I.B. 1840-1

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

Air-Cooled

TURBINE GENERATORS

1000 To 7500 KW

WESTINGHOUSE ELECTRIC CORPORATION
TRANSPORTATION AND GENERATOR DIVISION
EAST PITTSBURGH WORKS • EAST PITTSBURGH, PA.

NEW INFORMATION

EFFECTIVE MARCH, 1947
Printed in U.S.A.

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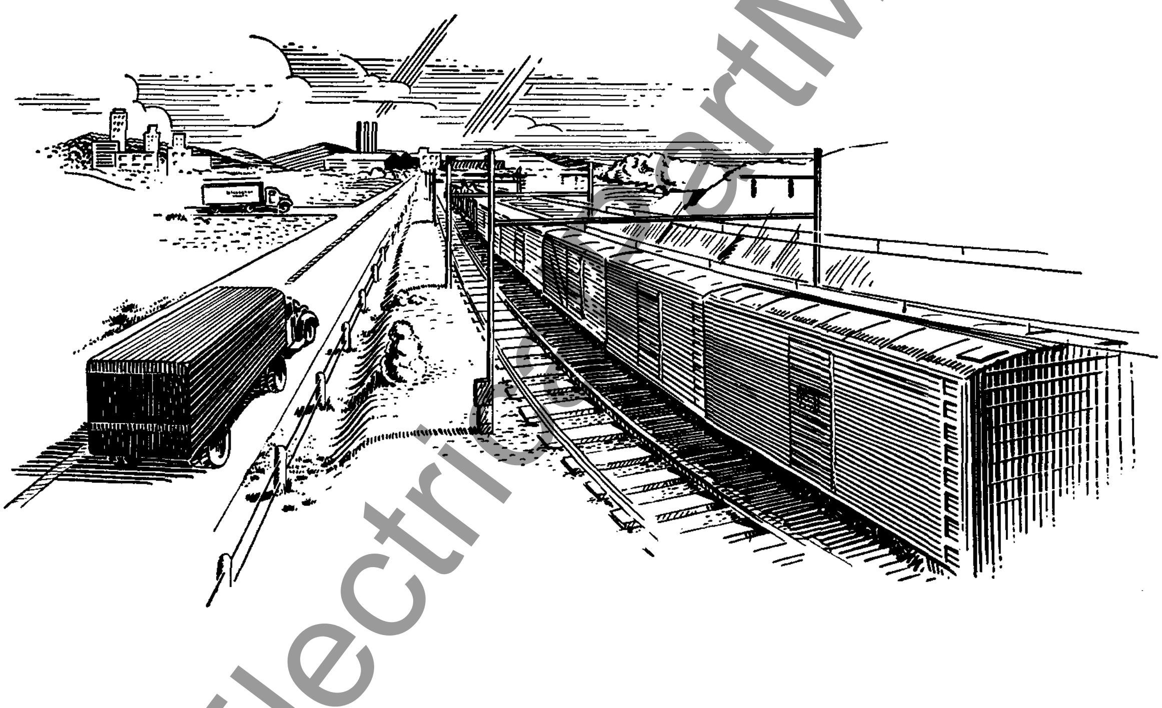

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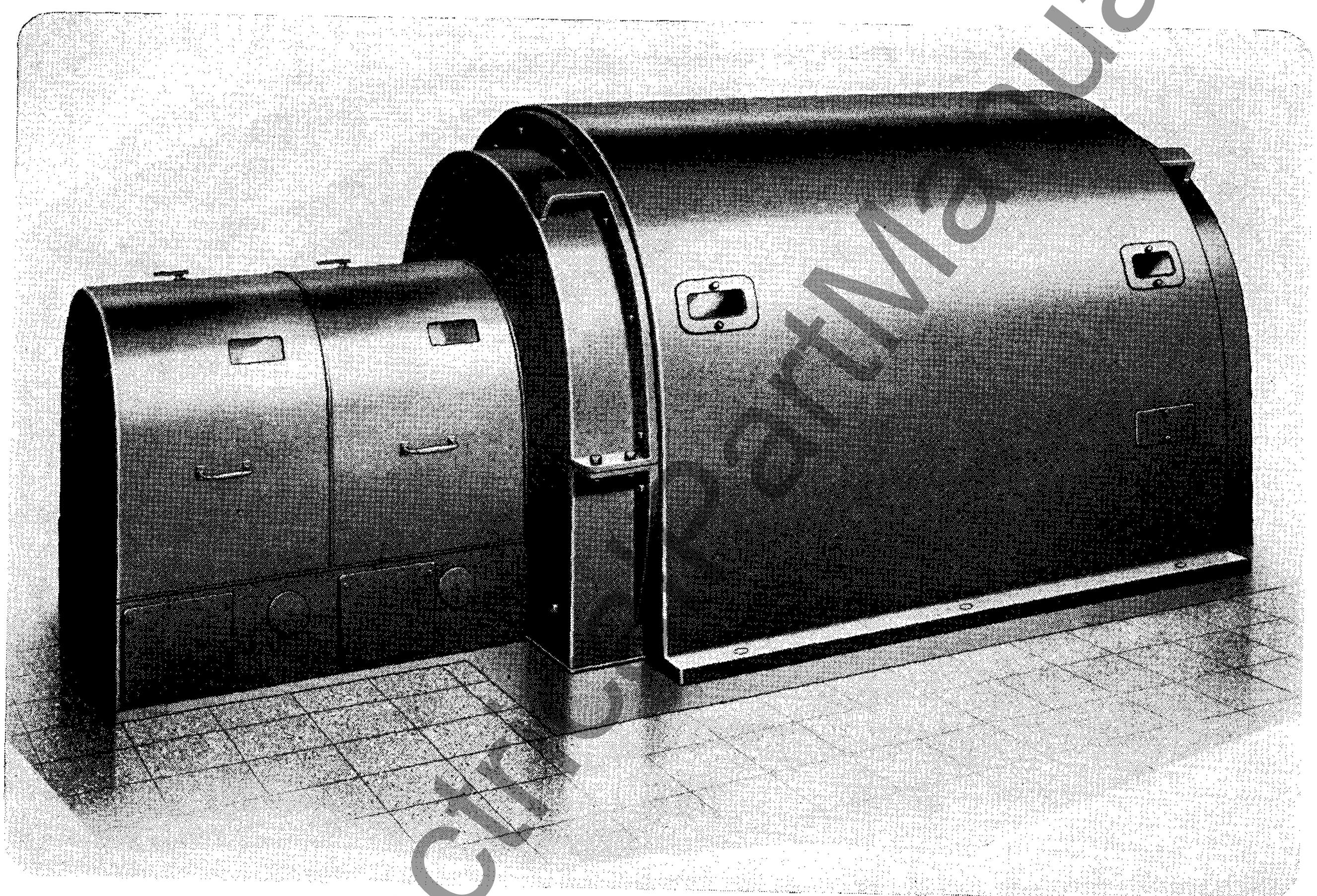


WESTINGHOUSE TURBINE GENERATORS

The air-cooled, steam turbine-driven, alternating-current generators covered in this Instruction Book are two-pole machines which range from 1000 to 7500 kw. They are designed to comply with the standards of the American Standards Association and the National Electrical Manufacturers Association.

A modern turbine generator when properly installed, operated and maintained will give years of service and will run for long periods without a shutdown.

This book is written with the intention of acquainting the operators with the construction and features of these generators; also, to serve as a guide during installation and operation so that maximum trouble-free life will be obtained.

PART ONE

DESCRIPTION

A general understanding, beforehand, of the construction of the generator is a great help when studying the succeeding sections, Installation, Operation, and Maintenance. Figure 1 shows a cutaway view of a typical turbine generator.

STATOR

Frame and Core. The stator frame is fabricated from steel plates and bars electrically welded into a rigid box section. A short length of duct work is provided on the bottom of the frame through which ventilating air is discharged. Holes drilled and tapped around the edges of the duct provide means for attaching customer's duct work. Port holes with removable glass serve both as lifting holes for handling during erection and windows for the inspection of the end windings during operation. The generator feet rest directly on the foundation.

The stator core is built up of low-loss segmental silicon steel laminations and is assembled on bars which span the length of the core. Both sides of the laminations are treated with an insulating material to prevent short-circuiting the laminations. Vent spacers are built in with the laminations at intervals of approximately two inches to provide passages through the core for the ventilating air. Adequate pressure is applied at intervals during the stacking operation to produce a tight core. Heavy end plates and non-magnetic finger plates are used at the ends

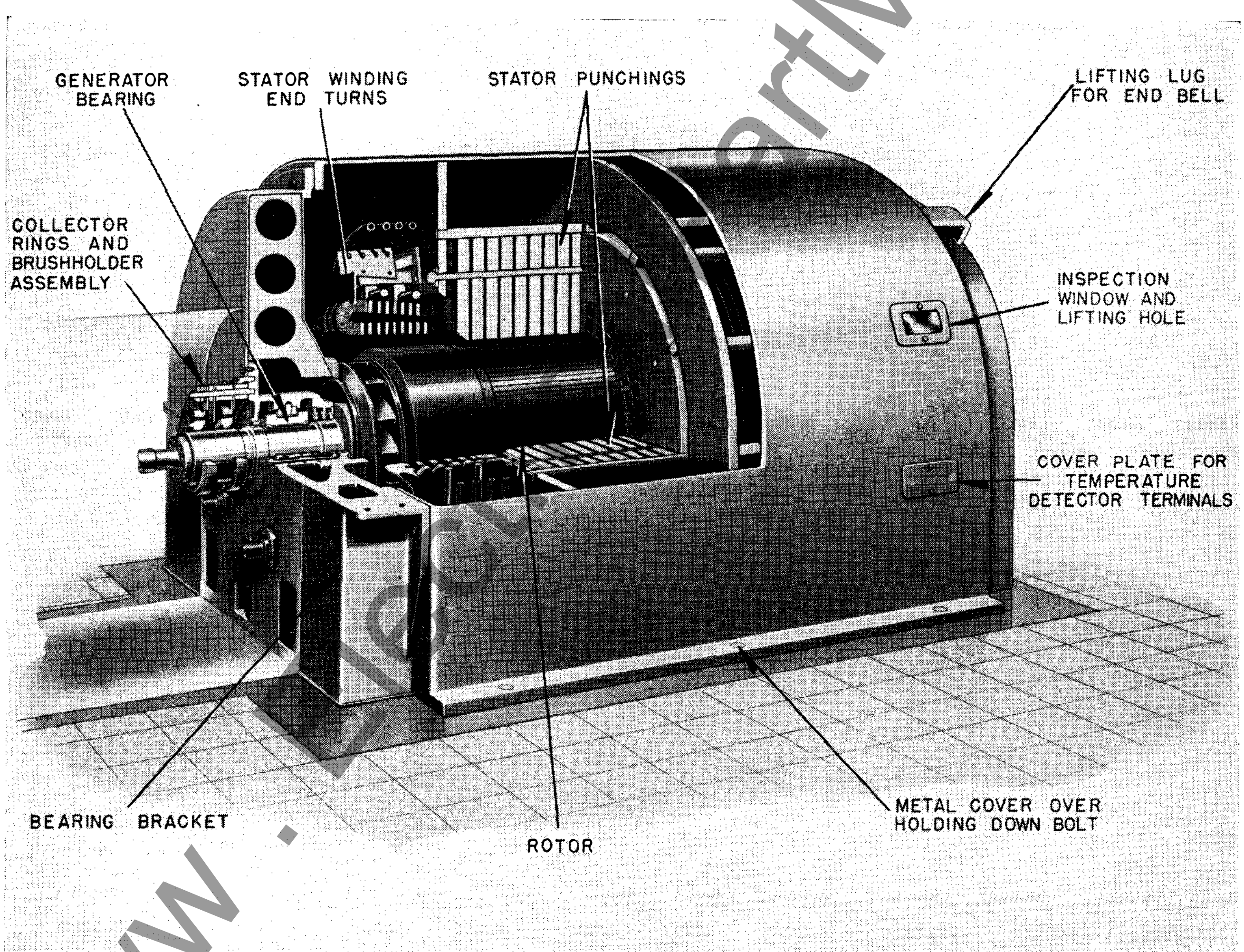


FIG. 1. Cutaway View of Generator

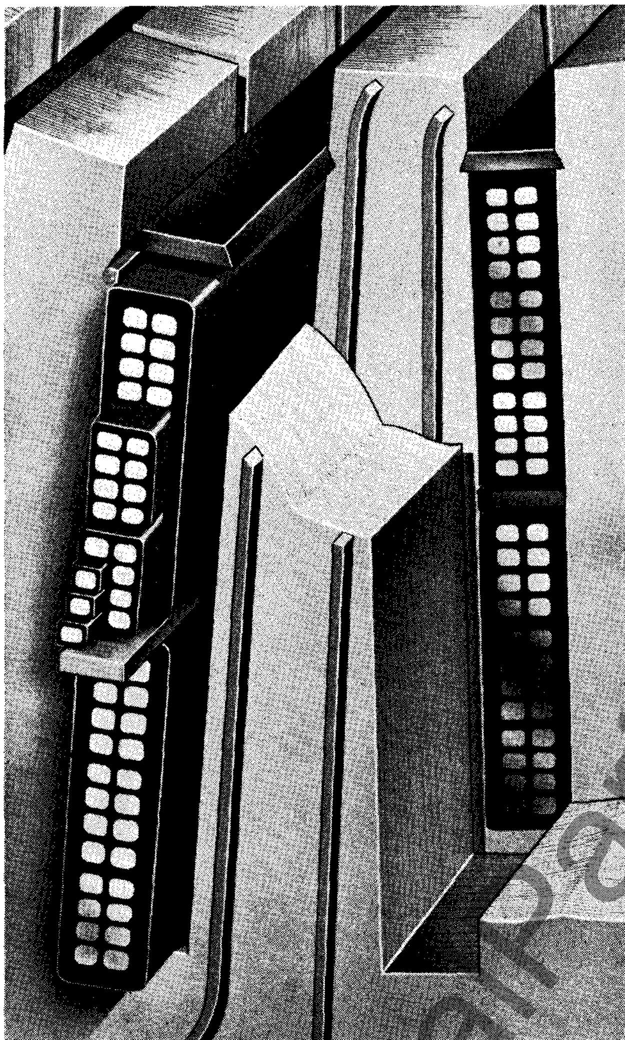


FIG. 2. Stator Coil Insulation

of the core to maintain adequate pressure at all times. The larger generators (4000 kw and above) have insulated through-bolts which extend axially through the punchings back of the slots. These provide additional clamping force on the end plates. After being assembled, the entire core is coated with varnish and baked to protect it from rust and to further insulate between punchings.

Winding. Interchangeable closed-type coils are used on these machines. Figure 2 shows the cross section of a typical stator coil in the slot. The stator windings of generators which have ratings of 5000 Kva or less and 6900 volts or less are provided with Class A insulation. All generators with ratings over 5000 Kva or voltage above 6900 volts have Class B insulation on their stator windings. When electrical conditions require it, groups of strands are transposed at the ends to reduce eddy current losses.

When the generator voltage is 6600 volts or more, the slot sections of the coil are treated with semi-conducting compounds to eliminate corona and its harmful effects in that portion of the coil.

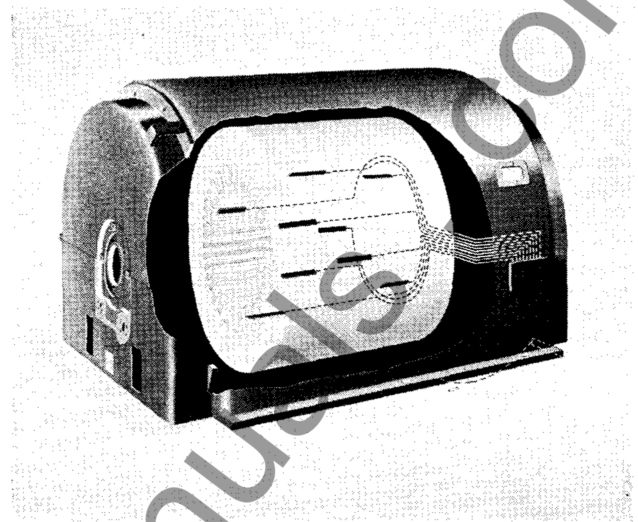


FIG. 3. Temperature Detector Arrangement

Temperature detectors calibrated for 10 ohms resistance at 25°C. are embedded between coils in various slots in the stator winding of the machine in order to obtain an indication of the operating temperature. (See Fig. 3.) The temperature detector leads are connected to a terminal board on the end of the generator as shown in Figure 26. The customer's detector leads may be brought out of the generator by means of a hole provided in the bottom of the generator frame.

The end turns of the windings are securely braced by archbound blocks and spacers between the coils tied in with glass cord. The coil ends are further supported by insulated steel bracing rings fixed on steel support brackets as shown in Figure 4.

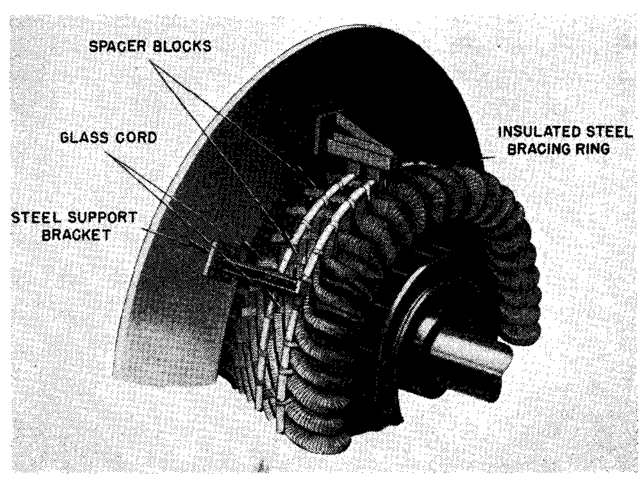


FIG. 4. Stator Winding End Turn Bracing

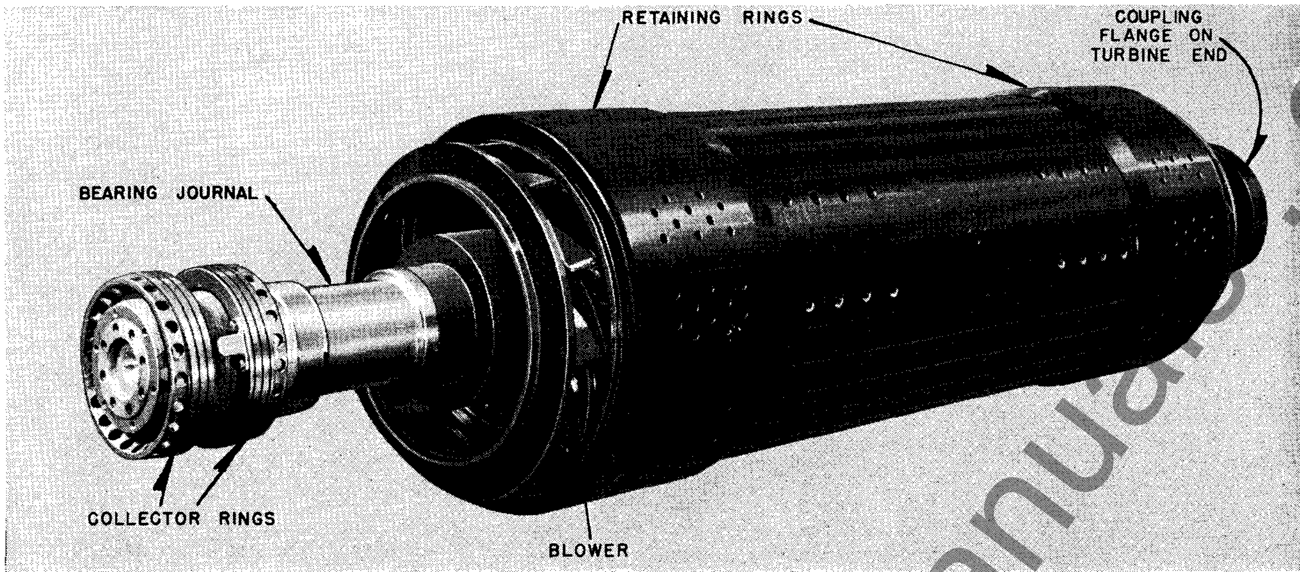


FIG. 5. Complete Rotor

ROTOR

Construction. The rotor is a one-piece steel forging with integral shaft ends. The surface of the rotor body is grooved to reduce losses and to increase heat transfer to the ventilating air. Radial slots for the windings are machined in the rotor body.

A complete rotor is shown in Fig. 5.

Winding. The arrangement of a typical rotor winding in place in the slot is shown in Figure 6. The insulation is full Class "B" with moulded mica between the winding and ground, and flat mica insulation between turns. The top turns are mica taped for extra insulation. Rotor coils are baked under high radial pressure until the winding becomes a solid mass. The coils are held in the slots by sturdy non-magnetic wedges.

The rotor end turns are supported radially by forged steel retaining rings which are lined with asbestos Micarta. The retaining rings are shrunk onto the ends of the rotor body as shown in Figure 7.

Ventilating air passes under the end of the retaining ring, flows over the rotor winding end turns and discharges through radial holes in the retaining ring. Axial support is provided to the coil end turns by means of fitted asbestos Micarta blocks which also serve to direct and control the flow of ventilating air over the end turns.

COLLECTOR

The collector rings are made of tool steel. These rings are then mounted on a steel bushing and insulated with mica. By mounting the collector outside of the bearing, easy accessibility to the brush rigging is obtained. The leads from the collector to the field winding are semi-circular copper bars separated by Micarta plates and located in a hole in the center of the shaft. Connections are made to

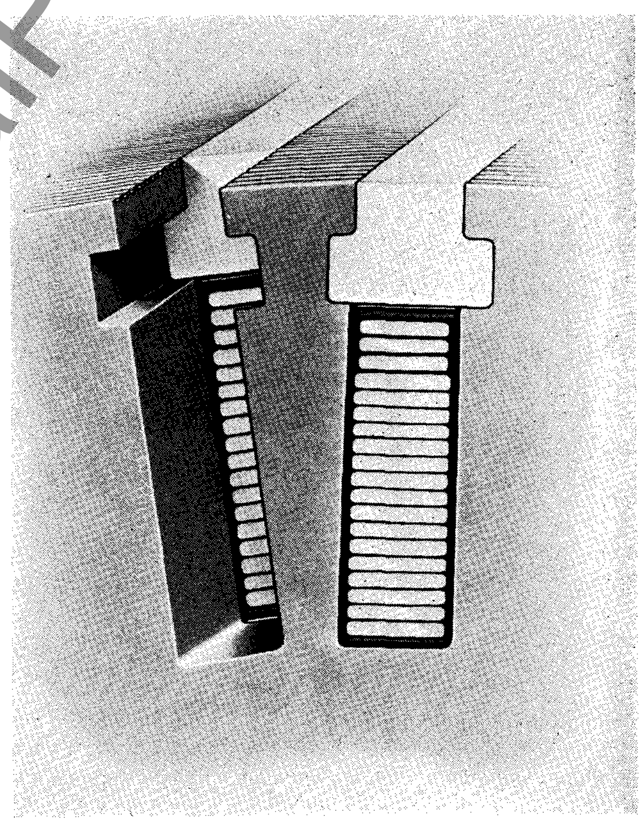


FIG. 6. Rotor Insulation.

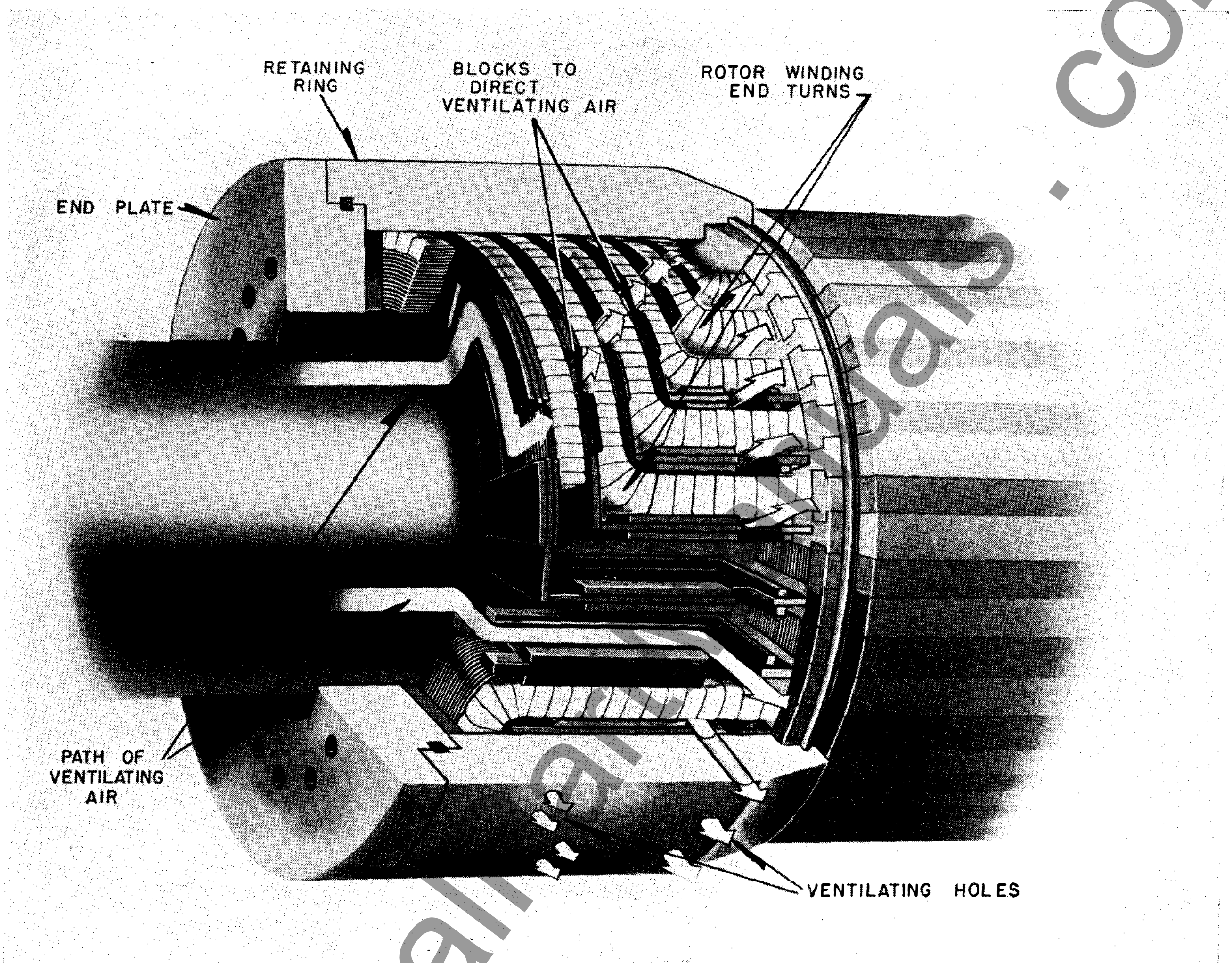


FIG. 7. Retaining Ring and End Turns

these bars by radial copper studs fastened into the bars. This can be seen in Figure 8.

The collector is ventilated by a stream of cool air which is bled from the exciter air supply. Holes drilled in the collector ring flanges circulate air and provide additional cooling surface. Spiral grooves on the wearing faces of the rings prevent hot spots and thus insure good current collection.

An adjustable coil spring on the brushholder maintains the desired brush pressure on the collector rings. Graduations on the brushholder indicate the force in pounds exerted on the back of the brush. The brushes are provided with pigtail connections to prevent corrosion of the holder. This corrosion is due to arcing between the holder and the brush. Corrosion has a tendency to impede the motion of the brush in the holder. These brushholders are designed so that brushes may be removed without tools and with the use of only one hand. They are mounted radially about the collector rings and are secured by means of bolts to the brushholder sickles. These sickles are mounted on insulated posts on the bearing bracket as shown in Figure 9.

BEARINGS

The collector end of the rotor is supported by a bracket type bearing. The bracket is bolted solidly to the outer frame of the generator. The turbine end of the rotor is solidly connected to an extension of the turbine shaft. Thus, the turbine shaft acts as a support eliminating the use of a bearing on that end of the rotor. Lubricating oil is supplied under pressure to the generator bearing from the turbine oil system. A cutaway view of the bearing is shown in Figure 10.

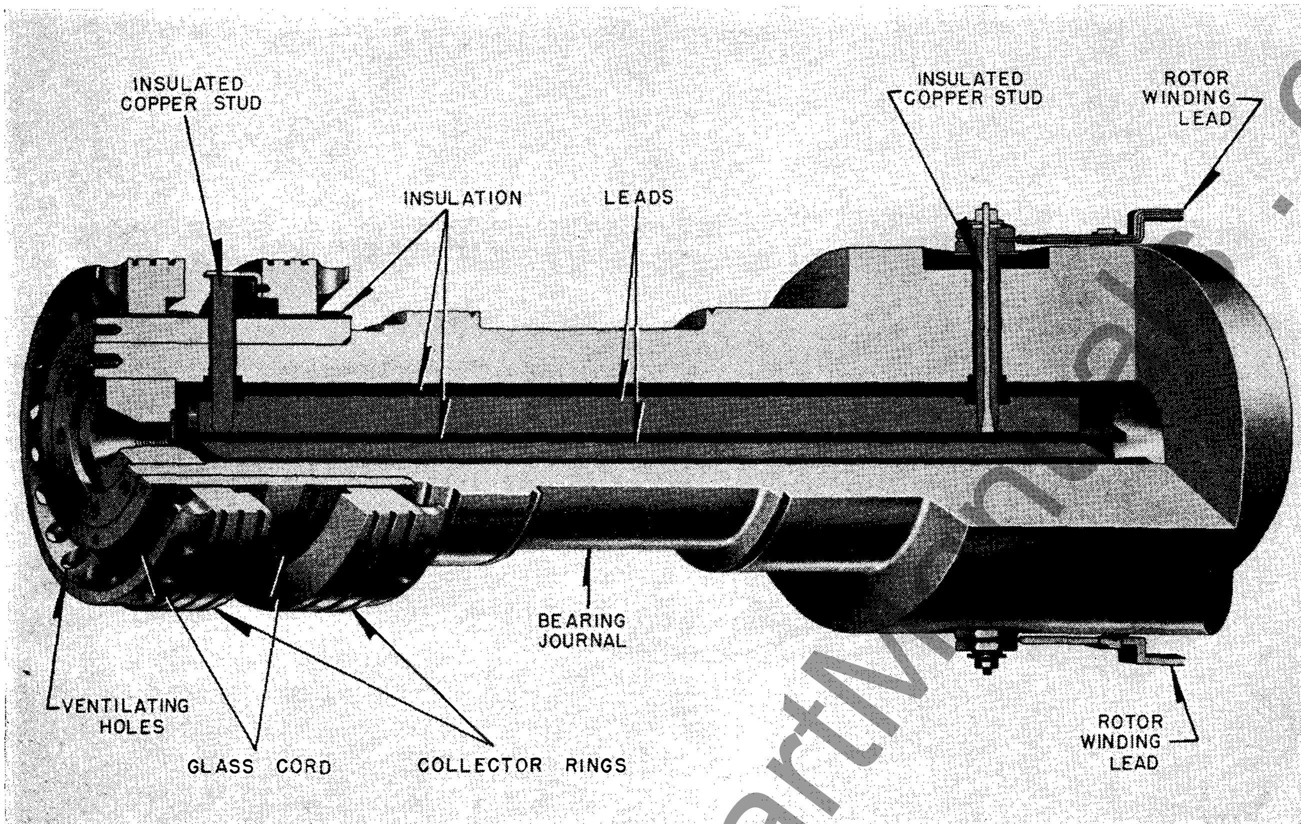


FIG. 8. Cutaway View of Collector

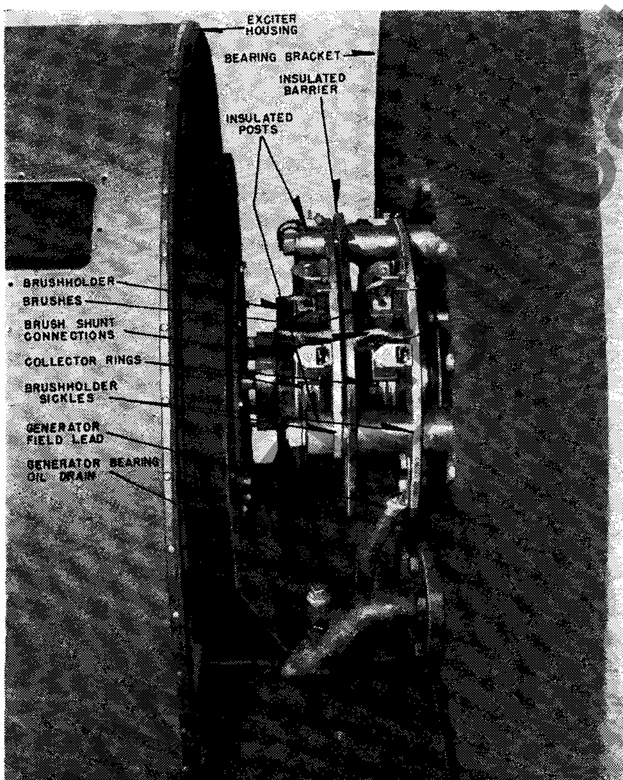


FIG. 9. Exciter Housing Rolled Back Giving Access to Collector

BRACKET AND END BELL

Type. The bracket on the collector end, and the end bell which is provided on the turbine end, are both of the double enclosing type; that is, they are constructed so that the inner part encloses the end turns of the stator winding, while the outer part forms a passage to guide air into the blowers.

Flow of Air. The air in the outer end bell section is usually below atmospheric pressure since it is the fan intake zone. Carbon dust from the collector rings, or oil from the bearings may be drawn in at the end bell seals unless some provision is made to prevent such action. Air from the high pressure zone is piped to the seal ring on the end bracket and end bell. From here the air flows out axially, blowing away any carbon dust or oil mist.

EXCITER

Construction. Figure 11 shows a turbine generator exciter which is a shunt-wound, self-excited, direct-current generator. The exciter is of the single-bearing, pedestal-type construction with special features to make it suitable for high speed service and long periods of uninterrupted operation. It is designed to have maximum brush accessibility and is provided with special brushholders which, like those on the collector, permit one-hand removal of the brushes by the maintenance man and without the use of tools. Due to the large volume of high-velocity air which passes through the exciter, special care is taken to provide maximum creepage distances on all electrical parts and to provide for ease of cleaning.

The exciter is mounted on a steel bedplate and this bedplate in turn rests on a steel seating plate. The exciter rotor is solidly connected to the generator rotor. Ventilation duct work and bearing oil piping is contained in the exciter bedplate.

Cooling. Cool air is piped from the high-pressure zone in the main generator to the exciter end bell. This air blows over the exciter armature, field, and commutator, and then returns through duct work to the main generator. The direction of flow prevents blowing carbon dust from the commutator into the windings. Filters, which are installed in the bedplate, remove carbon dust and any other foreign material from the air before it returns to the generator. These filter elements can be removed for cleaning.

Lubrication. Lubricating oil under pressure is supplied to the exciter bearing from the turbine oil system. The oil drains from the generator and exciter bearings are each provided with a thermometer.

Housing. The exciter and collector are enclosed by a housing which is mounted on wheels so that it can be removed readily to make adjustments on the brushes or other parts. Windows are provided on both sides and the inside of the housing is painted white to make inspection of all parts easier.

The wiring for the exciter and tachometer is brought to the bottom of the exciter bedplate so the men doing the installation work can connect to it more conveniently.

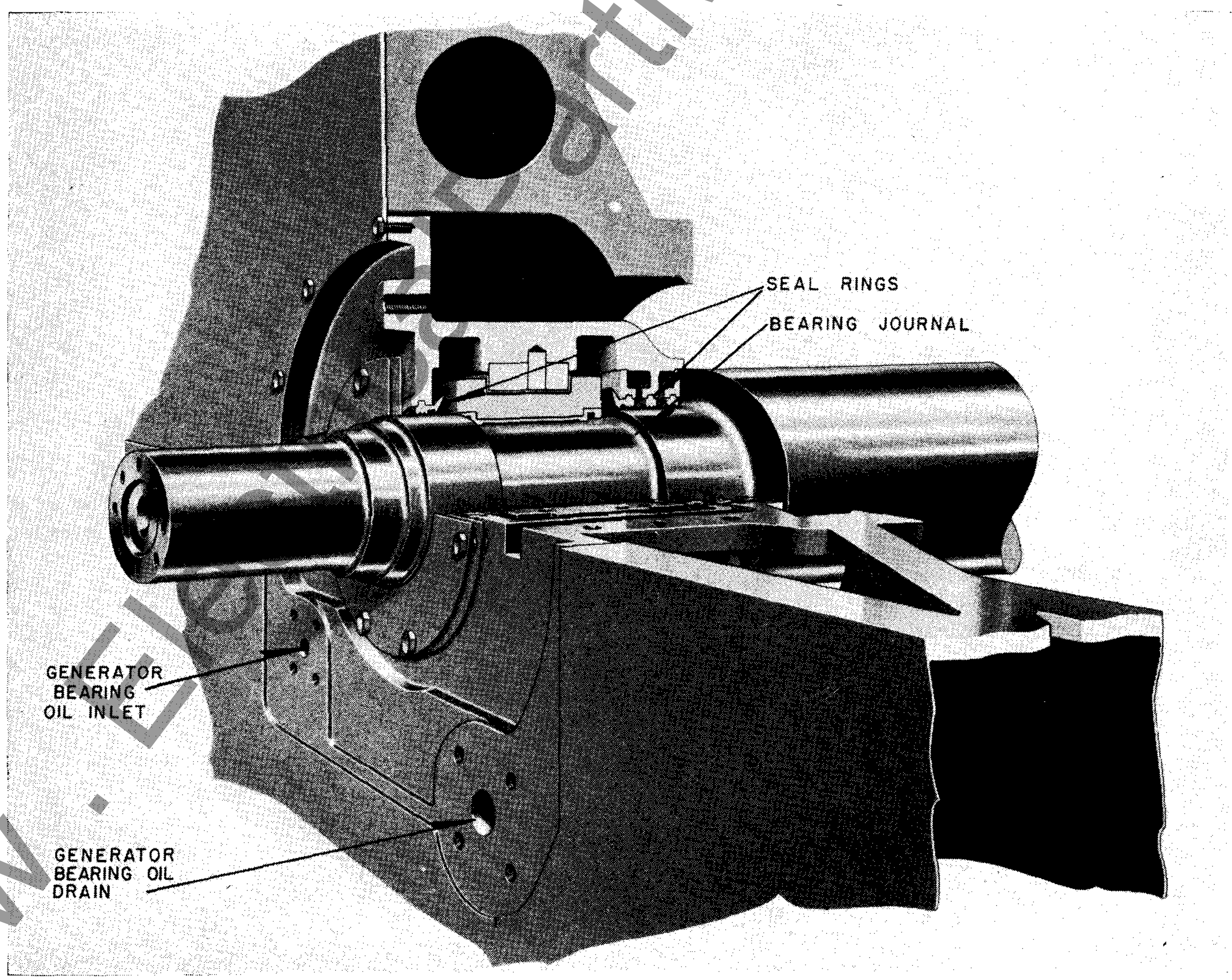


FIG. 10. Cutaway View of Bearing

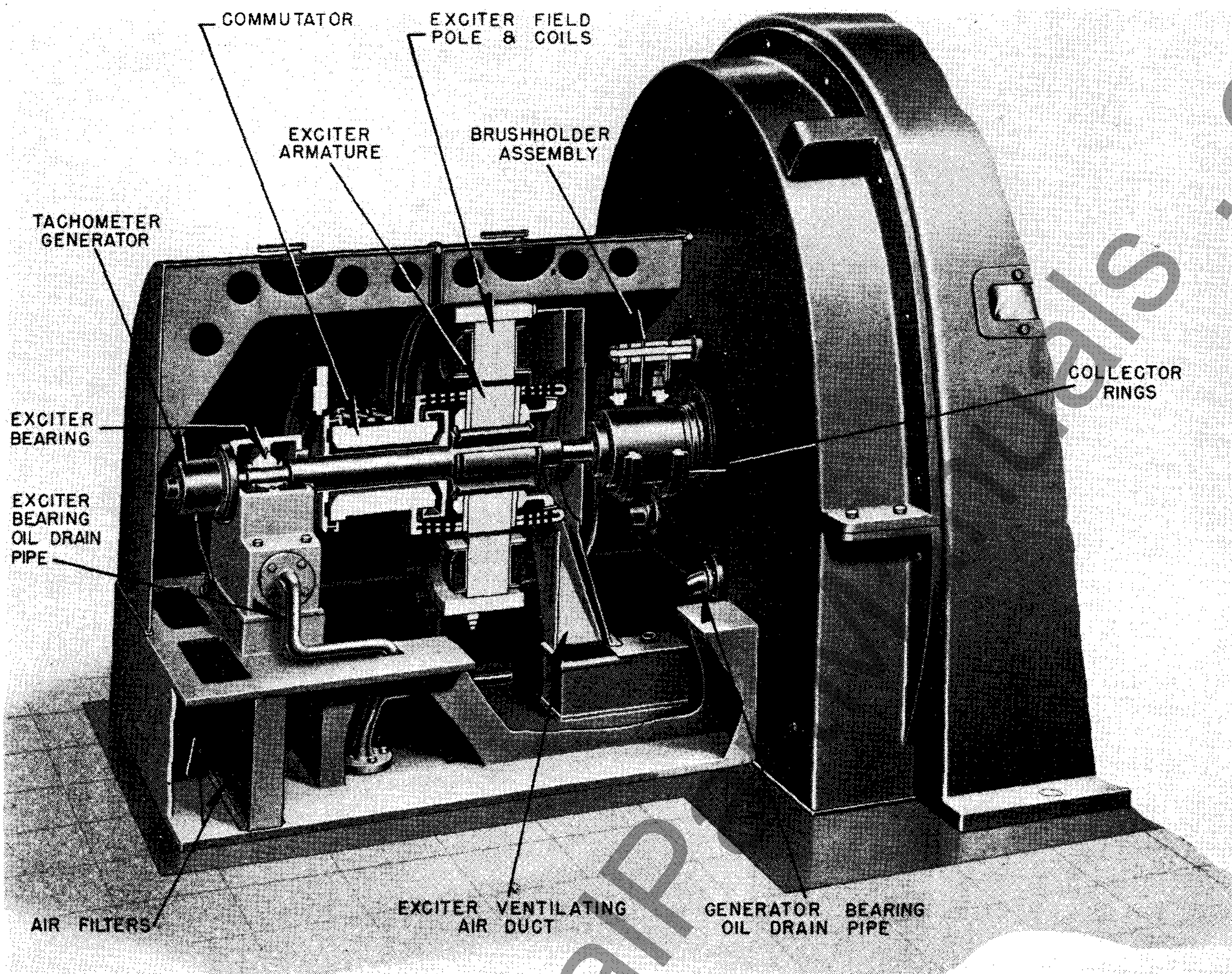


FIG. 11. Cutaway View of Exciter

TERMINALS

The six armature (stator) leads are brought out of the frame at the bottom of the collector end of the generator. Leads will be either cable or strap, depending on the magnitude of the currents to be delivered by the particular machine. The general arrangement of the leads is shown on Figure 12.

MECHANICAL ROTATION

The generator will rotate in the direction indicated by the outline supplement drawing furnished with the particular machine.

PHASE ROTATION

The voltages induced in the phases will reach positive maximum values in the order specified on the outline supplement drawing for the particular machine.

SHAFT CURRENTS

Variations in reluctance in the magnetic circuit of an alternating-current machine may cause periodic changes in the amount of flux which links the shaft. This change in flux may generate sufficient voltage to circulate current through the circuit consisting of shaft, bearings and frame. If this current is permitted to flow, it soon has a destructive effect upon the shaft journals and bearings.

As it is not practical to provide control of the generation of shaft voltages it becomes necessary to interrupt the path for circulating currents by inserting insulation as shown in Figure 13. The insulation consists of suitable thicknesses of Micarta placed between the bearing and the bearing pads, the use of insulated bolts and dowels, and of insulating gaskets placed between the bracket and

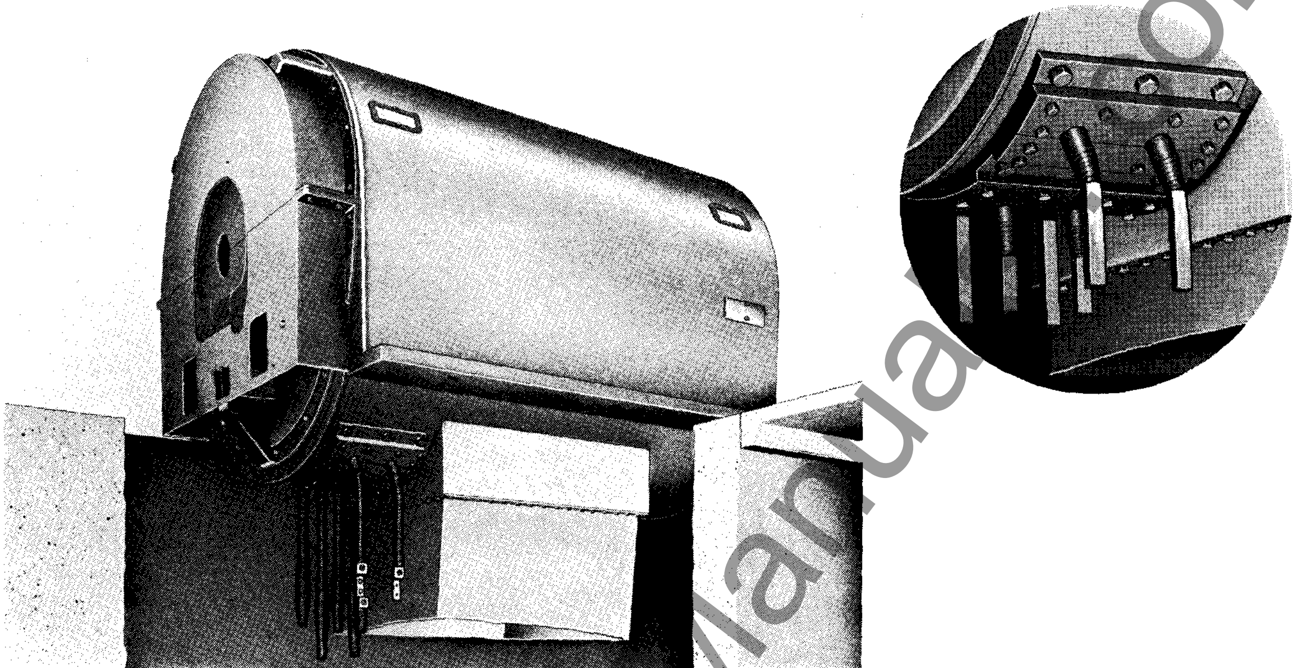


FIG. 12. Main Lead Arrangement

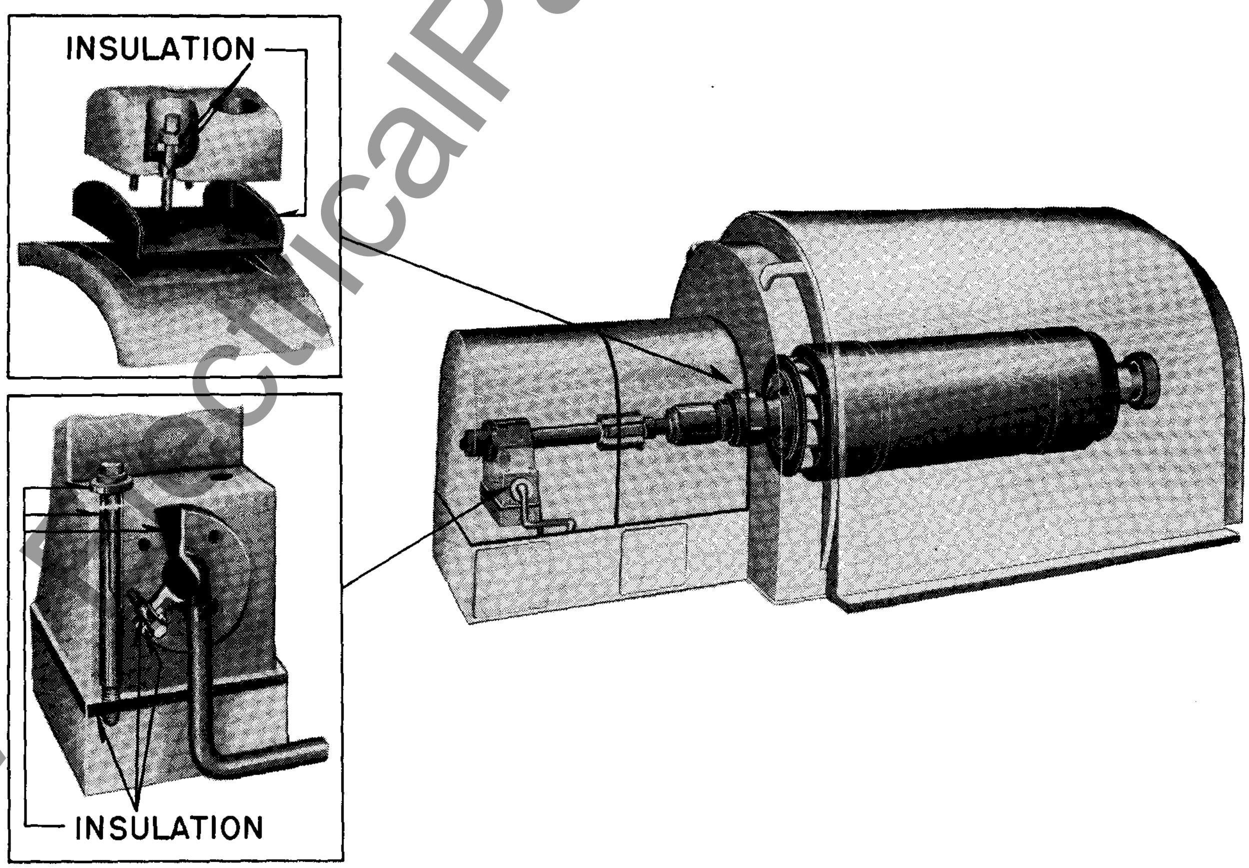


FIG. 13. Shaft Insulation

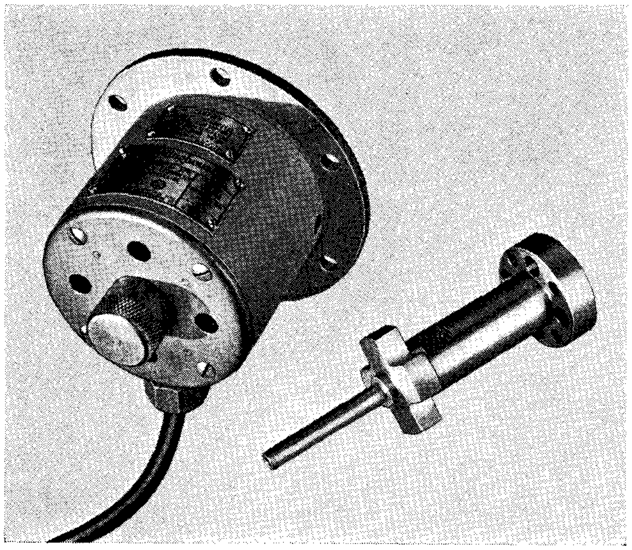


FIG. 14. Tachometer Generator

bearing seals, under the exciter pedestal and between the exciter oil lines and the pedestal.

TACHOMETER GENERATOR

Construction. Figure 14 shows the tachometer generator. The tachometer generator is direct connected to the exciter shaft and both the rotor and the stator of the tachometer generator are overhung. The rotor is driven through a solidly coupled nonmagnetic (brass) stub shaft. The stator is supported by a flange on the rear of the frame. The tachometer is constructed without bearings and with an air gap of approximately .030 inch (single gap) at each end.

The tachometer is an inductor generator which requires no moving coils or commutator. Its stationary field coil is separately excited with direct current.

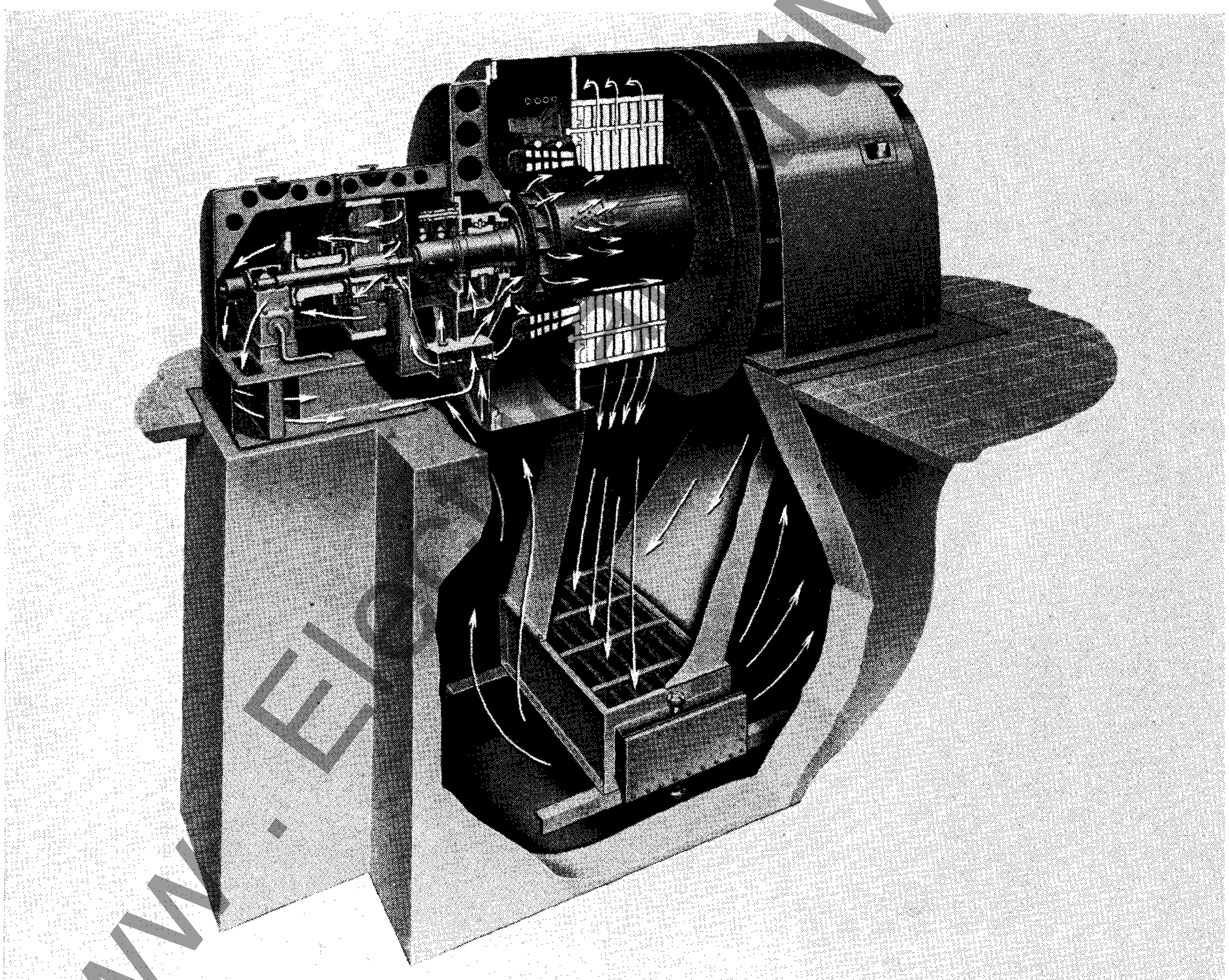


FIG. 15. Ventilation Scheme

The tachometer generator is ventilated by the passage of air through the holes in the cover and frame. The accuracy of the tachometer is not effected appreciably by ordinary variations in temperature.

BLOWERS AND VENTILATION

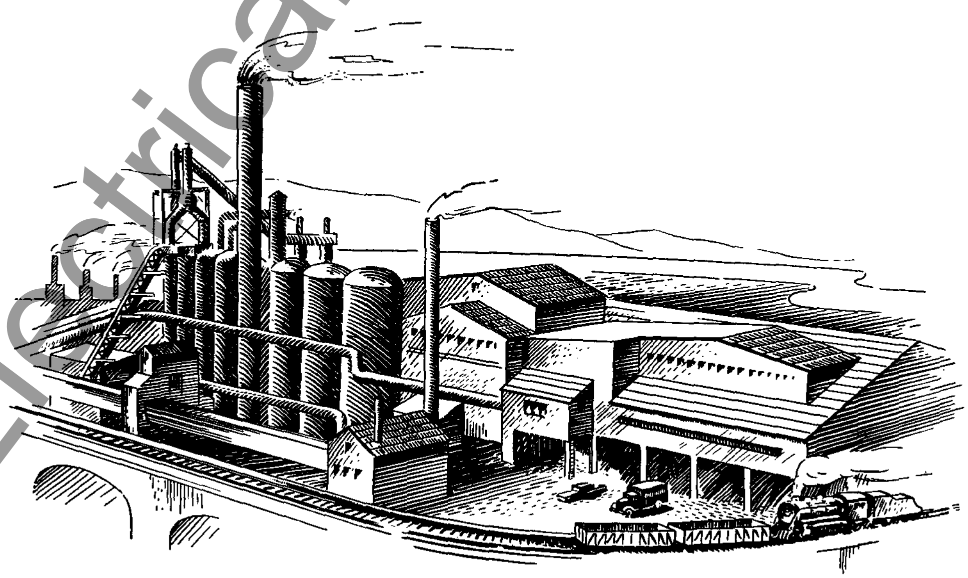
The most effective use of the active materials that go into the fabrication of all rotating machinery can be realized only if the machine is adequately ventilated.

Westinghouse turbine generators are designed and proportioned so that the cooling air is uniformly directed to all sources of heat generation. Centrifugal blowers, which are mounted on each end of the rotor (see Fig. 5) are liberally designed. The ventilating ducts in the stator core are of sufficient quantity and so distributed that uniform temperatures exist throughout the entire length of the machine.

Circuit. The ventilation circuit for the entire unit is shown in Figure 15. Air flows from the blower (most of it circulating about the end windings) and goes through the gap towards the middle of the core. A portion of the blower output passes under the end of the retaining ring and ventilates the rotor end windings. Another portion goes into the end bell of the exciter by means of duct work provided in the exciter bedplate.

The major portion of the air, after flowing through the gap between the rotor and the stator, flows radially outward through vent spaces in the stator core. The heated air then flows circumferentially in the space between the stator core and the outside frame, then through exhaust holes in the bottom of the generator frame. When a closed ventilation system is used, duct work under the generator leads the air through a cooler. This cooled air then returns to the generator through openings in the bottom of the end bells and passes through the blowers again. This cycle completely repeats about once every second.

The portion of air which ventilates the exciter flows over the rotor and stator and then to the commutator of the exciter. The air then returns to the generator outer end bell section after passing through air filters located in the return ducts in the exciter bedplate.



PART TWO

RECEIVING, HANDLING AND STORING

RECEIVING

When the generator reaches its destination, the purchaser should check the material actually received against the shipping lists to be sure that all parts have been received. This will avoid delays in installation. He should also examine the shipment immediately and if damage is noted, file claims as soon as possible with the delivering carrier.

HANDLING

Means are provided for attaching lifting devices to the stator frame, and the rotor can be handled by passing slings around the body and by putting the hook through a lifting tool which can be attached to the exciter end of the shaft. See Fig. 16. (This lifting tool is supplied with the machine).

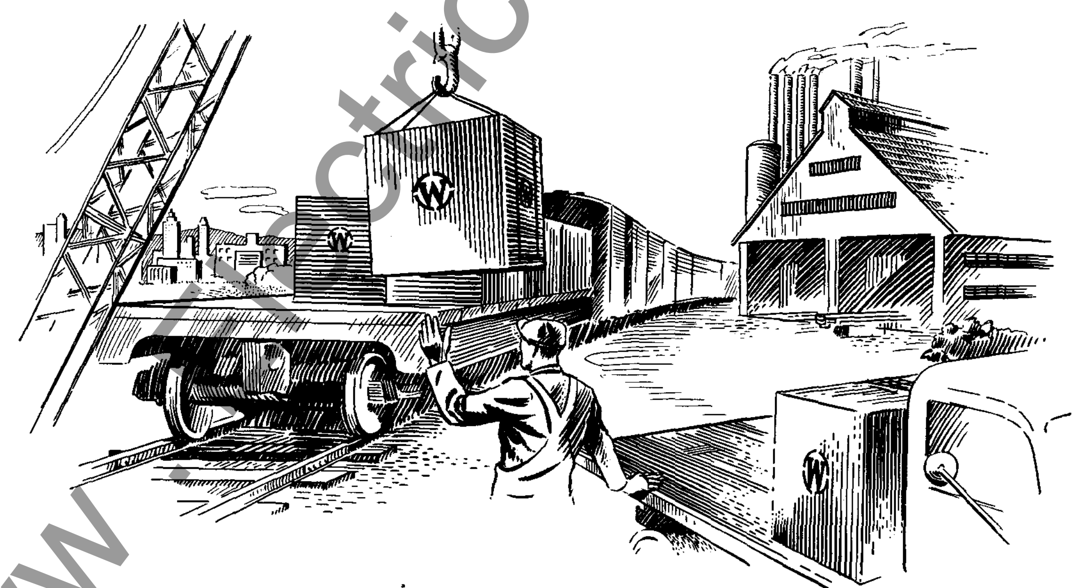
Important. Care must be taken to avoid bumping or damaging the retaining rings or touching the bearing journals.

To lessen the possibility of damaging the journals or of rust forming, the protective coating which is applied to the journals at the factory should not be removed until the unit is nearly installed and the rotor is ready to be placed in its final position.

Important. The exciter armature must never be supported by the commutator, either when blocked up or supported by a sling. It should be handled by a rope sling around the shaft, taking particular care that the ropes do not touch the windings. By using a spreader bar on the rope slings the chances of damage to the windings will be greatly reduced.

STORING

The generator should immediately be placed in a location protected from the weather and possible mechanical injury. The rotor should be completely wrapped with a tarpaulin, and the stator end winding protected by assembling the end bells or by covering with a tarpaulin. Space heaters should be placed below and around the stator windings and the rotor. These heaters must have sufficient capacity to maintain the temperature as determined by thermometers on the windings at approximately 20° C. above the ambient temperature.



INSTALLATION

ERECTING THE GENERATOR

Since the erection and alignment of high speed machinery such as turbine generators requires special care, this part of the work should be done by competent erection engineers. Complete instructions for erection of the turbine generator unit are supplied with the turbine. The information given here is intended primarily as an aid to future dismantling and assembly of the generator at inspection periods.

Inspecting. Before installing the rotor, carefully inspect the stator to see that no foreign objects such as waste, nuts, small tools, etc., are left in the machine and that no damage has occurred during shipment. Blow out all vent ducts to remove dirt which may obstruct the air flow. Any rust on the core should be brushed off, and the area coated with insulating varnish.

GENERATOR ROTOR

The method of installing or removing the rotor of the generator is shown in detail in Figure 16. This diagram also includes instructions for handling the bearing bracket and the end bell.

EXCITER

The exciter is shipped completely assembled on its bedplate and needs only to be set upon the seating plate and lined up before coupling to the generator rotor.

The exciter is aligned so as to make the face of the exciter coupling flange parallel and concentric with the end of the generator rotor. The two are bolted solidly together.

Note. Although the tachometer generator is shipped assembled with the exciter, it should be removed from the exciter assembly before the exciter is installed. Assemble the tachometer generator last as a safeguard against damage due to axial movement of the exciter shaft during installation.

TACHOMETER GENERATOR

Mounting. Refer to Figure 17 for the method of mounting the tachometer generator.

Important. Particular care should be taken to preserve the alignment of the rotor parts and to prevent damage to the field coil. This coil surrounds the shaft when the tachometer generator is assembled. Careless handling of the stator or rotor when the shaft is inserted in the field coil could break the field coil loose from its mounting or destroy the alignment of the rotor parts.

Assembly. The first step in the installation of the tachometer generator is to attach its rotor to the end of the exciter shaft. A spigot fit centers the stub shaft and socket-head cap screws draw it tightly into position. By rotating the turbine-generator unit for a few revolutions and using a dial indicator the alignment of the shaft can be checked. The outer end of the tachometer shaft must run true within .005 inch.

Next the stator of the tachometer generator should be installed. Do not allow the stator to strike or rest on the rotor. Before the mounting bolts are finally tightened, the air gaps should be made uniform.

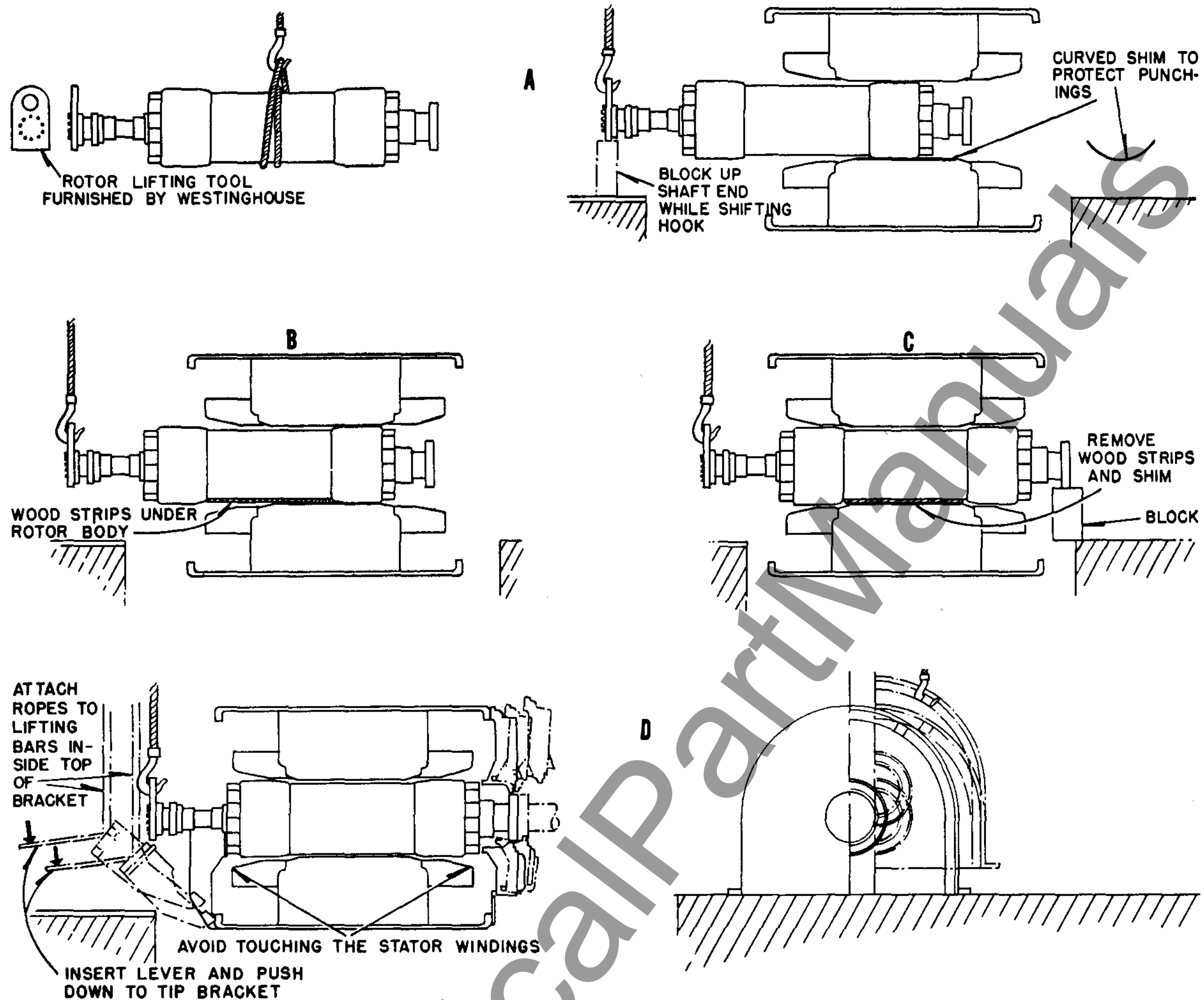
A nominal single gap of .030 inch is allowed between the rotor poles and the rear half of the armature core and between the outer end of the shaft and the hole in the end cover through which the shaft extends.

The air gaps may be checked with a length of .026 inch diameter (#22) wire. Access to the front air gap may be had at the outboard end of the unit where visual inspection will aid in centering the shaft in the opening in the cover.

The main air gap, between the rotor poles and the armature core, may be checked at four points by a length of the same diameter wire, bent slightly and inserted successively through the four ½ inch holes in the cover. Shims may be placed between the tachometer stator flange and the supporting bracket if necessary. Note that the front half of the armature core is bored to a diameter slightly greater than the diameter of the rear half of the armature core.

When the rotor is centered axially relative to the armature punchings, the outboard end of the tachometer shaft extends ¼ inch beyond the surface of the boss on the end cover.

Figure 18 gives the outline dimensions and information necessary for mounting the auxiliary equipment on the panel. This equipment is mounted by the purchaser. Screwdriver control is provided for the calibration rheostats as protection for the adjustment.



These steps should be followed when installing the rotor; when removing it, the same general procedure should be used in reverse order.

A. Lay a curved sheet iron (or fibre) shim in the stator bore. The shim should be approximately two feet wide, ¼ inch thick and of the same length as the stator bore itself. This will protect the punchings from damage. With a sling in the middle, lift and move the rotor into the bore as far as possible. Use care to avoid touching the windings. Block up the collector end of the rotor as shown, taking care not to touch the collector or bearing journal. Then, after changing the lifting hook to the lifting tool (shown attached to the end of the shaft) move the rotor into the bore. During this movement, the rotor should be stopped before the retaining ring (on the turbine end of the shaft) comes to the end of the bore. This will prevent the ring from dropping down on the stepped punchings. The retaining rings will support the rotor but they should not be subjected to any impact.

B. Next, cut three or four strips of wood approximately equal to the length of the rotor (between the retaining rings) and of such thickness that they will fit under the rotor body when it is resting on the retaining rings. Insert these wood strips under the rotor body and continue moving the rotor axially until it is in position. The purpose of these wood strips is to carry the weight of the rotor after the retaining ring goes beyond the end of the bore.

C. Block up the turbine end of the rotor and remove the curved shim and the wood strips from the gap.

D. Allowing the collector end of the rotor to rest on the bore, slide the bottom half of the bearing bracket under the shaft into position and bolt it to the generator frame. Lift the rotor and roll in the bottom half of the bearing, then lower the rotor down onto the bearing. (The bearing bracket has been dowelled at the factory so that the rotor will be accurately centered in the bore at the collector end.) Couple the rotor to the turbine shaft and install the end bells.

FIG. 16. Rotor Installation

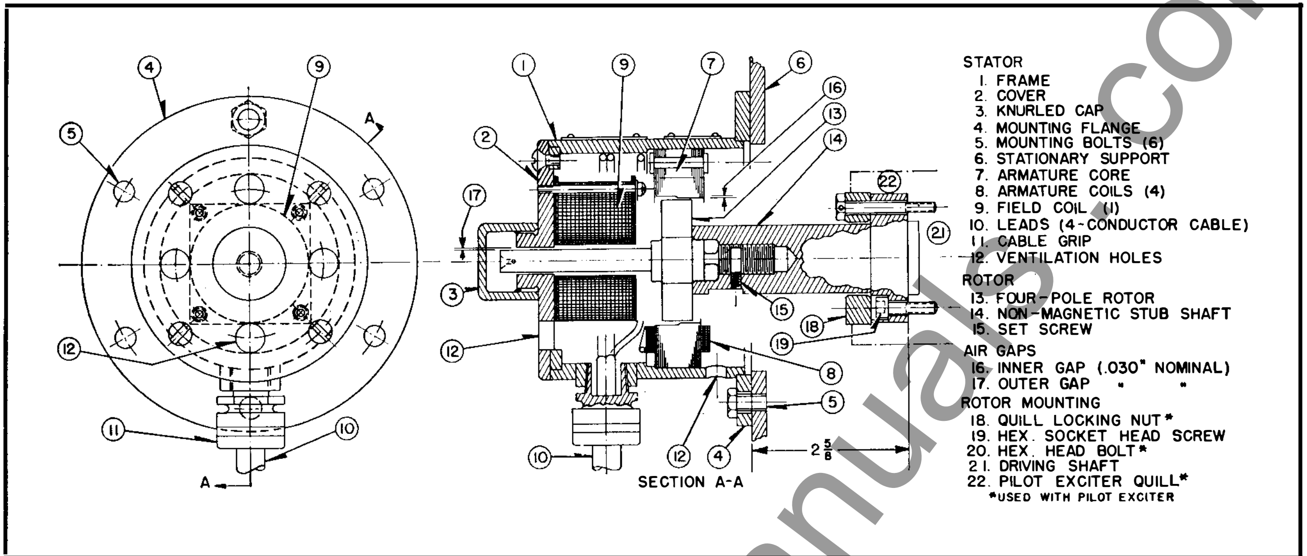


FIG. 17. Tachometer Generator Assembly and Mounting

Auxiliary Equipment. Figure 19 shows the auxiliary equipment and the connections to be made to the external circuits.

In the excitation circuit, a tapped resistor is connected in series with the field coil. The arrangements of the resistor taps is such that lead "X" in Figure 19 may be connected to tap "L1" for a 250 volt d-c source or to tap "L2" for a 125 volt d-c source. Lead "Y" in Figure 19 may be connected to tap "L3", "L4", or "L5", as noted in paragraph 6 under "Initial Operation", page 26.

The output of the armature coils is applied through a calibration rheostat to a Rectox type instrument.

ELECTRICAL CONNECTIONS

The terminals for all electrical connections on the generator and exciter are shown in Figure 20. The main lead conductors from the generator terminals to the switchgear should be checked to make sure that they are sufficiently supported and braced to withstand short circuit forces.

Figure 20 also shows the arrangement of the leads for the main generator, exciter and tachometer.

INSULATION RESISTANCE TEST

The insulation resistance of a winding may be defined as the resistance offered to a d-c voltage tending to produce a leakage of current through the insulation and over its creepage surface. It is a function of moisture and dirt as well as the condition of the insulating material. While not a measure of the dielectric strength of the insulation, when properly interpreted the insulation resistance values may give a useful indication of whether or not the machine is in suitable condition for operation or for high potential tests. 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.

Insulation resistance varies widely with changes in temperature, humidity, cleanliness of the winding, value of applied voltage, and time of voltage application. Many apparent inconsistencies can be explained by these factors. It is desirable, where successive or periodic readings are to be correlated, to test at a definite temperature and voltage and to apply this voltage for a definite time. Windings of large, high-voltage generators should be grounded for 10 minutes preceding each test to draw off any residual charge. If it is not practical to make the insulation resistance test at a specified temperature and humidity, it is desirable to record these values as well as the actual resistance.

It is difficult to give minimum safe values for insulation resistance of machines since they vary with type, size and voltage rating. The following formula is given to indicate the order of minimum values which may be considered acceptable for new armature windings. Using a 500-volt test circuit, reading should be taken after 60 seconds of voltage application, and testing with the generator at 75°C.

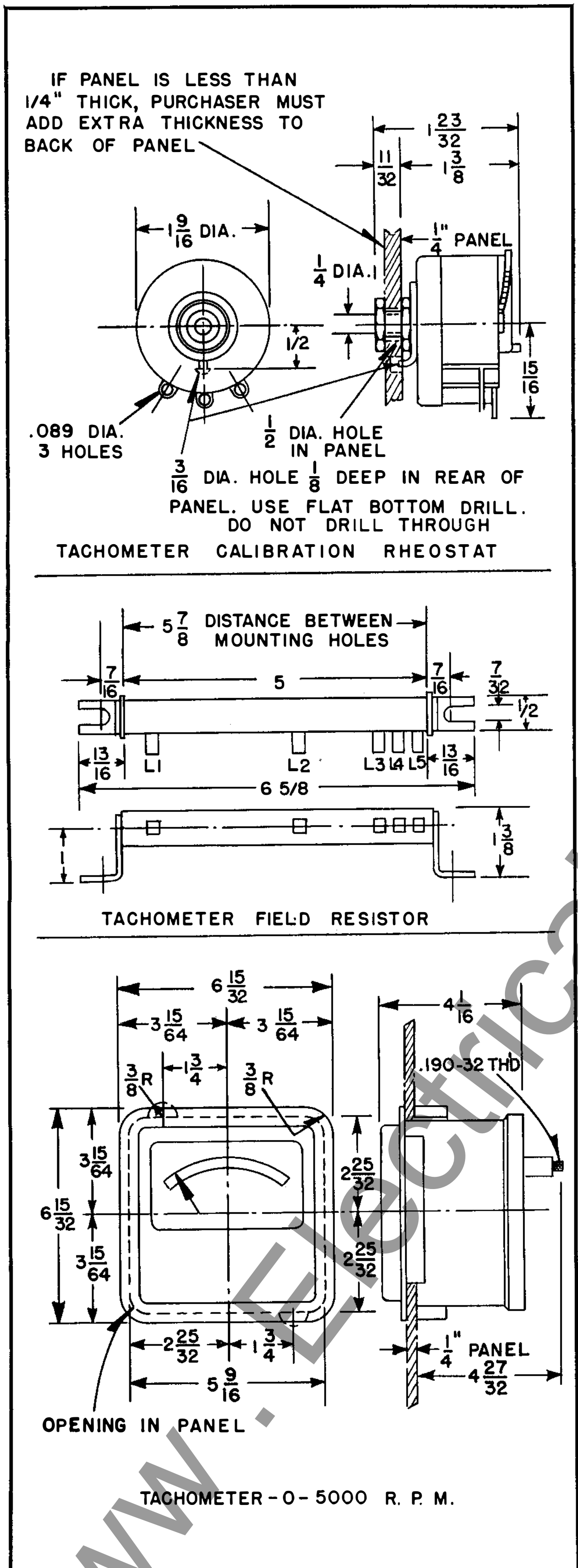


FIG. 18. Mounting of Tachometer Auxiliary Equipment

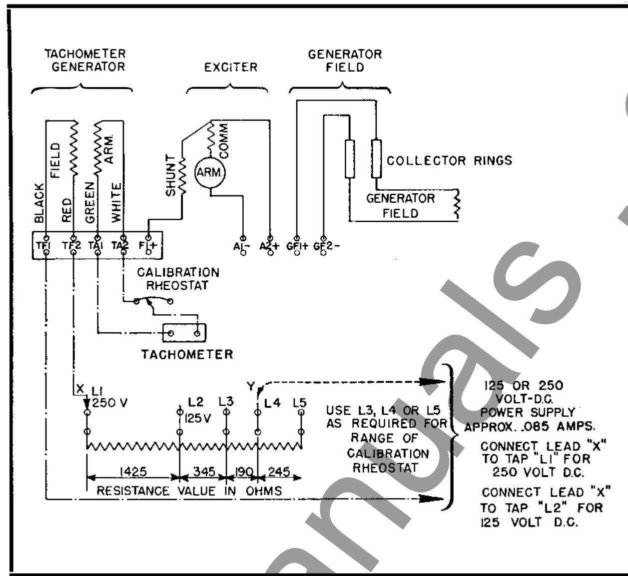


FIG. 19. Electrical Connections Diagram

$$R\text{ (Megohms)} = \frac{E\text{ (rated line-to-line volts)}}{\frac{\text{KVA (rated)}}{100} + 1000}$$

Example: 5000 Kva, 6900 volt generator

$$R = \frac{6900}{50 + 1000} = 6.6\text{ megohms}$$

The insulation resistance of the field winding at 75°C. should be at least one-half to one megohm. The insulation resistance can be measured by a megger or by using a 500 volt d-c circuit and voltmeter as shown in Figure 21. If the voltmeter method is used, the insulation resistance is calculated by the following formula.

$$R\text{ (megohms)} = \frac{R'(E - E')}{1{,}000{,}000\ E'}\text{, where}$$

R' = resistance of voltmeter in ohms.

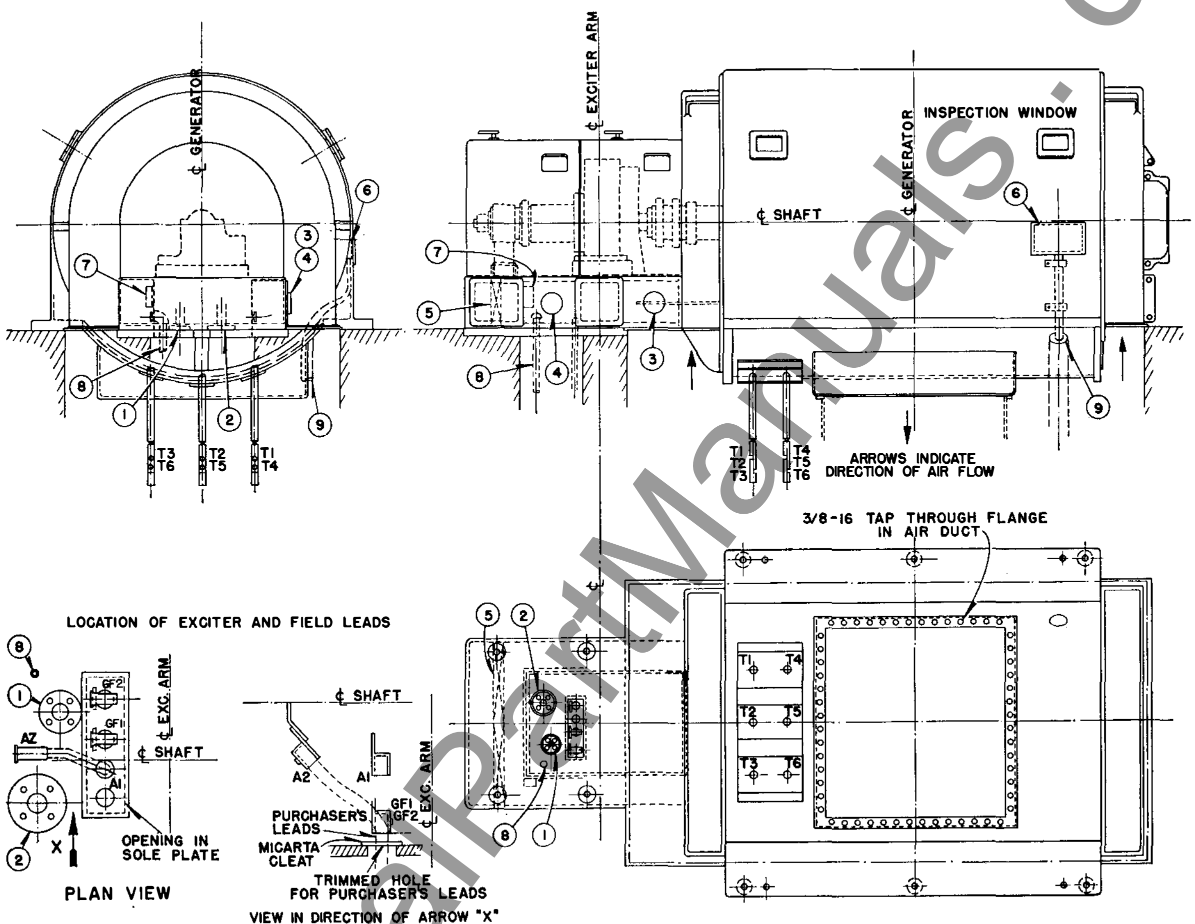
R = insulation resistance in megohms.

E = line voltage.

E' = voltage reading with insulation in series with the voltmeter.

A rough figure often used for temperature correction is that insulation resistance is doubled for each 10°C. drop in temperature, or halved for each 10°C. rise.

The only feasible way of increasing the insulation resistance when a machine is complete is by "drying out" the winding with heat.



DESCRIPTION

This illustration shows the location of air filters, and oil and electrical connections for the generator, exciter and tachometer.

1. Oil inlet (for generator and exciter bearing) 1 inch 300 pound A.S.A. raised face flange.
2. Oil outlet (for generator and exciter bearing) 1½ inch 300 pound A.S.S. raised face flange.
3. Space in which customer may mount dial type thermometer for generator bearing oil outlet temperature.
4. Space in which customer may mount dial type thermometer for exciter bearing oil outlet temperature.
5. Air filters for exciter ventilating air, 2 sections of 10 inch x 20 inch x 2 inch Type B "Air-Maze", assembled from the side.
6. Stator winding temperature detector terminal board.
7. Tachometer and exciter shunt lead terminal board.
8. Purchaser's 1 inch conduit for tachometer and exciter shunt leads, 1⅜ inch hole provided.
9. Purchaser's 2 inch conduit for leads from stator winding temperature detectors. 2½ inch diameter hole with removable cover provided in generator frame.

FIG. 20. Arrangement of Leads for All Electrical Connections

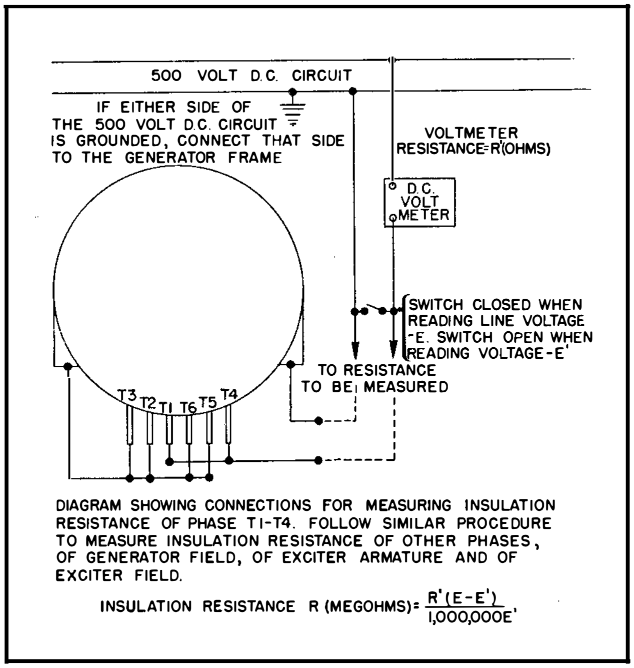


FIG. 21. Connections for Insulation Resistance Measurement

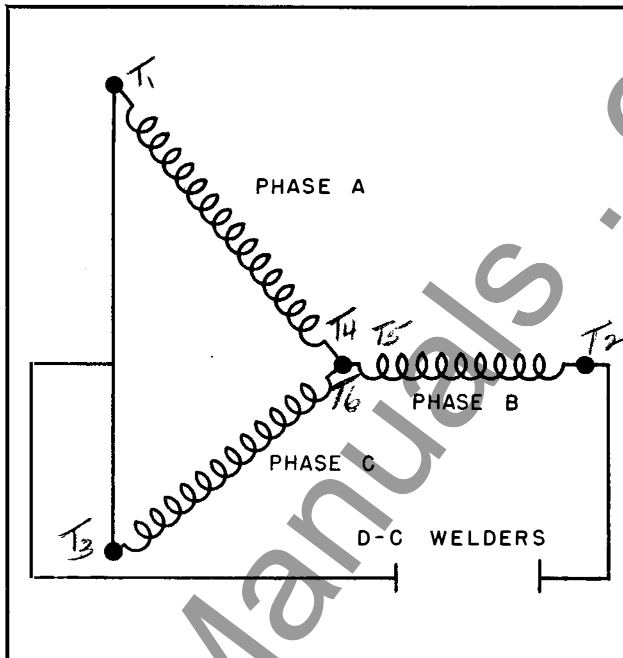


FIG. 22. Using D-C Welding Set to Circulate Current Through Windings

DRYING OUT WINDINGS

Note. The stator and rotor windings of the generator and exciter should be kept warm and dry from the time the unit is received until it is placed in service.

If the insulation resistance of all phases is satisfactory, and it is known that the generator has not been subjected to moisture, the dryout may be omitted. However, if the armature and field windings have absorbed moisture, as evidenced by low values of insulation resistance, they should be dryed.

Methods. Various methods of drying the windings can be used. The windings can be dried by the use of external heat as from space heaters.

Frequently d-c welding sets are available and can be used to circulate current through the windings. (See Fig. 22). Most welding sets can be operated in parallel, if necessary, to get a desired current. For suitable temperatures, the current should be about half of the rated a-c value given on the nameplate.

Important. Never circulate alternating current through a generator while it is standing still. By so doing, severe burning on the rotor will result.

Some operators prefer to heat the windings by operating under sustained short circuit at a speed determined by turbine requirements. If feasible, the ventilating air should be recirculated without water in the coolers so that the windage losses will help to increase the temperature of the whole structure.

The dry-out should be started with low current and gradually increase until the temperature of the stator and rotor windings is 75 to 85°C. as determined by the embedded detectors in the armature or the increase in resistance of the field winding. The currents should be limited so that the maximum temperature is not reached inside of six hours. The main generator field current should not exceed $\frac{1}{3}$ full load value at this time.

Effective drying cannot be accomplished unless means are provided to remove some of the moisture-laden air. This can best be done by leaving the portlites open and using small fans to force air into the bottom.

The insulation resistance drops rapidly at first as the winding heats up, then rises slowly as the moisture is removed and levels off as shown on Figure 23. The dry-out may be concluded when a fairly steady value is reached. Megohmmeter readings may be taken with the generator rotating, but the excitation must be off and the residual charge discharged to ground before the reading is taken.

HIGH POTENTIAL TESTS

Factory Test. The windings of the generator and exciter are subjected to a high potential test at

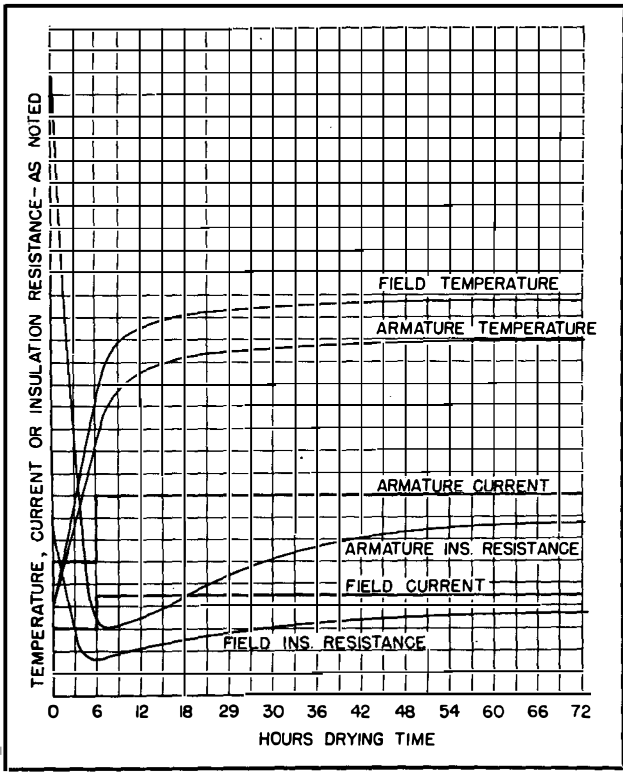


FIG. 23. Typical Insulation Resistance Curve

the factory to detect any weaknesses which may lead to a breakdown in service. The A.I.E.E. standard factory test for new armature windings is twice rated voltage plus 1000 volts for one minute. Fields are tested at 2500 volts.

At some later time it may be necessary to make winding repairs, or the generator may be subjected to a severe short circuit which disturbs the coil bracing and possibly damages the insulation. In cases of this kind the operator may wish to make another high potential test to determine if the repairs are satisfactory and the windings are ready for further service.

To allow for aging of the insulation, it is the usual practice to limit subsequent tests to approximately ⅔ of the original test voltage.

Important. **A high potential test should not be made unless the insulation resistance is satisfactory. Prior to tests, the winding should be thoroughly cleaned and cleared of all foreign materials.**

Test Transformer. The required Kva rating of the test transformer is determined by the size of the generator and the test voltage. If the test transformer is too small, its output voltage may be distorted and have dangerously high peaks that are not shown by the voltage indicating device. The frequency should not be higher than the rated frequency of the generator. Means should be provided to raise the voltage gradually, preferably by the use of an induction voltage regulator in the primary circuit of the test transformer.

Each phase of the stator winding should be tested by connecting the two ends with wire, and applying voltage between this connection and the frame. The other phases should be solidly grounded at both ends.

FINAL CHECK BEFORE STARTING

Before the unit is started, the following points should be checked:

1. Complete all necessary work of installation and alignment. The gap should be free of all foreign matter which may become jammed between the armature core and the rotor.

2. Be sure the windings are free from dirt and moisture. Dry out the machine if the insulation test indicates that the windings are not dry enough.

3. Check all electrical connections to be sure they are tight. Make certain the proper clearances exist between conductors. Do not allow the brush shunts to touch each other or any grounded part.

4. Check to be sure brushes are free in their holders. Adjust the brush-pressure to 2½ lbs. per square inch of brush area. The markings on the brush holder stem indicate total pressure so it is necessary to multiply the brush area by the unit pressure (2½ psi) to find the proper total pressure.

5. Check to be sure the bearing lubricating system is operating properly.

6. Check alignment of the tachometer stator and rotor as noted in "Assembly" under "Tachometer Generator", page 19.

OPERATION

STARTING THE TURBINE

Instructions are given with the turbine for the procedure to be followed in bringing the unit up to speed.

Start with all the rheostat resistance in the exciter field circuit. Then, when the unit is up to speed, adjust the rheostat for the value of voltage required on the a-c generator field.

Phase Rotation. Correct phase rotation should be obtained if the generator is connected according to the outline supplement drawing which is supplied with the machine. As a precaution, the phase rotation can be tested by starting a polyphase motor with the station bus, and then with the new generator. If the motor runs in the same directions with each power supply, the phase rotation is correct.

Synchronizing. Before the generator can be synchronized and thrown on the line, its field must be excited to generate rated a-c voltage at the stator terminals.

Any commonly used method can be used to synchronize the generator. The most general method is to use a synchroscope. If this instrument is not available, electric lights can be used and so connected that they will be dark when the voltages are equal and in phase. When the conditions for synchronizing exist, that is, when the generator voltage, phase rotation, and phase angle are correct, the line breaker can be closed, thereby connecting it to the line.

Initial Operation. When the unit is first operated the following instructions should be observed:

1. Make sure that the bearings are properly lubricated.

2. Watch all temperatures to be sure that none is excessive.

3. Check the brush rigging to see that the brushes are so adjusted that neither the brushes nor the collector rings will groove or develop an edge thread or "fin".

4. Solidly ground one end of a copper wire and touch the other end to the generator shaft. If a small spark occurs when the wire is removed from the shaft, the shaft insulation is satisfactory. If no spark occurs, the shaft is probably grounded and the insulation should be inspected. The generator is insulated at the bearings, under the exciter bearing pedestal, and at the oil line connections to the exciter bearing pedestal.

5. Observe the exciter commutation at frequent and regular intervals. The cause of any excessive sparking should be determined and remedied immediately. In this connection, refer to the subject "Sparking at the Brushes" on page 30.

6. When the generator unit has reached synchronous speed, the calibration rheostat for the tachometer should be adjusted until the instrument reads exactly the synchronous speed of the unit. If the output voltage of the tachometer generator is too low for compensation by the calibration rheostat when excitation lead "Y" is connected to tap "L4", change lead "Y" so as to connect to tap "L3", see Figure 19. In either case the final adjustment is made with the calibration rheostat.

POWER FACTOR

A turbine generator can be operated at a power factor lower than the rated value if the operating conditions demand it. However, in all cases, care must be exercised so that the generator field current does not exceed the rated value to avoid overheating the rotor. The reactive capability of a generator is shown in Figure 24. (Note that this curve applies only in case the particular generator has the same power factor rating as specified on the curve).

SINGLE-PHASE LOADS

When a generator carries a single-phase load or an unbalanced polyphase load, the rotor heating is greater than in the case of balanced loads, even though the field current is the same in each case. This extra heating is due to currents induced on the rotor surface. These surface currents cause considerably heating, especially at the joint between the retaining rings and the rotor body.

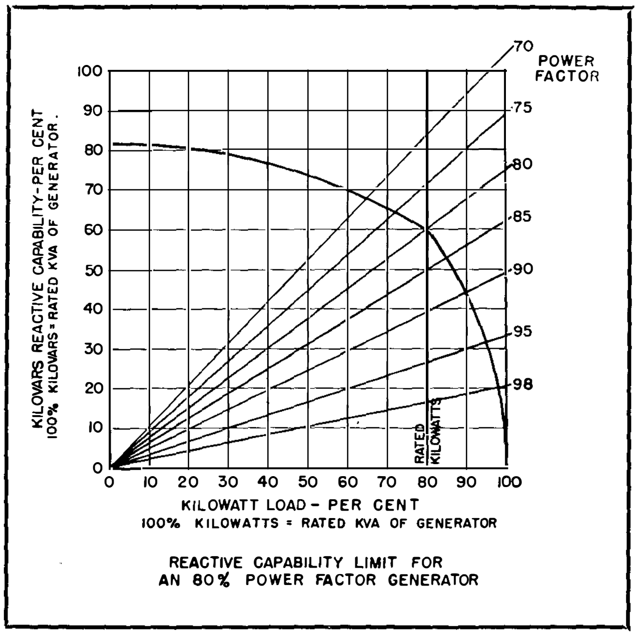
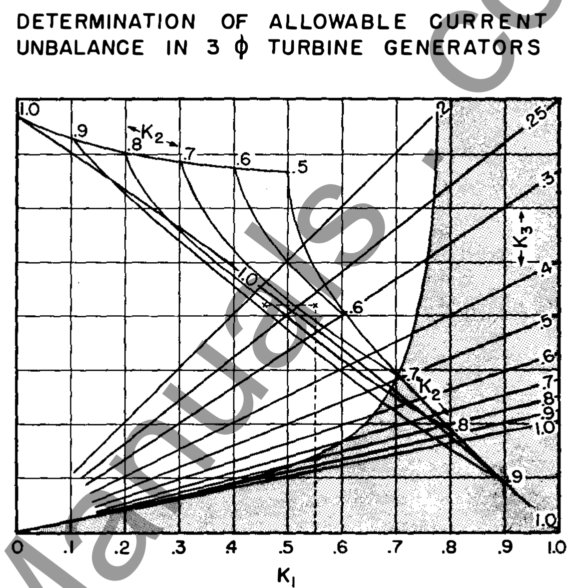


FIG. 24. Reactive Capability Curve



1. CALCULATE THE THREE FOLLOWING RATIOS:

$K_1 = \frac{\text{SMALLEST CURRENT}}{\text{LARGEST CURRENT}}$ $K_2 = \frac{\text{SECOND LARGEST CURRENT}}{\text{LARGEST CURRENT}}$

$K_3 = \frac{\text{LARGEST CURRENT}}{\text{RATED CURRENT}}$

2. ENTER CHART WITH K_1 ON HORIZONTAL SCALE & FIND INTERSECTION OF K_1 AND K_2. FROM THIS POINT PROCEED HORIZONTALLY EITHER LEFT OR RIGHT TO INTERSECT K_3. IF THIS POINT IS IN SHADED AREA, UNBALANCE IS EXCESSIVE. IF THIS POINT IS IN LIGHT AREA, UNBALANCE IS ACCEPTABLE.

EXAMPLE: GIVEN THREE CURRENTS, 200, 130, 110, AMPS AND RATED CURRENT = 900 AMPS.

$K_1 = \frac{110}{200} = .55$, $K_2 = \frac{130}{200} = .65$, $K_3 = \frac{200}{900} = .222$

UNBALANCE IS ACCEPTABLE (SEE POINTS PLOTTED ON CURVE).

FIG. 25. Unbalanced Load Curve

Experience indicates that a modern turbine generator with shrunk-on retaining rings can carry a single-phase, line-to-line load of approximately 20 per cent of the rated current without damage. Figure 25 shows how to calculate whether or not a given unbalanced load is within the permissible temperature limits of the rotor.

Single-phase short circuits may cause severe burning on the rotor surface since the currents are large. Protective relays should be used to remove the short circuit and prevent damage to the generator.

VIBRATION

Every Westinghouse turbine generator rotor is given a running balance before shipment.

The Westinghouse Corporation at an early stage in the development of high speed machines, realizing the importance of good balancing, designed a balancing machine which is very sensitive, being able to detect an unbalance as small as one inch ounce per thousand pounds of rotor weight. Rotors balanced to within this maximum residual unbalance will give no trouble due to balance.

The study of vibration in turbine generator units is a very complicated one. If trouble of this kind is to be successfully eliminated, the frequency, amplitude and the type of vibration must be determined. This cannot be done without the use of good vibration instruments. In addition, experience with these instruments is desirable. For these reasons, a Westinghouse Service Engineer should be consulted in case the vibration of a unit becomes excessive.

TEMPERATURE

The temperature of the stator winding as determined by detectors embedded in the winding is guaranteed not to rise more than 60°C. above the ambient at full rated load, power factor and voltage. The temperature of the rotor winding as determined by increase in the resistance of the winding itself is guaranteed not to rise more than 85°C. above the ambient at full rated load, power factor and voltage. These temperatures are based on air entering the generator at 40°C.

It is the practice of most conservative operating engineers to limit the voltage, kva, and field cur-

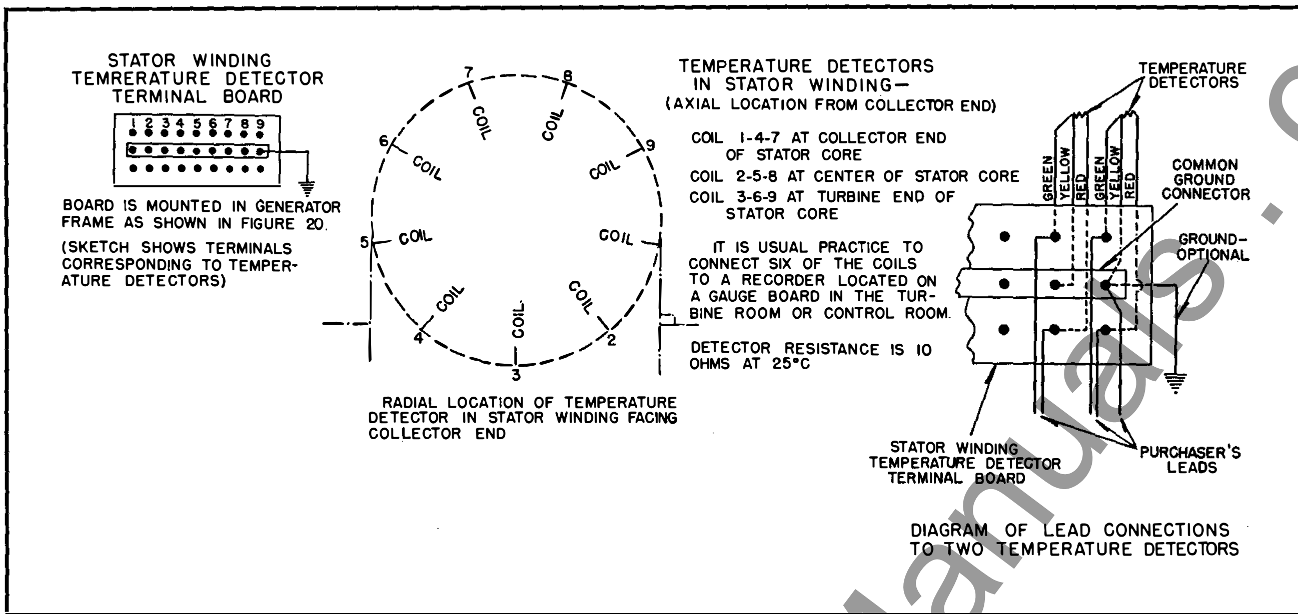


FIG. 26. Temperature Detector Lead Location

rent of a generator to the nameplate or contract values under normal load conditions. This is done to obtain long life for the windings, and to maintain satisfactory unit and system stability. It is understood and appreciated by most operating engineers that the nameplate rating and temperature guarantees of a generator can be appreciably exceeded without immediate danger of failure, but that such increased output is obtained at a sacrifice in the length of life of the windings.

Thermometers which are provided with the oil drains from the generator and exciter bearings, should be observed closely by the operator to detect any sudden change in temperature, and the cause determined and corrected immediately.

TEMPERATURE DETECTORS

Temperature detectors are embedded in the armature winding of the main generator to provide a means of measuring the operating temperature. Each detector consists of a coil of copper wire in a strip of moulded material approximately the same width as a stator slot. They are placed in the slots between the two armature coils, and distributed around the generator so as to indicate the temperature in each phase of the winding. The resistance of each detector is carefully adjusted at 10.0 ohms at 25°C. Over the range of usual generator temperatures, the temperature coefficient of copper is .00427 ohms per degree C. From this the total temperature "T" corresponding to any measured resistance "R" can be calculated from:

$$T = \frac{R}{10.0}(259.5) - 234.5$$

Three leads from each detector are brought out to a terminal block in a convenient place on the generator and are connected as shown in Figure 26. Complete instructions for wiring to the detectors are supplied with the temperature indicating instrument.

The rotor temperature can be calculated at any time by determining the resistance at that time and comparing it with the known resistance at a definite temperature. The following formula can be used:

$$T = \frac{R}{R_o}(234.5 + T_o) - 234.5$$

Where: T = total rotor temperature, degrees C.

R = resistance at temperature T

R_o = resistance at a known temperature T_o

The resistance of the rotor winding can be calculated from meter readings of voltage and current. In order to obtain satisfactory results, it is necessary to use calibrated instruments and read the voltage at the collector rings. A common method is to insulate one brush of each polarity from the brushholder assembly and read the voltage between them. If it is not practical to insulate a pair of brushes or get any other voltmeter leads on the collector rings, the voltage between the brushholder parts can be used. In this case, 3 volts should be deducted from the reading to allow for a drop of 1½ volts per brush. This drop is constant regardless of the magnitude of the field current.

OPERATING VOLTAGE

Generators are usually guaranteed to operate with safe temperatures at rated Kva and voltages within 95 to 105 per cent of rated voltage. At higher voltages, core temperatures increase because of the extra iron loss at the higher flux density, and field current increases in order to overcome the extra saturation in the magnetic circuits. At voltages below the rated value, the armature current must be increased to maintain rated Kva. This extra current results in higher winding temperatures. To avoid these high temperatures, the voltage should be maintained within the specified ranges.

CAUSES OF EXCITER HEATING

Field Coils. Heating of the exciter field coils may develop from any of the following causes:

1. Too high voltage.
2. Too great forward or backward lead of brushes.
3. Partial short circuit of one coil.
4. Overload.
5. Restricted ventilation.

Armature. Heating of the exciter armature may develop from any of the following causes:

1. Too great a load.
2. A partial short circuit of two coils which results in heating the two particular coils.
3. Short circuits or grounds on armature or commutator.
4. Restricted ventilation.

Commutator. Heating of the commutator may develop from any of the following causes:

1. Overload or continued operation at very low loads.
2. Sparking at the brushes.
3. Incorrect brush pressure.
4. Improper grade of brushes.
5. Restricted ventilation.

BRUSH POSITION ON COMMUTATOR

For commutating-pole machines, accurate adjustment of the brush position is necessary in order to obtain satisfactory commutation and regulation. If the brushes are given a backward lead on a commutating-pole generator, the machine will overcompound and may not commutate properly; with a forward lead of the brushes, a generator will undercompound and will not commutate properly.

When the brush position on a commutating-pole machine has once been properly located, no shifting is afterwards required or should be made. The correct brush position is located at the factory during test. This position is known as the "factory brush position" and is clearly marked on the brushholder supporting ring (rocker-ring). However, since the mark on the rocker-ring will not be correct after the position of the brushholder supporting brackets has been moved on the rocker-ring (as, for example, will occur when the brushholders are adjusted in order to compensate for commutator wear), it will be necessary to re-set the brushes on "kick neutral" and then shift the brush position until good commutation is obtained, or the previous voltage regulation is matched.

Spacing of Brushes. The position of one row of brushes having been located, the other brushes should be equally spaced around the commutator with reference to this first row of brushes. The brush spacing between all rows of brushes should be accurate to within $\frac{1}{32}$ inch. The best way to secure this spacing is to cut a narrow strip of tough paper exactly equal in length to the circumference of the commutator. This strip is then marked off into equal parts, corresponding to the number of brush-arms after which it is stretched around the commutator and the brushes spaced accordingly. This method gives far more accurate results than those obtained by spacing the brushes an equal number of commutator bars, which is dependent upon the uniform spacing of the bars. The latter method, however, may be used as a rough check.

Staggering of Brushes. The brushes are staggered at the factory to give an even wear to the commutator. The staggering is done in pairs of brush arms (not alternate arms); that is, one positive set of brushes with an adjacent negative set is offset to the right or left of an initial pair of positive and

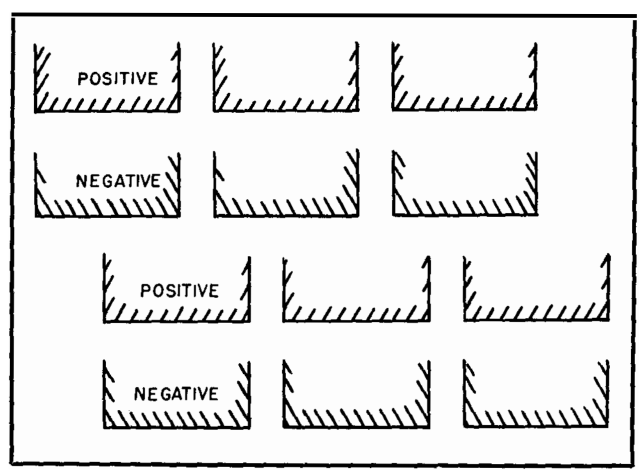


FIG. 27. Correct Method of Staggering Brushes

negative brush arms $\frac{3}{8}$ inch or more. The third pair of brush arms trail the first pair; the fourth, the second, and so on. See Figure 27. If the brushholder supports are removed from the rocker ring they should be reassembled so that correct staggering is obtained.

SPARKING AT THE 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 standards of the American Standards Association. 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 difficulties.

The usual causes are:

1. The machine may be overloaded.

2. The commutator may be rough due to high or loose bars, flat spots, or rough edges of the undercutting.

3. The commutator bar mica may be high.

4. The commutator may be dirty, oily, or worn out.

5. The brushes may not be set exactly on neutral.

6. The brushes may not be equally spaced around the periphery of the commutator.

7. Brushholders may be set too far away from the commutator.

8. The brushes may be sticking in the brushholders or have reached the end of their travel.

9. The brushes may not be fitted to the circumference of the commutator.

10. The brushes may not bear on the commutator with sufficient pressure. The brush tension should be adjusted to give $2\frac{1}{2}$ psi of cross-sectional area of the brushes.

11. Some brushes may have extra pressure and may be taking more than their share of the current.

12. The carbon brushes may be of an unsuitable grade.

13. The face of the brushes may be burned.

14. The brushes may be vibrating.

15. The brush angle may be incorrect.

16. The main or commutating-pole air-gaps may not be uniform.

17. The commutating-pole field air-gap may not be correct. Refer to "Adjustment of Commutating-Pole Field Strength," on page 31.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken, it will draw a bright spark as the break passes the brush position. This trouble can be readily located, as the commutator on each side of the disconnected bar will be more or less pitted.

Note. 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". "Bucking" or "Flashing" are very expressive terms descriptive of what happens when arcing occurs between adjacent brushholder arms. In general, "bucking" is caused by excessive voltage, or by abnormally low surface resistance on the commutator between brushholders of opposite polarity. Any condition tending to produce poor commutation increases the danger of "bucking". Among other causes are the following:

1. Rough or dirty commutator.

2. A drop of water from the roof, leaky steam pipes or other source dropping in the commutator.

3. Short circuits on the line producing excessive overloads.

If "flashing" continues after the first two possible causes have been eliminated, the trouble will usually be due to causes external to the machine which must be corrected before the "flashing" trouble will be eliminated.

LOCATING THE ELECTRICAL "KICK-NEUTRAL"

Where it is necessary for any reason to locate the electrical neutral position on commutating-pole machines in the field, it may be correctly and simply located by the Electrical or "Kick" method if due care is exercised.

This method is based on measurement of voltages induced in the armature coils as the current in the main field of the machine is interrupted. Voltages induced in the conductors located at equal distances to the right and left of the pole centers are equal in magnitude and opposite in direction. If the terminals of a low-range voltmeter be connected to commutator bars corresponding to conductors located midway between poles, no deflection will be caused by breaking the field current. When the brushes are set so that the center lines of their faces correspond with the center lines of the commutator bars between which there is no induced voltage, they are on neutral.

If the number of commutator bars is not evenly divisible by the number of poles, use the following method:

With the machine at a standstill, raise all brushes. Replace one of them on each arm by a special brush of the same thickness. (This special brush should be beveled to a knife edge parallel with its longer side and in the center of its face.) Connect leads from adjacent brush arms to a d-c voltmeter, preferably one having 0.5, 1.5, and 15-volt scales. Separately excite the shunt field from a d-c source through a quick-break switch. Insert enough external resistance in the excitation circuit to keep the field current small at the beginning. Use the smallest field current that gives a good deflection on the low scale of the voltmeter. When "kick" voltage is read for the first time, begin with the 15-volt scale and change to lower scales only when it is certain that the voltage is within their respective ranges. Before the switch is opened for each reading, wait long enough for the induced voltage caused by closing the circuit to decay. Shift the rocker ring to the point at which voltage is minimum when the field circuit is opened. If the machine has double brushholders, the center of the brushholder is placed on the neutral mark instead of either of the double-holder brushes.

If the number of bars between center lines of brushes on adjacent arms results in half a bar being included in the commutator pitch (such as 20½ bars between center lines), this alternative method is used:

Raise all brushes. With voltmeter points on bars 1 and 21 in the approximate neutral zone, open the field circuit as described in the previous paragraph and read deflection. Move voltmeter points to bars 1 and 22 and read deflection as the field circuit is opened. Rotate the armature slightly until the two readings are equal but opposite in polarity. This indicates that the correct neutral is exactly on the center line of bar 1 and on the mica between bars 21 and 22. The rocker ring is shifted until the center lines of the arc of the brush surfaces are exactly over these positions. The same procedure applies here for double brush holders.

If the number of bars is evenly divisible by the number of poles use the following method:

Raise all brushes. Determine commutator pitch. For example, if the machine has 20 bars per pole pitch, the throw for a multiple-wound armature would be bar 1 to bar 21. With voltmeter points on bars 1 and 21 in the approximate neutral zone, open the field circuit as described in the previous paragraph and read deflection. Move voltmeter points to bars 2 and 22 and read deflection as the field is opened. Rotate the armature in either direction and repeat these operations until the two readings are equal but opposite. This indicates that the correct neutral is exactly on the mica between bars 1 and 2 or between bars 21 and 22. The rocker ring is shifted to these points as explained in the previous paragraph.

If the armature cannot be rotated, the neutral is located by the use of a curve or a calculation. If the number of bars is divisible by the number of poles, proceed as outlined in the previous paragraph. Read induced voltages between bars 1 and 21, 2 and 22, 3 and 23, etc., until a point is reached at which the polarity of the induced voltage reverses. Then record four readings, two on either side of the reversing point, plot induced voltages as ordinates and the numbers of commutator bars as abscissae. Keep in mind that the number indicates the center line of the end of the bar. After the exact point of reversal has been determined from the curve, mark the relative position on the commutator. This is the correct neutral. Shift the rocker ring as described in two paragraphs previous to this.

The brush position, as located by factory test, may or may not be on the electrical neutral because the brushes are set on test and the machine shipped with them in a position to give the best operation, both in regards to commutation and other operating characteristics.

ADJUSTMENT OF COMMUTATING-POLE FIELD STRENGTH

To produce the best commutating conditions, the commutating-pole adjustment is made at the factory and, normally, no reason for changing it after the machine is installed should arise. However, if such reason does arise, the proper change in excitation may be determined as follows:

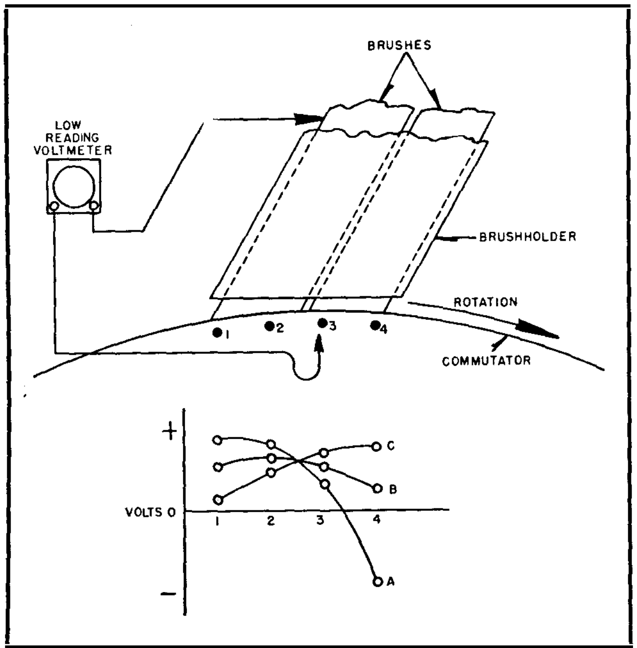


FIG. 28. Adjustment of Commutating-Pole Field Strength

Reading the Voltage. Using a low-reading voltmeter, read the voltage between the brush-holder bracket and the commutator at four equi-distant points across the face of the brush (along the circumference of the commutator). This reading should be taken when the machine is running at normal load and voltage. These voltages can be most conveniently read by touching the voltmeter pointer lead to the commutator surface at four points. Reading should be taken from positions 1 to 4 in the direction of rotation. Take curves for both positive and negative brushes for several brush arms.

These readings, if plotted as shown in Figure 28, indicate, for example, in curve "A" over compensation; i.e., excessive commutating field strength; curve "B" correct compensation; curve "C" under compensation.

Changing the Commutating-Pole Strength. 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. However, adjustment by changing the air-gap is the most usual method. In case of over compensation, the air-gap should be increased; in case of under compensation, the air-gap should be decreased. When adjustment is made by shunting, an inductive shunt, which has 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 the shunt when the load suddenly changes.

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

EXCITATION FAILURE OF EXCITER

When starting up, a self-excited exciter 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 a dirty commutator or to brushes sticking in their holders, or perhaps to a fault in the field rheostat. Examine all connections and if they are found to be in good condition, try a temporarily increased pressure on the brushes or 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 bell. However, this is not an infallible test because some magnetos will not ring through a circuit of such high resistance found in some field windings even though the magneto bell be intact. If no open circuit is found in the rheostat or in the field winding, the trouble is probably in the armature. If, after the examination, nothing is found wrong with the connections or the winding it may be necessary to excite the field by other means.

Exciting the Fields. The residual magnetism may be restored to the exciter fields by exciting them from another generator or some other outside source, with voltage not exceeding the rated generator voltage, as follows: (See Figure 29.)

1. Open the line switch and raise all exciter brushes from the commutator.

2. Connect the negative lead from the exciting source to either the negative brushholders or the negative terminal of the machine.

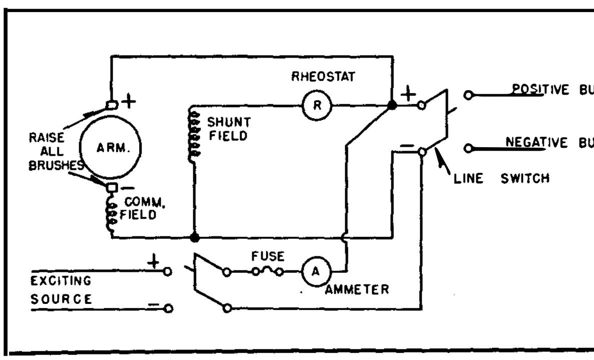


FIG. 29. Connections for Restoration of Residual Magnetism of Exciter

3. Connect the positive lead from the exciting source in series with a switch, 15-ampere fuse, and suitable ammeter to either the positive brushholder or the positive terminal of the machine.

Note. If excited from another generator, it may be more convenient to connect from a negative brushholder on the exciting generator to a negative brushholder on the machine being excited and, similarly, from a positive brushholder through the switch, fuse, and ammeter to a positive brushholder.

4. Turn the exciter field rheostat to the "all in" position.

5. Close the exciting switch momentarily while adjusting the exciter field rheostat to obtain not more than normal field current. If the shunt winding is all right, its field will show considerable magnetism.

6. Reduce the exciting voltage before opening the exciting current. If this cannot be done, place a discharge resistor across the field, then open the exciting switch. The discharge resistor should have a resistance of 10 and 20 times that of the exciter field.

Where the exciter operates in parallel with another generator, the field may be simply excited from the paralleling generator by raising the brushes, turning the field rheostat "all in" and momentarily closing the line switch. The voltage of the exciting generator should also be reduced to a minimum before opening the line switch if possible; otherwise, use a discharge resistor as described above.

CAUSES OF INSUFFICIENT EXCITER VOLTAGE

The following causes may prevent exciters from developing their normal e.m.f.

1. The speed of the unit may be below normal.

2. The switchboard instruments may be incorrect and the voltage may be higher than that indicated or the current may be greater than is shown by the readings.

3. The brushes may be incorrectly set.

4. A part of the field rheostat or other unnecessary resistance may be in the field circuit.

REVERSING POLARITY OF EXCITER

To change the polarity, it is necessary to reverse the residual magnetism of the fields, which is done by exciting the shunt field momentarily in the opposite direction from some outside source.

EXCITER ADJUSTMENTS

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

Never open the shunt field circuit of the exciter until the field rheostat is turned all the way in, thus reducing the field current to zero.

TRANSFER OF EXCITATION SYSTEMS

To transfer the excitation from the direct-connected exciter to another machine or vice-versa the procedure is as follows:

1. Adjust the voltage of the incoming d-c generator slightly higher than that of the machine to be relieved.

2. Close the incoming generator's circuit breaker. Keep one hand on the incoming generator's rheostat and at the same time watch the ammeter of the incoming generator.

3. Gradually decrease the voltage of the machine to be relieved and simultaneously increase the voltage of the incoming generator. Keep the field excitation of the a-c generator constant.

4. Watch carefully the ammeter in the armature circuit of each d-c machine and when the incoming generator is supplying the entire excitation, the circuit breaker of the relieved machine may be opened.

SHUTTING DOWN

Instructions are given in the turbine instruction book for the procedure to be followed when shutting the unit down.

Whenever the generator unit is shut down, it should be kept warm and dry. If the machine is to be shut down for a considerable period of time, more extensive provisions should be made to protect the machine from dirt, moisture, rust, and corrosive fumes.

Note. It is advisable under such conditions to lift the brushes from the collector rings.

MAINTENANCE

OBSERVING MACHINE TEMPERATURE

The appearance of excessive temperature in any part of the machine is an indication that trouble exists. The situation should be investigated immediately and the cause of the trouble removed. Routine checks on temperature are recommended so that such conditions may be discovered before serious damage is done.

CARE OF COLLECTOR RINGS AND BRUSHES

The collector rings and brush rigging should be kept free from dirt, carbon dust and oil. All brushes should be removed from the holders at regular intervals and throughly wiped off, and the insides of the holders carefully cleaned.

If sparking of the brushes occurs, it is generally caused by one of the following: (Also refer to "Sparking At the Bushes" page 30.)

1. Particles from the edge of the brush or other dirt getting between the brush and collector ring. To correct this, be sure the brushes ride on the center of the ring. Keep the brush rigging clean.

2. Lack of free movement of the brush in the holder. This is usually caused by dirt which fuses to the brush and the holder.

3. Insufficient brush pressure. Check the pressure by a small spring balance to see if the calibration on the holder is correct. Adjust the pressure to 2½ pounds per square inch of brush area.

4. Rough or untrue collector rings. To check the collector ring truth, put a dial indicator on the back of a brush while the unit is rolling at slow speed. If the rings are rough or out of round, true them up by grinding while the unit is running at full speed, then polish with fine sandpaper and crocus cloth. Do not use emery cloth.

Note. Replacement collector rings may also be slightly eccentric after assembly on the shaft. If so, they may be trued up in the same manner.

5. Vibration of brushholder. If the unit has become out of balance, vibration of the brush rigging may lead to sparking at the brushes. This can be corrected by balancing the unit.

An imprint of the brushes will be found, at times, on the surface of the collector rings. This usually occurs on a machine which is exposed to moisture or acid fumes. When the machine is not operating, the fumes act on the surface of the ring which is not in contact with the brushes. The difference in surface condition caused by this action may cause a slight burning as the ring rotates.

Brush imprints may also be caused by unbalance or eccentricity in the rotor which causes the shaft and collector to move toward one side on each revolution. In this case the brush may jump off and arc, leaving a print.

When a new brush is installed, it is important to check it for freeness of movement in the brushholder. If the brush is tight, it should be sanded. A clearance of 10 mils on each side is desirable.

Brush prints due to moisture or fumes will occur at any point where the machine happens to stop, while prints due to unbalance or eccentricity will always occur at the same place on the rings.

BEARINGS

With reasonable maintenance and attention the generator and exciter bearings should give long and trouble-free service.

The temperature of the bearings should be observed regularly so that a sudden change or an unusual rise in temperature can be detected. The cause of overheating should be determined and corrected immediately.

OIL LEAKS

If an oil leak occurs where the shaft comes through the oil seal, it is probably caused by some damage to the seal strips, or by an obstruction in the oil drain lines. Each oil seal has a trap in the drain holes, and some leakage may occur before this trap fills up. For that reason, the trap should be filled with oil before the seal is installed.

INSULATION RESISTANCE

As mentioned on page 21 of this instruction book, insulation resistance or "megger" readings of both stator and rotor windings should be taken at regular intervals. Records should be kept of the winding temperature as well as the actual "megger" reading. A trend toward lower insulation resistance is a warning that a failure of the insulation is possible; therefore, the readings obtained at any particular time should be compared with the previous readings in order to be of maximum significance. In order for these readings to be of value for comparison, the tests should be made at the same temperature and with the same voltage applied for the same length of time. It is preferable to make these tests immediately after shutdown while the machine is warm and relatively free from moisture.

In generators equipped with stator throughbolts, the insulation resistance of each throughbolt should be checked whenever the generator end bells are removed.

INSPECTION

Note. Instructions regarding the handling of parts as given under "Handling" and "Storing" should be observed during inspection.

Six Months. The generator and exciter should be given a careful inspection after the first six months of operation. At least one-half of the generator end bell should be removed at each end so that the stator coils, finger plates and end punchings can be examined.

If the generator is operated with a closed circuit system of ventilation, very little dirt should collect on the windings and in the air passages. If a closed system is not used and the windings after six months operation are so dirty that cleaning is necessary, steps should be taken to eliminate dirt by installing a closed cooling system or an effective air filter.

The finger plates and end punchings should be examined for local hot spots, and the end windings and coil braces checked for tightness and for distortion due to short circuits.

One Year. After one year of operation, the generator should be dismantled for a thorough inspection. Take off both end bells and remove the rotor. All dust and dirt should be removed by the methods outlined under "Cleaning Methods", which follows this section.

The core and coils should be inspected for evidences of local hot spots, loose coil bracing, or any other unusual condition.

The rotor should be inspected for loose wedges and surface heating, especially at the joints between the retaining rings and rotor body. The collector rings, field leads, brushholders and brushes should be cleaned and the collector rings checked for tightness.

Since dangerous heating of the rotor surface and retaining rings may occur under short circuit and single-phase load conditions, it is recommended that the rotor be given a careful inspection whenever a turbine generator is subjected to a severe short circuit or heavy single-phase load.

If the retaining rings are severely burned at the contact surfaces between the retaining rings and the rotor body, the manufacturer's engineering representative should be called in to make a detailed examination of the damaged parts and to pass on the mechanical fitness of the rings for further service. Considerable skill is required to remove or replace a retaining ring properly. A Westinghouse Service Engineer can give valuable assistance if any work on the rotor is necessary.

CLEANING METHODS

Wiping Cloths. If only dry, loose dust or dirt has collected, wiping with a dry cloth may be satisfactory. Waste should not be used since the lint will adhere to the insulation and collect dust, moisture and oil.

Compressed Air. Blowing out dirt with air at about 25 pounds pressure is usually effective, particularly when the dirt has collected in places which cannot be reached with a cloth. Be sure the air is free from moisture that may have condensed in the air lines. Dust removed by blowing is scattered, however, and will settle on other parts from which it must be removed with a wiping cloth. Adjacent machines should be protected from flying dust by a suitable cover or shield.

Caution. Care should be used to prevent personal injury from the air hose, and goggles should be used to avoid eye injury from flying particles.

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

Solvents. When grease or oil is present, wipe with a cloth moistened (not dripping) with a petroleum solvent of a "safety type" such as a Stoddard solvent or similar materials available under various trade names. When a material is difficult to remove, carbon tetrachloride may be used instead of the petroleum solvent.

Note. Do not use carbon tetrachloride on leads or other rubber insulation because of its deteriorating effect on these items.

Caution. The petroleum solvents are inflammable and comparatively non-toxic, but they are less effective than carbon tetrachloride, and tend to leave an oily film on evaporation. Use neoprene gloves to prevent skin irritation when using either petroleum solvents or carbon tetrachloride.

Carbon tetrachloride is non-inflammable, but highly toxic, and its vapor is heavier than air so it accumulates in pits or other confined spaces. If possible, suitable ventilation should be provided to avoid breathing vapors. When ventilation is not sufficient to prevent a distinct odor of carbon tetrachloride, a chemical cartridge respirator or gas mask must be used. If this solvent is used, the operators should work in pairs so that if one is overcome, the other can help him to fresh air.

General Precautions. In using solvents, the following general precautions should be observed to minimize fire risk and provide for the safety of the workers:

1. Provide adequate ventilation.

2. Avoid saturation of workers' clothing with solvent.

3. Remove any saturated clothing when leaving the job.

4. Keep fire extinguishers handy.

5. Prevent sparks by:

A. Keeping metal tools from striking metal parts of the apparatus.

B. Eliminating the use of shoes with protruding nails.

C. Grounding the nozzle when using a hose to spray cleaning solution (or varnish).

Whenever possible, the parts which have been cleaned should be dried with clean cloths in order that the insulation varnish may not become soft from prolonged exposure to the solvent. If the varnish coating of the windings shows considerable deterioration, the windings should be retreated with a varnish furnished by the manufacturer. In any case, the machine should be given an opportunity to dry out thoroughly before being placed in service.

After the machine is re-treated with varnish, it should be given a suitable high voltage insulation test to locate possible weaknesses at a time when they can be conveniently repaired.

TREATMENT OF CORE AND WINDINGS

The stator windings and core are coated with varnish to protect them against dirt and moisture. If this material shows signs of deterioration, the parts should be re-treated with material recommended by Westinghouse.

CARE OF EXCITER

General Rules. Keep the exciter clean and free from oil and dust, especially from copper or carbon dust at all times.

Keep the commutator clean. Oil will penetrate mica and if it is allowed to enter 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 also 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 clean 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.

An air hose should be applied to the air ducts between the spokes of the armature spider since an accumulation of dirt at these places will impede the free flow of cooling air.

A coat of insulating varnish applied to the armature and field coils after they have been cleaned will protect the insulation.

Give the machine a thorough inspection occasionally. The higher the voltage of the machine, the oftener this should be done.

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

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

CARE OF BRUSHES

Modern brushes have characteristics that eliminate the need for any oiling of the commutator for lubrication. Oil affects mica adversely and should not be allowed to come in contact with it. The brushes are set at an angle of approximately 30° against rotation.

Besides maintaining the brushes in the proper position as described on page 29 under "Brush Position", make frequent inspections to see that:

1. Brushes are not sticking in the holders.

2. Pig-tail shunts are properly attached to brushes and holders.

3. Tension is maintained as the brushes wear.

4. Worn-out brushes are replaced before they reach their limit of travel and break contact with the commutator, or cut it due to contact with the metal clip.

5. Remove any free copper picked up by the face of the brush. A more complete treatise on brush selection and application is given in the Instruction Book "Selection, Application and Care of Brushes for Commutators and Slip Rings for Power Station Apparatus."

When a new brush is installed, be sure it is free in the brushholder. A clearance of about 10 mils is desirable.

Seating of Brushes. The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing face. This can be easily accomplished after the brushholders have been adjusted and the brushes inserted. Fit the brushes in each brushholder separately by drawing a sheet of sandpaper under the brushes in the direction of rotation while pressing them firmly against the commutator. Be careful to keep the ends of the sandpaper as close to the commutator surface as possible to avoid rounding the edges of the brushes. The sandpaper should cut the brushes only in the direction of normal rotation. Lift the brushes as the sandpaper is drawn back. Never use emery cloth or emery paper to seat brushes on account of the continued abrasive action of the emery which becomes bedded in the brushes.

CARE OF COMMUTATORS

The commutator is perhaps the most important feature of a d-c machine and one that is most sensitive to abuse. Under normal conditions, it should require a little attention beyond frequent inspection.

The commutator should take on a polished dark brown or chocolate color after a few weeks operation. Such a commutator needs no attention other than to be kept clean. Use of oil 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 under-cutting that may cause "burning" and "flashing". Do not allow oil to come in contact with the commutator mica, as the oil will penetrate the mica and carbonize it, causing burnouts.

All commutators are thoroughly baked and seasoned before leaving the factory.

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, rapid wear of the brushes, and greatly limit the machine's ability to satisfactorily handle overloads.

The surface of the commutator should be kept smooth. Sometimes a little sandpapering is all that is necessary.

If the commutator becomes badly roughened, it will be necessary to turn down or grind the commutator.

All standard commutators have the mica undercut below the surface of the copper. This prevents high mica which causes sparking commutation and burns away the copper. As the commutator wears, the mica should be undercut to a depth of $\pm \frac{1}{64}$ of an inch below the adjacent copper.

Trouble is sometimes experienced from the burning out of mica insulation between segments. This is most commonly caused by allowing the mica to become oil soaked. It is rarely, if ever, definitely traced to excessive voltage between bars. When this burning does occur, it may be effectively stopped by scraping out the burned mica and filling the space with a solution of sodium silicate (water glass), or other suitable insulating cement.

Grinding. The surface of the commutator should always be kept smooth. If it becomes badly roughened, the Westinghouse Service Department should be consulted with regard to grinding the commutator, since this operation requires experience and special equipment if it is to be carried out in a workmanlike manner.

REPAIRING EXCITER WINDINGS

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.

Temporary Armature Repairs. A simple method of making temporary repairs in an armature in case of a short circuit or open circuit of one of the coils is to cut out that coil by cutting the leads which connect the coil with the commutator bar, and then short-circuiting this bar with the following bar. This may readily be done by simply soldering the two necks together. By this means an armature may be kept in commission until some more convenient time arises in which to replace the damaged coils.

Repairing Main Field Coils. If it is necessary to remove a shunt field coil, disconnect the coil from those on each side, remove the bolts which hold the pole to the frame, and remove the pole and coil.

The shunt winding is wound directly on its pole so that if a new coil is to be installed, it will be necessary to replace the complete pole and coil assembly.

Care should be taken in reconnecting the coils so as to obtain the proper polarity of the coils. A very simple means of testing the polarity of shunt field coils is by means of a needle or a piece of steel wire suspended from the middle by a string. The polarity should be alternately north and south around the frame. Bring the polarity needle within the magnetic field of any pole. One end of the needle will point towards this pole and this end should be repelled by the next pole and so on around the frame. If this reversal of the needle does not occur there is evidently a wrong connection of the field coil.

Repairing Commutating Field Coils. If it is necessary to remove one of the commutating field coils, disconnect the coil from those on each side, remove the bolts which hold the pole to the frame, and remove the pole and coil. The commutating coil may be removed from its pole and repaired or replaced by a new coil and the complete field reassembled in the frame.

AIR FILTERS

The air filters in the exciter bedplate should be cleaned when they restrict the air flow enough to cause a noticeable increase in the exciter temperature. This temperature can best be determined by increase in resistance of the exciter shunt field.

The pressure drop across the filter can also be used to determine when a filter should be cleaned. When the pressure drop increases to ½ or ¾ inch of water the filters should be cleaned.

Cleaning. To clean, remove the filters from the air ducts. Flush out dirt with hot water or steam and allow to dry completely. Spray front and rear with just enough oil to coat wires. An ordinary hand spray is satisfactory. Allow to drain for 24 hours. Only a very thin coat of oil is necessary for the correct operation of the filter. Excess oil may be blown off with an air hose so that it will not be blown through the machine.

CARE OF TACHOMETER

Because of the absence of bearings, commutator, and collector rings, there is little maintenance required by the tachometer generator. However, if the tachometer generator shows excessive temperature it can be an indication that the alignment is incorrect and that the rotor is rubbing against the stator at either or both of the air gaps.

If the instrument does not read the exact synchronous speed of the unit when the unit is operating at its continuous temperature level, the calibration rheostat should be adjusted as noted under "Initial Operation", page 26.

Observe the following precautionary measures:

1. Remove the tachometer generator if a sine wave generator is to be mounted on the shaft end to check the balance of the rotor. The tachometer shaft will not support the additional load.

2. Remove the tachometer before breaking the turbine coupling. The shaft displacement required to clear the spigot fit in the coupling is greater than the axial clearance in the tachometer.

Dismantling. Before dismantling or removing the supporting or driving shaft, first remove the stator and then the rotor.

REPAIR WORK

Repair work can be done most satisfactorily at the nearest Westinghouse repair shop. However, interchangeable renewal parts can be furnished to purchasers who are equipped to do the work.

ORDERING OF PARTS

When ordering renewal parts, give the complete nameplate reading of the machine. Always give the name and style number (if known) of the part wanted, also the stock order number of the apparatus on which the part is to be used. Refer to the back cover of this book for the nearest sales office from which to order parts.

RENEWAL PARTS

The following is a list of renewal parts recommended to be stocked by the user of this apparatus to minimize interrupted operation caused by breakdowns. The parts recommended are those most subject to wear in normal operation or those subject to damage or breakage due to possible abnormal conditions.

This list of renewal parts is given only as a guide. When continuous operation is a primary consideration, additional insurance against shutdowns is desirable. Under such conditions more renewal parts should be carried, the amount depending on the severity of the service and the time required to secure replacements.

RECOMMENDED RENEWAL PARTS

NAME OF PART	NO. PER UNIT	RECOMMENDED STOCK FOR ONE GENERATOR
Collector Brushes	1 Set	2 Sets
Exciter Brushes	1 Set	2 Sets
Bearing Lining	1 Set	1 Set
Exciter Air Filter	1 Set	1 Set

MEMORANDUM