52.24	79.29	107.85	135.1	
% Efficiency		87.2	91.5	92.6	92.7	92.6	
Brush Density		8.3	16.05	23.8	31.6	39.3	
Brush Contact Res.		0.01665	0.0144	0.01244	0.01055	0.0091	

Resistance of Armature 25° cent. 0.0893 Ohms, Warm 0.098 Ohms at 51° cent.
Resistance of Shunt Field 25° cent. 97.4 Ohms, Warm 105.3 Ohms at 47° cent.
Resistance of Series Field 25° cent. 0.0358 Ohms, Warm 0.0386 Ohms at 45° cent.
Resistance of Series G.S.S. 0.079 Ohms.
Dimensions of Brushes 1¼ in. × ⅜ in. No. of Studs 6. No. per Stud 4. Coeff. of Friction = 0.2.
Brush Contact Area, One Side 5.625 Sq. In. Brush Pressure 1¼ Lb. per Brush.

CALCULATION SHEET NO. 11

mined by the condition of the commutator and brush contact surface. This coefficient varies considerably at first and only reaches a constant value after a considerable period of operation. The coefficient used in the above formula for the calculation of brush friction has been obtained by the Company by means of exhaustive tests on brushes of different types with various pressures and commutators. These tests extended over a long period to obtain constant and satisfactory conditions for both brush and commutator surface. The resulting values of brush friction can, therefore, be relied on to give accurate and final results.

W_3 = Bearing friction from core loss test.
Wb = Watts output $= I_L \times V_L$.

The brush contact resistance, R_5, is that taken from a curve, made for different types of brushes, corresponding to the brush current density per square inch at any given load.

$$\text{Brush current density per square inch} = \frac{I_4}{\frac{1}{2}\text{ total brush area}}$$

$$\text{One-half the total brush area} = \frac{l \times w \times s \times t}{2} \quad \text{where}$$

l = Length of brush parallel to the shaft
w = Width of brush
s = Number of studs
t = Number of brushes per stud.

For reasons similar to those just given, the Company has made extensive tests to determine the contact resistance of different types of brushes, from which curves have been plotted with brush current densities as abscissæ and either brush contact resistance per square inch or IR drop in brush contact as ordinates. In order to measure the contact resistance directly, the commutator would have to be short-circuited and the voltage drop measured from the commutator to the surface of each brush. This would be a long operation entailing considerable expense. The results also could not be reliable owing to the newness of commutator and brushes. It is, therefore, preferable to use the brush contact resistance obtained from the curves mentioned.

If W_3 = bearing friction from core loss test, then total loss in watts $= \Sigma W = W_1 + W_2 + W_3 + I_4^2R_4 + I_4^2R_5 + I_6^2R_6 + (I_6V_L - I_6^2R_6) + I_8^2R_8 + I_9^2R_9 + I_{10}^2R_{10} + I_{11}^2R_{11}$.

The quantity $I_6V_L - I_6^2R_6 = I^2R$ loss in the shunt field rheostats.

The watts input W_a will then be

$$W_a = W_b + \Sigma W, \text{ where } W_b = \text{watts output} = I_L V_L$$

$$\text{The efficiency } E = \frac{W_b}{W_a}$$

In case a core loss test is not made, the running light is substituted in the formula for the quantity $(W_1 + W_2 + W_3)$. If the segregation of the losses in the series and commutating pole fields and their respective German silver shunts is not required the resistances R_8 and R_9 may be combined to equal R_{sF}, likewise R_{10} and R_{11} to equal R_{cF}.

The total losses then will be

$$\Sigma W = \text{Running light} + I_4^2R_4 + I_4^2R_5 + I_6 V_L + I_L^2R_{sF} + I_L^2R_{cF}.$$

To calculate resistances hot when calculating efficiencies, the temperature should be obtained from the formula:

$$T = (K \times \text{rise by thermometer}) + 25° \text{ cent.}$$

K is the ratio between the rise in temperature by thermometer and that determined by resistance measurement. Resistance measurements of temperature have been determined by actual tests on a large number of different armatures and fields. For all armatures, or field spools of revolving field machines $K = 1.25$. For stationary ventilated field spools $K = 1.7$. See Calculation Sheet 11 and Fig. 70 for form used in calculating and plotting efficiency.

D-c. Motor

The efficiency of a direct current motor may be calculated as follows:

Using the same nomenclature as above

$I_4 = I_L - I_6$

Watts Input $W_a = I_L V_L$

W_1 = Core loss taken from the core loss curve corresponding to $V_L - IR$

Then
$$\Sigma W = W_1 + W_2 + W_3 + I_4^2R_4 + I_4^2R_5 + I_6^2R_6 + (I_6 V_L - I_6^2R_6) + I_8^2R_8 + I_9^2R_9 + I_{10}^2R_{10} + I_{11}^2R_{11}$$

as before

Watts output $W_b = W_a - \Sigma W$ and

$$E = \frac{W_b}{W_a}$$

Since motors are always rated according to horse-power output

$$H.P. = \frac{W_b}{746}$$

If, as in the case of d-c. generators, only a running light is taken and it is desired to combine the resistances of the series and commutating pole fields with their respective shunts and to combine the losses in the shunt field and rheostats, then

$$\Sigma W = \text{Running light} + I_4^2R_4 + I_4^2R_5 + I_6 V_L + I_L^2R_{sF} + I_L^2 R_{cF}$$

In the case of shunt motors

$$\Sigma W = \text{Running light} + I_4^2R_4 + I_4^2R_5 + I_6 V_L$$

The remarks made above in reference to the calculation of brush friction and brush contact resistance, also in reference to the calculation of hot resistances, as well as to *all other* efficiency calculations, apply here. (See Calculation Sheet 12.)

It will be seen from Fig. 75 that motor efficiencies are plotted against amperes line as abscissæ and per cent efficiency and h.p. output as ordinates. The horse-power curve should be produced to intersect the abscissæ line at running light *amperes line*.

CALCULATION SHEET NO. 12

EFFICIENCY AND LOSSES OF A 70 H.P., 500 V., 6-POLE, 850 R.P.M., D-C. MOTOR

Volts Line	500	500	500	500	500
Amperes Line	29	58	87	116	145
Amperes Field	2.43	2.43	2.43	2.43	2.43
Amperes Arm.	26.5	55.5	84.5	113.5	142.5
IR	3	6	9	12	15
E−IR	497	494	491	488	485
Speed					
Core Loss	2500	2475	2450	2400	2350
Brush Friction	460	460	460	460	460
Bearing Friction	530	530	530	530	530
I^2R Armature	63	275	638	1150	1820
I^2R Brush	12	50	105	172	243
IE Field	1215	1215	1215	1215	1215
Total Losses	4780	5005	5398	5927	6618
Kw. Input	14.5	29	43.5	58	72.5
Kw. Output	9.72	24	38.1	52.07	65.88
H.P. Output	13.02	32.1	51	69.7	88.3
% Efficiency	67	82.8	87.6	89.8	90.8
Brush Density	4.71	9.89	15	20.2	25.4
Brush Contact Resis.	0.0178	0.0162	0.01476	0.0133	0.01195

Resistance of Armature 25° cent. 0.0816 Ohms, Warm 0.0895 Ohms at 50° cent.
Resistance of Field 25° cent. 169 Ohms, Warm 191.5 Ohms at 60° cent.
Dimensions of Brushes 1¼ in. × ½ in. No. of Studs 6. No. per Stud 3. Pressure per Brush 1½ lb.
Brush Contact Area, One Side 5.62 Sq. In.

Synchronous Converter

The method employed to calculate the efficiency of a standard synchronous converter is similar to that used for d-c. generators except for the additional I^2R and friction losses of the a-c. brushes. Because of the neutralizing action of the motor and generator current it should be noted that only a certain percentage of the I^2R loss of the armature must be used for calculating the efficiency of the machine. This percentage varies for different machines as follows:

Single-phase	147%
Two-phase	39%
Three-phase	59%
Six-phase	27%

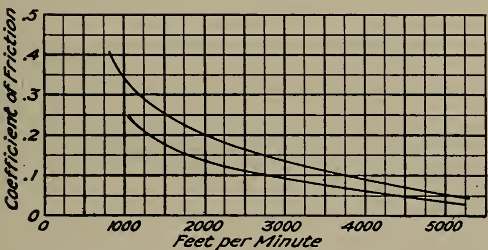

Fig. 190

*COEFFICIENT OF FRICTION OF A-C. BRUSHES

The calculation of the a-c. brush contact resistance requires a measurement of the alternating current flowing in the armature. This also varies in different types of machines. The following are the constants by which the direct current should be multiplied to obtain the alternating current.

For Single-phase	1.41
Two-phase	0.707
Three-phase	0.943
Six-phase	0.472

As with the d-c. brush contact resistance, a curve must be referred to of the a-c. contact resistance. This should be used and no direct measurement of resistance attempted. In every case the contact resistance should be calculated per ring, the total loss being obtained by multiplying by the number of rings.

Brush contact area per ring = width of brush in inches × arc of contact in inches × the number of brushes.

$$\text{The brush density per ring} = \frac{\text{Alternating current}}{\text{Brush contact area per ring}}$$

*Upper curve taken with copper collector rings. Lower curve taken with gun metal collector rings.

CALCULATION SHEET NO. 13

EFFICIENCY AND LOSSES OF A 300 KW., 600 V., 4-POLE, 25 CYCLE, 3-PHASE SYNCHRONOUS CONVERTER

% Load	0	25	50	75	100	125	150
Volts Line	600	600	600	600	600	600	600
Amps. Line	0	125	250	375	500	625	750
Amps. Shunt Field	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Amps. Arm. D-C.	2.65	127.6	252.6	377.6	502.6	627.6	752.6
Amps. Arm. A-C.		120.2	238	356	474	592	710
Core Loss	4760	4760	4760	4760	4760	4760	4760
Brush Friction D-C.	1134	1134	1134	1134	1134	1134	1134
Bearing Friction	2654	2654	2654	2654	2654	2654	2654
I^2R Armature ($.59 \times$ D-C. I^2R)	0	269	1056	2340	4170	6500	9300
I^2R Brushes D-C.	0	101	340	641	960	1280	1720
I^2R Shunt Field	900	900	900	900	900	900	900
I^2R Rheostat	690	690	690	690	690	690	690
I^2R A-C. Brushes		18	70	156	276	431	555
I^2R A-C. Brush Fric.	211	211	211	211	211	211	211
Total Losses	10349	10737	11815	13486	15755	18560	21924
Kw. Output		75	150	225	300	375	450
Kw. Input	10.3	85.7	161.8	238.5	315.7	393.5	471.9
% Efficiency	0	87.4	92.7	94.3	95.0	95.3	95.4
Brush Density A-C.		8.85	19.5	29.2	38.9	48.5	58.2
Brush Density D-C.		8.5	16.9	25.2	33.6	41.9	50.2
Brush Contact Resis. A-C.		0.00123	0.00123	0.00123	0.00123	0.00123	0.00110
Brush Contact Resis. D-C.		0.0062	0.00534	0.00451	0.0038	0.00326	0.00304

Resistance of Armature D-C. End 25° cent. 0.0243 Ohms, Warm 0.0280 Ohms at 65° cent.
Resistance of Shunt Field 25° cent. 111.3 Ohms, Warm 128 Ohms at 65° cent.

Dimensions of Brushes { $1\frac{5}{8} \times 1\frac{7}{8}$ arc of contact (A-C.); $\frac{3}{4} \times 1\frac{1}{4}$ (D-C.) } No. of Studs 4 D-C./12 A-C. No. per Stud 8 D-C./1 A-C.

Brush Contact Area, One Side { 15 Sq. In. D-C.; 12.2 Sq. In. per ring (A-C.) } Brush Pressure 2 Lb. per Brush.

Coeff. of Friction = 0.2 D-C. Coeff. of Friction = 0.12 A-C.

The resistance obtained from the curve, corresponding to this value divided by the brush area per ring is the contact resistance per ring.

The a-c. brush friction should be calculated in the same manner as used for d-c. measurements, the coefficient of friction being taken from a curve. (See Fig. 190.) Calculation Sheet 13 and Fig. 95 show the form used in calculating and plotting the efficiency of a synchronous converter.

A-c. Generator

For a-c. generators the method is as follows:

Let V_L = Volts line

W_b = Output = $\sqrt{3}\ V_L I_L$ for three-phase and $2\ V_L I_L$ for two-phase.

I_L = Amperes line.

I_1 = Amperes field.

R_1 = Hot resistance of armature between lines.

R_2 = Hot resistance of field.

W_1 = open-circuit core loss corresponding to $V_L + IR$ on the core loss curve

W_2 = short-circuit core loss corresponding to I_L on the short-circuit loss curve

W_3 = friction and windage obtained from core loss test

I_1 is calculated for each load, as when calculating for regulation (See Chapter 9, page 182.)

IR is the drop in the armature $= \frac{\sqrt{3}}{2}\ I_L\ R_1$ for three-phase machines and $L_L\ R_1$ for two-phase.

$\Sigma W = W_1 + \frac{1}{3}\ W_2 + W_3 + \frac{3}{2}\ I^2_L\ R_1 + I_1^2\ R_2$ for three-phase machines

$= W_1 + \frac{1}{3}\ W_2 + W_3 + 2 I_L^2 R_1 + I_1^2 R_2$ for two-phase machines

Watts input $= W_a = W_b + \Sigma W$

Efficiency $= \frac{W_b}{W_a}$

W_3 need not be considered if the machine is furnished without base, shaft or bearings.

The above method of calculation is used when the machine is to operate at unity power-factor.

If it is desired to calculate the efficiency at any other power-factor the following calculations must be made:

$I_L = \frac{\text{Kw.}}{V_L \times \sqrt{3} \times \%\text{P-F.}}$ and $W_b = \sqrt{3} \times V_L \times I_L \times \%$ P-F. for three-phase machines

$I_L = \frac{\text{Kw.}}{V_L \times 2 \times \%\ \text{P-F.}}$ and $W_b = 2 V_L \times I_L \times \%$ P-F. for two-phase machines

I_1 should be calculated for various power-factors as given under regulation.

EFFICIENCY AND LOSSES OF A 5000 KW., 11000 V., 28-POLE, 60 CYCLE, 3-PHASE GENERATOR

% Load	0	25	50	75	100	125
Volts Line	11000	11000	11000	11000	11000	11000
Amps. Line	0	65.5	131	196.5	262	317
Amps. Field	220	224	228	235	245	257
IR		12	24	36	48	50
V+IR	11000	11012	11024	11036	11048	11050
Core Loss	143000	143000	143100	143600	144100	147000
1/3 Short Cir. Core Loss			200	580	1300	2500
I^2R Arm.	0	1330	5320	12000	21300	31100
I^2R Fld.	14500	15000	15600	16600	18000	19800
Friction	25000	25000	25000	25000	25000	25000
Total Losses	182500	184330	189220	197700	209700	225400
Kw. Output	0	1250	2500	3750	5000	6250
Kw. Input	182.5	1434	2689	3948	5210	6475
% Efficiency	0	87.3	93	95	96	96.5

Res. Arm. (Line) 0.1927 Ohms 25° cent. 0.207 Ohms Hot.
Res. Fld. 0.2795 Ohms 25° cent. 0.3005 Ohms Hot.

The change in the line current will affect:

I_1, W_1, W_2, and the I^2R of the armature. See Fig. 87 and Calculation Sheet 14.

Synchronous Motors

Using the same nomenclature as for a-c. generators the following method is used for synchronous motors:

I_1 is either taken from the phase characteristic or is calculated

W_a = watts input $= \sqrt{3}\, V_L I_L + I_1^2 R_2$ for three-phase or $2\, V_L I_L + I_1^2 R_2$ for two-phase.

W_b = watts output $= W_a - \Sigma W$

$$\text{Efficiency} = \frac{W_b}{W_a}$$

W_1 = open-circuit core loss corresponding to $V_L - IR$ on the core loss curve.

$$\text{Horse-power output} = \frac{W_b}{746}$$

See Calculation Sheet 15 and Fig. 90.

Induction Motors

The calculation of the efficiency of induction motors is made from the results of the separate special tests taken as given in Chapter 12, according to the following method:

CALCULATING THE CHARACTERISTICS OF AN INDUCTION MOTOR

In calculating the characteristics of an induction motor the tabulation given on Calculation Sheet 20 is followed through. The slip at maximum load is first calculated and then values of slip below that amount are assumed so as to give several approximately equally spaced points on the curve and the horse power outputs corresponding to these values of slip are found by following the tabulated form. Curves are then plotted with horse power as abscissae and slip, torque, efficiency, etc., as ordinates.

CALCULATION SHEET NO. 15

EFFICIENCY AND LOSSES OF A 1070 H.P., 13200 V., 6-POLE, 25 CYCLE, 3-PHASE SYNCHRONOUS MOTOR

% Load	0	25	50	75	100	125	150.
Volts Line	13200	13200	13200	13200	13200	13200	13200
Amps. Line		9.5	19	28.5	38	47.5	57
Amps. Fld.	50.1	50.6	51	55.1	59.7	63.8	68.9
IR		34.5	69	103	168	172	205
(V – IR)	13200	13165	13131	13097	13032	13028	12995
Core Loss	13900	13800	13700	13600	13500	13400	13300
1/3 Short Cir. Core Loss		47	107	190	310	473	760
I^2R Arm.		565	2265	5100	9040	14100	20400
I^2R Fld.	3550	3630	3680	4300	5050	5770	6710
Friction	6272	6272	6272	6272	6272	6272	6272
Total Losses	23722	24314	26024	29462	34172	40015	47442
Kw. Input	23.72	220.63	436.68	654.3	871.05	1089.8	1306.7
Kw. Output	0	196.32	410.66	624.8	835.9	1049.8	1259.3
H.P. Output	0	263.2	550	837	1121	1408	1689
% Efficiency	0	89	94.1	95.5	96.1	96.3	96.4

Res. Arm. (Line) 3.86 Ohms 25° cent. 4.18 Ohms Hot 47° cent.
Res. Fld. 1.34 Ohms 25° cent. 1.42 Ohms Hot 46° cent.

EXCITATION ON 100 H.P., 440 V., 6-POLE, 500 R.P.M., 3-PHASE INDUCTION MOTOR

Volts	Amperes	Watts No. 1 −	Watts No. 2 +	Total Watts
544	57	13900	18000	4100
497	46.5	9550	13180	3630
467	41.0	7700	11000	3300
437	36.5	6310	9350	3040
398	31.8	4800	7490	2690
348	27	3300	5640	2340
299	22.5	2310	4300	1990
248	18.4	1440	3130	1690
197	14.8	686	2110	1425
174	13.2	497	1840	1343
148	11.7	239	1440	1201
124	10.2	124	1240	1116
98.5	9.5	+149	895	1044
81	9.3	239	745	984
61.4	9.5	273	696	969

SINGLE-PHASE 1-2

477	70		3900	
437	60		3430	
397	52.5		3060	

SINGLE-PHASE 2-3

477	70	3950		
437	60	3430		
397	52.5	3060		

CALCULATION SHEET NO. 16

POSITION CURVE ON 100 H.P., 440 V., 6-POLE, 500 R.P.M., 3-PHASE, FORM M INDUCTION MOTOR

Position	Volts	Amp.	Amp. at Normal Volts
1	63	118	824
2	63	124.5	870
3	63	134	935
4	63	121	845
5	63	116	810
6	63	130	907
7	63	129	900
8	63	119.5	835
9	63	124	866

CALCULATION SHEET NO. 17

SLIP CURVE ON 100 H.P., 440 V., 6-POLE, 500 R.P.M., 3-PHASE, FORM M INDUCTION MOTOR

Volts	Amp.	R.P.M.	Per Cent Slip
440	88	9	1.8
440	118	14	2.8
440	148	19	3.8
440	177	24	4.8

CALCULATION SHEET NO. 18

IMPEDANCE TEST ON 100 H.P., 440 V., 6-POLE, 1200 R.P.M., 3-PHASE, FORM M INDUCTION MOTOR

Volts	Amperes	Watts. No. 1 +	Watts No. 2 −	Total Watts
6.7	14	90	0	90
16.6	36	425	25	400
21.3	45	749	74	675
28.8	60	1413	198	1215
34.7	72.3	1923	248	1675
38.2	79.6	2380	397	1983
44.2	92.5	3150	546	2604
49.6	104	3920	596	3324
56.5	118	5200	893	4307
63.7	132.5	6500	1115	5385
74.5	154	8740	1500	7240
85.6	177	11300	2010	9290
103.7	214			
115.5	239			
146	300			
SINGLE-PHASE 1-2				
75.7	134.5		3520	
66.3	119		2765	
56	101		2010	
SINGLE-PHASE 2-3				
75.7	135	3640		
66.3	119	2820		
56	101	2010		

CALCULATION SHEET NO. 19

CHARACTERISTICS OF A 100 H.P., 440 VOLT, 6-POLE, 500 R.P.M., 3-PHASE, FORM M, INDUCTION MOTOR

EXPLANATORY NOTES

b_0 = Susceptance.
E = Rated terminal volts
E_0 = Volts per phase
e = Counter e.m.f. of rotor in terms of stator
e_{so} = E_0 − reactive component of e.m.f.
F = Friction watts from curve
F_0 = Friction watts per phase
g_0 = Conductance
I = Assumed full load amperes per line
I^1 = Calculated amperes per phase
I_h = Core loss component of exciting current
I_m = Exciting current (running light)
P = Mechanical power of rotor in watts per phase
$P-F_0$ = Output of rotor in watts per phase
R = Resistance of stator per phase
R_1 = Resistance of rotor per phase
R_2 = Resistance of rotor per phase in terms of stator
S = Slip at normal voltage and current, taken from slip curve
S_1 = Assumed slip at various loads
T = Torque in synchronous watts
V = Impedance volts at normal amperes, from curve
W = Impedance watts at normal amperes, from curve
W_1 = Core loss watts
X = Reactance of stator
X_1 = Reactance of rotor in terms of stator

FORMULÆ

3-PHASE MOTORS

$b_0 = \frac{I_m}{e_{so}}$

$E_0 = \frac{E}{\sqrt{3}}$

$e_{so} = E_0 - I_m X$

$F_0 = \frac{F}{3}$ for motor; $\left(\frac{F}{6}\right.$ for motor-generator set$\left.\right)$

$g_0 = \frac{I_h}{e_{so}}$

$I_h = \frac{W_1}{3\,E_0}$

I_m = Running light amperes

$I^2R = \frac{3}{2}$ (res. between lines at 25 deg.) $\times (I_m^2)$

$R = \frac{1}{2}$ (res. between lines at 65 deg.)

$R_1 = \frac{1.1\,E_0\,S}{I}$

$$R_2 = \frac{W}{3I^2} - R$$

$$W_1 = \text{Excitation watts} - (I^2R + F)$$

$$X = \frac{1}{2}\sqrt{\left(\frac{V}{\sqrt{3}\,I}\right)^2 - (R+R_2)^2}$$

$$X_1 = X$$

$$\text{Torque} = \frac{21.12\ T}{\text{Syn. r.p.m.}}$$

$$\text{H.P.} = \frac{P - F_0}{248.7}$$

$$\text{P-F. (at zero load)} = \frac{\text{Exc. watts}}{\sqrt{3}\ EI_m}$$

$$\text{Slip at max. output} = \frac{R_1}{R_1 + \sqrt{(R+R_1)^2 + (X+X_1)^2}}$$

2-PHASE MOTORS

$$b_0 = \frac{I_m}{e_{so}}$$

$$E_0 = E$$

$$e_{so} = E_0 - I_m X$$

$$F_0 = \frac{F}{2} \text{ for motor; } \left(\frac{F}{4} \text{ for motor-generator set}\right)$$

$$g_0 = \frac{I_h}{e_{so}}$$

$$I_h = \frac{W_1}{2\ E_0}$$

I_m = Running light amperes

I^2R = 2(res. between lines at 25 deg.) × (I_m^2)

R = Res. between lines at 65 deg.

$$R_1 = \frac{1.1\ E_0\ S}{I}$$

$$R_2 = \frac{W}{2I^2} - R$$

$$W_1 = \text{Excitation watts} - (I^2R + F)$$

$$X = \frac{1}{2}\sqrt{\left(\frac{V}{I}\right)^2 - (R+R_2)^2}$$

$$X_1 = X$$

$$\text{Torque} = \frac{14.08\ T}{\text{Syn. r.p.m.}}$$

$$\text{H.P.} = \frac{P - F_0}{373}$$

$$\text{P-F. (at zero load)} = \frac{\text{Exc. watts}}{2\ EI_m}$$

$$\text{Slip at max. output} = \frac{R_1}{R_1 + \sqrt{(R+R_1)^2 + (X+X_1)^2}}$$

S_1	.014	.021	.028	.035
S_1^2	.000196	.000441	.000784	.001225
$S_1^2X_1^2$	.000003272	.000007362	.00001309	.00002046
R_1^2	.004393	.004393	.004393	.004393
$R_1^2+S_1^2X_1^2$	.004396272	.004400362	.00440609	.00441346
S_1R_1	.0009279	.0013915	.001856	.00232
$a_1=\frac{S_1R_1}{R_1^2+S_1^2X_1^2}$	.2111	.3163	.4214	.5258
g_0	.010435	.010435	.010435	.010435
$b_1=a_1+g_0$	.221535	.326735	.431835	.536235
$S_1^2X_1$	.00002533	.000057	.00010135	.0001584
$a_2=\frac{S_1^2X_1}{R_1^2+S_1^2X_1^2}$	.005761	.01296	.023	.0359
b_0	.14725	.14725	.14725	.14725
$b_2=a_2+b_0$	.153011	.16021	.17025	.18315
b_1^2	.04905	.10675	.1864	.2874
b_2^2	.02341	.02567	.02899	.03355
$b_1^2+b_2^2$	.07246	.13242	.21539	.32095
$\sqrt{b_1^2+b_2^2}$	.2692	.364	.464	.5663
Rb_1	.00908	.01339	.0177	.02198
Xb_2	.01978	.02071	.022	.02368
$c_1=1+Rb_1+Xb_2$	1.02886	1.03410	1.0397	1.04566
Xb_1	.02862	.04221	.0558	.0693
Rb_2	.006273	.006567	.00698	.00751

CALCULATION SHEET NO. 20

CALCULATION SHEET NO. 20 (Continued)

$c_2 = Rb_2 - Xb_1$	−.022347	−.035643	−.04882	−.06179
c_1b_1	.2278	.3377	.4488	.5602
c_2b_2	−.003418	−.005708	−.00831	−.011315
$c_1b_1 + c_2b_2$	.224382	.331992	.44069	.548885
c_1^2	1.058	1.069	1.0805	1.093
c_2^2	.000499	.00127	.001895	.003818
$c_1^2 + c_2^2$	1.058499	1.07027	1.082395	1.096818
$\sqrt{c_1^2 + c_2^2}$	1.029	1.035	1.04	1.0475
$e = \frac{E_0}{\sqrt{c_1^2 + c_2^2}}$	246.9	245.3	244.3	242.5
e^2	60940.	60200.	59670.	58800.
$I^1 = e\sqrt{b_1^2 + b_2^2}$	66.45	89.3	113.36	137.4
$T = e^2a_1$	12870.	19040.	25150.	30920.
$1 - S_1$	.986	.979	.972	.965
$P = T(1 - S_1)$	12690.	18640.	24440.	29840.
F_0	300.	300.	300.	300.
$P - F_0$	12390.	18340.	24140.	29540.
$P_0 = e^2(c_1b_1 + c_2b_2)$	13670.	19990.	26300.	32280.
Eff. $= \frac{P - F_0}{P_0}$	.906	.9175	.918	.9155
P-F. $= \frac{P_0}{E_0I^1}$	.81	.882	.914	.9255
H.P. = (See notes)	49.84	73.75	97.1	118.8
Torque = (See notes)				

SUMMARY OF SPECIAL TEST

EXCITATION RUNNING LIGHT

	Volts	Amperes	Watts
Polyphase	440	36.7	3026
Single-phase	440	60.5	3460
Friction watts			900

STATIONARY IMPEDANCE

Polyphase	57	118	4375
Single-phase	57	102	2050

Impedance amp. at rated volts = 910. Max. = 936. Min. = 810. Slip (S) = 2.8 per cent at normal load of 440 volts, 118 amperes.

Resistance between lines at 25 deg. cent. = 0.071 ohms; at 65 deg. cent. = 0.082 ohms.

CALCULATION CONSTANTS

$E_0 = 254.$	$X = 0.12926$	$I_h = 2.601$
$R = 0.041$	$X_1 = 0.12926$	$I_m = 36.7$
$R_1 = 0.06627$	$X_1^2 = 0.0167$	$e_{so} = 249.26$
$R_1^2 = 0.004393$	$I^2R = 143.4$	$g_0 = 0.010435$
$R_2 = 0.06377$	$W_1 = 1982.6$	$b_0 = 0.14725$
	$F_0 = 300$	

SUMMARY OF CHARACTERISTICS

Per cent load	50	75	100	125
Horse power	50	75	100	125
Amperes line	67	93	120	143
Per cent efficiency	90.4	91.6	91.8	91.1
Per cent power-factor	81	88.8	92	92.9

CALCULATION SHEET NO. 21

STATIONARY TORQUE ON A 15 H.P., 220 V., 6-POLE, 60 CYCLE, 2-PHASE INDUCTION MOTOR

Lever Arm.	Controller Pos.	Volts	Amp.	W + F	W − F	W + F + T	W − F + T	W	W + T	T	Norm. T 1 Ft.
2 ft.	1	220	21–41	16.25	14.25	33	33	15.25	33	17.75	35.5
	2	220	36–39	17.25	14.25	50.75	48.75	15.75	49.75	34	68
2.292 ft.	2	220	38–37	17.25	16.25	47.75	47.75	16.75	47.75	31	71
	3	220	57–34	17.25	16.25	54.75	53.75	16.75	54.25	37.5	86
	4	220	96–44	17.25	17.25	67	66	17.25	66.5	49.25	113
	4	220	98–45	17.25	17.25	68	66	17.25	67	49.75	114
	6	209	121–92	16.25	16.25	78	78	16.25	78	61.75	156
	7	187	195–97	17.25	16.25	61.75	59.75	16.75	60.75	44	139
	8	175	173–162	16.25	15.25	51.75	50.75	15.75	51.25	35.5	128.7

Lever Arm. = 2 ft. and 2.292 ft.
Normal running torque at 1 ft. radius = 65.6 lb.

CALCULATION SHEET NO. 23

RUNNING TORQUE TEST ON A 75 KW., 2300 V., 26 POLE, 276 R.P.M., 3-PHASE SYNCHRONOUS MOTOR

GENERATOR								MOTOR									
Volts	Amp.	EI	*I^2R	EI Brush	Stray Power	Output ATI	Amp. Fld.	Volts	Amp.	$\sqrt{3}$ EI	W_1 +	W_2 −	Total Watts	R.P.M.	Torque at 1 Ft.Rad.	P-F.
0	0	0	0	0	2600	2600	3.0	1163	24.15	48700	17290	9280	8010	276	66.3	16.45
278	16	4450	16	13	2420	6899	3.0	1163	25.8	52000	21500	7520	13980	263	185	26.9
264	25.5	6730	40	31	2300	9101	3.0	1163	27.05	54550	23510	5600	17910	254	252	32.9
250	36	9000	80	54	2170	11304	3.0	1163	28.65	57750	25930	4800	21130	244	326	36.6
242	42	10160	109	67	2040	12376	3.0	1163	30.1	60700	28100	4160	23940	234	372	39.4
227	48	10900	143	82	1880	13005	3.0	1163	31.2	62950	29380	3200	26180	222	413	41.6
212	52	11010	168	94	1715	12987	3.0	1163	32.3	65080	30580	2720	27860	210	435	42.8
191	58.2	11110	210	110	1500	12930	3.0	1163	34.25	69050	32960	2400	30560	193	472	44.2
163	63.5	10350	250	123	1150	11873	3.0	1163	36.15	72850	34800	2240	32560	165	507	44.7
123	69	8490	295	138	750	9673	3.0	1163	38.2	77000	37120	1600	35520	126	540	46.1
117	69	8070	295	138	670	9173	3.0	1163	39.05	78700	38220	1600	36620	117	551	46.5
85	72	6120	321	144	480	7065	3.0	1163	41.15	83000	39530	2240	37290	92	541	44.9
0	0	0	0	0	2600	2600	3.0	1163	24.15	48700	17430	9120	8310	276	66.3	17.05

Motor—R.L.C. 6-75-250/1000.
Arm. res. =0.062
No. brushes =24.
Size " =1¼ by ⅜.
Kind " =Speer dry.

* Includes arm. and series and com. field if used.

STARTING TEST ON A 425 KW., 11000 V., 8-POLE, 25 CYCLE, 3-PHASE SYNCHRONOUS MOTOR

	Volts Line			Amp. Line			Ind. Volts per Spool	Pos. at Start	Time to Syn.
	1–2	2–3	1–3	1	2	3			
Rest . . .	1340	1430	1480	15	17.5	15.2	52	1	
Start . . .			2650		35		90.7		
Syn. . . .	2650	2650	2650	9.2	9	8.9			66 Sec.
Rest . . .	1255	1340	1340	15	16	13.6	47	2	
Start . . .		2560			30		88.3		
Syn. . . .	2560	2560	2560	9.5	9.3	9.2			70 Sec.
Rest . . .	1155	1300	1320	15	14	12.7	45	3	
Start . . .			2380	29.5			84.7		
Syn. . . .	2380	2380	2380	10	10.2	10			70 Sec.
Rest . . .	1248	1260	1165	15	12.8	13.8	44	4	
Start . . .		2590		33			80.8		
Syn. . . .	2590	2590	2590	9	9.3	9.5			68 Sec.
Rest . . .	1400	1308	1302	15	13.9	16.2	49	5	
Start . . .	2620					32	87		
Syn. . . .	2620	2620	2620	8.9	9.1	9.3			64 Sec.

Is there any tendency to stick at half speed? No.

CALCULATION SHEET NO. 24

MOTOR CORE LOSS AND SATURATION ON A 1000 KW., 600 V., 8-POLE, 375 R.P.M., 6-PHASE SYNCHRONOUS CONVERTER

Direct Volts Arm.	Amp. Arm.	Amp. Field	Speed	IE	I^2R Arm.	Core Loss and Friction	Volts A-C. Side
258	54	2.36	375	13920	30	13890	179
273	51	2.50	375	13910	20	13890	188
300	49	2.81	375	14710	20	14690	210
348	44	3.3	375	15300	20	15280	240
415	39.5	4.05	375	16400	10	16390	288
452	38.5	4.45	375	17400	10	17390	309
503	37.6	5.24	375	18900	10	18890	350
565	37	6.22	375	20900	10	20890	389
600	37	7.12	375	22200	10	22190	421
630	37.9	7.89	375	23850	10	23840	439
660	38.1	8.88	375	25100	10	23090	462
687	41.1	9.8	375	28200	10	28190	479
					BRUSHES		
600	35.5	7.1	375	21300	D-c. down, A-c. up		
600	33.5	7.1	375	20100	D-c. up—(except 2), A-c. up		
600	35.1	7.1	375	21050	D-c. up—(except 2), A-c. down		

D-c. brush friction—1200.
A-c. " " — 950.
Total friction windage from curve 11800.
Res. of armature at end of C.L. = 0.0088.

CALCULATION SHEET NO. 25

CALCULATION SHEET NO. 26

EFFICIENCY AND REGULATION OF A DYNAMOTOR 1500/750 V., TYPE CDM-13

MOTOR				GENERATOR						
Volts Line	Amp. Line	Amp. Shunt Field	Volts Field	Volts	Amp. Series Field	Amp. Load	Speed	Input Watts	Output Watts	Per Cent Efficiency
1500	3.82	0.235	732	742	2.7	6.28	1464	5730	4660	81.2
1500	4.64	0.235	730	735	3.55	7.97	1472	6960	5860	84.2
1500	6.54	0.233	725	729	5.65	11.77	1474	9810	8600	87.7
1500	9.15	0.230	720	724	8.07	16.75	1479	13730	12130	88.4
1500	10.65	0.228	718	723	9.48	19.95	1482	16000	14530	90.8
1500	12.87	0.225	705	709	11.8	24.3	1486	19300	17220	89.5
1500	14.58	0.222	704	704	13.5	27.9	1493	21880	19650	90.0
1500	16.60	0.220	698	698	15.83	32.4	1498	24900	22650	91.0
1500	19.1	0.215	689	689	17.96	37.1	1508	28650	25600	89.4
1500	25.2	0.210	664	664	24.7	50.2	1538	37800	33350	88.4

MOTOR CORE LOSS ON A DYNAMOTOR 1500/750 V., CDM-13

Volts Machine	Amp. Machine *	Amp. Shunt Field	Volts Shunt Field	Volts Generator Arm.	Speed	IE Input	Friction	Total I^2R Arm. and Fields	Core Loss
867	0.96	0.28	419	428	1010	832	255	121	456
976	1.00	0.32	475	484	1096	976	285	155	536
1092	1.05	0.36	530	542	1180	1147	318	194	635
1190	1.08	0.38	577	591	1256	1295	350	222	723
1307	1.15	0.43	630.5	649	1340	1502	388	274	840
1358	1.18	0.445	659	668	1376	1602	405	296	901
1410	1.20	0.460	683	702	1412	1692	424	318	950
1465	1.22	0.480	710	730	1450	1785	441	345	999
1478	1.23	0.485	718.5	736	1458	1830	445	352	1033
1520	1.24	0.495	736	756	1492	1884	464	368	1050
1576	1.25	0.520	760	782	1526	1968	481	399	1088
1622	1.26	0.540	780	805	1560	2045	499	425	1121

* Amp. machine include amp. shunt field.

CALCULATION SHEET NO. 27

MOTOR CORE LOSS ON DYNAMOTOR (Cont'd)

FRICTION READINGS—(SERIES FIELD ONLY)

Volts Line	Amp. Motor	Volts Generator	R.P.M.	IE	I^2R of Arm. and Field	Friction
450	1.02	250	1470	459	6	453
437	1.015	243	1444	444	6	438
423	1.005	235	1402	425	6	419
405	0.990	225	1355	401	5	396
387	0.980	215	1300	379	5	374
370	0.975	206	1265	361	5	356
357	0.965	198	1230	345	5	349
345	0.950	190	1198	337	5	332
330	0.940	182	1150	310	5	305
316	0.935	175	1109	296	5	291
300	0.920	165	1063	276	5	271
290	0.915	160	1031	266	5	261
277	0.910	153	989	252	4	248

Res. Hot.—After Core Loss—Mot. Arm. 1.0 ohms
Gen. Arm. .94 "
Mot. Series Field 1.42 "
Gen. Series Field 2.07 "
Shunt Field 1260 "

SHUNT REGULATION ON A 100 KW., 600 R.P.M., 125 VOLT D-C. GENERATOR

	Volts Line	Amp. Line	Volts Fld.	Amps. Fld.	Speed
No load, normal volts .	125.0	0	66.2	7.56	600
¼ load, rheostat as above	118.8	200	62.0	7.1	600
¼ load, normal volts . .	125.0	200	71.0	8.1	600
½ load, rheostat as above .	114.2	400	65.0	7.5	600
½ load, normal volts . .	125.0	400	73.0	8.4	600
¾ load, rheostat as above .	113.1	600	66.0	7.6	600
¾ load, normal volts . .	125.0	600	92.0	10.6	600
Full load, rheostat as above	112.2	800	83.0	9.5	600
Full load, normal volts .	125.0	800	103.0	11.9	600
No load, rheostat as above	145.3	0	117.0	13.5	600

CALCULATION SHEET NO. 28

EFFICIENCY AND REGULATION ON HT-60-400-6600/11400Y-480

Connection (primary) 6600, (secondary) 480.
Temp. deg. cent. (efficiency) 25, (regulation) 25.
Core loss (per cent) 0.62 at 1.0 P-F.
Core loss (per cent) 0.775 at 0.8 P-F.
Core loss (watts) 2480.
I^2R primary } 2096.
I^2R secondary }
Total loss 4576.
IR per cent 0.524.
IZ per cent 4.
Per cent total loss 1.14, at 1.0 P-F.; 1.43 at 0.8 P-F.
Kw. input 404.58, at 1.0 P-F.; 324.58 at 0.8 P-F.
Kw. output 400, at 1.0 P-F.; 320 at 0.8 P-F.

Per Cent Load	100 PER CENT POWER FACTOR		80 PER CENT POWER-FACTOR	
	Test	Guar.	Test	Guar.
	PER CENT EFFICIENCY			
150				
125	98.9	98.5	98.6	
100	98.9	98.5	98.6	
75	98.8	98.4	98.5	
50	98.5	97.9	98.2	
25	97.5	96.2	96.9	
	PER CENT REGULATION			
100	0.602	0.75	2.84	

Resistance at 25 deg. cent. (primary) 3.13, (secondary) 0.0105.

CALCULATION SHEET NO. 29

EFFICIENCY AND REGULATION ON WCT-25-2800-38100/66000Y-2300

Connections (primary) 66,000, (secondary) 2300.
Temp. deg. cent. (efficiency) 25, (regulation) 25.
Core loss (per cent) 0.54 at 1.0 P-F.
Core loss (per cent) 0.676 at 0.8 P-F.
Core loss (watts) 15140.
I^2R primary } 40900.
I^2R secondary }
Total loss 56040.
IR per cent 1.46.
IZ per cent 4.52.
Per cent total loss 2, at 1.0 P-F.; 2.5 at 0.8 P-F.
Kw. input 2856, at 1.0 P-F.; 2296 at 0.8 P-F.
Kw. output 2800, at 1.0 P-F.; 2240 at 0.8 P-F.

Per Cent Load	100 PER CENT POWER-FACTOR		80 PER CENT POWER-FACTOR	
	Test	Guar.	Test	Guar.
PER CENT EFFICIENCY				
150				
125	97.8	97.6	97.3	
100	98.0	97.9	97.6	
75	98.2	98.0	97.8	
50	98.2	98.0	97.8	
25	97.5	97.2	96.9	
PER CENT REGULATION				
100	1.55	1.7	3.76	

Resistance at 25 deg. cent. (primary) 36.45, (secondary) 0.1151.

CALCULATION SHEET NO. 30

NOMENCLATURE

Type

The following abbreviations are used to designate the type of the apparatus listed:

AB	Transformer, air blast, single-phase.
ABQ	Transformer, air blast, two-phase.
ABT	Transformer, air blast, three-phase.
ABH	Transformer, air blast, six-phase.
AS	Alternator, revolving armature, single-phase.
AQ	Alternator, revolving armature, two-phase.
AT	Alternator, revolving armature, three-phase.
AH	Alternator, revolving armature, six-phase.
ASB	Alternator, revolving field, single-phase.
AQB	Alternator, revolving field, two-phase.
ATB	Alternator, revolving field, three-phase
AHB	Alternator, revolving field, six-phase.
ACS	Double current generator.
ASI	Synchronous motor, revolving field, single-phase.
AQI	Synchronous motor, revolving field, two-phase.
ATI	Synchronous motor, revolving field, three-phase.
AHI	Synchronous motor, revolving field, six-phase.
BR	Feeder potential regulator.
C	D-c. generator, turbine driven.
CC	D-c. generator, turbine driven, with comm. pole.
CB	Enclosed d-c. motor.
CBC	Enclosed d-c. motor with comm. poles.
CDM	Dynamotor.
CL	D-c. motor or generator.
CLC	D-c. motor or generator with comm. pole.
CO	D-c. motor for crane service.
CP	Air compressor with d-c. motor.
CPA	Air compressor with a-c. motor.
CPI	Air compressor with induction motor.
CQ	Small d-c. motor (Lynn make).
CV	Small d-c. motor (Lynn make).
CVC	Small d-c. motor (Lynn make) with comm. pole.
CY	D-c. motor for mine service.
DLC	D-c. motor or generator with comm. poles.
DMC	D-c. motor or generator with comm. poles.
GE	D-c. railway motor.
GEA	A-c. railway motor.
GEI	Railway induction motor.
H	Transformer (core type) single-phase.
HQ	Transformer (core type) two-phase.
HT	Transformer (core type) three-phase.
HC	Synchronous converter, six-phase.
HCC	Synchronous converter, six-phase, with comm. poles.
HCB	Synchronous converter, six-phase, split pole.
HCBC	Synchronous converter, six-phase, split pole, with comm. poles.
HM	D-c. motor for mining service.
I	Induction motor, three-phase.

IQ	Induction motor, two-phase.
IS	Induction motor, single-phase.
KT	Induction motor, three-phase for crane service.
IRH	Potential regulator, induction type, six-phase.
IRQ	Potential regulator, induction type, two-phase.
IRS	Potential regulator, induction type, single-phase.
IRT	Potential regulator, induction type, three-phase.
ISB	Induction alternator, single-phase.
IQB	Induction alternator, two-phase.
ITB	Induction alternator, three-phase.
LM	Mining locomotive.
MCF	D-c. generator or motor with compensating winding in the pole face.
MD	D-c. mill motor, totally-enclosed.
MDO	D-c. mill motor.
MDS	D-c. mill motor.
MI	A-c. mill motor induction type.
MP	D-c. generator or motor (multipolar).
MPC	D-c. generator or motor (multipolar) with comm. poles.
NR	Starting compensator for induction motor.
OC	Transformer (oil-cooled) single-phase.
OCQ	Transformer (oil-cooled) two-phase.
OCT	Transformer (oil-cooled) three-phase.
OCH	Transformer (oil-cooled) six-phase.
PCS	A-c. commutator motor for variable speed.
PCR	A-c. commutator motor for regulating.
QC	Synchronous converter, two-phase.
QCB	Synchronous converter, two-phase, split pole.
QCC	Synchronous converter, two-phase, with comm. pole.
RI	Repulsion induction motor.
TA	Voltage regulator for a-c. generators.
TD	Voltage regulator for d-c. generators.
RLC	D-c. motor comm. poles variable speed.
RC	D-c. motor comm. poles for machine tools.
TC	Synchronous converter, three-phase.
TCB	Synchronous converter, three-phase, split pole.
TCC	Synchronous converter, three-phase with comm. pole.
WC	Transformer (water-cooled) single-phase.
WCQ	Transformer (water-cooled), two-phase.
WCT	Transformer (water-cooled), three-phase.
WCH	Transformer (water-cooled), six-phase.
YC	Synchronous converter, split pole, comm. pole.

Class Rating

Following the type letters is a set of figures denoting the "class rating" of the apparatus. This class rating is variable, but for the more common apparatus conforms usually to the following:

Generators, Motors, and Synchronous Converters

Poles—kw.—speed, e.g., MPC-6-500-720.
Some ratings give the size of frame, or use an arbitrary number. e.g., DLC-201 (30 h.p.-1100) CB 14; CP-21; GE-210; MD-108.

Transformers

Cycles—kv-a.—volts primary—volts secondary, e.g., AB-25-500-4400-220.

Potential Regulators

Poles—kv-a.—cycles—volts primary—volts secondary—amperes secondary, e.g., IRH 4-280-25-200-25-3700.

Form

Form letters are used to denote details of mechanical construction or to show that the apparatus was built for some particular purpose.

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