# Westinghouse

# Motor-Generator

## INSTRUCTION BOOK

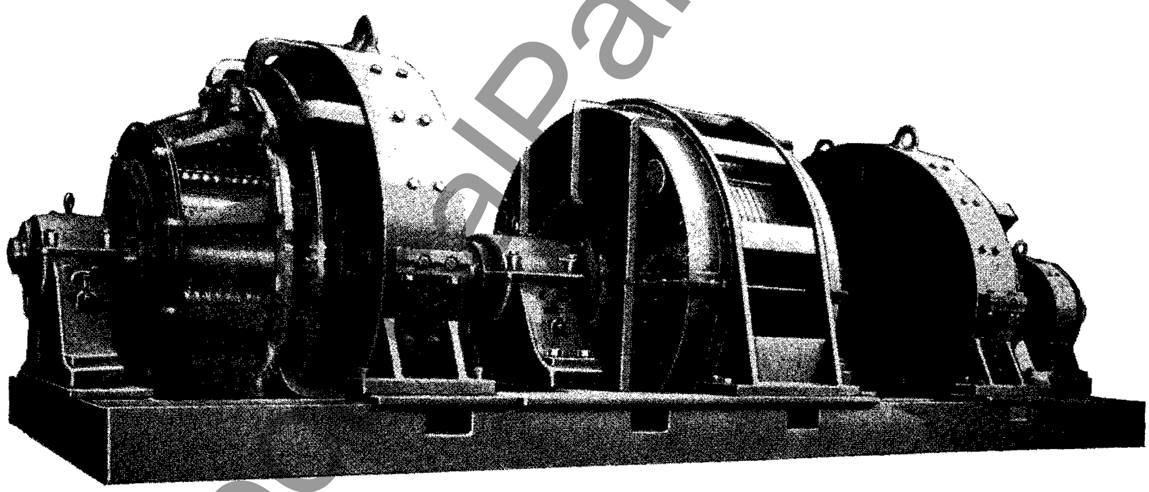


Fig. 1—3000 Kw. Motor-Generator

Westinghouse Electric & Manufacturing Company

East Pittsburgh Works East Pittsburgh, Pa.

I. B. 5411-A

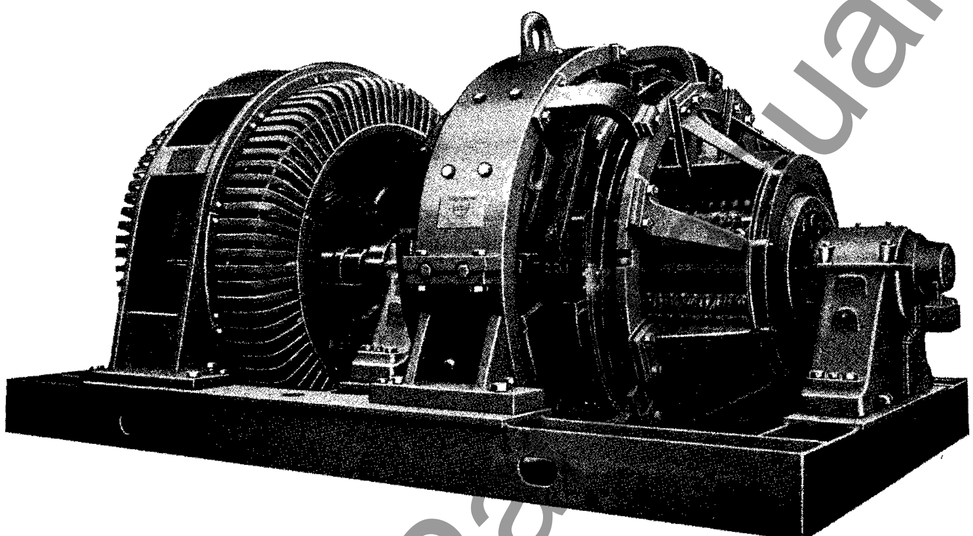


Fig. 2—1000 Kw. 250 Volt 720 Rpm. Motor-Generator

# Important Notice

## Mechanical Re-determination of Neutral Position

### On Fabricated Type D-C. Brush Riggings

At any time, the following mechanical method for determining the factory neutral position, can be applied:

With a convenient constant radius, using the two countersunk holes in the front edge of the frame as centers, scribe two arcs to intersect on the commutator surface between the ends of the bars and the first brush, so that the point of intersection is visible when the brush arm is in place.

If the axial center line of a brush contact surface be made to coincide with the point of arc intersection, the brush will be in the factory neutral position. The position of one brush arm is thus established and the other brush arms can be spaced with reference to it.

# Westinghouse

# Motor-Generators

## GENERAL INFORMATION

The motor-generators covered by this Instruction Book, include the larger a-c.—d-c. sets with either synchronous or induction motor drive. The well known advantages of the synchronous motor, such as its adjustable power factor, high efficiency and constant speed, have brought the synchronous set into far more general use than the induction set. For that reason, the instructions given here will deal largely with the synchronous type although, where differences of construction or operation require it, exceptions will be made to cover the induction type.

## CONSTRUCTION

### General

The smaller sets are built with the two machines mounted on a single bedplate and with three bracket bearings for supporting the rotors. The shafts are coupled together solidly with either cast iron couplings which are pressed on the shaft ends or, more often, with flanges which are forged as part of the shafts.

Larger sets have three pedestal bearings with the shafts coupled together in the same manner.

Three unit sets consist of a single motor driving two generators. The motor is placed in the center and there are four pedestal bearings.

### Exciters

Exciters may be mounted on either or both ends of the set. The exciter frame is usually supported by a stand which is bolted to an extension of the bedplate. This allows the stand and the exciter stator to be removed in case it becomes necessary to remove one of the main rotors for repairs. The exciter armature may be mounted on an extension of the main shaft or on a small shaft coupled to the end of the main shaft.

### Bedplates

The bedplates are fabricated from structural steel beams. For very large sets it may be necessary to make the bedplate in sections bolted together or to use separate side rails and end rails which are not joined at the corners but which are mounted separately on the foundation. Cast-iron bedplates were used formerly but these have been superseded by the fabricated steel structures. The cross member of the bedplate which carries the center pedestal bearing of a three-bearing set is sometimes made removable. This allows greater accessibility when repairs are made. Four-bearing sets have two cross members or bridges for the two center pedestals and one of these is usually removable. It is sometimes necessary to support the bridges in the center by means of vertical columns which extend into the pit and rest on concrete piers. These are bolted to sole plates at the bottom and to the bridge at the top.

### Bearings

The bearings are lubricated by means of oil rings. There are openings at the top of the bearing cap which permit inspection of the rings. The oil level can be determined by raising the spring cover on the sight hole which is provided on the pedestal. There is a drain cock which allows all of the oil in the reservoir to be removed. For large high speed machines it is often necessary to water-cool the bearings. Water inlet and outlet pipe connections are attached to the bearings in these cases. Some of the large sets are provided with a high pressure oil system for lubricating the bearings during starting. A small inlet pipe and a larger return pipe are furnished with the bearing when this system is used.

### Insulated Pedestals

Slight variations in the magnetic circuit of one of the machines may cause a periodic change in the amount of flux linking the shaft. The result of this is that a small voltage is generated in the shaft which tends to set up a current through the circuit formed by the shaft bearings and bedplate. If such a current is allowed to flow it soon has a destructive effect upon the journals and bearings. Small pits are usually formed on the surface of the shaft and these are sufficiently rough to score the surface of the bearing. Occasionally, the babbitt itself appears to be eaten away by the current.

To avoid this trouble certain of the pedestals are insulated from the bedplate so as to break up the flow of current. See Fig. 3. Usually, the two end pedestals are insulated, although this practice varies with the design of the particular set involved. A sheet of insulation about $\frac{1}{16}$ inch thick is placed between the bottom of the pedestal and the bedplate, and insulating tubes and

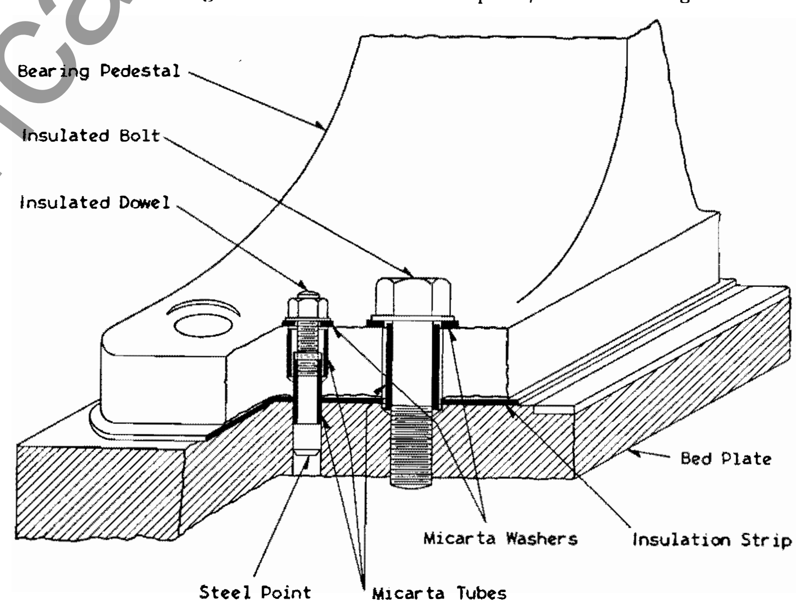



Fig. 3—Method of Insulating Bearing Pedestal from Bedplate

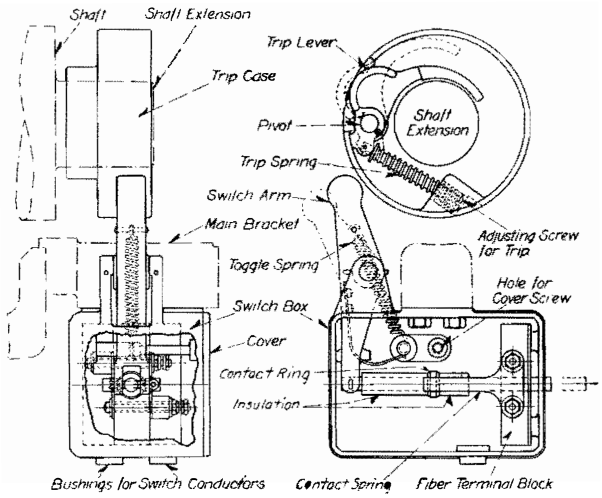



FIG. 4—SPEED LIMIT DEVICE DETAILS. SEE PAGE 23 FOR LIST OF PARTS

washers are used around the bolts and dowels. If water or oil piping is connected to the bearing, an insulated union is used. Care should be taken to see that there is no metallic connection between an insulated pedestal and the bedplate. If this precaution is not observed, the insulation becomes useless and bearing current is permitted to flow. Metallic connection may result from any of the following: Piping which touches both the pedestal and bedplate and which has no insulated union; guard rail; metal ladder set against the pedestal; tools left in contact with both pedestal and bedplate; pump or other device geared to the main shaft. A break in the insulation may occur during erection due to careless handling and it is well to test for this with a bell and battery or with a test lamp. If a machine has bearing currents it is usually possible to detect this by placing one end of a copper wire on the pedestal and touching the other end on the shaft from which sparks can be drawn. The wire simply shunts part of the current which otherwise flows through the bearing surfaces.

Many of the smaller sets have very little tendency to produce bearing currents and these may be operated safely without pedestal insulation. No insulation is furnished with machines in this class.

## Oil Pressure for Starting

The use of a high pressure oil system reduces the starting friction of large motor-generators and permits the use of lower starting voltages and currents. The equipment consists of a four cylinder pump driven by a small motor and the necessary piping.

The pressure developed by the pump is about 1000 lbs. per square inch which is sufficient to lift the shaft from the bearing and provide a perfect oil film.

If any of the bearings are insulated from the bedplate the piping connected to them should be equipped with insulated unions. (See page 3).

## Speed Limit Device

**The Speed-Limit Device**—As a safeguard against overspeeds, a speed-limit device is attached to one end of the shaft, consisting of a spring closed switch. When the machine reaches a certain speed above normal, a centrifugal governor mechanism operates the switch and opens the circuit-breakers, thus cutting off the machine from its source of supply. A circuit opening switch is regularly supplied with Westinghouse speed limit devices but a circuit closing switch can be supplied when desired.

**To Reset the Switch**—It is merely necessary to move the switch arm back to the normal position by hand. This can readily be done at any time whether the machine is running or not and without opening the switch box.

**Assembly of Speed-Limit Device**—All speed-limit devices are set and tested at the Works. The switch box complete is shipped attached to the pedestal. Bolt up parts in place, fasten the trip case to the shaft, next push in the switch arm; there should be at least 1/8 inch between the switch arm and the trip-case. (See Fig. 4).

**Adjustment of Speed-Limit Device**—When testing for overspeed the d-c. machine can be run as a motor, the d-c. bus or the set can be belted to a motor. It is important to have complete control of the speed during the test. Use a tachometer or any reliable direct-reading speed indicator, but do not use the ordinary revolving dial indicator.

Then test for overspeed; the switch should trip at about 15 per cent above normal speed. Bring the speed up slowly and watch for the tripping speed of governor trip-lever.

Should it be found necessary to reset the governor proceed as follows:

First determine the tripping speed, assemble the governor as shown in (See Fig. 4). Screw in the adjusting screw even with the governor case, and give the screw about one-half turn inward at each run until it trips at the overspeed. Then tighten the small locking screw on the side of the trip-case.

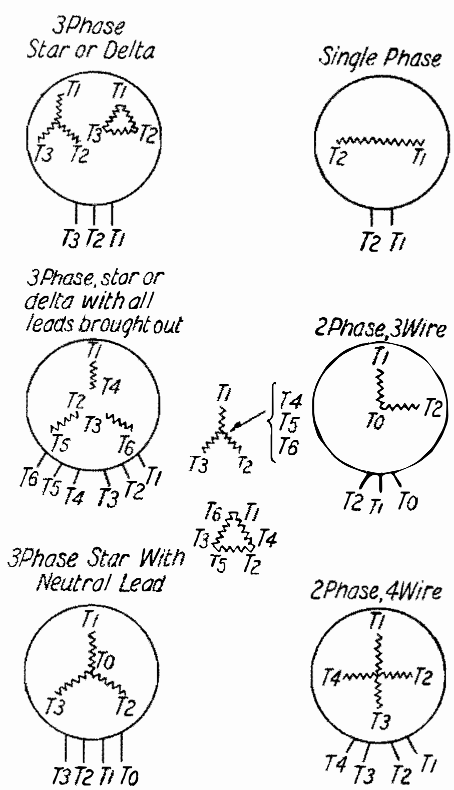



FIG. 5—STANDARD ARRANGEMENT OF LEADS FOR VARIOUS WINDINGS

Before starting each test see that the switch arm is in and pull the trip-lever several times by hand to see that it works freely.

**Inspection**—Speed limit devices should be tested and lubricated at regular intervals as a part of the routine inspection to insure that all parts are operative and all circuits complete. **Failure to maintain the overspeed device and wiring in proper condition may result in the loss of a machine.**

## Fans

Fans or blowers are attached to the rotors of most generators and motors to assist in forcing ventilating air through the machines. In some cases these are straight radial vanes each of which is bolted to the rotor. For other machines a completely assembled blower having inclined blades is bolted to each side of the rotor. The blades are inclined in such a way that they are not radial, the edge of the blade nearest the shaft being ahead of the outer edge in the direction of rotation. (See Fig. 6.) It is important that the set be run in such a direction that this relation is obtained since the amount of air delivered by the fan is greatly reduced when it is run in the opposite direction.

## Leads

**A-C. Leads**—The arrangement of leads for various types of windings is shown in Fig. 5. The leads are brought out normally at the bottom of the frame on the collector end of the machine and are equipped with terminals into which the purchaser's cable may be inserted.

**Phase Sequence**—The phase sequence, or phase rotation as it is sometimes called, is in the order of $T_1$, $T_2$, etc., when the mechanical rotation is in a clockwise direction viewed from the collector end of the machine. When the rotation is counterclockwise, viewed from the collector end, the phase sequence is in the reverse order.

A name plate, indicating direction of rotation, is attached to the rocker ring of the brush rigging of the D-C. generator.

**D-C. Leads**—The generator leads, except on small capacity machines are usually brought out underneath the generator frame.

## Methods for Disassembly for Repairs

The following general directions for removing the stators and rotors or for making them accessible for repairs apply to machines of standard design. For sets having special constructional features, there may be exceptions to these rules.

### Three Bearing Sets

(a) For cases in which either of the rotors is too large in diameter to be entirely removed from the stator, due to interference with the end member of the bedplate, the center bridge is made removable. This allows the center pedestal and bridge to be taken out and the stator of either machine to be shifted toward the center a sufficient distance to clear its rotor. The coupling bolts should be removed before the bearing is taken out so as to prevent an excessive strain on them. The rotor of the machine to be repaired should be supported at the inner end by a rope from a crane or by jacks or blocking from below. The other rotor may be allowed to rest against the stator.

(b) When both rotors are small enough in diameter to clear the bedplate the center bridge is not removable and the rotors should then be taken out of the stators in a direction away from the center. In some cases it is necessary to unbolt the center pedestal from the bedplate and, after removing the bearing cap, to lower the pedestal into the pit beneath the machine so that it will not interfere with the coupling. If there is a direct connected exciter it is necessary first to remove the exciter frame and its supporting stand. If the exciter rotor is coupled to the main shaft it should be removed also.

**Three Unit Sets with Four Bearings** The usual arrangement of three unit sets is an a-c. driving motor in the center with a d-c. generator on each end. One

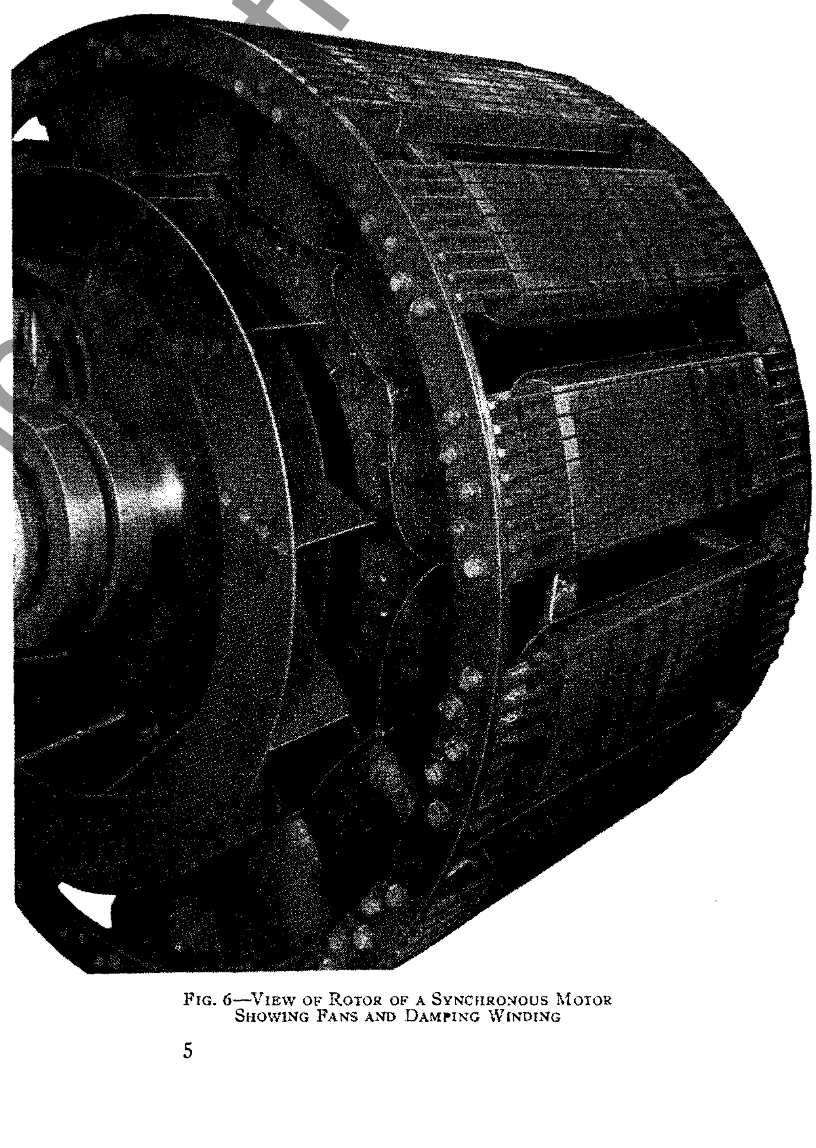


Fig. 6—View of Rotor of a Synchronous Motor Showing Fans and Damping Winding

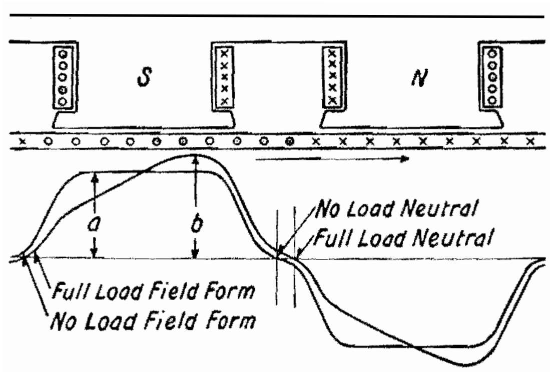



Fig. 7—Non-Commutating-Pole Generator

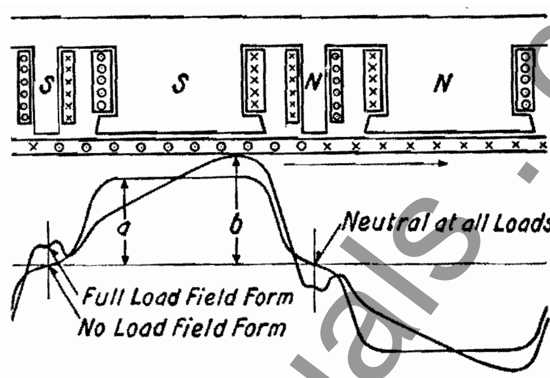



Fig. 8—Commutating-Pole Generator

of the two bearings next to the motor is mounted on a removable bridge. When this bridge and the bearing are removed the motor stator can be shifted along the bedplate a sufficient distance to clear the rotor and thus make both stator and rotor accessible for repairs. The armatures of the d-c. machines can be taken out of the stators when the end pedestals have been removed. An alternative method of handling the d-c. machines is to unbolt the upper half of the frame and lift it off entirely thus making the armature accessible for repairs. In the case of a compensated generator it is necessary to open up the compensating winding before the top half of the frame can be removed.

## Types of Direct-Current Generator Construction

There are two general types of construction, which are being used in direct-current machines: One type using commutating poles only and the other type, which is a variation of the commutating-pole type and which is called a "compensated" machine using a pole face winding in addition to the commutating poles. The commutating poles are small poles placed between the main poles. These small poles are magnetized by a winding which is in series with the armature, so that the flux furnished to assist commutation will vary with the armature current. The brushes are so placed that the coil undergoing commutation comes under the influence of the flux from the commutating poles, this flux being of such value and direction that the cutting of it produces in this coil, a voltage which neutralizes the voltage of self-induction. In a generator, the flux from the commutating pole must be in the same direction as the flux from the main pole immediately ahead and in a motor, the flux from the commutating pole must be in the same direction as the flux from the main pole immediately behind.

The commutating pole maintains the neutral position midway between the main pole pieces, for either a motor or a generator, and since the commutating-pole winding is in series with the armature, a change from generating load to motor load automatically changes the polarity of the commutating poles.

The **compensated** machine may be looked upon as a modified commutating-pole machine. The commutating-pole machine has the exciting winding concentrated about the commutating pole while the compensated machine has a part of the exciting winding distributed in the main pole face. The total excitation is the same in both cases. In the illustrations (Figs. 7 to 9), the direction of the currents and the shape of the magnetic fields are shown for the non-commutating-pole machine, the commutating-pole machine and the compensated machines. (The non-commutating-pole diagram is shown for comparison only, as this type of machine is not used in motor-generators.)

As the commutating-pole machine is simpler in mechanical construction than the compensated machine, the question naturally arises as to why the latter construction is used. In order to explain this, it is necessary to consider the function of the commutating-pole winding. Figs. 10 and 11 show the magneto-motive forces which are present in both types of machines. The essential difference, as will be noticed from an inspection of the diagram, is that in the commutating-pole machine, the armature reaction is not neutralized in the zone "a-b", while on the compensated-pole machine the armature reaction is completely neutralized under the main pole. In order to maintain the best commutating condition, the flux from the commutating pole must change in exact proportions to the change of load. As soon as there is any saturation in the commutating pole, this exact relation is destroyed and the commutation limit is soon reached.

As the commutating pole must carry both the useful flux for commutating and also any leakage flux which may be produced by its winding, it is evident that reducing the leakage flux will in-

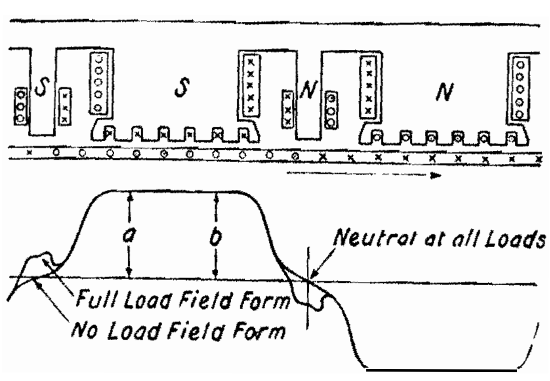



Fig. 9—Compensated Generator

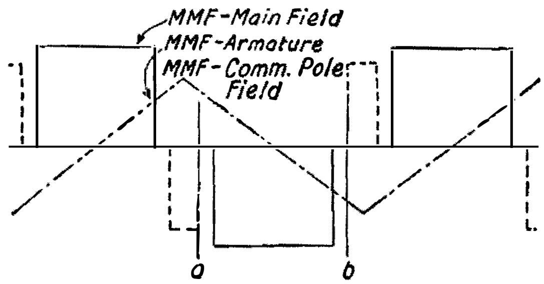



FIG. 10—M.M.F. IN COMMUTATING-POLE GENERATOR

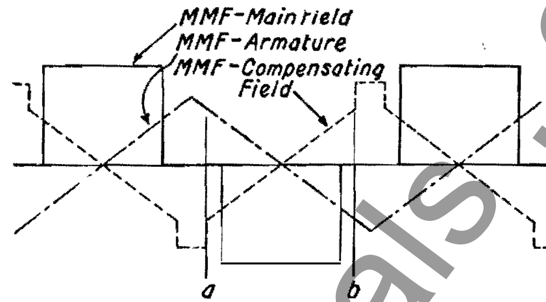



FIG. 11—M.M.F. IN COMPENSATED GENERATOR

crease the commutating limit of the machine. The most effective way of reducing this leakage flux is to distribute the commutating-pole exciting field winding in the main pole faces and thereby increase the length of the path of leakage flux. This construction becomes what we have called the compensated machine and it possesses two distinct advantages over the plain commutating-pole machine. It has a greater maximum commutating capacity and the armature cross-magnetization is neutralized under the main poles, so that the maximum voltage between adjacent commutator bars is correspondingly less. By taking advantage of these points, it becomes possible, by the aid of compensation to increase the speed of generators and to make motors which will meet more difficult cycles of operation. Within the limits of commutation, the commutating-pole machine commutates just as well as the compensated machine, but the limiting factor in commutation is the saturation of the commutating-pole magnetic circuit, and the main factor in saturating this circuit is the leakage flux, and as there is less leakage in this part of the compensated machine, the overload limit is correspondingly increased.

As the number of commutator bars per pole decreases with an increase of speed, a high average voltage between adjacent commutator bars is the result, and if the number of commutator bars is arbitrarily increased in order to obtain low average voltage between bars, the armature reaction is correspondingly increased, and the distortion of the main flux becomes greater, resulting in a high peak voltage between adjacent commutator bars. As has been shown in the compensated machine, there is little distortion of the main pole flux; consequently, with the same degree of safety, a higher voltage between commutator bars is permissible. That is, with the same peak voltage between commutator bars the compensated machine can have a higher average voltage between bars than the commutating-pole machine. Hence, for very high speeds, the compensated machine makes higher ratings possible. For the same reason the compensated machine, for a given speed, makes higher voltage machines possible.

The elimination of armature reaction by the use of distributed pole face windings improves voltage regulation **and greatly reduces commutating pole saturation.** It is possible to carry rapidly fluctuating peak loads without disturbance to commutation making possible many applications to which straight commutating pole machines are unsuitable. The straight line voltage regulation of compensated generators requires a careful investigation of parallel operation with other equipments.

The pole face windings and the necessary connections for the same introduce a certain amount of complication, which cannot be avoided, and as a result the compensated machine is not as easily dismantled and not as easily repaired as the commutating-pole machine. The better performance is obtained at a sacrifice of simplicity.

**Three Wire Generators**—The neutral wire for a three-wire, two-voltage system can be obtained from any Westinghouse generator by connecting collector rings to suitable points in the armature winding and connecting a balance coil between two collector rings (See Fig. 12).

The middle point of the balance coil is the neutral point to which the third or neutral wire of the system is connected. Two rings and one balance coil or four rings and two balance coils may be used depending on the space available for collector rings, the amount of unbalanced current, etc.

The commutating-pole windings and series field windings in three-wire generators are divided into two circuits (adjacent coils being in different circuits), one circuit being connected in the positive and one in the negative side. This is done to obtain the same excitation independently of the unbalancing. Consider the case of a generator with the series field in the negative side only and

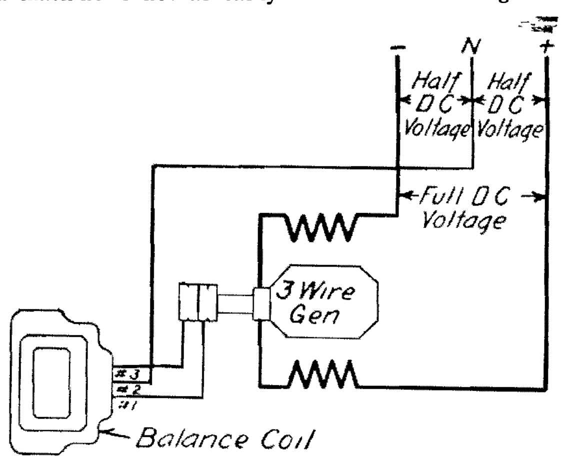



FIG. 12—DIAGRAM SHOWING CONNECTIONS OF BALANCE COILS FOR THREE-WIRE D-C. GENERATOR, 125-250 VOLTS

with all the load on the positive side. The current will flow from the positive brush, through the external circuit, back through the neutral wire without passing through the series-field winding.

**Equalizers**—As there are two series fields, two equalizer leads and busses are required.

**Ammeter Shunts** can be located in both negative and positive sides of the generator, in order that the meters will indicate the current in both armature leads.

# INSTALLATION

## General

The following instructions and precautions are intended to aid in the installation of motor-generators. In many cases the instructions are of a very general nature since the wide variety of types and sizes and the numerous special features that may be included make it difficult to give detailed instructions that are applicable to all units. The service of an experienced erection engineer is invaluable and must be relied upon for a great many of the details of installation.

For diagrams of connections see Figs. 31 to 35, pages 26 to 30.

## Foundations

The foundation should consist of solid concrete walls or piers whenever possible and should be carried down far enough to rest on a solid sub base. A competent engineer who is familiar with local conditions should lay out this part of the work. If it is necessary to support the bedplate on steel work instead of concrete, the girders should be well braced and supported by columns so as to prevent vibration.

The pits beneath the machines should be made deep enough to give plenty of working space for connecting the leads. They should be properly drained and if possible should be ventilated.

## Protection

The machines should be protected carefully against moisture both before and after erection. Water or steam from leaking pipes, rain, snow or condensation from the atmosphere should be excluded. It is particularly important to keep the windings and commutator dry since moisture lowers the insulation resistance and increases the likelihood of a breakdown. If a machine is brought from cold surroundings into a warm room, it should be kept covered until its temperature has risen to room temperature so as to prevent condensation on the windings and other parts. (See pages 10 and 11 for methods of drying out windings.)

Care should be taken in transporting and handling the machines to see that the windings are not damaged. A blow upon any part of the windings is liable to injure the insulation and result in a burn out of the coil.

Lifting of the machines by cranes should be done with the greatest care. The stators of the a-c. machines are usually provided with lifting holes in the sides of the frame in to which the crane hooks may be inserted. The d-c. stators have eye bolts for lifting. The rotors should be lifted preferably with rope slings looped around the shafts. In no case should the ropes or chains be allowed to exert pressure on the windings, commutator or collector rings. The entire set should never be lifted by the bedplate since the bedplate has not sufficient strength to carry the weight except when it is resting on a solid foundation. In the case of small sets which are shipped assembled and are to be lifted as a whole the crane hooks should be attached to the stator frames and one or more pieces of heavy timber should be wedged between the two frames at the top to prevent distortion.

## Location of Machines

It is of the greatest importance in laying out a power house or substation that the location of the sets be governed largely by the following considerations:

(1) The machines should not be, exposed to moisture from leaky pipes escaping steam or condensation of atmospheric moisture on overhead glass or a metal roof.

(2) They should not be exposed to the corrosive action of acid fumes or other injurious gases.

(3) They should not be exposed to dirt from coal handling or similar causes.

(4) Since the total temperature, and consequently the capacity of the machine, depends upon the temperature of the surrounding air, it is evident that the location should be in a room as cool and well ventilated as is consistent with proper protection from dirt and moisture.

(5) The position of the set should always be such that the commutator and collector rings, which require special attention, are readily accessible for inspection.

## Aligning Motor-Generator Sets

When considering the installation of motor-generator sets, such apparatus may be divided into two general classes, namely:

(1) Units shipped assembled.

(2) Units shipped unassembled.

Each class may again be divided into two-bearing and multi-bearing units.

**Two Bearing Units**—The aligning and leveling of two bearing units that have been shipped assembled is a relatively simple operation. The unit should be placed on the foundation with the bedplate resting on steel plates, shims or wedges. These supports should be of sufficient height to permit satisfactory grouting and they should be so located that they will carry the weight of the pedestals, rotor and the frame without distorting the bedplate. The unit should be brought into alignment with, and also leveled to the elevation of other apparatus or "bench marks" as required. The foundation bolts must have sufficient freedom of movement to permit such alignment. The pedestal caps should be removed so that the bearing alignment may be checked. Most satisfactory results in leveling horizontal electrical apparatus are usually secured by using a very accurate spirit level on the shaft or bedplate pads. It is sometimes desirable to use a piano wire "line" in checking the alignment of the pedestals or the stator bore, or in determining if the bedplate is distorted, but this is seldom necessary when a two bearing unit is being installed.

When the alignment (including the level) is satisfactory the nuts on the foundation bolts should be tightened snugly and the level should be again checked to make sure that the bedplate has not been distorted. If this check is satisfactory, the bedplate should be grouted. When the grout has hardened the nuts on the foundation bolts should be drawn down tight.

The grouting should be carried up nearly to the top surface of the bedplate so as to give rigid support for the machine. (See Figure 13).

**Multiple Bearing Units**—All standard modern multiple bearing motor-generator sets are made with two separate shafts bolted together by the use of flanged couplings. These couplings may be either of the pressed on type or with half couplings forged integral with the shaft.

Multiple bearing units may be classified for methods of shipment and alignment as:

1. Small motor-generator sets.
2. Large motor-generator sets.

**Small Motor-Generator Sets**—Standard units of this classification are provided with three main pedestal type bearings. When additional bearings are provided for exciters they are usually of the bracket type. This classification covers units that may be shipped with the main elements assembled. They will have a maximum rating of approximately 1500 kv-a., although this will depend to a considerable extent on the speed, which of course directly affects the dimensions and weights, which in turn control the method of shipment.

The method previously described, for aligning two bearing motor-generator sets should be used in the preliminary alignment of three bearing units. Before grouting the bedplate, however, the shaft alignment must be checked. Since the coupling faces are always machined perpendicularly true to the shaft axis, the shaft alignment can be checked very satisfactorily by loosening the coupling bolts and "breaking" the coupling so that a thickness (feeler)

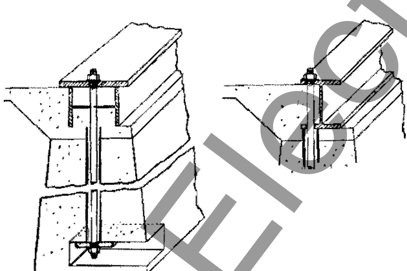


FIG 13—SETTING OF STRUCTURAL STEEL BEDPLATES

gauge may be inserted between the half coupling faces. The factory allowable tolerances for such alignment are:—

(A) The difference between the readings at either side —.001" for any size flange.

(B) The difference between the readings at the top and bottom—not to exceed .002" per 12" of flange diameter, but a maximum of .004" for any diameter of flange.

If the opening at the top and bottom of the coupling faces are not uniform the larger opening must always be at the top.

When the small motor-generator sets are being aligned, the adjustments to secure top and bottom flange alignment are made by elevating the ends of the bedplate. Care must be used to insure both ends being raised as near as possible the same amount.

During the coupling alignment the shafts should be rotated in the bearings 180° from the original checking position and the coupling separation should be re-checked at top, bottom and sides to again prove the shaft alignment and the truth of the coupling faces.

**Large Motor-Generator Sets**—As it concerns shipment and installation methods, this classification covers units that because of weight and dimension limitations must be shipped unassembled. The bedplate for a large motor-generator set should be aligned and leveled and it is usually grouted in before the various parts of the unit are assembled on it. These parts are assembled in accordance with regular practice for apparatus of this type. The final alignment is secured as described for small multiple bearing motor-generator sets except that the bedplate is maintained level from end to end and the shaft coupling faces are brought into alignment by the adjustment of the bearing pedestals by means of the use of steel shims between the pedestal and the bedplate pads. The tolerances given for small motor-generator set couplings also apply to large motor-generator sets.

Briefly, the steps for alignment are as follows:—

**Small Motor-Generator Sets Shipped Unassembled**—

1. Set the bedplate approximately level.
2. Mount the bearing pedestals, taking care to match the center line markings.
3. Mount the stators and rotors in the conventional manner.
4. Open the couplings enough to allow checking with a feeler gauge between the coupling faces.
5. Adjust the alignment to the following allowances.

   A. The allowable tolerance at either side is .001" for any size flange.

   B. The allowable tolerance at the top or bottom is not to exceed .002" per 12" of flange diameter with a maximum of .004" for any flange diameter.

**Note**—The adjustments to secure top and bottom flange alignment are made be elevating the bedplate. Care must be used to insure that both ends are raised an equal amount. If the opening at the top and bottom coupling faces is not uniform, the larger opening must always be at the top of the coupling.

6. Rotate the rotors in their bearings 180° from the original checking position and repeat the measurements made with the feeler gauge to prove the shaft alignment and the truth of the coupling faces.

**Small Motor-Generator Sets Shipped Assembled**—The same steps should be taken as for sets shipped unassembled with the exception of 1, 2 and 3 being omitted.

**Large Motor-Generator Sets Shipped Unassembled**—Large motor-generator sets are to be assembled much the same as the small motor-generator sets except that the bedplate must be equally level at all times.

To secure coupling alignment an equal amount, as near as possible, of sheet steel shims should be placed under both outboard pedestals. The same tolerances apply to all machines regardless of size.

The division line between small and large motor-generator sets is approximately 1500 kv-a., but will vary to some extent with the speed.

## Insulation Resistance

The insulation resistance of windings is measured, usually, with an instrument called a megger. This measurement gives an indication of the condition of the insulation particularly with regard to moisture and dirt. The actual value of resistance varies greatly in different machines depending on the size and voltage. The chief value of the measurement therefore, is in the relative values of resistance of the same machine taken at various times. During a drying out run, for example, the insulation resistance rises as the winding dries out. When measurements are made at regular intervals as part of the maintenance routine, it is thus possible to detect an abnormal condition of the insulation and take steps to remedy it before a failure occurs.

The insulation resistance of armature windings of machines in good condition is usually not less than the following:

$$\text{Insulation resistance (in megohms)} = \frac{\text{Machine voltage}}{\text{Rated Kw.} + 1000}$$

## Drying Out Windings

If there is reason to believe that the windings have been exposed to moisture during shipment or erection, it is well to subject them to a drying process before putting the machine into regular operation. The windings can be dried by passing current through them or by the use of external heat.

**A-C. Machine**—One way of circulating current through the motor windings without subjecting them to foll voltage, is to drive the machine and short-circuit the armature applying enough field excitation to give somewhat less than full load armature current. This implies that the d-c. machine of the set can be used as a driving motor which is not always possible. If both machines are in need of drying, as is usually the case, this method is not applicable, since the drying process should not involve subjecting either machine to full voltage.

A second method is to apply a low voltage, from an external source, to the armature winding. If the current is kept down to less than full load current there is a possibility that the machine will not rotate. If it does not rotate or if it rotates at less than synchronous speed, the damper winding should be watched to see that it does not overheat. The field winding should be short-circuited during the drying operation.

In all cases of drying by means of current in the windings, the temperature measured by thermometer should not be allowed to exceed 65°C. If the temperature is measured by imbedded detectors it may be allowed to go as high as 80°C. In general, the drying should proceed slowly at first and the heating should be increased gradually as the insulation dries. It is well to take readings of insulation resistance by means of a megger at intervals as this gives a good indication of the state of the insulation.

In many cases, it is impracticable to dry the windings by heat generated within the machine and external heat must be used. A tarpaulin should be used to cover the machine and some source of heat, preferably electric heaters, placed within the enclosure.

**Drying Out D-C. Generators.**

(1) Drive the generator by the motor or from some external source, such as a separately belted motor, and short-circuit the armature, beyond the ammeter using a very weak field excitation. If the generator is shunt-wound, low voltage, separate excitation must be employed; if compound-wound the armature may be short-circuited ahead of the series field coils or the series coils reversed.

Direct-current generators are very sensitive when operated as series machine and there is danger of generating an excessive current if the short-circuit is applied beyond the series field.

(2) The field coils may be dried by applying from some separate source of excitation, approximately two-thirds of the normal direct-current voltage.

There is always danger of serious injury to the windings when drying out with current since the heat generated in the inner parts is not readily dissipated; furthermore, coils containing moisture are much more susceptible to injury from overheating than when thoroughly dry. The temperature of

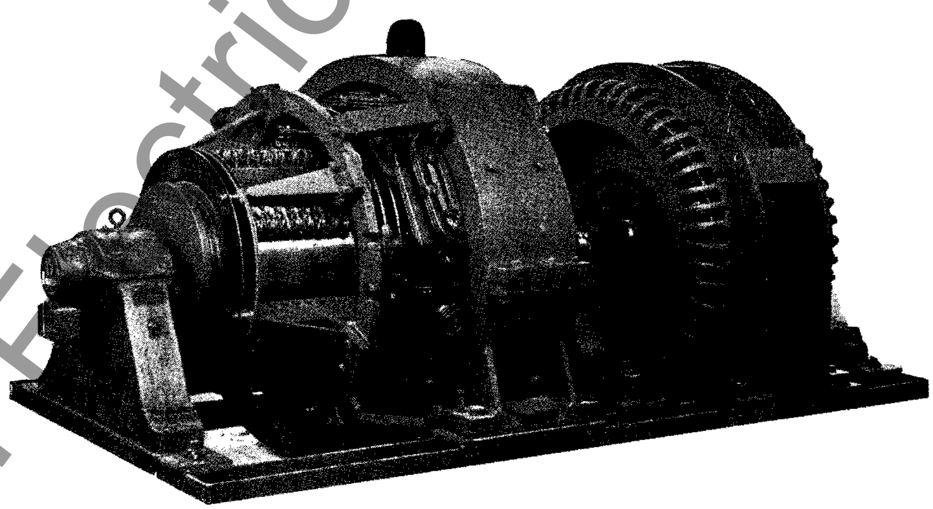


Fig. 14—750 Kw. 250 Volt, 900 Rpm. Motor-Generator

all accessible parts should be carefully observed during the drying out process and never allowed to exceed 80°C., total temperature. Several hours or even days may be required for thoroughly drying out large machines.

During the drying out process the temperature should not be allowed to drop below that of the surrounding air as moisture then condenses on the coil surfaces and the effect of the previous drying would be largely lost.

During the drying out run, readings of the insulation resistance should be taken at regular intervals and plotted as a curve, using time for the horizontal scale and resistance for the vertical scale. The drying out should continue until the resistance has begun to increase. If the insulation contains appreciable moisture the resistance will decrease during the first part of the drying out process.

Heating windings by current is more effective than any process of heating from the outside, such as enclosing the machine and heating the air by electric heaters, because in the former method the inside of the coils becomes hotter than the outside and moisture is driven outward. With external heating the reverse is true.

If the apparatus is to be stored before being put in service, consult the nearest Service Department for detail recommendations.

**Drying Out Induction Motors**—Induction motors can be dried by operation at no load and low voltage (the primary current and heating increases as the voltage is reduced) or by the application of a still lower voltage that will circulate a sufficiently heavy current at standstill. If a suitable low alternating voltage is not available, direct-current, if available, may be used. Lacking any source of current the motor can be dried by enclosing it as completely as possible by wood or canvas and heating the enclosure by external means.

## Connections

**Main Leads**—In laying out the wiring of several compound-wound generators that are to operate in parallel, particular attention should be paid to the relative resistance of the several circuits.

If the generators are of the same size and make, the only feature requiring special attention is that all the cables which lead from the various machines to the bus-bars be of equal resistance. This means that if the machines are at different distances from the switchboard, the same length of cable should be used for each generator or resistance inserted in the low resistance leads.

If the generators differ in design or size, the matter requires more attention. In this case the difference in potential or drop in voltage between the terminals of the machine and the bus-bars to which they are connected should be exactly the same for every generator when each is carrying its proper share of the load. To secure the best results, the total drop between generator terminal and switchboard must not only be the same at equal loads, but the drop in corresponding sections of the connecting cables of the different machines should also be equal; i.e., the drop in the positive lead from any one generator at full load should equal the drop in each of the other positive leads when carrying full load. The same condition should be secured in the negative lead, in the equalizer connections and in series field windings. It may be necessary in achieving the desired results to alter the length or size of connecting cables, and occasionally to add resistance to some of the circuits.

**Equalizer Leads**—In compound-wound direct-current generators operated in parallel, an equalizer lead is required. With grounded railway circuits, it is desirable to have the equalizer connection made on the negative or grounded side of the generator since with this arrangement it is unnecessary to carry the equalizer connections through the switchboard and the wiring is greatly simplified. This is the standard arrangement in Westinghouse generators.

The equalizer lead should have small resistance. It is the usual practice to make the equalizer leads equal to the main leads. In installations where long equalizer leads are necessary, a larger equalizer may be advisable in order to maintain a sufficiently low resistance.

**Series Shunt**—A series shunt consists of a low resistance connection across the terminals of the series field, by means of which the compounding effect of the series winding may be regulated by shunting more or less of the armature current past the series coils. It may be in the form of grids, on large machines, or of ribbon resistors on smaller machines. In the latter case it is usually insulated and folded so as to take but a small amount of space.

**Resistance in Feeders**—With circuits subject to frequent and severe short-circuits, such as in many railway installations, it is desirable to connect the feeders from substations to the trolley (or other distributing line) at some distance from the substation, in order to have some resistance between the generator and the point of short-circuit even when the short-circuit occurs directly at the point of feeder and trolley connection.

In some cases the same result can be more conveniently obtained by inserting grid resistors in the feeder within the substation.

In deciding whether this resistance is necessary, it must be remembered that any commutating machine will "buck" on dead short-circuit. The only question involved is whether the number or severity of the short-circuits to be expected requires the resistance in order to protect the service from interruption.

**Balance Coil Connections of Three-Wire Generators**—Wires connecting the balance coil to the machine must be short and of low resistance. Any considerable resistance in this connection will affect the voltage regulation. The unbalance current flows along these connections; consequently, if they have much resistance, the resulting drop in potential reduces the voltage on the heavily loaded side.

Switches are not ordinarily placed in the circuits connecting the collector rings to the balance coil. When necessary the coil may be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance coil connections to the switchboard and back, requiring heavy leads to keep the drop low; or if heavy leads are not used, then poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them which will not be taken care of by the main circuit-breakers.

# OPERATION

**Parallel Operation of Direct-Current Generators**—The inherent regulation characteristics of the armature of a direct-current machine have much to do with its parallel operation with other machines. When two direct-current armatures are coupled in parallel and delivering load to the same external circuit it is necessary, in order to obtain stable conditions, for each armature to tend to "shirk" its load; that is, it must naturally tend to transfer load to the other machine. This tendency to shirk may be either in bad speed regulation due to the prime-mover which drives the armature, or in the drooping voltage characteristics of the armature itself.

A drooping speed characteristic indirectly produces a drooping voltage characterstic in the armature and therefore both causes lead to the one characteristic, namely, drooping voltage, as the condition for stable parallel operation. This drooping voltage characteristic must be the inherent condition. In some applications, the voltage at the armature terminals may rise with increase in load, but its rise is due to some external condition such as increased field strength and not to conditions in the armature itself.

**Drooping Voltage Characteristics**—Direct-current machines, without commutating-pole windings naturally give drooping voltage characteristics in the armature windings. If two such armatures are paralleled they tend to divide the load in a satisfactory manner, provided their prime movers regulate similarly in speed. If means are applied for giving a rising voltage characteristic to the machines, such as series coils in the field, then the armature terminals must be paralleled directly in order to maintain stability. If, for instance, the armatures are not paralleled directly by equalizer connections but the paralleling is done outside the series coils, then the operation will be unstable unless the machines still have drooping voltage characteristics. If they have rising characteristics, then parallel operation is impracticable. If either machine should take an excess of load its voltage would rise while that of the other machine would fall due to decreased load. This condition would naturally force the first machine to take still more load and the second one to take still less until the first machine actually fed current back through the other machine and it would be necessary to cut them apart to avoid injury. However, by paralleling the two armatures inside the series coils, that is, between the series coils and the armature terminals, this unstable condition is avoided. The armatures inherently have drooping voltage characteristics, and the series coils are paralleled at both terminals, forcing them to take currents inversely proportional to their resistances at all times, thus compounding both machines equally.

**Rising Voltage Characteristics**—If direct-current machines are so designed or operated as to give rising instead of drooping armature characteristics, then parallel operation is liable to be unstable. This condition could be obtained in non-commutating-pole machines by prime movers which tend to speed up with increasing load, thus producing rising voltage on the armature. Ordinarily, such speeding up of the prime mover would have to be in rather large proportions as the normal drooping characteristics of the ordinary armature are fairly large; however, prime movers having a rising speed characteristic are comparatively rare.

A second condition which can give a rising voltage is not infrequently found in the commutating-pole type of direct-current machine. (See Fig. 15.) The commutating-pole winding is connected directly in opposition to the winding on the armature. The maximum magnetizing effect of the armature winding is found at the points on the armature corresponding to the coils which are being commutated.

The commutating pole is intended to be placed directly over these points and the winding normally has such a value that it not only neutralizes the magnetizing effect of the armature winding at these points, but it also sets up a small magnetic field in the opposite direction which assists in the commutation of the armature coil.

**Effect of Commutating-Pole Positions**—When this commutating pole winding is placed directly over the commutating position of the armature winding it will have practically no effect on the armature characteristics. If, however, the commutating-pole winding is not placed over these positions it will have an effect on the voltage characteristics of the machine tending to either raise or lower the voltage, depending upon the position of the commutating pole with respect to the commutating position. The commutating points on the armature depend directly upon the brush position. If the brushes are rocked backward or forward from the point corresponding to the mid-position between the poles, then the position of the commutated armature coils moves backward or forward with the brushes. (See Fig. 15.)

Herein lies a possible trouble in parallel operation for the commutating points can be so shifted with respect to the commutating-pole that the armature voltage characteristics can be made to rise instead of droop. As explained before, this is an unstable condition for parallel operation.

Let Fig. 16 represent two main poles and two commutating poles, with the brushes set in a position corresponding to the middle point of the commutating-pole. The polarity of any commutating pole and main poles is indicated in this figure. The polarity of any commutating pole when the machine is running as a generator is always the same as the polarity of the main pole immediately in front of it. When the brush is placed in a position corresponding to an exact intermediate point in the commutating pole it is evident that the armature coils

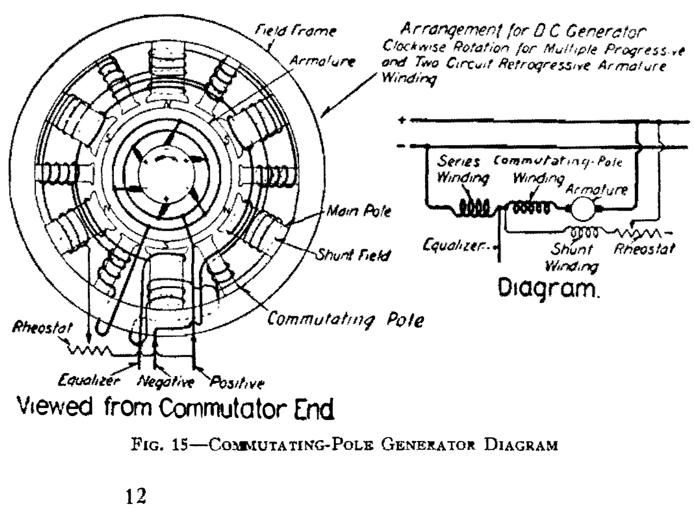



Fig. 15—Commutating-Pole Generator Diagram

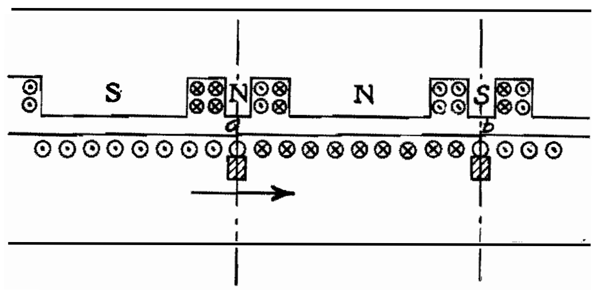



Fig. 16—Two Main Poles and Two Commutating Poles

lying between two commutating points, that is, the winding between **a** and **b** in Fig. 17 are acted upon by induction from the main pole and by half the induction from the commutating poles adjacent to the main pole. However, as these two commutating poles are of opposite polarity and the induction is the same from each, it is evident that they have equal and opposite effects on the armature winding between **a** and **b** and therefore do not affect its voltage.

**Back Lead**—In Fig. 17 the brushes are given a slight back lead so that the commutation is under the traveling magnetic flux from the commutating poles. It is now evident that between **a** and **b** the induction is from the main pole and from one commutating pole principally. With the back lead at the brushes, the commutating pole is the one immediately behind the main pole and therefore of the same polarity. This commutating pole, therefore becomes a magnetizing pole and adds to the electromotive force generated between **a** and **b**. As the strength of this commutating pole is zero at no load and rises with load, it is evident that it tends to give an increased voltage between **a** and **b** as the load increases and tends to produce a rising voltage characteristic instead of a drooping one.

As stated before, the number of ampere-turns in the commutating pole is considerably greater than in the armature, but ordinarily the effect of these ampere-turns is almost neutralized by the opposing effect of the armature winding. However, with the back lead, as indicated in Fig. 17, the opposing effect of the armature winding is shifted to one side of the commutating pole and thus the commutating pole ampere-turns become more effective in actually magnetizing the armature, but become less effective in creating a commutating field for the coils which are now being reversed by the brushes. On account of this less effective field it may be necessary in practice to still further increase the ampere-turns on the commutating pole in order to bring the traveling magnetic fringe up to suitable value for producing proper commutation.

It is evident that this increased number of ampere-turns on the commutating pole increases the induction under other parts of the commutating pole as well as under the trailing tip, and this increase under the other parts of the pole still further increases the voltage between **a** and **b**.

With a back lead, therefore, the commutating pole may have the same effect as the series winding on the main field; that is, it may compound the machine so that the voltage at the terminals is rising instead of falling, even without any true series winding on the main poles. The machine, therefore, becomes an equivalent of a compound-wound machine and the generator may be unstable when paralleled with other machines.

**Forward Lead**—Take the case, next, where the brushes are given a forward lead, as shown in Fig. 18. Comparing this with Fig. 17, by the same reasoning it is evident that the commutating pole is now opposing the effect of the main pole, in the winding between **a** and **b**. The interpole therefore tends to produce a drooping voltage characteristic and has just the opposite effect to the series winding. In this position of the brushes the commutating winding tends to give good characteristics for parallel operation, but as the effect of the commutating pole is in opposition to the main pole it is evident that more series winding is required on the main field in order to over-compound the machine as a whole. Also, with the brushes in this position the commutating pole is not as effective in producing good commutation and therefore more ampere-turns are required on the commutating winding. Therefore, both windings must be increased when the brushes are given this forward position but parallel operation should be stable.

**Correct Brush Position**—It is evident, therefore, from the above considerations that for best results the brushes should be so set that the true point of commutation comes midway under the commutating pole. If this position is found exactly, then the commutating pole should have practically no effect on the voltage characteristics of the armature, and parallel operation with other generators should be practicable. A very slight forward lead is favorable to paralleling, but lessens the compounding.

As a back lead at the brushes, wher the machine is acting as a generator, tends to improve the compounding and lessens the series winding required on the main field, it might be suggested that

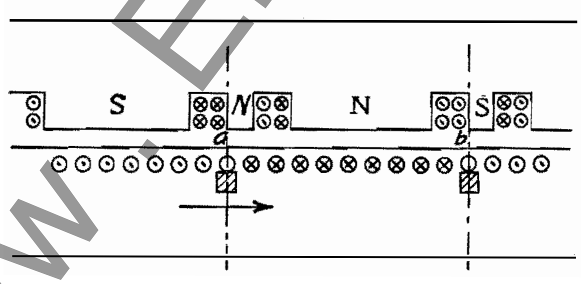



Fig. 17—Brushes Given a Slight Back Lead

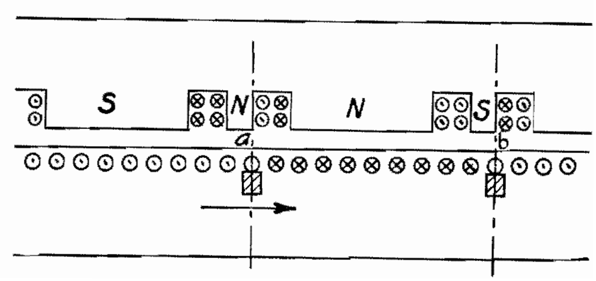



Fig. 18—Brushes Given a Slight Forward Lead

this gives a cheaper and more efficient machine and that therefore this arrangement should be used, with some means added for overcoming the unstable conditions of paralleling. One means proposed for this is an additional equalizer connected between the commutating poles and the armature terminals. This has been used in one or two instances, but in principle the arrangement is inherently wrong. When the commutating-pole windings are paralleled, then the currents in them must divide according to their resistance.

This condition would not be objectionable provided the armature currents also varied in the same proportion. With slow changes in load this condition might be obtained. However, there are conditions of operation where the armature currents will not rise and fall in proportion and therefore the commutating pole windings, with this arrangement, would not always have the right value to produce the desired commutating fields. Each armature should be connected directly in series with its own commutating poles and the currents in the two should rise and fall together for best results. This condition will not be obtained when an equalizer is connected between the armatures and commutating poles and this solution of the problem should therefore be avoided in general.

**The equalizer should always be connected between the series winding and the commutating-pole winding,** the commutating-pole winding being treated as part of the armature circuit.

**Adjustment of Load Division and of the Equalizer Circuit**—With two compound-wound generators operating in parallel, one of which takes less than its proper share of the load, the division of load can be changed by the following adjustments.

(a) The shunt field rheostats may be adjusted to give better **average** division. If one generator compounds less than another and it is desired to maintain the higher full-load voltage, the average load of the former generator can be increased by increasing the shunt field excitation.

(b) The shunts on the series-field winding can be adjusted, decreasing the resistance of the shunt on the overloaded generator, if possible, or increasing the resistance of the shunt on the underloaded generator. It should be borne in mind, however, that changing the ampere-turns in the series field by changing the shunt resistance also changes the resistance of the complete field circuit. This change in resistance must be compensated for by a corresponding change in resistance in another part of the series-field circuit so that the resistance of the total circuit remains unchanged. From another standpoint, a shunt on one series-field may be considered a shunt on both series-fields, the effect varying only by reason of the resistance of the leads and busses being added to one shunt circuit and not to the other.

(c) If the relative ampere-turns are correct, but the series-field resistances are differently proportioned, the resistance of the leads between the series-field and equalizer bus can be changed to compensate for a difference in the series-field resistances. The resistance in the series circuit of the generator taking more than its share of the load should be increased. This adjustment varies the resistance of one series-field without introducing a third parallel circuit between the equalizer and main bus, and for this reason the adjustment is less complicated than in (b).

In making the above adjustment it is advisable to make the changes systematically.

The several generators should be operated separately and the voltages at all loads should be made as nearly equal as possible by adjustments of the shunt-field rheostat and by changing the series-field current by means of shunts across the series field. It may be advisable to operate the several generators with different no-load voltages in order to obtain a better average agreement between the several voltage regulation curves. It is not so important that the voltages at partial loads agree as it is at full load and overloads. At partial loads the load division may depart from the correct division without over-loading the generator that takes the greater share of the load.

When the several regulation curves have been made to agree as nearly as possible, then the resistances of the several equalizer circuits should be checked and changed, when necessary, by changing the resistance of the equalizer leads to make the resistances inversely proportional to the generator ratings. For example, if a 500-kilowatt generator and a 1500-kilowatt generator are operated in parallel, the resistance of the series-field circuit (including a shunt if used) the main lead from the series field to main bus, and the equalizer leads should be in the case of the 1500-kilowatt generator one-third of the resistance of the corresponding circuit of the 500-kilowatt.

**Excitation of Direct-Current Generators**—When starting up, a generator may fail to excite itself. This may occur even when the generator operated perfectly during the preceding run. It will generally be found that this trouble is caused by a loose connection or break in the field circuit, by poor contact at the brushes due to dirty commutator or perhaps to a fault in the rheostat, or incorrect position of brushes. Examine all connections; try a temporarily increased pressure on the brushes; look for a broken or burnt out resistance coil in the rheostat. An open-circuit in the field winding may sometimes be traced with the aid of a magneto; but this is not an infallible test as some magnetos will not ring through a circuit of such high resistance, even though it be intact. If no open circuit is found in the rheostat or in the field winding, the trouble is probably in the armature. But if it be found that nothing is wrong with the connections or the winding it may be necessary to excite the field from another generator or some other outside source. Calling the generator we desire to excite No. 1, and the other machine from which current is to be drawn, No. 2, the following procedure should be followed. Open all switches and remove all brushes from generator No. 1; connect the positive brushholder of generator No. 1 with the positive brushholder of generator No. 2; also connect the negative holders of the machines together (it is desirable to complete the circuit through a switch having a fuse of about five amperes capacity in series). Close the switch. If the shunt winding of generator No. 1 is all right, its field will show considerable magnetism. If possible reduce the voltage of generator No. 2 before opening the exciting circuit; then break the connections. If this cannot be done, throw in all the rheostat resistance of generator No. 1; then open the switch very slowly, lengthening out the arc which will be formed until it breaks.

A very simple means for getting a compound wound machine to pick up is to short-circuit it through a fuse having approximately the current capacity of the generator. If sufficient current to melt this fuse is not generated, it is evident that there is something wrong with the armature, either a short-circuit or an open-circuit. If, however, the fuse has blown, make one more attempt to get the machine to excite itself. If it does not pick up, it is evident that something is wrong with the shunt winding or connections.

If a new machine refuses to excite and the connections seem to be all right, reverse the connections, i.e., connect the wire which leads from the positive brush to the negative brush and the wire which leads from the negative brush to the positive brush. If this change of connection does no good, change back and locate the fault as previously advised.

**Circuit-Breaker Protection on Reverse Direct-Current**—Whenever there is a source of direct-current in parallel with a generator, a relay should be provided that will open the direct-current breaker in case the direct-current reverses. A reverse current relay prevents overspeed resulting from accidents or bad operation.

**Setting of Circuit-Breakers in Railway Substations**—In some railway systems the conditions are such that short-circuits occur on the feeder or trolley circuits that are so severe that the generators flash and the arc holds until the generator "kills" itself. In such cases the severity of the short-circuits should be reduced by the insertion of resistance in the affected feeders as described on pages 9—10.

In this connection it should be remembered that in the case of severe short-circuit the current increases rapidly compared with the speed at which the breaker will operate. In the case of a short-circuit immediately outside the substation the current may easily reach five to ten times the normal rated current of the generator assuming the ordinary types of carbon circuit-breaker are used and this current value will be practically independent of the circuit-breaker setting.

**Direct-Current Machine and Feeder-Breakers**—The direct-current machine breaker should be equipped with an over current tripping mechanism in which a definite minimum time element may be introduced. The feeder-breakers should be equipped with a series type instantaneous trip mechanism. Non-compensated or partially compensated d-c. generators which will satisfactorily commutate very large momentary currents providing the direct-current machine breaker does not open, may flash with no greater currents if the breaker is opened. In multiple feeder stations the selective action between opening of the instantaneous type feeder breaker and time delay machine breaker, is of value in that it tends to eliminate flashing due to sudden dropping of heavy loads. In normal operation the selective action between opening of machine and feeder breaker may be sufficient to prevent the opening of the machine breaker on faults that are readily isolated by the opening of the feeder-breaker. In single feeder stations the time element in conjunction with the machine-breaker is of no value as the opening of the feeder-breaker ruptures the entire value of machine current.

**Emergency Instructions**—(1) When direct-current generators flash over or the breakers come out from excessive current, it is always wise to note the direct-current voltmeter before throwing in on the line again, as these troubles very frequently cause a reversal of polarity in the fields, making them build up in the opposite direction. It this should be the case, it will be necessary to reverse polarity.

(2) When the alternating-current power goes off for any reason, shut down the set at once, opening all switches.

(3) When the alternating-current breakers come out, open the direct-current breaker (if not tripped out automatically) and the switches, and then proceed to start as in first starting.

(4) When a direct-current generator flashes over and is cut out of circuit, it is best to shut down and examine the commutator and brushes and clean up any burrs which may have been caused. If this is not possible, the commutator may be cleaned, by exercising great care, after the set has been put in service.

## Caution

**Leave all the switches open when the motor-generator is not operating.**

**When the shunt-field circuit of a generator or motor is excited, never open it quickly unless a path for the inductive discharge is provided. The circuit can be opened slowly, if desired, the arc at the opening serving to reduce the field current gradually. Do not permit any part of the body to bridge this opening, or a serious shock will be received; better use but one hand, keeping all other parts of the body clear of the circuit.**

**Always follow a fixed regular order in closing and opening switches unless there are special reasons for departing from this order. A routine method will aid in avoiding mistakes. Close switches carefully, keeping firm hold of the handles until completely closed.**

**Keep small pieces of iron and bolts and tools away from the frame. Any such fragment attached to the pole of a field magnet may jam between the armature and pole and cause serious damage.**

## Field Current Adjustment of Motor

The power factor of any synchronous motor may be controlled by varying the field current. Motors are rated at either 100 per cent power factor or at some leading power factor, usually 80 per cent. The field current necessary to give the rated power factor at full load is recorded on the motor nameplate. If the maximum leading kv-a. is wanted at all times, the field current should be set at this value even though the load is less than rated output. With this excitation, motors that are rated at 100 per cent power factor will give a small amount of leading kv-a. at reduced loads. A machine of usual proportions will have about 30 per cent reactive kv-a. at no load and this will decrease to zero reactive kv-a. at full load. A motor rated at 80 per cent power factor has 60 per cent reactive kv-a. at full load. If the excitation is kept constant, the reactive kv-a. increases slightly as the load is reduced, rising to about 75 per cent of rated kv-a. at no load. The total kv-a. is reduced from 100 per cent to 75 per cent as the load decreases.

If there is no need for supplying reactive kv-a. the excitation may be adjusted so as to maintain 100 per cent power factor at all times. This will result in minimum losses and highest economy. There is one objection, however, to lowering the excitation below the rated value, and that is the reduction in pull out torque. A machine rated at 80 per cent power factor and operated at 100 per cent power factor, may pull out of step with a fairly small increase in load whereas a motor rated at 100 per cent power factor usually has a momentary overload capacity of at least 50 per cent.

An increase in field current will increase the pull out torque. Thus, in an emergency, a motor could be made to hold in step at a considerable overload by over-exciting the field. The length of time that this could be continued is limited by heating.

## Unbalanced Voltage and Single Phase Operation

The ability of a synchronous motor to operate on unbalanced voltage or, in the extreme case, to operate single phase, depends largely on the design of the amortisseur or damper winding. Single phase operation produces heavy currents in the damper winding, which may cause overheating in a machine not designed for such operation. The field current required for a given load may also be increased to such an extent that the output is seriously limited. Operation with unbalanced voltage has the same effect as single phase operation but in a less degree.

For machines not designed for single phase operation, 20 to 30 per cent of normal current single phase is usually safe. Higher values may be permissible if the damper winding is liberal. The degree of unbalanced polyphase operation that is permissible depends likewise on the design of the individual machine. In any case of unbalancing of more than five per cent at full load, it is advisable to watch the temperatures of all parts closely.

It is impossible, of course, to start the motor in the usual manner if only single phase power is advisable. If one line is opened up after the machine is in operation on a three phase circuit it will operate single phase with the limitations stated above.

## Starting a Synchronous Motor Driven Motor-Generator

If the machine is equipped with a high pressure oil system to reduce starting friction, the oil pump should be started first. Full pressure will be built up, normally, in a few seconds.

Close the starting switch applying reduced voltage from the starting transformers to the stator windings. During this time, the field winding should be closed through a short-circuiting switch or, if the motor has a direct connected exciter, or is excited from the main d-c. machine, it may be connected to its source of excitation. A rheostat may or may not be in the circuit with the field in either case. In no case should direct-current be applied to the field when the machine is to be started, nor should the field be left open circuited.

In the case of motor generator sets, the no load running losses furnish so small a load on the synchronous motor that the motor may pull into synchronism before the excitation is applied. In the case where the synchronous motor is started with the field closed through a short circuiting switch, the excitation should be applied while the motor is still on the starting tap, in order that the Kv-a. inrush due to the process of synchronizing may be reduced to a minimum. If the field is connected during the starting period across a direct connected exciter or across the main d-c. machine, the field is applied automatically.

After the excitation has been applied, the running switch can then be closed, transferring the machine from the starting voltage to the full line voltage.

This method differs from the practice on Industrial Drives, where it is necessary to change to the running voltage before applying the field in order to obtain the maximum pull-in torque and where the motor will seldom pull into step without the field being applied.

# MAINTENANCE

## Caution

**At all times keep the motors and generators clean and free from oil and dust, especially from copper or carbon dust.**

**Oil is penetrating in mica and if oil is allowed to get into the mica of a commutator, from an oily vapor atmosphere or from oil leakage from the bearings, the mica will be damaged and burnouts may occur in the armature.**

**The insulation should be kept free from dirt and oil. An occasional cleaning of the coil ends with an air hose is recommended, and this should be followed by a thorough wiping with a cloth. The dirt which clings to the field coil washers should be removed carefully since it may accumulate and form a conducting path from coil to ground.**

**A coat of insulating varnish applied to the armature and field coils after they have been cleaned will protect the insulation. An air hose should be applied to the air ducts through the stator punchings on the a-c. motor and between the spider spokes on the d-c. generator, since an accumulation of dirt at these points will impede the free flow of cooling air.**

With high-voltage machines a small accumulation of dust on the windings may be the cause of serious burnout. It is advisable to install an air pump for supplying compressed air with a piping system so distributed that a short section of hose will enable the attendant to reach all parts of the winding on any machine to blow out the dust. The pressure used in such service should not exceed 25 pounds per square inch, as a high pressure may lift the insulation wrappings and blow dust within the coils. Always allow any accumulation of water in the pipes to be blown out before turning the air blast on the machine.

In blowing dust out of machines, the adjacent machines should be protected from flying dust by a suitable cover or shield.

A preferable method of cleaning machines is by a vacuum cleaning system whereby all the dirt is carried away from the machines and the danger of blowing dirt into adjacent machines is completely avoided.

Where insulated parts, subject to copper or carbon dust, are accessible they should be wiped clean with a dry cloth, in addition to cleaning as described above.

It will facilitate the cleaning of insulated parts if they are painted with insulating varnish at regular intervals. At the time selected for painting the machine should be given a suitable high-voltage insulation test to locate possible weaknesses at a time when they can be conveniently repaired.

**Grinding in Brushes**—The ends of the carbon brushes should be carefully fitted to the curvature of the commutator; this can be done by putting sandpaper under each brush while pressing it firmly against the commutator as shown in Fig. 19. The sandpaper should

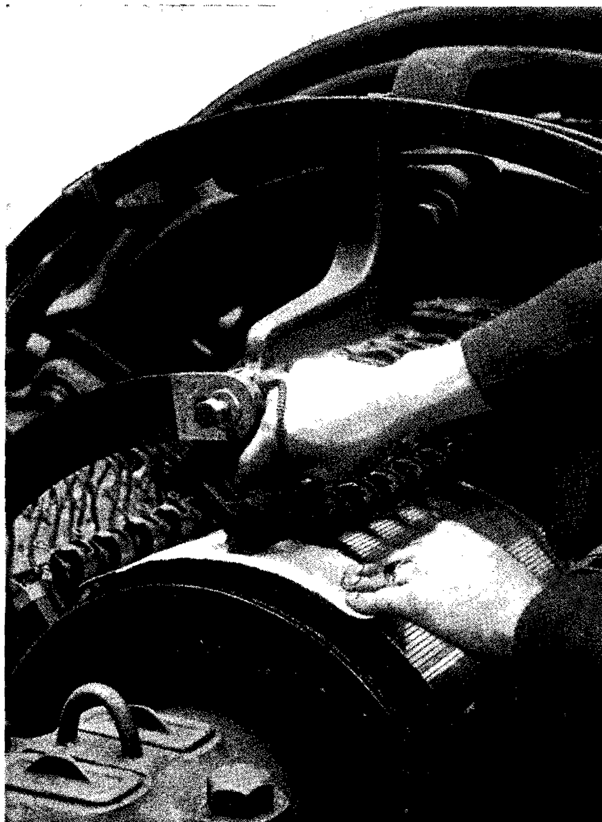


FIG. 19—GRINDING BRUSHES OF A D-C. GENERATOR

cut the brush only on the forward stroke and in the direction of normal rotation.

**Spring Tension** — The brushholder springs should be adjusted to a uniform tension of from 2 to 2½ pounds per square inch of cross-sectional area of the brush. The direct-current brushes are usually of the graphite type. This grade of brush is practically free from carbon or hard gritty material. Among its important characteristics are—high current carrying capacity, high lubricating quality, low friction coefficient and consequently low friction losses, and low resistance drop.

The absence of abrasive qualities makes this type of brush unsuited for non-undercut commutators, where the mica must be worn down by the brush. The low resistance drop also makes it in some cases unsuited for non-commutating-pole machines which inherently have relatively high voltage induced in the armature coils undergoing commutation, producing large currents in the low resistance brush face.

The brushholder arms and brushholders are correctly spaced and adjusted before the machine leaves the Works, but due to subsequent disassembling orrough handling during shipment, they may be displaced. These adjust, ments should be checked, in all cases before the machine is put in service. The brushholder arms should be parallel to the commutator bars; and the relative spacing of the brush arms around the commutator, as determined from the edges of the brushes, must be uniform. The preferable method of checking this latter point is to stretch a piece of paper tape around the commutator under the brushes, allowing the ends to overlap to some extent. Care must be taken that it is smooth and parallel with the edge of the commutator at all points. Make a fine clear mark with a sharp pencil on the tape exactly at the toe of the brush on each arm resting on the tape. Some marks of identification should also be made so that, after removing the tape from the machine, the arms corresponding to the marks may be readily identified. Remove the tape and measure the space between the marks, adjusting the arms until approximately equal spacing results. Brushes must be ground in as indicated in the preceding paragraph before spacing brushes. The difference in spacing should not be more than $\frac{1}{32}$ inch.

**All of the direct-current brushes should be gone over once a week to make sure that they move freely in their holders. Shunts on the direct-current brushes should always be kept in well rounded shape and never mashed down, otherwise proper brush contact on the commutator will not be obtained.**

All direct-current brushholders should be kept as near as possible to within about ⅛ inch of the commutator. As wear on the commutator makes it necessary, follow it up by changing the position of the holders.

Keep the commutator smooth. Grinding about once a year is a safe means for best operation, particularly on automatic units. Keep the mica well undercut and bars properly chamfered. Keep the undercutting well cleaned out. Whenever commutator flashing is experienced, the commutator should always be smoothed up with at least a hand stone and polished off with sandpaper. If the flash of a severe nature, the commutator should be ground with a regular grinding outfit.

**Direct-Current Brush Position and Brush Arm Spacing**—In **non-commutating-pole machines** the correct running position of the brushes is "ahead" of the no-load neutral and is found by trial. In **commutating-pole machines** the brush position is fixed and the correct adjustment is determined before shipment.

The relative positions of the ring, which carries the brushholder arms, and the field frame are indicated by a dowel pin. With the dowel pin in place, the rocker ring can be placed only in the correct position.

The brushholder arms are correctly placed and adjusted, before the machine leaves the plant. This insures the correct brush spacing. The arms, however, may become displaced, due to subsequent disassembly or rough handling, during shipment. In consequence, spacing should be checked to be sure that variations of more than $\frac{1}{32}$ inch do not exist between arms, and care taken to see that the arms are parallel to the commutator bars before the machine is put in service.

**Location of Neutral Point**—The no-load "neutral" point on the commutator is that point at which a minimum voltage is induced between bars when the machine is running without load with only the main pole windings excited.

In case it is necessary to check the location of the neutral point one of the following methods should be followed:

On non-commutating-pole machines the "neutral" should be found while running the machine as a shunt motor from the direct-current end or by driving the machine by some external power with the shunt field winding excited. Use a low reading voltmeter with .5—1.5 and 15 volt scales preferably. Use two pointed leads for the meter. Hold the points one commutator bar width apart on the commutator and move them along until the point of minimum voltage is located. This method is not the most accurate, but is usually satisfactory for non-commutating-pole machines.

For commutating-pole machine there are two methods, either of which, if properly used, is sufficiently accurate.

**First—The "Neutral Kick"**—This method is based on the fact that when the field-circuit of any direct-current machine is opened, an induced voltage is generated in the armature windings. In case the brushes are in the exact neutral position the resultant voltage so generated is zero.

Arrange to separately excite the shunt field from any convenient source of power with a quick-break switch in the circuit. If line voltage is used, a resistance or lamp bank should be used in series with the field circuit to give a small current in the field. A low reading voltmeter should be used for measuring deflections.

Determine the proper commutator bar pitch for the machine. If, for instance, the machine has 36 bars per pole, the throw for a multiple wound armature will be bar 1 to bar 37.

Hold the voltmeter leads on bars 1 and 37, in the neutral zone, and then open and close the field switch and note deflection on the meter.

The deflection, if any, will be only a momentary kick. If deflection takes place it indicates that the bars being registered are not in the neutral position.

Assume for example, that holding the voltmeter terminals on bars 1 and 37 that a deflection of 10 volts to the **left** is registered by the voltmeter needle when the quick break switch is closed. The switch should be left closed now until needle settles back to 0. The switch should then be opened and a deflection of 10 volts to the **right** will be obtained, as the induced voltage is in opposite directions when opening and closing the field circuit.

Next move the voltmeter terminals to bars 2 and 38. Suppose now when the field switch is closed a deflection of 10 volts to the **right** is obtained, and after allowing needle to come to rest, and switch is opened, a deflection of 10 volts to the **left** is obtained. This indicates that the correct no load neutral in this case is exactly on the mica between the two pairs of bars tried. The rocker arm should therefore be shifted until the **centre of the direct-current brushes is exactly over this neutral mica position.**

When equal readings cannot be obtained by moving voltmeter leads ahead, or back, on any two pairs of commutator bars it is necessary to turn the armature slightly until such a condition is obtained.

**Second—"Running Neutral"**—This method is based on the fact that if the brushes are in the correct no load neutral position no active electromotive force will be generated by the commutating-pole flux when the machine is mechanically driven on open circuit with the commutating windings separately excited.

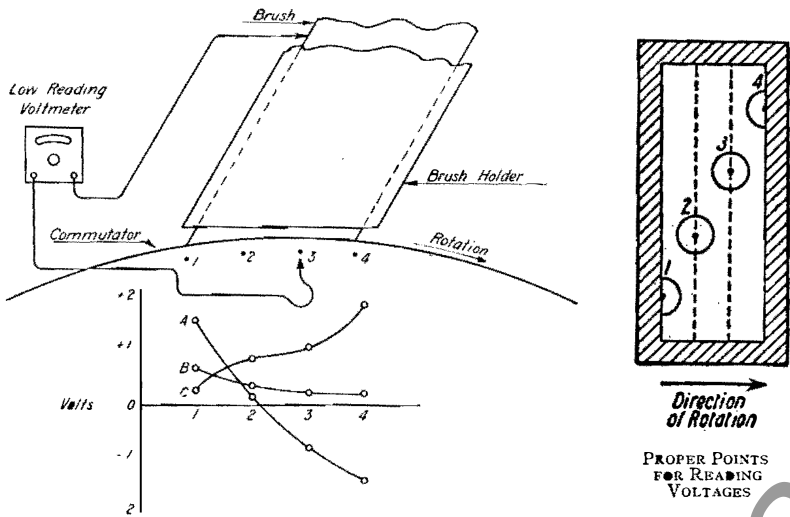
Beveled brushes should be inserted, one in each arm, and so beveled that the faces on these brushes will be wide enough to bridge one mica segment. The face of the brush must be ground in for good commutator contact and must not be wide enough to make contact with more than two commutator bars with any commutator position. A reversing switch should be connected in the separately excited shunt field-circuit and some arrangement made for separately exciting the commutating-pole winding at from two to four per cent of its normal current. The commutating-pole circuit should be disconnected from the armature and the armature left open-circuited. Use a low reading voltmeter such as was suggested for the "kick neutral" across arms of opposite polarity. Bring the machine up to approximately normal speed and by exciting the main field, for an instant only, in a direction contrary to normal, demagnetize it entirely, that is, until no deflection shows on the lowest scale of the voltmeter. Any deflection then obtained by exciting the commutating poles will be due to the commutating pole flux alone. First excite the commutating-pole windings with about two per cent of their normal current and shift the brushes until no deflection is obtained on the lowest scale of the voltmeter. Check the residual magnetism of the main poles from time to time keeping it at as low a value as possible by demagnetization as explained above. After determining the best location for the brushes at this excitation, raise the commutating-pole current to about four per cent of normal and check results. If no difference is found reverse the current in the commutating-pole and try again, still checking the residual from time to time. In some cases higher currents may be used, but the leakage flux soon becomes large enough to destroy the symmetry of the normal field form and indefinite results will be obtained.

This method, if used carefully, gives very accurate results. It may be noted that the position of the brushes is at the peak of the commutating-pole field form and as this peak is rather sharp the effect of displacement will be very marked. Since the machine is running, errors due to brush resistance or to a brush resting on mica only, are entirely eliminated, making this method preferable to the "kick method".

**Adjustment of Commutating-Pole Field**—The commutating-pole adjustment to give the best commutating conditions is made at the shipping point and, in general, no reason for changing it after the generator is installed will arise. However, if such reasons should arise the proper change in excitation may be determined as follows:

(1) With a low reading voltmeter read the voltage between the brush and the commutator at four equi-distant points along the width of the brush (along the circumference of the commutator) when the machine is running at normal load and voltage. These voltages can be most conveniently read by inserting a hard wood or fibre block in an end brushholder having four radial holes correctly spaced in which the voltmeter "point" can be inserted. This is shown in Fig. 20.

Readings should be taken from one




PROPER POINTS FOR READING VOLTAGES

FIG. 20—ARRANGEMENT FOR DETERMINING PROPER ADJUSTMENT OF COMMUTATING-POLE FIELD

to four in the direction of rotation. Take curves under both positive and negative brushes for several brush arms.

These readings, if plotted as shown in Fig. 20, indicate for example in curve A, over compensation; i.e., excessive commutating field strength curve B, correct compensation; curve C, under compensation.

(2) Changes in commutating-pole strength to secure correct compensation can be made by changing the air gap or by shunting part of the current from the commutating-pole winding. Adjustment by changing the air gap is the more usual method. In case of over compensation the air gap should be increased and in case of under compensation the air gap should be decreased. When adjustment is made by shunting, an inductive shunt, having approximately the same ratio of self-induction to resistance as the commutating-pole winding is advisable. This insures proper division of current between the field winding and shunt when the load suddenly changes.

The measurement of brush curves and the adjustment of the commutating-pole strength should only be undertaken under the supervision of an experienced engineer.

**Commutator Seasoning and Grinding**—The satisfactory operation of a d-c. generator is as dependent on the condition of the commutator as on any other one item. It is a well recognized fact that a commutator only becomes thoroughly "seasoned", (the insulation baked out and all parts in their final set position) after operating for a considerable time. Owing to lack of facilities for current loading at the factory, it is not feasible, in all cases, to get the commutators finally seasoned before shipment. It should be understood that a certain amount of commutator seasoning will take place during the first year after the generator is put into service, particularly if the commutator is of large size.

That the commutator needs attention will usually be indicated by its becoming rough due to a general unevenness, high or low bars, flat sections or eccentricity. If these conditions are not corrected they will result in poor commutation, overheating of the commutator, a rapid deterioration of the brushes, clips and pigtails, and greatly limit the machine's ability to satisfactorily handle overloads.

If the commutator is in very bad condition, it may be necessary to use a turning tool, but for ordinary cases a grinding tool, Fig. 21, is preferable and is recommended. Commutators should always be ground at 100 per cent normal speed. Turning requires a much lower speed; it should not be higher than 150 feet per minute. Before grinding a commutator, the machine should have been in service a sufficient length of time to bring the temperature of the commutator up to a constant value of at east 50° C. rise above the surrounding air. Machine should then be shut down and the bolts holding commutator "V" ring, shown in Fig. 22, tried for tightness in accordance with instructions from the East Pittsburgh engineering department. If any tightening on the bolts is obtained, the process of alternate heating and tightening should be repeated until the commutator bolts cannot be tightened further. The tightening of the commutator is all done with click wrenches. These click wrenches give a click indication when the pull for which they are set is exceeded. Our District Service departments all carry these click wrenches as part of their standard equipment, for use in tightening commutators.

Commutators of the so-called 3V construction (Fig. 24) have now been superseded by the 2V type of construction shown above in Fig. 22. Reference to this 3V type of construction should therefore be understood to pertain only to apparatus now in service.

In tightening commutators having the 3V construction (Fig. 24) the outside (Aux. V) bolts should always be backed off slightly, say ½ turn, before attempting to tighten the bolts of the main V. After machine is given its final tightening, it should be run for at least 12 hours to reach a constant temperature on commutator of at least 50°C. rise before grinding.

FIG. 21—GRINDING DEVICE FOR TRUING COMMUTATORS

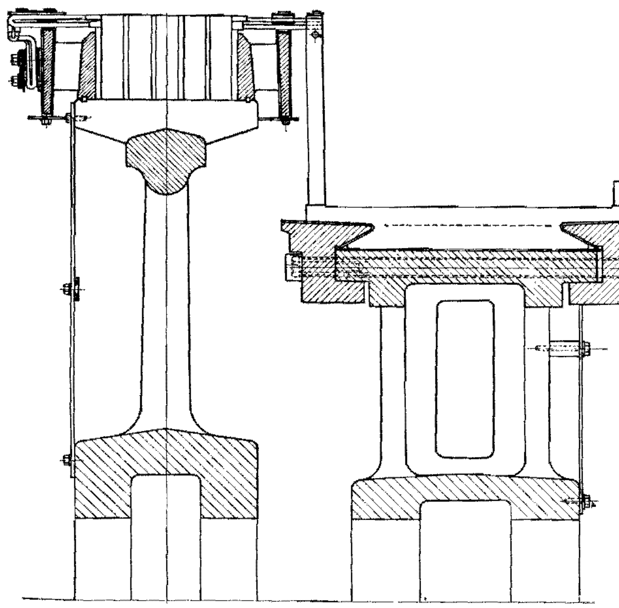


FIG. 22—2V THROUGH BOLT TYPE COMMUTATOR

After commutators have been made properly tight they should then be ground or turned to a true surface. Before grinding, the brushes should be lifted off the commutator, as the copper and stone dust will rapidly wear them off. The dust will also become imbedded in the brush contact surface and later damage the commutator or cause poor commutation. The armature winding should also be **thoroughly** protected during this operation to prevent an accumulation of dirt and metal chips, which may result in an insulation failure when the machine is again put in service. This protection can usually be best obtained by using a circular shield of fullerboard, or similar material, around the commutator at the end next to the armature. This shield can be easily supported from the brushholder arms and should extend from the commutator surface to an inch or two above the surface of the armature. Another method is to shellac circular segments of heavy paper to the commutator necks, making an air-tight shield that revolve with the armature. A shield of some kind should also be put at the front end of the commutator around the shaft. so as to prohibit any dust or chips from being drawn back under the commutator and into the windings.

A vacuum dust collecting outfit is now being used quite generally by our Service Engineers when commutators are being ground. This outfit works on the same principle as the ordinary household vacuum sweeper. The nozzle is of special shape so that it fits close up against the grinding stone and collects the discharge dust as it leaves the stone. A flexible hose permits the nozzle to follow the stone back and forth across the commutator. It has been found that with this arrangement from 85 to 90 per cent of the dust is collected that otherwise would be thrown off into the room and into the machine.

After grinding a commutator the machine should always be thoroughly cleaned by blowing out with **dry** compressed air or by wiping out with rags before replacing it in service, or by both.

**Emery cloth or paper should never be used** on account of the continued abrasive action of the emery which becomes embedded in the copper bars and brushes.

In cases where it is desired to obtain a high temperature on the commutator for seasoning, this can be conveniently accomplished by removing the direct-current brushes from their holders and replacing them by maple block brushes By imposing a high tension on these wooden brushes and running the machine at its normal rated speed the desired temperature for seasoning will usually be found to be easily obtained. It may also be heated by external sources, but due to the inability to heat uniformly in this way, the former method will ordinarily be found to be preferable.

**Undercutting Commutator Mica**—All standard commutators have the mica between bars undercut $\frac{1}{16}$ inch. After grinding or turning a commutator, the undercutting should be cleaned out and the edges of the bars scraped to remove burrs. **It is particularly important that the edges of the bars be well rounded.** Failure to do this has caused machines to buck on sudden changes in load or when the circuit-breaker opens.

If it is necessary to re-undercut the mica due to grinding or turning the commutator or due to wear after long operation this may be done with a hack saw blade held between suitable guides, or, more conveniently and accurately with motor-driven circular saws. (See Fig. 23).

**Care of Commutators**—The ideal appearance of a commutator surface is a polished dark brown or chocolate color. Such a commutator needs no attention other than to be kept clean. Use of oil, grease, vaseline, or so-called commutator compounds will gum up the commutator causing a deposit of carbon and metal dust on the surface and particularly in the undercutting that may cause "burning" and "flashing".

**Do not allow oil to come in contact with the mica of commutators, as the**

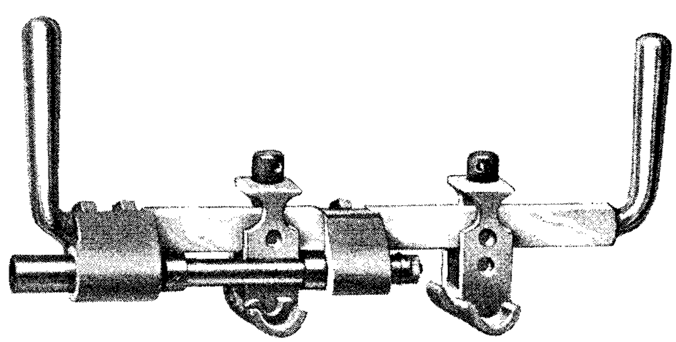


FIG. 23—SMALL PORTABLE TOOL FOR UNDERCUTTING MICA

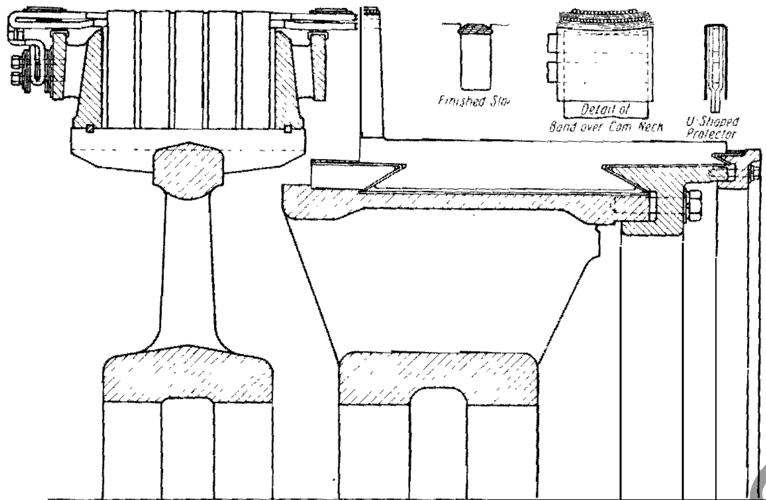



Fig. 24—Section of Commutator Showing 3V Type of Construction

**oil will penetrate the mica and carbonize it and cause burnouts.**

**Sparking at Direct-Current Brushes**—Some sparking under the brushes on modern high-speed commutating apparatus should not be construed as discreditable performance. The personal element involved in the interpretation of satisfactory commutation makes the subject a difficult one for reaching agreement in many cases. An effort to arrive at some common basis of reasonable commutation requirements has accordingly been made in the 1925 Standards of the American Institute of Electrical Engineers. Under paragraph 5—254, successful commutation is defined as follows: "Successful commutation is attained if neither the brushes nor the commutator are burned or injured in an acceptance test or in normal service to the extent that abnormal maintenance is required. **The presence of some visible sparking is not necessarily evidence of unsuccessful commutation."**

Sparking may either be due to mechanical or electrical causes.

The usual causes of sparking from mechanical faults are:

(1) Rough commutator, due to high bars, high mica (if commutator is not undercut), flat spots, or rough edges of undercutting.

(2) Vibration, originating in brush rig.

(3) Unequal spacing of brushholder bracket arms.

(4) Incorrect setting of direct-current brushholders too far away from commutator, or misalignment of the holders on the bracket arm.

(5) Incorrect brush tension.

(6) Brushes sticking in holders.

If the sparking is due to electrical causes, it will be seen to vary appreciably with load changes on the machine. The more common electrical causes of sparking met with in operation are:

(1) Brushes on all arms or on part of the arms incorrectly set with respect to neutral points.

(2) Brushes of wrong composition or resistance.

(3) Incorrect adjustment of commutating-pole winding.

(4) Non-uniformity of main or commutating-pole air-gaps.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature.

If sparking occurs that cannot be accounted for by overloads or other service conditions, wrong adjustments, or mechanical defects, an experienced engineer should be consulted to remedy the fault.

**"Bucking" or "Flashing"** between arms of opposite polarity is caused by excessive voltage generated in the coils short-circuited by the brush or between adjacent commutator bars, or abnormally low surface resistance on the commutator between adjacent brush arms. Any condition tending to produce poor commutation increases the likelihood of "bucking". Bucking is usually caused by the following:

(1) Rough or dirty commutator.

(2) A drop of water on the commutator, from the roof, leaky steam pipes or other source.

(3) Excessive overloads or short-circuits on the direct-current side.

(4) Frame or bedplate grounding It is necessary that the resistance from the machine frame to the station ground should be of such a nature that the current incident to an arc from the commutator to one of the grounded circuits should not be of a sufficiently appreciable value to cause damage. See grounding machine frame under "Application and Protection" heading.

**"Bucking" or "Flashing" Remedies**—If flashing continues after the first two possible causes have been eliminated the trouble will usually be due to causes external to the machine.

Flashing is limited to higher voltage machines and can in most cases, especially on railway machines, be traced to excessive overloads usually caused by short-circuits. The only way to correct this is to protect the machines from these short-circuits. This can often be accomplished by increasing the resistance in the feeders. A re-adjustment of machine and feeder breakers will very often improve results. Experience has shown that the majority of flashing troubles **are due to external local conditions** which must be corrected before the flashing trouble will be eliminated.

## Motor Collector Rings

Sparking at the collector rings may be due to any of the following causes:

Rough surface of ring. (This condition usually follows prolonged sparking originating from some other cause.)

Eccentric rings.

Brushes tight in holders.

Oil on collector rings.

Vibration of brush rigging.

If sparking exists the rings should be stoned or turned to give a smooth surface and, if possible, the source of the trouble removed. The brushes should have a close fit on the rings and should slide freely in the holders. If the brushes stick in the holders, contact with the ring will result and burning will take place.

## Bearings

When a machine is started particular attention should be given to the bearings to see that they are well supplied with lubricant. The oil rings should revolve freely and carry oil to the top of the journals.

Bearings may be operated safely at a temperature of 80° Centigrade (176° Fahrenheit) and, for a limited time, they may operate as high as 100° Centigrade (212° Fahrenheit). It should be remembered that a bearing may be below this temperature and may be safe even though it is hot enough to burn the hand when held against the outside.

A rapid rise in the temperature of a bearing is usually an indication of trouble and requires prompt attention. The machine should be taken out of service immediately, but, if possible, it should be kept rotating at low speed until the bearing has cooled. Fresh oil should be fed to the bearing and on the journal through the openings over the oil rings.

The cause of overheating may be any of the following:

Insufficient oil in the reservoir.

Dirty oil or oil of poor quality.

Failure of oil rings to revolve.

Excessive pressure or end thrust caused by poor alignment of the machine.

Bent shaft.

Rough bearing surface, which may have been the result of careless handling.

**Keep the Oil in the Bearings Clean**—The frequency with which the bearings must be refilled depends so much on local conditions, such as the severity and continuity of the service, the room temperature, the state of cleanliness, etc., that no definite instructions can be given. Until local conditions show another interval to be more suitable, bearings should be refilled every six months.

Only the very best grade of oil—having a viscosity of from 185 to 200 seconds, Saybolt, should be used.

It always proves a false economy to use cheap oil. If the oil is to be used a second time it should be filtered and if warm allowed to cool before the bearings are refilled. Even new oil should be examined carefully and filtered or rejected if it is found to be gritty.

# RENEWAL PARTS

## Repairing

Repair work can be done most satisfactorily at our nearest Service Shop. However, interchangeable renewal parts can be furnished, as listed below, to customers, who are equipped for doing repair work.

## Recommended Stock of Renewal Parts

On pages 23, 24 and 25 is a list of the renewal parts and the minimum quantities of each that should be carried in stock. These are the parts most subject to wear in ordinary operation and damage or breaking due to possible abnormal conditions. The maintenance of such stock will minimize service interruptions due to breakdowns.

**Ordering of Repair Parts**—Repair parts of any standard Westinghouse set may be secured on short notice. To avoid misunderstanding always give the serial number of the stationary or of the rotating part of the machine as the case may be. The former will be found stamped on the nameplate and the latter on the end of the shaft. When material for coils is ordered, it should also be stated whether or not insulation for the winding is also desired.

**Rebabbitting Bearings**—The old babbitt should first be melted out and a suitable mandrel prepared. Split bearings should be babbitted one-half at a time and the mandrel should consist of a half-cylinder with shoulders running along its length on which the sides of the bearings may rest so as to form a close fit when the bearing housing is in position for babbitting. Pieces of felt should be placed between the ends to prevent the babbitt from running into the oil well in the spaces back of the bearing shell. Use only the best babbitt metal. The melted babbitt should be poured in the gate until it begins to overflow, and a few moments should elapse before it is removed from the mandrel, in order that the bearing may become quite hard. The bearing housing should then be bored or reamed to the proper size, the holes for inspecting the working of the oil rings drilled, and the oil ring slots melted or cut to the proper depth. The finishing can be done with a file. If the mandrel is a smooth half-cylinder, the oil grooves should be chipped out. The grooves may be cast by properly designing the mandrel.

**Repairs to Insulation**—If a defect develops in the outside of a field or armature coil, it can sometimes be repaired by carefully raising the injured wire or wires and applying fresh insulation. More extensive repairs should not be attempted by inexperienced, or unskilled workmen.

**Sectional Bands**—Large generator armatures are provided with sectional bands instead of the more familiar continuous bands, greatly facilitating the repair of large armatures.

Fig. 25 shows the tool used in connecting and disconnecting sectional bands.

To make the final connection between the free ends, after the different sections

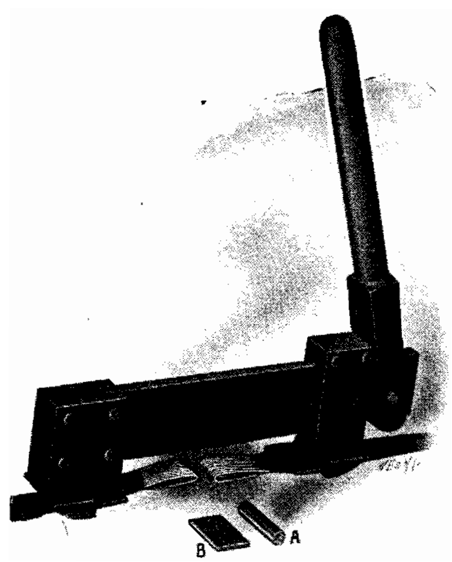



Fig. 25—Banding Tool

have been keyed together into an open hoop and are in position on the armature, place the tool as shown in Fig. 25, the two jaws gripping the projecting ends of the fixed pieces let into the ends of each section for this purpose. With the tool in the position shown in Fig. 25, bring down the handle, forcing the movable jaw forward along the beam and interweaving the loops on the section ends. Insert the steel pin A in the holes through the movable jaw and beam, and with the tool clamped in this way, remove the handle and advance it to the next hole in the beam. This operation is repeated until the ends of the band are interlocked sufficiently to permit the steel key piece B to be inserted (see Fig. 25). All that remains is to remove the tool and paint or shellac the joint.

To remove the band, reverse the preceding process. Relieve the tension on the joint by tightening the band with the tool and then drive out the key piece.

## Caution

**In soldering connections use an acid that will not act on the insulation or the copper; an alcoholic solution of resin is a suitable soldering flux.**

**In soldering commutator connections do not allow bits of solder to drop down where they may short-circuit commutator bars.**

**Keep the commutator brushes and insulation clean.**

**Never use emery cloth or emery paper on commutator collector or brushes.**

## RECOMMENDED STOCK OF RENEWAL PARTS

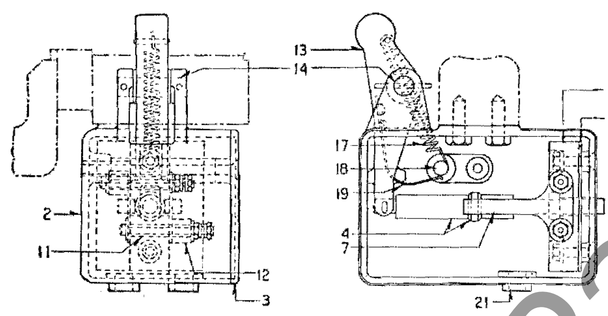



FIG. 26—MECHANICAL SPEED-LIMIT SWITCH

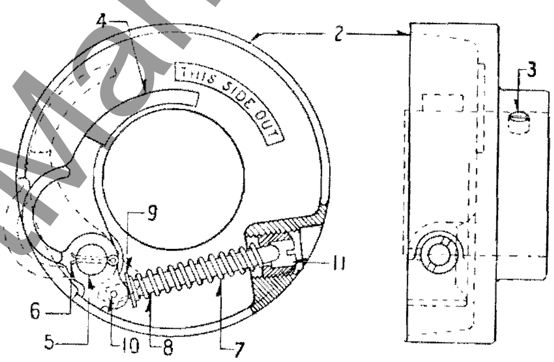



FIG. 27—GOVERNOR

**Mechanical Speed-Limit Switch**

| Ref. No. | Name of Part | No. Per Switch | Quantity Recommended for Stock | | |
|---|---|---|---|---|---|
| **Switches in use up to and including** | | | **2** | **5** | **15** |
| **1** | Speed limit switch complete | 1 | 0 | 0 | 1 |
| **2** | Switch box | 1 | 0 | 0 | 1 |
| **3** | Switch box cover | 1 | 0 | 0 | 1 |
| **4** | Contact plunger—open circuit | 1 | 0 | 0 | 1 |
| **4** | Contact plunger—closed circuit | 1 | 0 | 0 | 1 |
| **5** | Micarta insulating plate | 1 | 1 | 1 | 2 |
| **6** | Fibre switch base | 1 | 1 | 1 | 2 |
| **7** | Contact spring | 2 | 1 | 2 | 4 |
| **11** | Micarta insulating tube | 2 | 1 | 1 | 2 |
| **12** | Micarta insulating tube | 2 | 1 | 1 | 2 |
| **13** | Switch lever | 1 | 0 | 0 | 1 |
| **14** | Hinge pin for switch lever | 1 | 0 | 1 | 1 |
| **17** | Spring for switch lever | 1 | 1 | 1 | 2 |
| **18** | Spring post | 1 | 0 | 0 | 1 |
| **19** | Flat spring for switch lever | 1 | 1 | 1 | 2 |
| **21** | Insulating bushing | 2 | 1 | 2 | 4 |

**Governor for Mechanical Speed-Limit Switch**

| Ref. No. | Name of Part | No. Per Switch | Quantity Recommended for Stock | | |
|---|---|---|---|---|---|
| **Governors in use up to and including** | | | **2** | **5** | **15** |
| **1** | Governor complete | 1 | 0 | 0 | 1 |
| **2** | Governor case | 1 | 0 | 0 | 1 |
| **3** | Headless set screw | 2 | 0 | 0 | 2 |
| **4** | Governor lever | 1 | 0 | 0 | 1 |
| **5** | Steel shaft | 1 | 0 | 0 | 1 |
| **7** | Operating spring | 1 | 1 | 1 | 2 |
| **8** | Guide | 1 | 0 | 0 | 1 |
| **9** | Steel washer | 1 | 0 | 0 | 1 |
| **10** | Headless set screw | 1 | 0 | 0 | 1 |

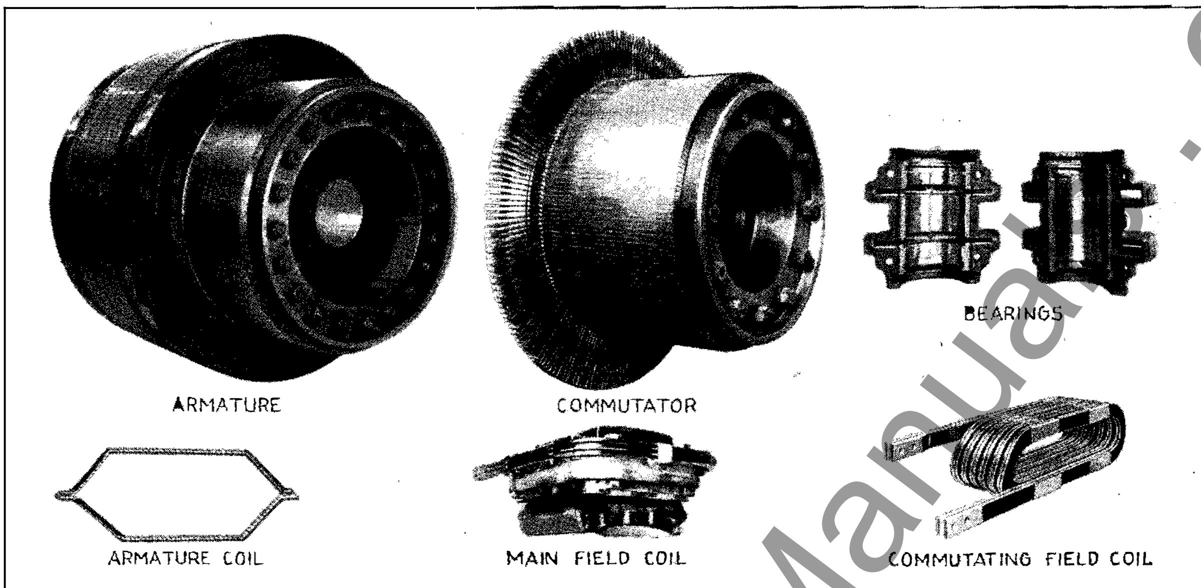



FIG. 28

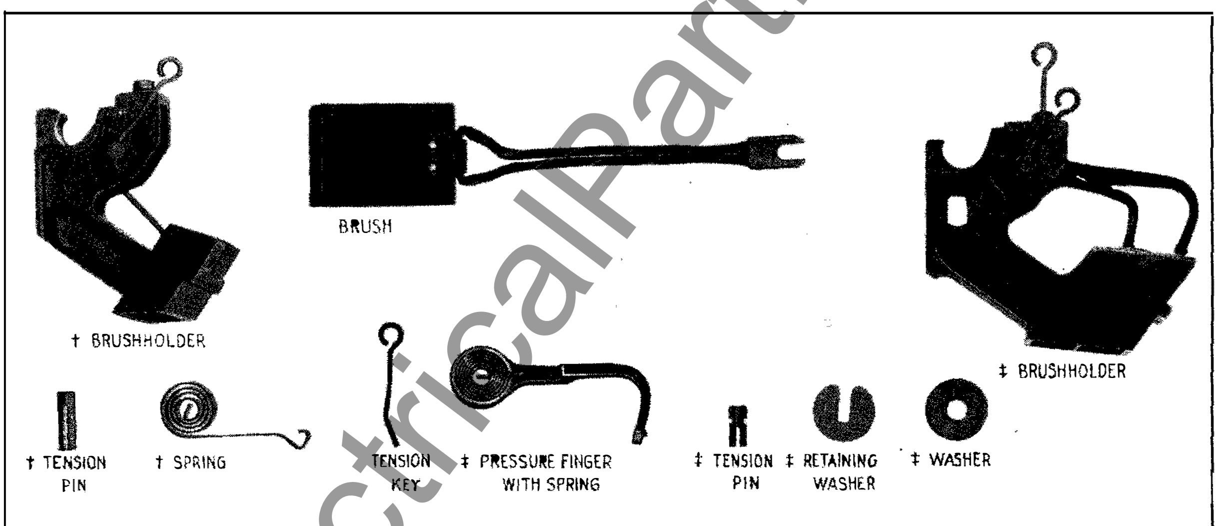



FIG. 29

†Single Brushholder ‡Double Brushholder

## Recommended Stock of Renewal Parts—Continued

| Units in use up to and including | | 2 | 5 | 15 |
|---|---|---|---|---|
| NAME OF PART | NO. PER SET | QUANTITY—RECOMMENDED FOR STOCK | | |
| **Generator** | | | | |
| Armature Coils | 1 Set | ⅓ Set | ⅔ Set | 1 Set |
| Rewinding Material | 1 Set | ⅓ Set | ⅔ Set | 1 Set |
| Main Field Pole with Coils Complete—Open | 1 Set | 1 | 1 | 2 |
| Main Field Pole with Coils Complete—Crossed | 1 Set | 1 | 1 | 2 |
| Brushes | 1 Set | 1 Set | 2 Sets | 3 Sets |
| Brushholders | 1 Set | 1 | 2 | 4 |
| Spring | 1 Set | 2 | 4 | 6 |
| Pressure Finger | 1 Set | 2 | 4 | 6 |

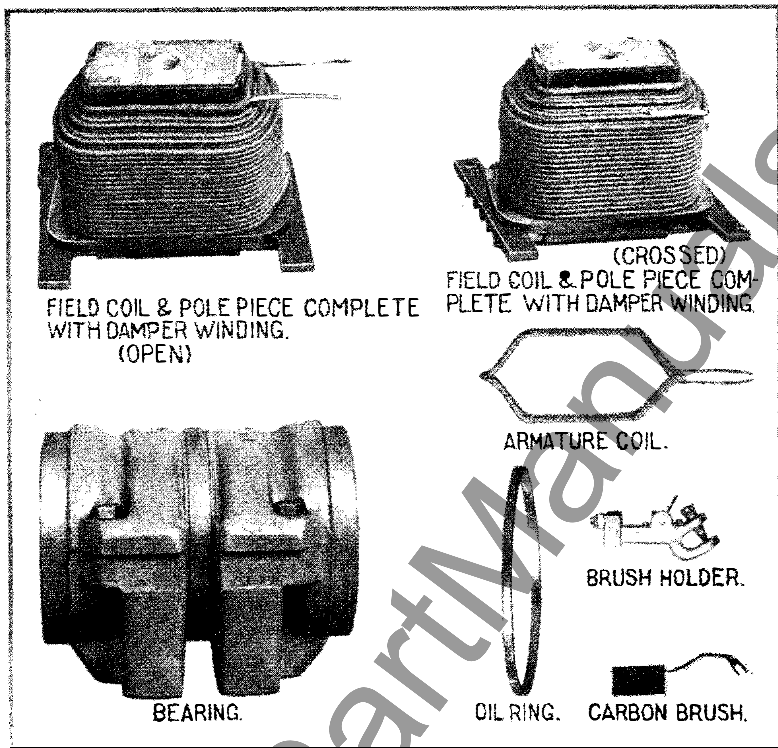



Fig. 30

## Recommended Stock of Renewal Parts—Continued

| Units in use up to and including | | 2 | 5 | 15 |
|---|---|---|---|---|
| Name of Part | No. Per Set | Quantity—Recommended for Stock | | |
| **Synchronous Motor** | | | | |
| Armature Coils | 1 Set | 1/3 Set | 2/3 Set | 1 Set |
| Rewinding Material | 1 Set | 1/3 Set | 2/3 Set | 1 Set |
| §Field Coils Complete—Open | 1 Set | 1 | 1 | 2 |
| §Field Coils Complete—Crossed | 1 Set | 1 | 1 | 2 |
| §Main Field Pole with Coil Open | 1 Set | 1 | 2 | 4 |
| §Main Field Pole with Coil Crossed | 1 Set | 1 | 2 | 4 |
| Brushes | 1 Set | 1 Set | 2 Sets | 3 Sets |
| Brushholders | 1 Set | 1 | 2 | 4 |
| Spring | 1 Set | 2 | 4 | 6 |
| Pressure Finger | 1 Set | 2 | 4 | 6 |
| **Mechanical Parts** | | | | |
| *Bearings | 1 Set | 1 | 2 | 3 |
| *Oil Ring | 1 Set | 1 | 2 | 2 |

§When coil is wound on the pole it is necessary to order pole and coil together.
*The above recommendation is for each different kind.
A recommended List of Renewal Parts for your complete equipment will be supplied upon request to the nearest District Office.
Parts indented are included in the part under which they are indented.

## Wiring Diagrams

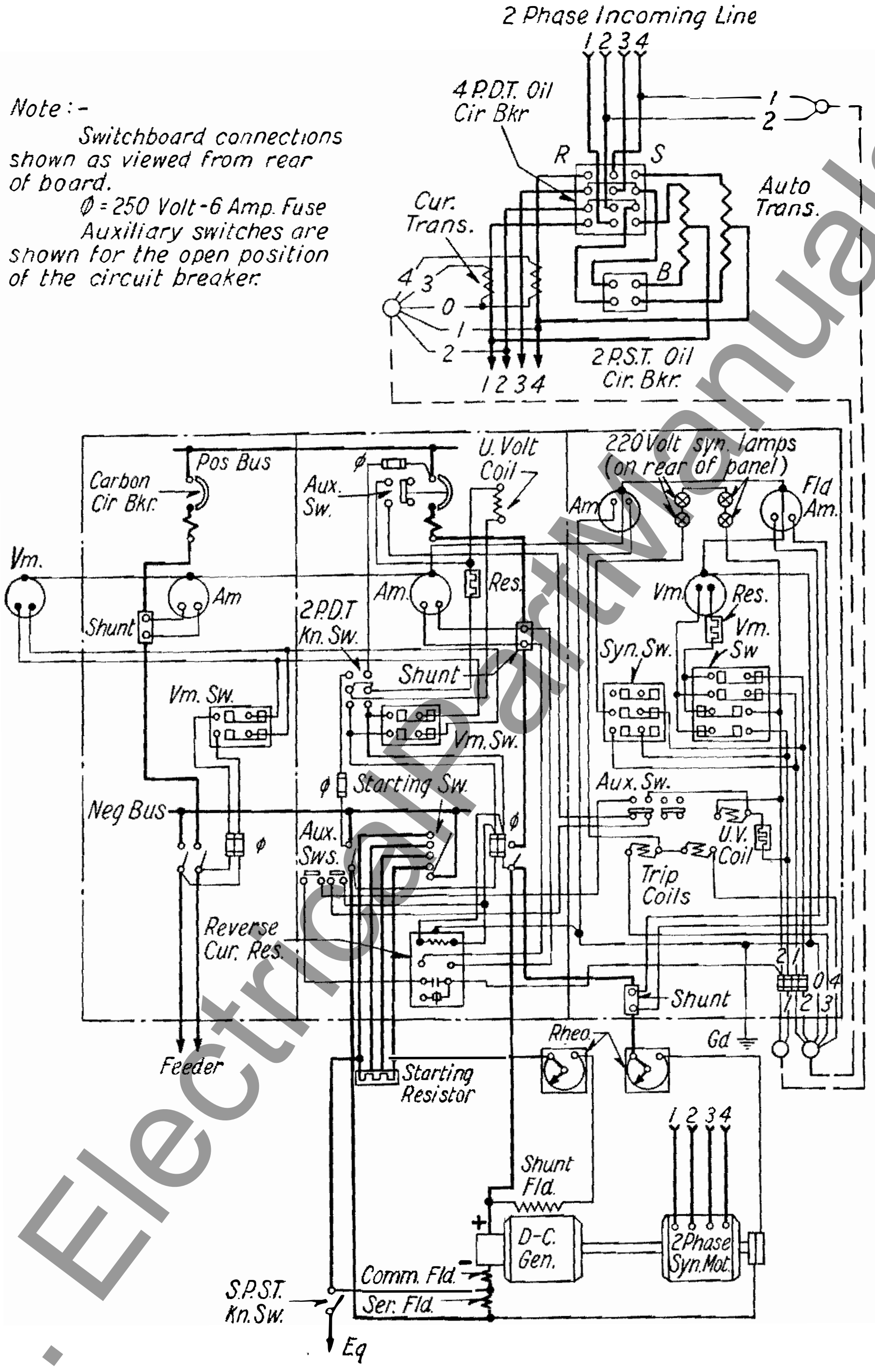



Fig. 31—440-Volt, 2-Phase Incoming Line and 440-Volt, 2-Phase, Self-Starting Synchronous Motor Driving a 250-Volt, 2-Wire D-C. Generator and Arranged for Starting Either from the D-C. End or from the A-C. End by Means of Two Single-Phase Auto-Transformers. The Motor is Excited from the D-C. Generator

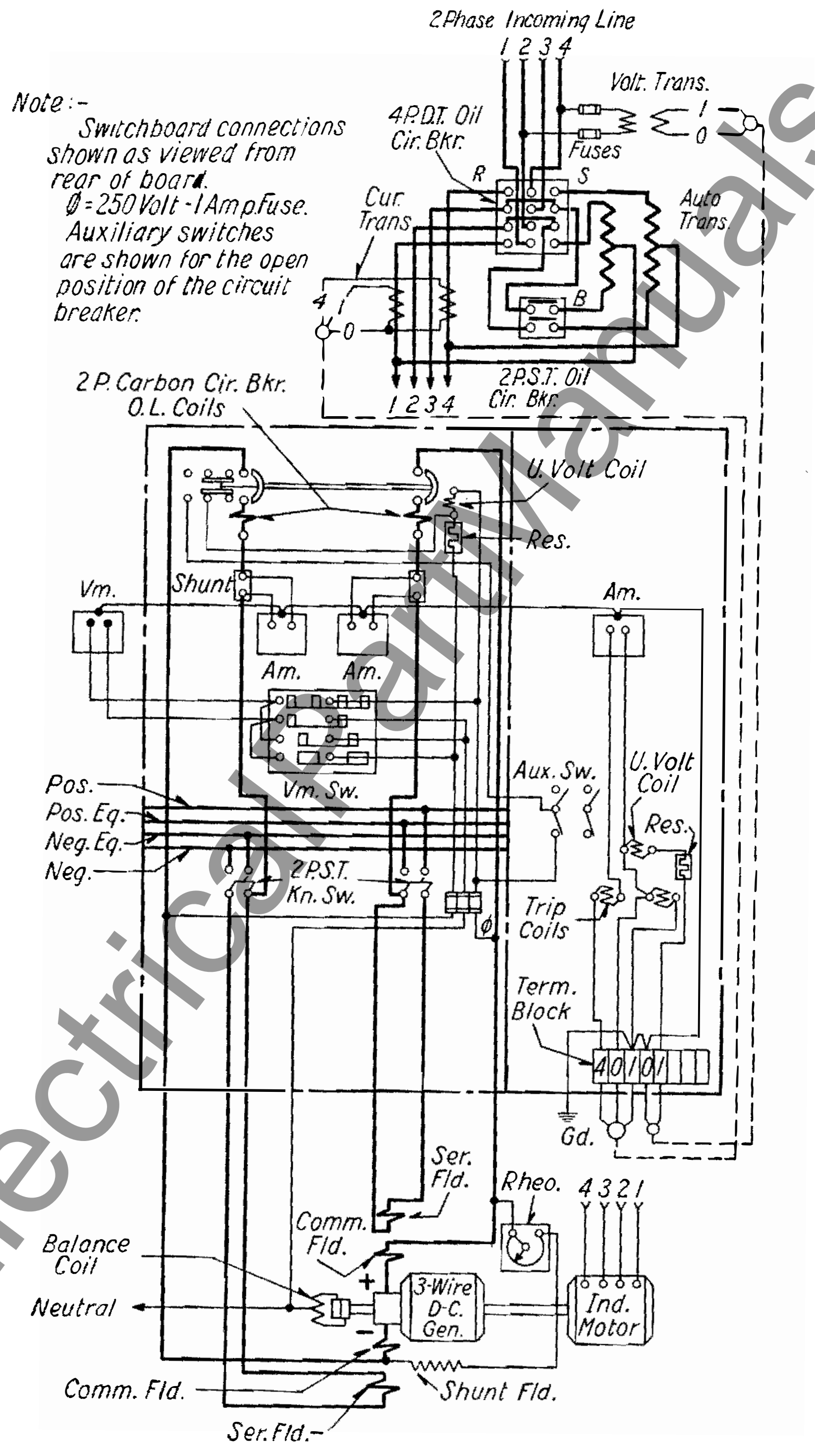



Fig. 32—2200-Volt, 2-Phase, Incoming Line, 2200-Volt, 2-Phase, Self-Starting Induction Motor Driving a 250-Volt, Three-Wire D-C. Generator. Arranged for Starting from A-C. End by Means of Two Single-Phase Auto-Transformers

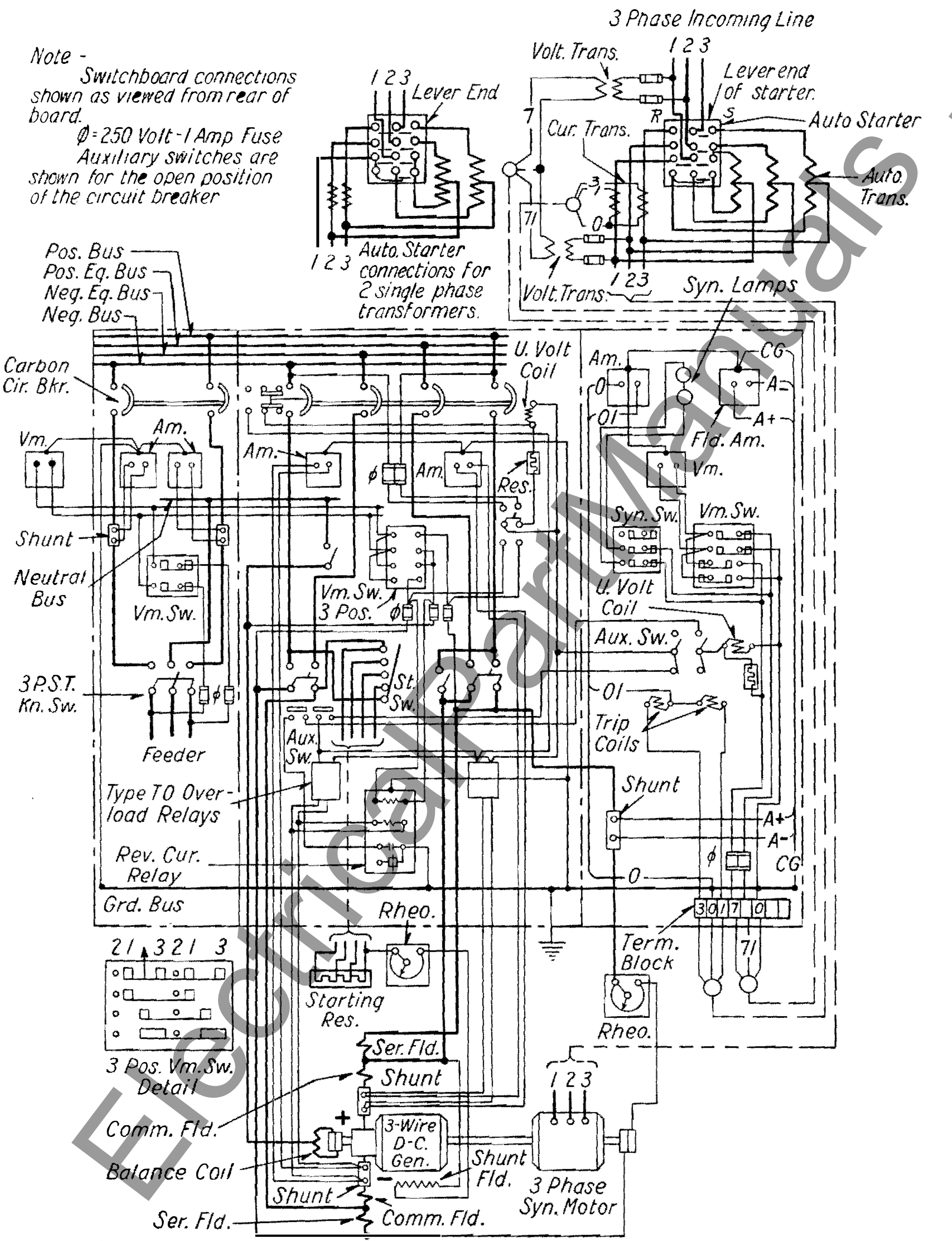



FIG. 33—6600-VOLT, 3-PHASE, INCOMING LINE AND 6600-VOLT, 3-PHASE, SELF-STARTING SYNCHRONOUS MOTOR DRIVING A 250-VOLT, 3-WIRE D-C. GENERATOR. ARRANGED FOR STARTING FROM EITHER D-C. END OR A-C. END BY MEANS OF TWO SINGLE-PHASE OR ONE THREE-PHASE AUTO-TRANSFORMER. MOTOR IS EXCITED FROM D-C. GENERATOR

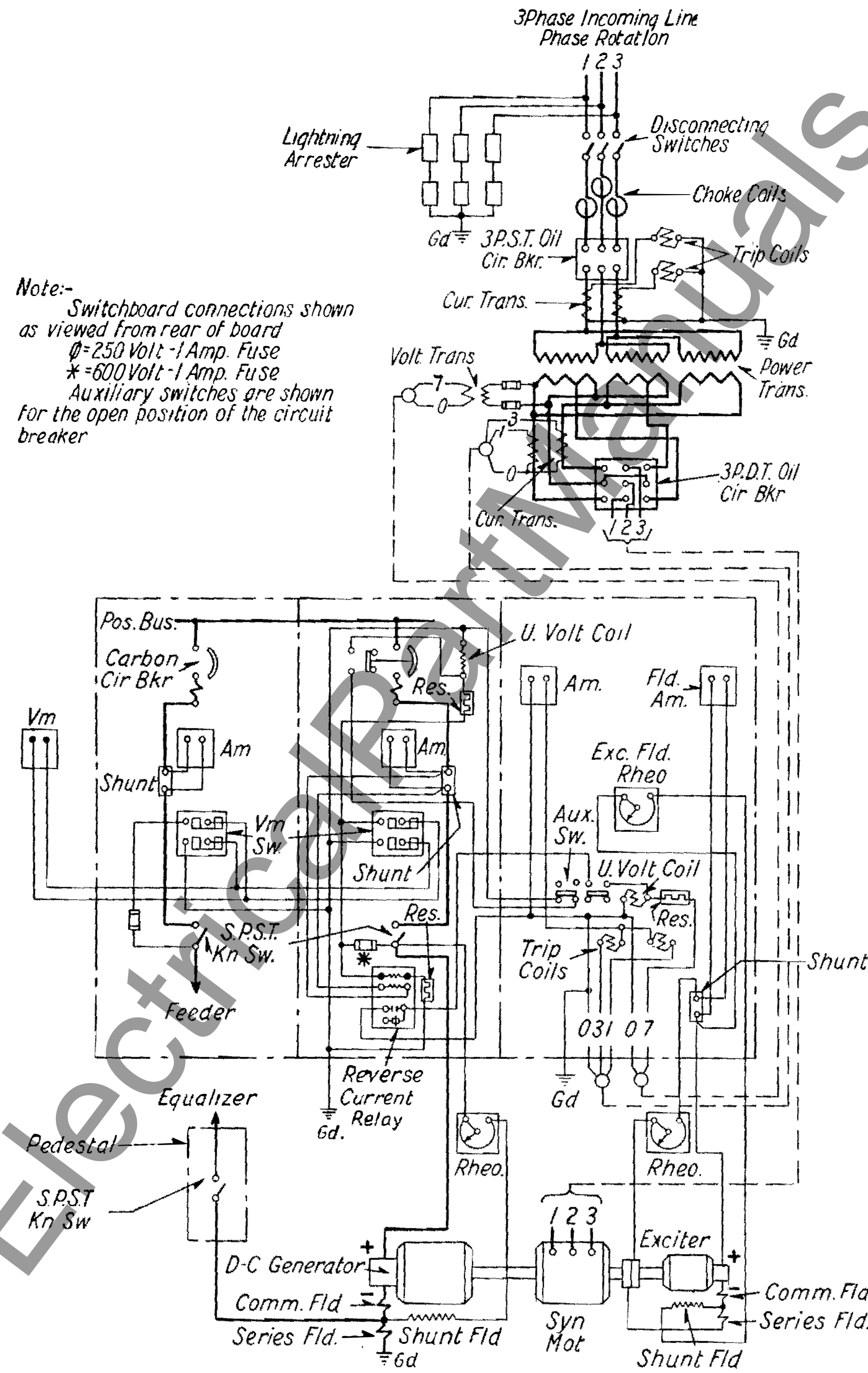



Fig. 34—3-Phase, Incoming Line with Ungrounded Neutral, and 2200-Volt, 3-Phase Self-Starting, Synchronous Motor Driving a 600-Volt, Two-Wire, D-C. Railway Generator, Arranged for Starting from A-C. End by Means of Starting Taps on a Step-Down Transformer.

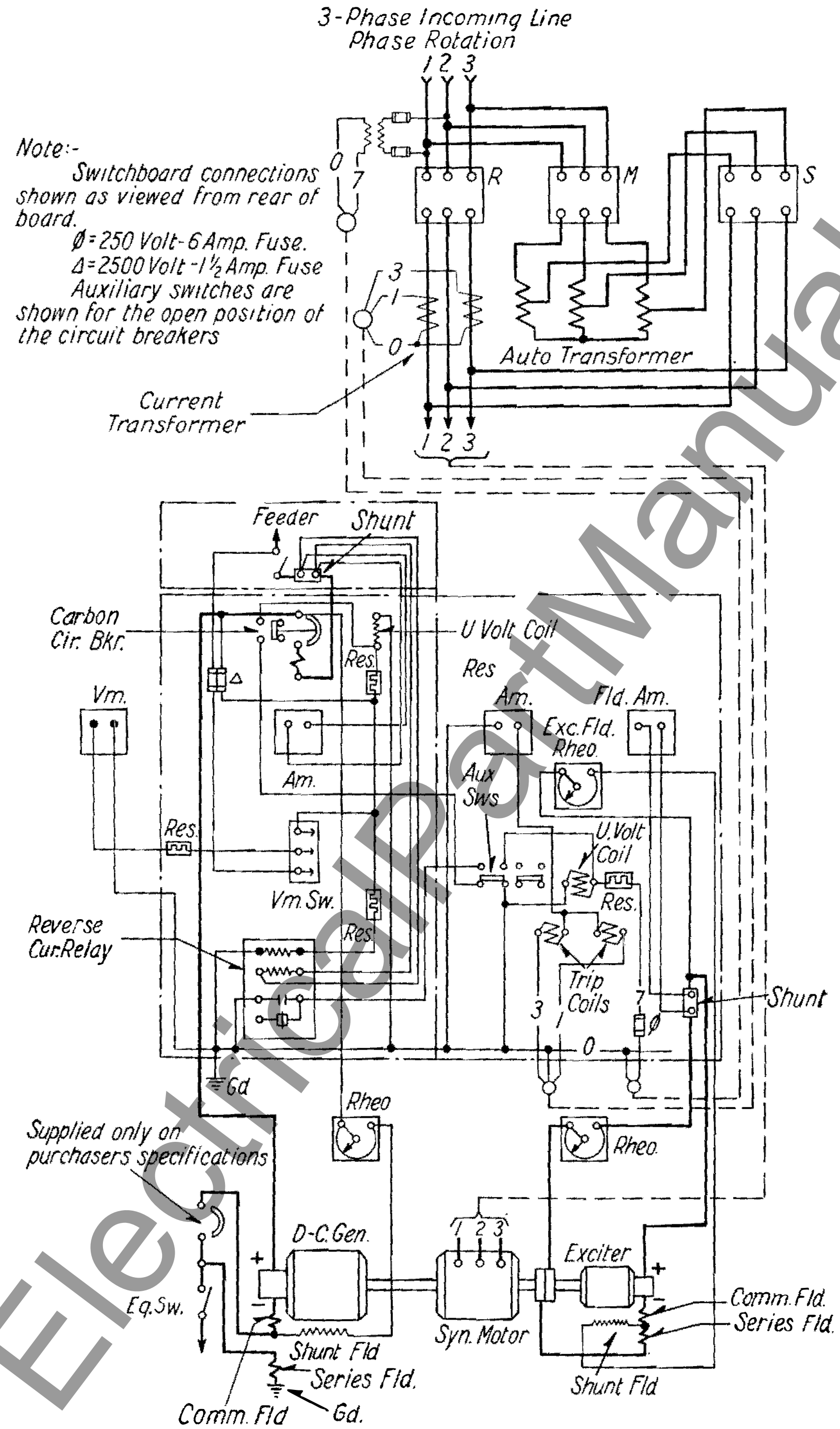



FIG. 35—13200-VOLT, 3-PHASE, 60-CYCLE, A-C. SELF-STARTING SYNCHRONOUS MOTOR DRIVING A 1500-VOLT, D-C. RAILWAY GENERATOR. ARRANGED FOR STARTING FROM A-C. END BY MEANS OF A 3-PHASE AUTO-TRANSFORMER

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