INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

Synchronous Horizontal
A-C GENERATORS

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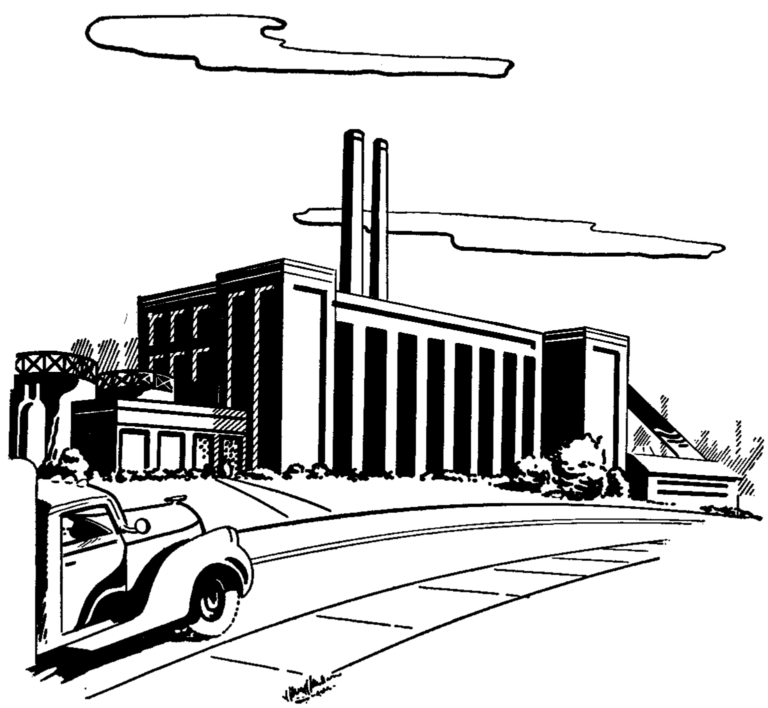

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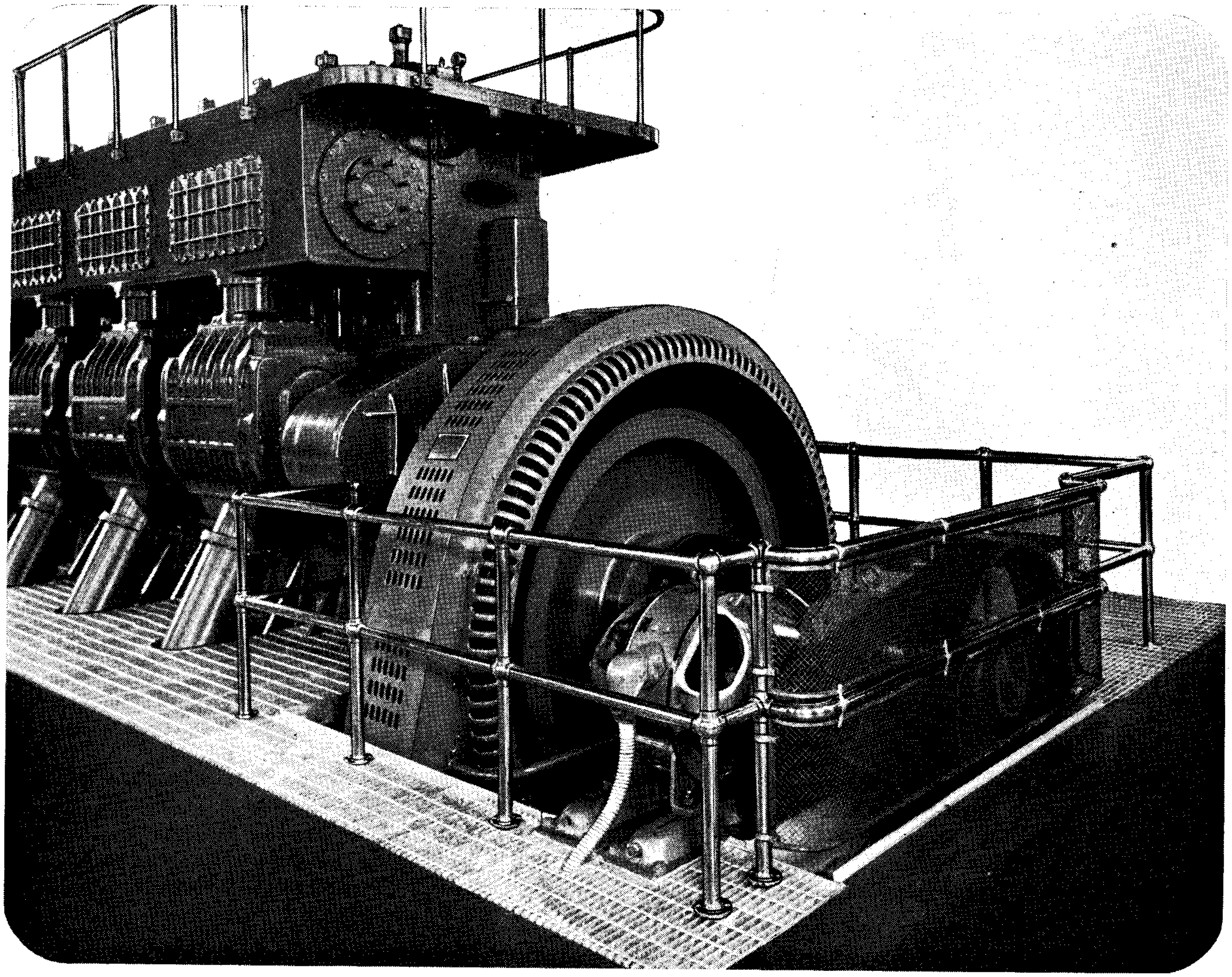


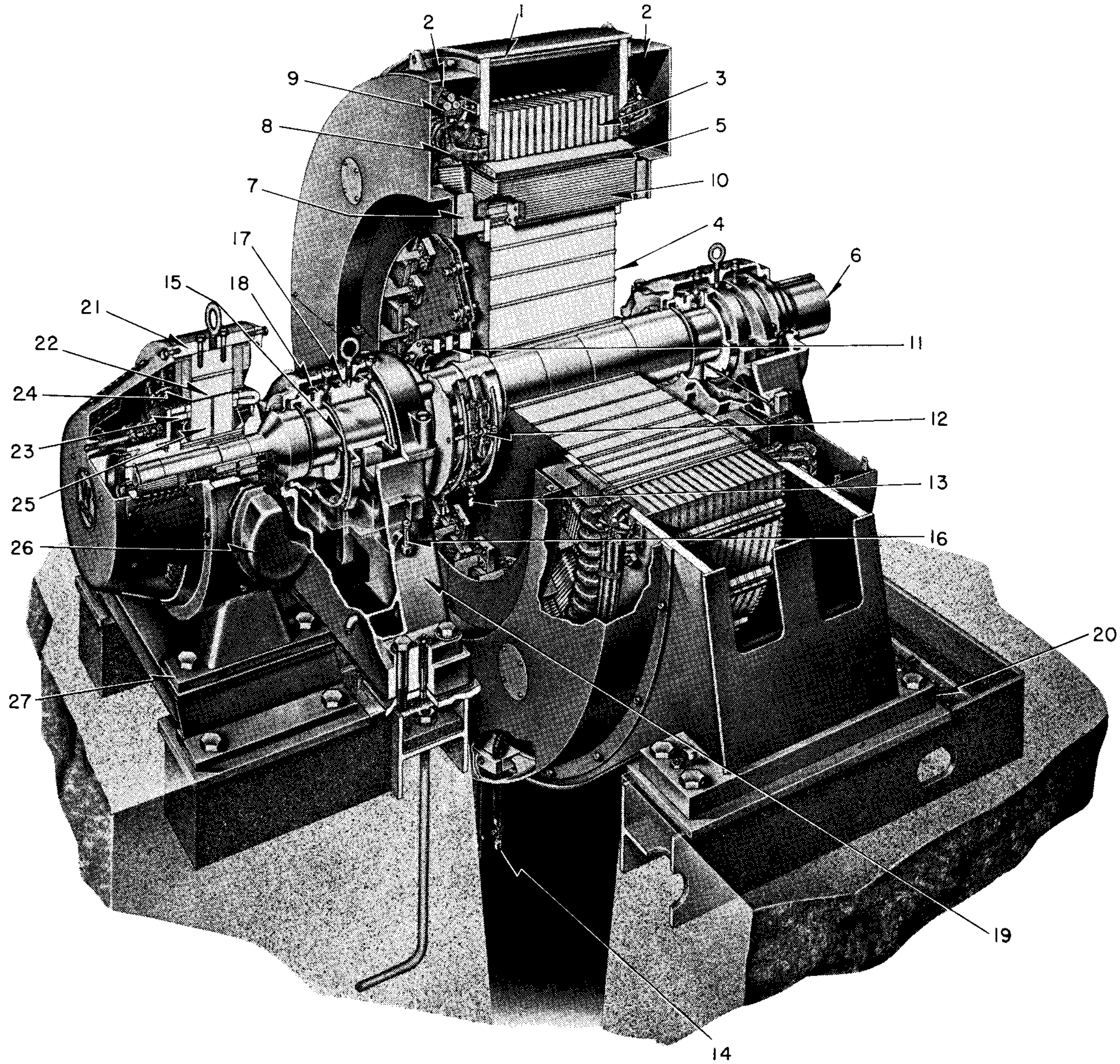
Engine-Type Diesel Driven Generator

Salient-Pole Synchronous Horizontal A-C GENERATORS

Long life and minimum outage for your generator can be obtained by following carefully the instructions given in this book for installation, operation, and maintenance.

Keep all rotating machines clean. A strict maintenance schedule will pay big dividends in reduced repair bills. By inspection at regular intervals, most troubles will be found and corrected before they can become serious enough to cause a shutdown or hazard to personnel.

Of necessity, this book cannot cover all the details and variations in generator construction, operation, and maintenance but it does give the more important principles which apply to every rotating machine.



GENERATOR

1 Generator Frame
2 End Bells
3 Stator Core
4 Rotor Spider
5 Field Pole
6 Shaft, Coupling End
7 Blower Blade
8 Stator Coils
9 Stator Coil Connection
10 Field Coil
11 Collector Rings
12 Brushholders
13 Collector Leads
14 Stator Leads
15 Bearing Oil Ring
16 Bearing Oil Level Sight Gauge
17 Bearing Shell
18 Bearing Housing
19 Bearing Pedestal
20 Frame Foot

EXCITER

21 Exciter Frame
22 Field Pole
23 Armature Coils
24 Field Coil
25 Armature Core
26 Lead Conduit
27 Frame Foot

FIG. 1. Cutaway View of High Speed Pedestal Bearing Type Generator

PART ONE

DESCRIPTION

A general understanding of the construction features of the apparatus is necessary in order that the succeeding chapters on installation, operation and maintenance be the most helpful. It is recommended that the reader study the illustrations along with the following description of component parts.

STATOR

Stator Frame. Stator frames are fabricated from steel plate electrically welded to form a rigid box section. Openings are provided in the frame wrapper plate for discharge of the ventilating air. Provisions are made in some cases for the purchaser to connect the discharge openings to duct work leading to the outside air.

Suitable lifting holes or a lifting eye bolt is provided in the frame for handling during assembly. On enclosed machines removable cover plates are furnished over lifting holes.

Stator Core. The stator core is composed of high grade silicon steel laminations, each of which is coated on both sides with an insulating material in order to keep eddy currents from flowing, thus reducing iron losses to a minimum. In all except some small machines, the laminations are arranged in stacks approximately two inches thick, the stacks being separated from one another by thin metal vent fingers providing radial air ventilating ducts at regular intervals throughout the core.

Laminations are individually anchored to the axial core building bolts and are clamped securely on the ends by heavy finger pieces and end plates.

Stator Windings. The stator or armature coils are form wound and interchangeable. Eddy currents are reduced to a minimum by selection of suitable conductor and strand sizes. The assembled group of insulated wires is impregnated with insulating varnish to fill all air spaces and to solidify the coil.

On machines rated above 4160 volts, the coil is re-impregnated under vacuum and pressure.

All coils are tested with high frequency voltage to detect any flaws which might eventually cause breakdown between turns.

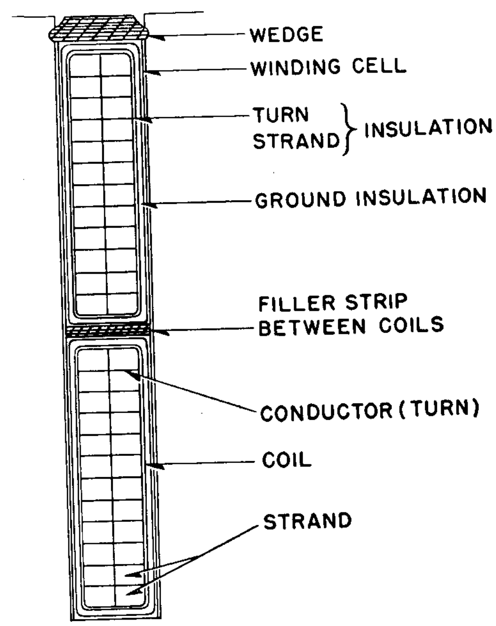


FIG. 2. Typical Coil Slot Cross Section

The coils are held in the slots of the stator core by wedges driven into grooves between the coil and air gap as shown in Fig. 2. The coil ends are braced as required by the individual machine characteristics to withstand the maximum mechanical stresses which would be caused by a short circuit. This is normally accomplished by lashing the coils to a metal ring and inserting rows of wood, treated paper, or Micarta spacers between the coil sides. The completed stator is normally dipped or sprayed with varnish and then baked as a precaution against moisture conditions.

ROTORS

Low Speed. Low speed rotors are made with a fabricated spider built with a center of steel plates which are welded onto a rolled steel rim on which the field poles are bolted on. The bolts are tapped directly into the assembled pole punchings. The collector rings are mounted on insulated studs on the spider hub.

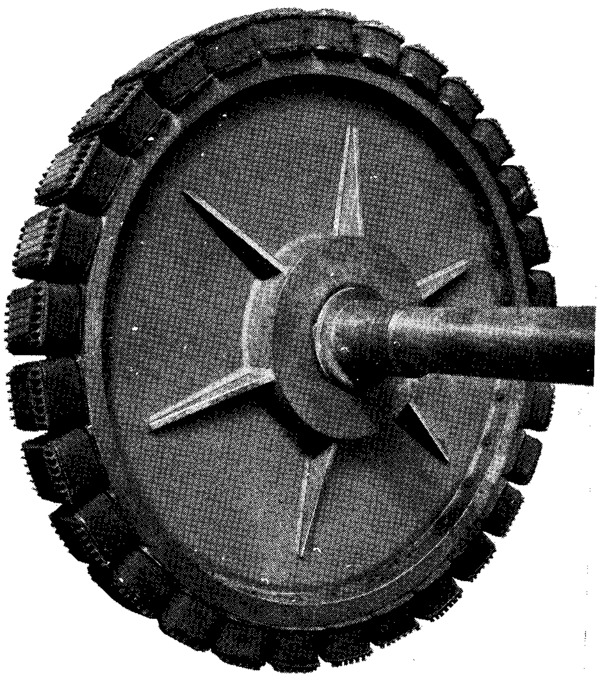


FIG. 3. Low Speed Rotor with Solid Spider

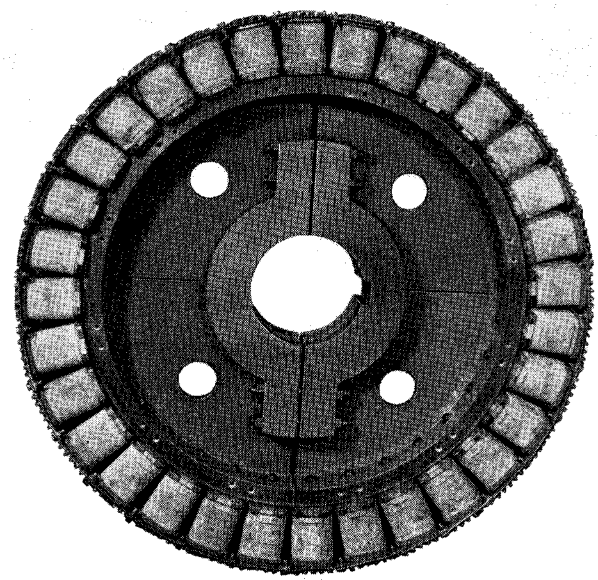


FIG. 4. Low Speed Rotor with Split Spider

A few low speed rotors have split spiders. The rim halves are fastened together by means of shrink links and the hub halves are fastened by bolts. (See Fig. 4) The collector rings are also split.

Shafts are not furnished with engine type machines. The prime mover manufacturer usually supplies the shaft for both the prime mover and the generator.

Water wheel generator rotors are designed for 85% (or greater) overspeed as required, while rotors for other applications are designed for 25% overspeed.

High Speed. High speed rotors are composed of an assembled group of spider laminations pressed and keyed on the shaft. The field poles are built up of steel laminations riveted or bolted together under high pressure and have dovetail projections to mate with slots in the spider (See Fig. 5).

The poles are secured to the spider by two tapered keys and a liner. The taper of the keys is so slight (.005" per in.) that there is no tendency for them to slip once they are set. As an added precaution against slipping, locking plates are usually bolted over the ends of the tapered keys.

The collector rings are usually mounted on the shaft on these high speed units.

Field Windings. Wire field coils come in two general classes:

1. Those wound directly on the pole piece.

2. Those wound on a mandrel and inserted over the pole piece at assembly.

Both are insulated from the pole body by a suitable insulating cell and on the top and bottom by wood or micarta collars capable of resisting the centrifugal forces involved. The coils are wound carefully and each layer is brushed thoroughly with insulating varnish as it is wound. The materials used depend on the class of insulation ordered and the mechanical and electrical requirements of the particular machine.

Strap field coils are usually used on the larger and higher speed machines. These are made of copper strap wound on edge and insulated between turns by asbestos and shellac. The outer edges of the straps are covered only with shellac to provide maximum heat transfer to the cooling air. Often there are certain turns which are extended beyond the normal ends of the coil to provide additional cooling surface. (See Fig. 6).

Damper windings consist of uninsulated conductors embedded in slots in the pole face and joined to segments at each end, usually by brazing. These segments may or may not be connected between poles depending on electrical, mechanical, or contract specifications. If they are connected,

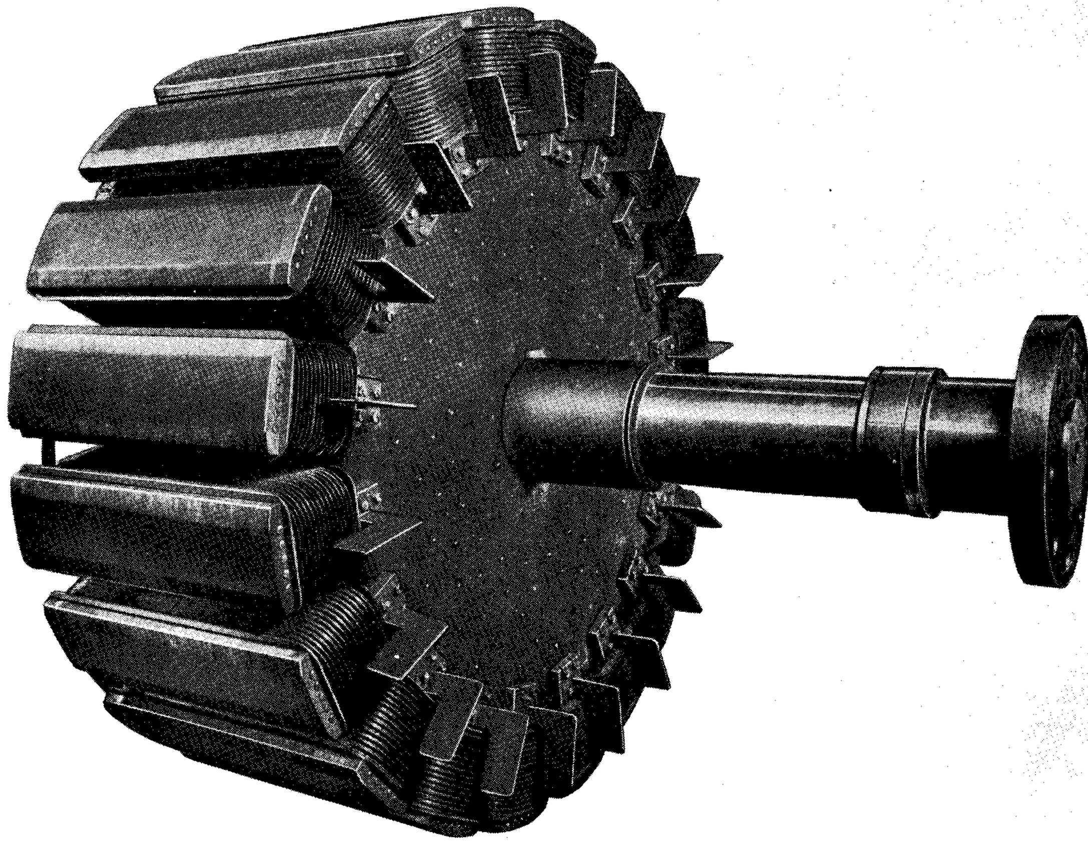


FIG. 5. High Speed Rotor

on low speed machines the segments are bolted together between poles; and on higher speed machines the segments are bolted to a steel ring of characteristics suitable for the stresses incurred at the overspeeds.

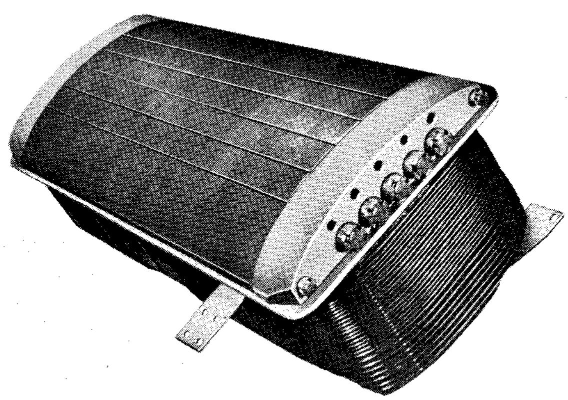


FIG. 6. Pole Piece with Strap Copper Winding

BEARINGS

There are two general styles of bearings used on these machines, sleeve bearings and anti-friction bearings.

The various anti-friction type bearings are usually grease lubricated at low speeds and oil lubricated at high speeds, as specified by the bearing manufacturer.

Sleeve bearings are most common and are oil-lubricated. They are provided with oil rings which rotate with the shaft, dipping in a bath of oil in the bearing housing, thus pulling oil up and over the journal. There are openings at the top of the bearing cap for inspection of the oil rings. A glass sight gauge is normally provided on the oil reservoir for determining oil level, but on certain bearings the oil fill stand pipe becomes an oil level indicator and the level is correct when the pipe is full. There is a drain plug which allows all of the oil in the reservoir to be removed.

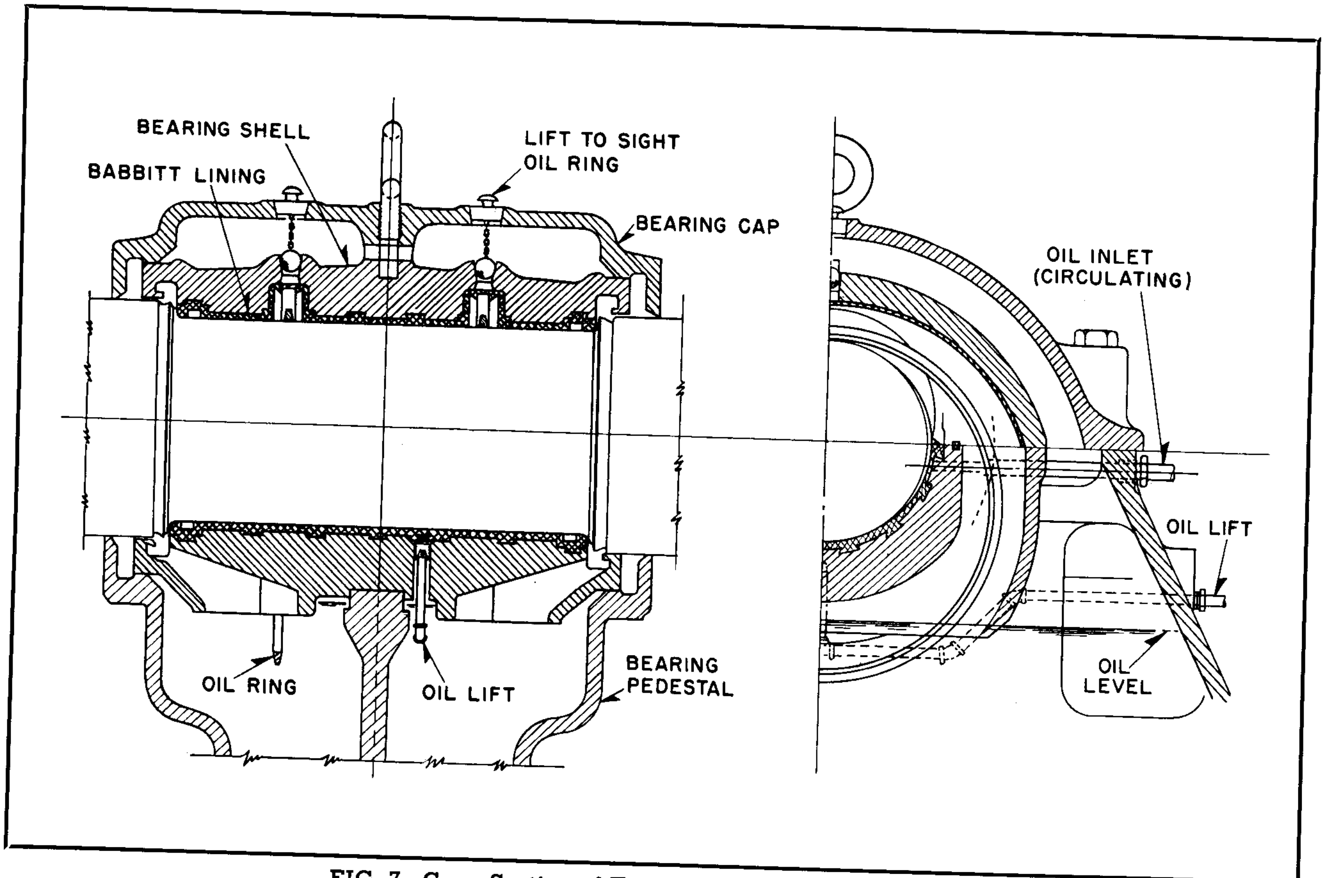


FIG. 7. Cross Section of Typical Sleeve Bearing Assembly

On large high speed machines the loss in the bearings often becomes so great that the heat cannot be dissipated by the bearings at a permissible temperature rise. In such cases, it is necessary to provide some external means of dissipating the excess loss.

The standard method is to circulate the oil from the reservoir through the external coolers to the bearings by means of a motor driven pump. Another method is to circulate cooling water through coils in the pedestal reservoir. The rate of oil circulation in the bearing and water circulation in the cooler depends on the bearing loss. Suitable pipe connections are provided in the bearings to permit use of oil circulating systems when required.

Bearing assemblies have only minor differences whether assembled in brackets or on pedestals. Some small sleeve bearings on exciters are not split, the bearing being made to slide out from the bracket axially.

Bearings of engine-type machines are usually supplied by the prime mover builder.

When bearing temperature relays or thermometers are supplied they are mounted on the side of the bearing housing and the sensitive portion of the instrument is embedded in the bearing shell very close to the bearing babbitt.

All sleeve bearings have babbitted oil ring guides to reduce the wear of the rings. The bearings large enough to be split horizontally have a relief at the split to distribute the oil evenly over the entire bearing surface. See Figs. 7, 8, and 9 for typical sleeve and anti-friction type bearing assemblies.

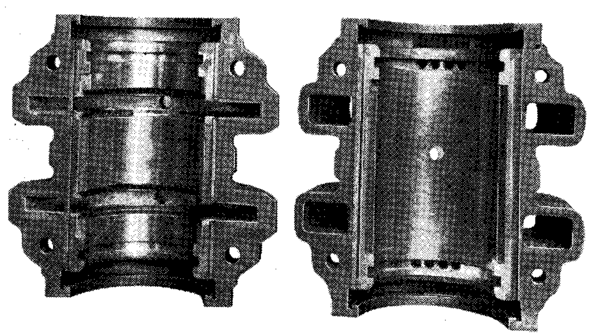


FIG. 8. Split Sections of Sleeve Bearings

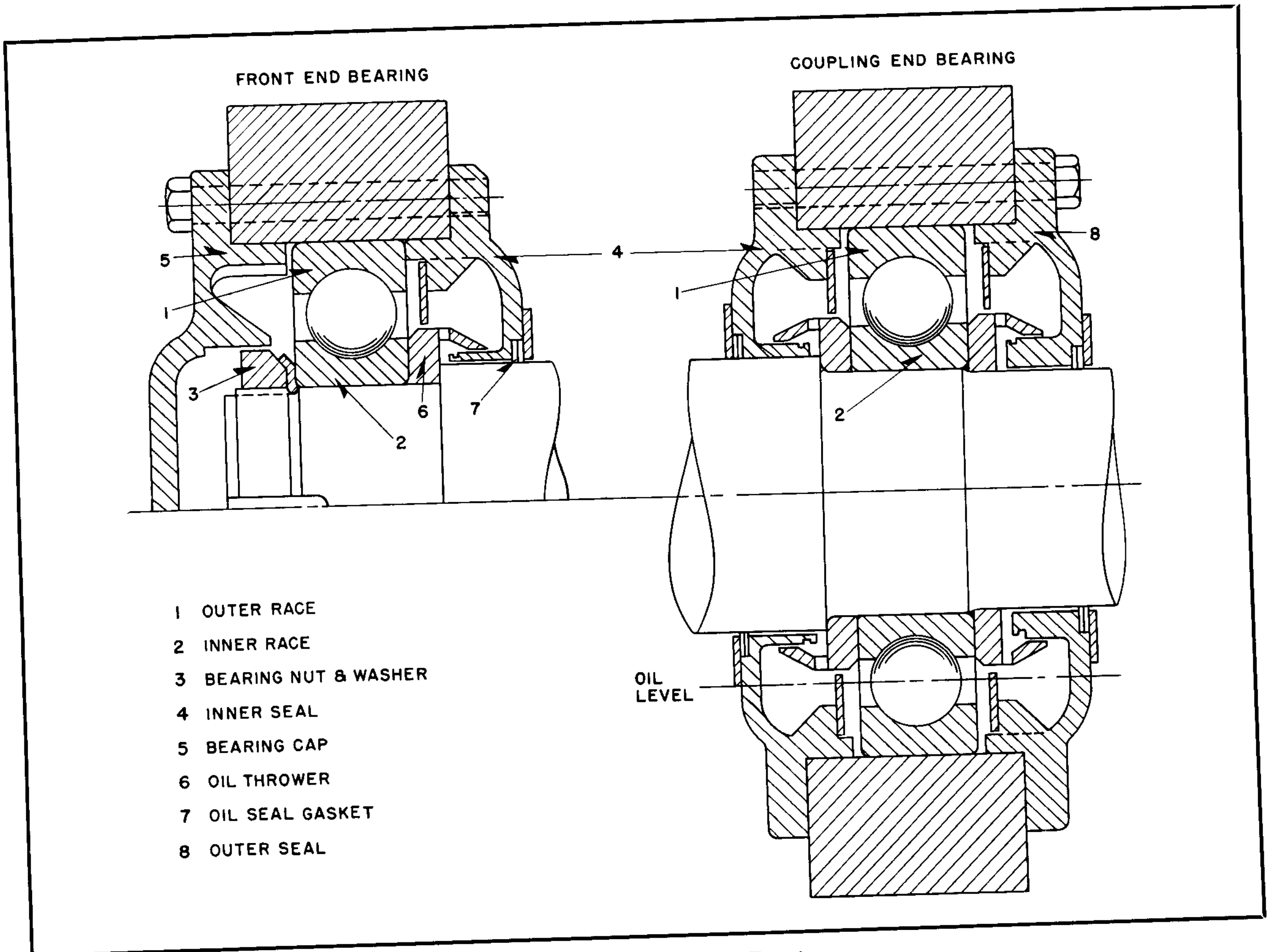


FIG. 9. Anti-Friction Ball Bearings

SHAFT CURRENTS

Variations in reluctance in the magnetic circuit of an alternating current machine may cause cyclic 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 bedplate or reinforcing in the concrete. If this current is permitted to flow, it soon has a destructive effect on the shaft journals and bearings.

Normally the shaft first takes on a satin finish appearance and later small pits form on the surface of the shaft. The bearing babbitt in most instances will show evidence of having been eaten away by the current in small pits. Babbitt eaten away by current is characterized by deep irregular holes, which in serious cases penetrates to the bearing shell.

It is not practicable in the design of most machines to provide control of shaft currents, therefore, most machines are provided with one or more insulated pedestals or, the bearing is insulated from one bracket. (See Fig. 11.) Pedestal insulation is fully covered on page 19 of this book.

BEDPLATE

Bedplates, when provided, are fabricated from standard structural shapes, arranged to obtain the maximum rigidity for the mass of material used. For many machines, soleplates are supplied, which consist of separate side rails and end rails for the bearings. These rails are not joined at the corners but are mounted separately on the foundation.

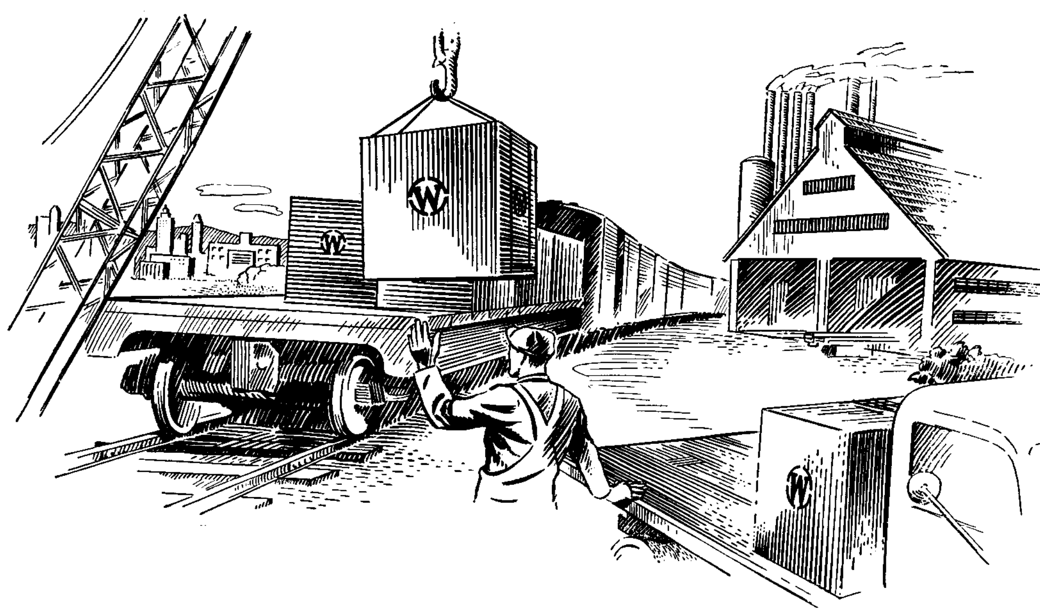
VENTILATION

Fans or blowers are attached to the rotors of most generators to assist in forcing ventilating air through the machines. In some cases these are straight radial vanes or "paddles" each of which is separately bolted to the rotor.

For other machines, a completely assembled blower having inclined blades is bolted to each side of the rotor. The blades are inclined in such a way that, while their planes are parallel to the shaft, they are not placed radially, the edge of the blade nearest the shaft being in advance of the outer edge in the direction of rotation. It is most important that the machine be run in such a direction that this relation is obtained since the amount of air delivered by the fan is greatly reduced when it is run in the opposite direction.

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

Westinghouse generators are designed and proportioned so that the cooling air is uniformly directed to all sources of heat generation, thus providing for long insulation life and maximum dependability. The fans mounted on the rotor are liberally designed; the ventilating ducts in the stator core (when required) are liberal in number and so distributed that uniform temperatures exist throughout the entire length of the machine.



PART TWO

INSTALLATION

RECEIVING

Before shipment, all generators are inspected, and tested to eliminate electrical and mechanical defects. If the crate or wrapping appears damaged upon receipt, the machine should be unpacked at once, in the presence of a claim adjuster, and all apparent injuries and breakage reported to the carrier.

Important. When writing to the Westinghouse Electric Corporation concerning the machine, always give the serial number which appears on the nameplate and on the end of the shaft.

Storing. Apparatus which cannot be installed as soon as received should be unpacked, examined, and stored in a room which is clean and dry and where temperature variations are small and slow. It is very important to keep the windings dry since moisture tends to lower the insulation resistance and increases likelihood of insulation breakdown. If possible the machine should be kept warmer than the room air by heaters. Heaters must be such that the products of combustion do not condense on the electrical parts or form a fire hazard. Electric heaters are most suitable for this purpose.

If nothing else is available, it will be possible in some cases to keep the machine dry and warm by placing a number of large light bulbs with the machine in a tarpaulin enclosure. If possible, the tarpaulin should allow a small amount of air circulation. Metal surfaces not covered by rust resisting coating should be so covered.

Handling. All lifting should be done by means of the eyebolts or lifting holes provided. Never lift or support the stator by the core punchings or coils. When lifting completely assembled machines which are mounted on a bedplate, slings should be attached in the openings on the bedplate. Arrange the slings so that the weight is distributed uniformly and use care to avoid distortion of the bedplate.

LOCATION

It is important that the location of the machine meet the requirements of the National Board of Fire Underwriters and all local regulations. The following additional considerations should also govern the location:

1. Install the machine so that it is well ventilated and easily accessible for cleaning, inspection and assembly.

2. Avoid exposure to mill and coal dust or any other injurious substances.

3. Protect the machine from moisture and chemical or oil fumes.

The generator room must be well ventilated so that the hot air can escape and will not be recirculated through the machine. Unless the room is large and well ventilated, natural ventilation will not be sufficient. If the machine is designed to take air from the pit, suitable ducts must be provided in the foundation. The outline drawing shows the recommended minimum size of the pit and location of ducts.

FOUNDATION

The foundation should consist preferably of solid concrete walls or piers and should be carried down far enough to rest on a solid sub-base. A competent consulting engineer who is familiar with foundation design should design and supervise this part of the installation.

If it is necessary to support the bedplate on steel girders instead of concrete, the girders should be well braced and supported by adequate columns so as to prevent vibration. A rigid foundation is essential so that vibration and misalignment during operation will be reduced to a minimum.

The pit beneath the generator, if required, should be deep enough to give ample working space for connecting the leads which are normally brought out below the machine.

In order to place the foundation bolts accurately, the outline drawing should be consulted and a wood template constructed. A suggested method of anchoring the foundation bolts is shown in Fig. 10. This method has the advantage of flexibility for easy lining up of the bolts with the holes in the bedplate or soleplates. Whatever method of placing foundation bolts is used, they must be firmly anchored in the foundation.

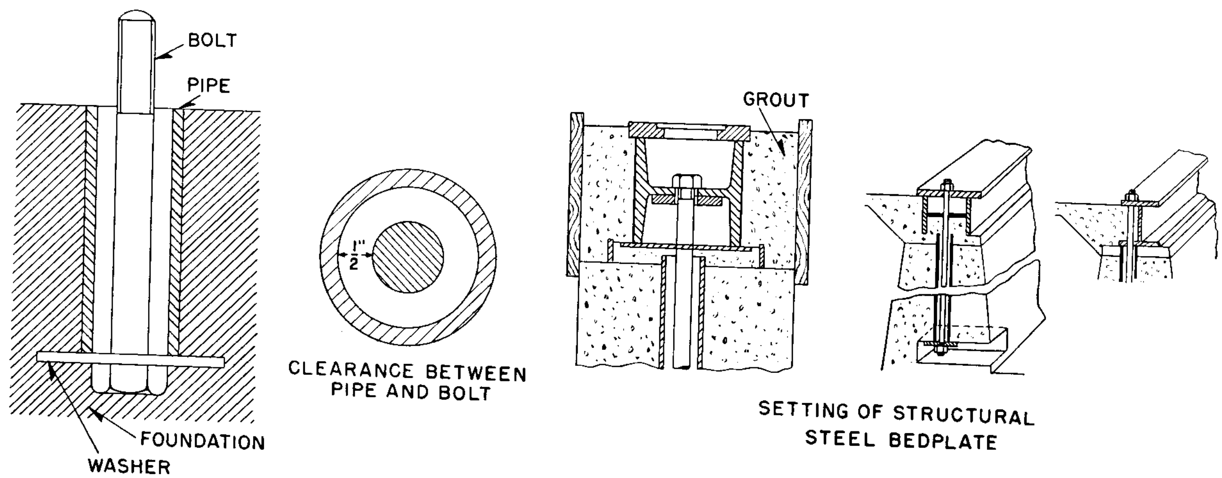


FIG. 10. Method of Anchoring Foundation Bolts, and Typical Arrangements of Bedplates and Grout Forms

The surface of the foundation should have a rough finish in order that the grout to be added later may have a good bond with the concrete.

Important. When planning a foundation, great care must be taken that the bedplate will not be too high in elevation. It is always possible to raise the bedplate with leveling plates but very difficult to lower it if too high as this would require removing some of the foundation surface.

PROCEDURE BEFORE ERECTION

The erection or "setting up" of the generator is a matter requiring great care and attention to detail, for the subsequent successful performance of the machine will depend to a great extent on its line-up and rigidity with respect to the foundation. Before beginning to erect the machine, the following points should be checked to avoid trouble once the operation has begun:

1. Check all items at the site of the erection against the manufacturer's shipping report. If all the equipment cannot be accounted for, the shortage should be reported at once to avoid undue delay in erection. Likewise, any damaged equipment should be reported as soon as discovered.

2. Locate foundation bench marks to permit establishing the centerline of the unit and the elevation of the foundation surface.

3. Check the foundation against the outline drawing of the generator to be sure that the pit, if any, and any cable, bus, or ventilating ducts that may be indicated have been provided in their proper locations and are of suitable dimensions to permit correct assembly of the unit and its accessory equipment.

4. Check the size, location, and elevation of the top of the foundation bolts against the outline drawing.

5. Make up a sufficient number of leveling plates and shims to make sure that the bedplate will not be distorted when it is placed on the plates. These plates should be of steel approximately 1/4" by 4" and should be sawed or burned in lengths so they will extend about 2" beyond each flange of the bedplate.

On large units, it is often advantageous to use a pair of tapered keys on the leveling plates for adjustment.

For purposes of description of the erection operation, the generators will be divided into two classes:

(a) Those with bearings mounted in brackets attached to the stator.

(b) Those with independently mounted pedestal bearings.

For purposes of explanation of the erection of pedestal machines, a two bearing generator will be used as an example. It is understood that the principles of lining up a shaft are the same no matter how many bearings are supplied on the set.

BRACKET BEARING MACHINES

Small bracket bearing machines which are shipped assembled on the bedplate are erected by skidding or lifting the bedplate onto the roughened foundation, with the leveling plates in place. The foundation should be of such elevation that the bedplate may rest on the leveling plates placed so that they will carry the weight of the machine without distortion.

The bedplate is then brought into exact level and elevation by means of micrometer thickness shim stock of approximately the same area as the steel plates. The machine should then be placed on the bedplate and the level and elevation again checked and corrected if necessary.

Coupling Alignment and Allowances. The machine is aligned by the use of a thickness gauge between coupling faces on the generator and prime mover shafts. The distance between flanges is checked at top and bottom and on either side with the shaft rotated in a number of positions (usually 4). The measurements should not vary so that the flanges are out of parallel more than .002 inch and should preferably be .001 or less.

The vertical and lateral position of the generator should be checked in each of the above positions by means of an accurate steel straight edge held on the edges of the flanges parallel to the shaft.

After the alignment and elevation appear to be satisfactory, the foundation bolts should be drawn up tight and the alignment again checked and corrected if necessary. When the alignment is satisfactory with the foundation bolts drawn up tight, the bedplate may be grouted in accordance with Fig. 10.

PEDESTAL BEARING MACHINES

The larger machines are usually shipped dismantled, the extent of the dismantling depending on the physical size of the machine. In some very large machines, the poles and field coils are shipped separately from the spiders and the stators are shipped in pieces. These parts have to be reassembled in the field and the work requires the supervision of a skilled erection engineer.

When the stator frame is bored at the factory, the sections are bolted together with .068 inch liners located at the joints of the sections. (See Fig. 11). The stator core is designed with approximately .032 inch gap at each split in the core to permit the insertion of fishpaper.

By means of the .068 inch frame gap the splits in the core can be packed and the frame sections bolted together with positive assurance that the fishpaper packing is tight. After the assembly is complete, there must be a definite clearance (.010 inch) between the frame sections at the location B, Fig. 11, to be sure that the fishpaper is tight.

The purpose of the fishpaper is to secure the laminations firmly in place and thereby prevent vibration of the core, loose iron and objectionable noise.

The stator coils which were omitted from the slots near the parting of each section can now be placed in the slots and the winding completed. It is very desirable that this work be done by an experienced erector.

In order to complete the winding it is necessary to raise the top and bottom sides of a number of the coils already in the stator sections. These coils were only temporarily secured in the slots near the partings in each frame section.

The number of coils which must be raised depends on several factors such as the depth of the slots, the throw of the coils, the width of the core and the class of insulation. Usually it is found desirable to raise from three to five times the number of coils in a throw to insure the most satisfactory results.

The coils which are to be raised and also those which are to be wound into the machine, must be heated to make them reasonably flexible so that the insulation will not crack and break down on the high potential test.

It is quite common to use a low voltage d-c welding generator for this purpose, although any other source of low voltage d-c power is suitable for circulating current in the winding. This current should be kept less than full load current. Refer to Page 22, under "Electrical Test".

After the coils are all in position, the winding is completed by making the connections between individual coils and between coil groups.

The winder should study the "Wiring Around Frame" drawing and the "Diagram of Connections" for the particular machine to be sure the coils are connected properly and that the "Wiring Around Frame" details are completed in line with the manufacturing drawings.

The various parts of the machine that must be disassembled for shipment are match-marked at

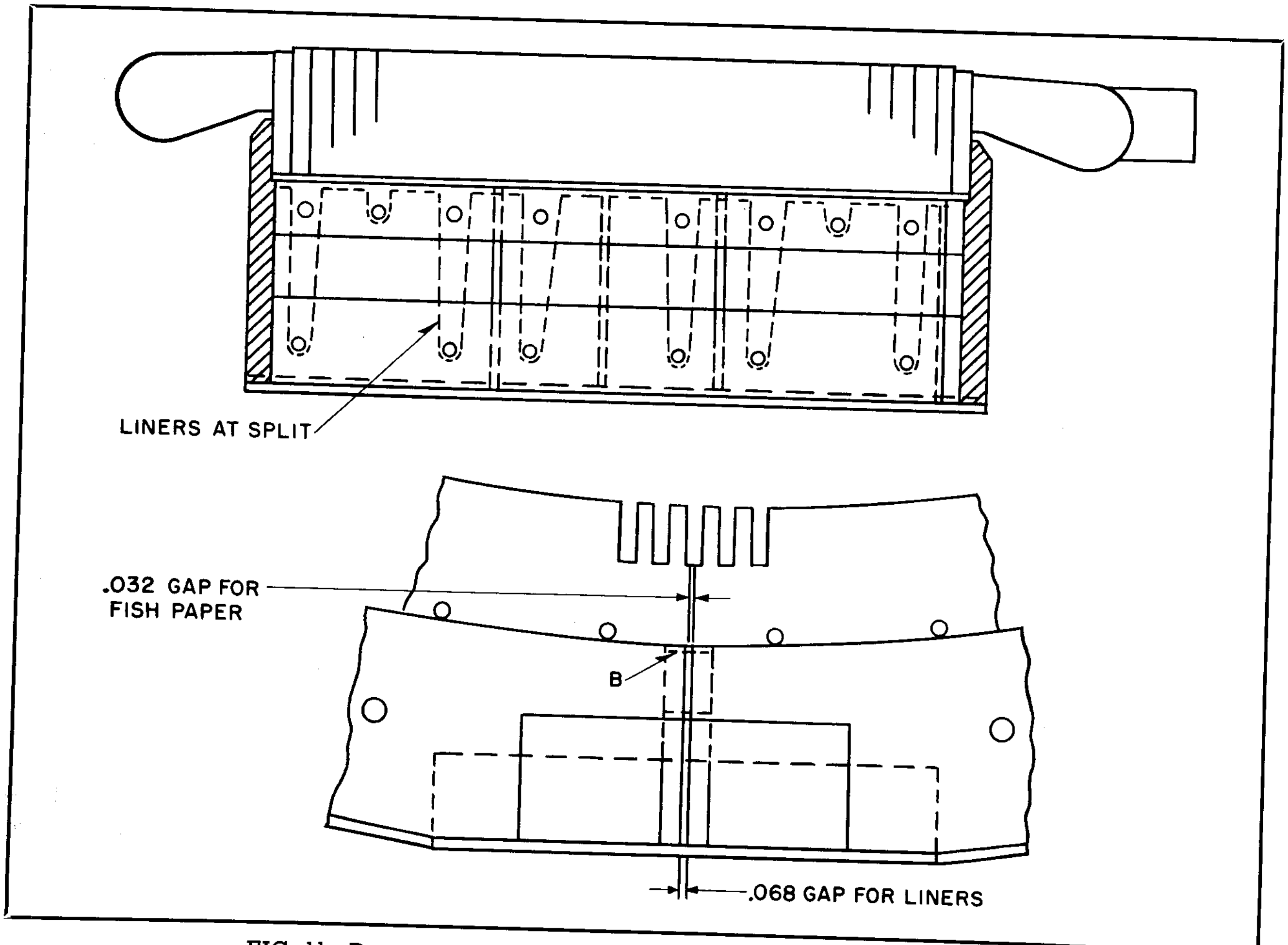


FIG. 11. Provision for Packing Stator Sections at the Splits of the Iron

several points to facilitate assembly. The marking consists of numbers stamped near the joint between two parts and are so arranged that when the parts are assembled correctly, a number on one part is adjacent to the same number on the other part. No attempt will be made to describe the assembly of such parts for all types of machines. Instructions are given on Page 20 for engine type generators whose spiders are placed on the engine manufacturer's shaft in the field.

ERECTION

The following points in the erection after assembly of large machines are of vital importance and should be carefully observed:

1. Alignment of Bedplate. The bedplate should be placed on the foundation and set by the use of wedges or shims and an accurate spirit level in such a way that its top surface is level and that when the machine is mounted on it, the shaft and coupling will be in a sufficiently close alignment with any coupled apparatus that the final correction can be made without the necessity of shifting the bedplate.

Caution. Make sure that any correction that is to be made is additive, that is, make sure the bedplate is not too high as additional correction can only be added, not subtracted. In many cases it may be preferable because of the deflection of the foundation under the weight of the machine to level and align the bedplate with the machine in position on it. (See point 3). After the bedplate is properly set, the foundation bolts should be pulled tight and the alignment again checked.

2. Grouting the Bedplate. The benefit expected from a heavy solid foundation will not be realized if a poor job of grouting on the bedplate is done. The grout should fill all the spaces in the structural steel bedplates and should be carried flush with the top of the bedplate so that a solid tie between the bedplate and the roughened surface of the foundation is obtained. Grout is a very rich concrete usually one part Portland cement to one and one half to two parts sharp sand.

3. Placing Machine on Bedplate. The method of placing the stator, rotor, and pedestals in position will vary with the size of the machine. First the stator is lifted or skidded into approximate position and the rotor placed within it and allowed to rest in the core on a fiber or cardboard pad to protect the punchings from damage. Then the pedestals are slid into position under the journals by blocking up or hoisting the rotor.

When handling the rotor with a sling, avoid damaging the windings by using a spreader bar. If the sling is placed on the journal surfaces, use rags as padding to protect against scratches.

4. Alignment of Shafts. When solid couplings are used on coupled type generators, the faces of the coupling should be checked for parallelism by the use of thickness gauges between them. If the generator has a single bearing, the coupling should be opened just far enough so that the weight on the coupling end of the shaft is carried by the rabbet fits.

If it is a two bearing generator, the coupling faces should be entirely isolated from each other and the lateral and vertical alignment as well as the angularity of the faces should be checked carefully and the pedestals shifted to bring them into line. Refer to page 17 under "Coupling Alignment and Allowances." The alignment of the flexible couplings (when used) should be checked by the method recommended by the coupling manufacturer.

The pedestals are adjusted vertically by placing shims under their bases and laterally and longitudinally by shifting them about. After each corrective adjustment, the pedestal bolts must be retightened to check the alignment.

5. Pedestal Insulation. Pedestal insulation is provided with certain machines of such a size or using such a combination of pole and punchings that control of shaft voltage is not practicable. This insulation is installed in order to break the circuit of the circulating current through shaft, bearings, and bedplate.

The insulation may be provided usually on the outboard end between the pedestal and foundation, or between the bearing shell and housing. The insulation consists of Micarta sheets and tubes to

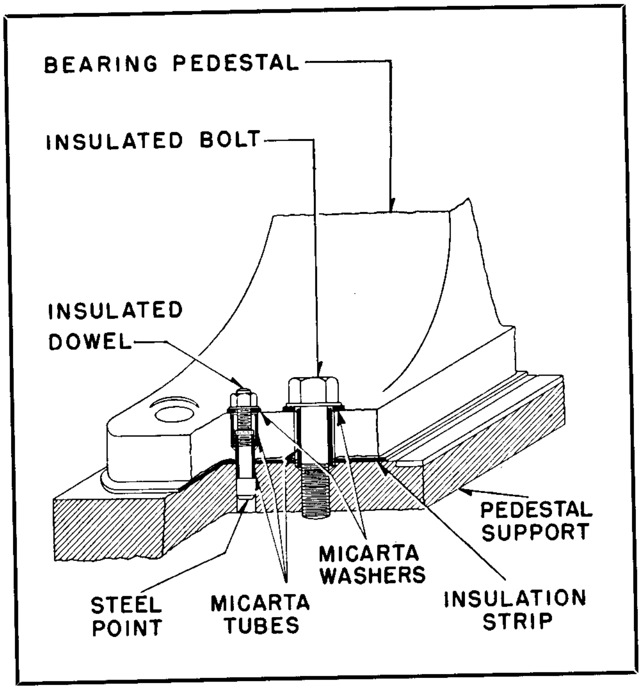


FIG. 12. **Method of Insulating Bearing Pedestal from Bedplate**

insulate the pedestal, bolts, and dowels from the bedplate in the more common insulated pedestal type of insulation. (See Fig. 12). If oil or water piping is connected to the bearing, insulated unions are used.

Care should be taken to see that there is no metallic connection between an insulated pedestal and the bedplate. If this precaution is not observed, the insulation becomes useless and bearing current is permitted to flow. Such metallic connection may be any of the following:

(a) Piping which touches both the pedestal and bedplate and which has no insulated union.

(b) Guard rail.

(c) Metal ladder set against the pedestal.

(d) Tools left in contact with both pedestal and bedplate.

(e) Pump or other device geared to the main shaft.

A break in the insulation may occur during erection due to careless handling and it is well to test for this with a bell and battery or with a test lamp. To make this test a section in the shaft-pedestal-bedplate circuit must be free from ground, the customary procedure being to raise the shaft free from the insulated pedestal bearing.

If a machine has bearing currents it is usually possible to detect them when machine is running at rated speed and voltage by placing one end of a copper wire on the pedestal and touching the other end to the shaft from which sparks can be drawn.

If sparks occur when this procedure is performed at both ends of the machine bearing currents are present, and insulation should be provided or if insulation is already provided, it should be replaced with new insulation unless periodic inspection of bearings show that insulation is unnecessary. If, however, sparking occurs at the insulated end only or at neither end, bearing currents are probably not present.

A more positive test of the bearing insulation should be conducted if bearing currents are suspected. The wire test as given above is not a positive indication of the presence of bearing currents. It serves only as a simple approximate method in which the wire shunts the current which otherwise flows through the bearing surfaces.

Machines whose pedestals are mounted on a separate sole plate from the stator on a concrete foundation should have their pedestals insulated also, since the possibility of reinforcing steel in the concrete completing the circuit between pedestals is present. Machines which are coupled on both ends must be provided with an insulated coupling.

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

6. Adjusting the Air Gap. After aligning the rotor on any machine which has bearings mounted independently from the stator, the stator must be adjusted so that there is an equal air gap between the rotor and stator all around the circumference of the rotor. This adjustment is made by placing shims under the stator feet and is done after the stator has been positioned axially so that its magnetic center corresponds with the magnetic center of the rotor.

It should be noted that the axial magnetic neutral position of the stator is usually close to but not necessarily the physical center position.

The usual procedure is to place the stator in the physical center position, if the magnetic neutral position has not already been determined, and then shifting the stator after the machine has been operated at rated voltage if the rotor tends to float to one end and cause end thrust on the bearings. It is important that the stator be located on the magnetic neutral position to avoid end thrust on generator and prime mover bearings.

After the stator is located in the magnetic neutral position, the air gap should be measured in at least four equally spaced points about the circumference of the rotor by means of feeler gauges long enough to obtain an average reading to the center of the core as measured from each end. In using feeler gauges, care must be exercised that the varnish on the stator and rotor surfaces does not affect the measurements.

Feeler gauges may be made from lengths of shim stock of various micrometer thicknesses. When making feeler gauges, it is best to have the two outside pieces of fairly thick stock to form a protective sheath for each insertion of the group into the air gap. The center pieces of stock may be changed to determine the air gap size.

The air gap should be adjusted by shims under the stator feet until diametrically opposite measurements are within 10% of each other. If the air gap is not uniform, the unbalanced magnetic pull may overload the bearings and also cause the stator iron to heat unevenly.

7. Conclusion. Bolt the end bells in place. Connect leads and piping, paying careful attention to the drawings furnished. Make sure piping is properly insulated in the case of insulated pedestals.

Assembling Engine Type Generator Rotors on Engine Shafts

SOLID ROTORS

The general or standard construction of engine type rotors is solid, that is, neither the hub nor rim are split.

When it is not considered desirable to ship the engine shaft to the generator works for "pressing on" the generator rotor, the work can be done quite readily in the field.

There are several ways to mount a solid rotor on an engine shaft:

1. Engine shaft can be forced into generator rotor by force.

2. Bore of generator rotor can be expanded by heat.

3. Engine shaft can be reduced in size by cooling to very low temperatures. (This method can be used effectively where hollow shafts are involved or in winter the shaft may be taken outdoors to cool).

In view of the fact that in general, adequate facilities are not available to "press-on" rotors in the field and that most engine shafts are not hollow, the usual procedure is to expand the rotor by the application of heat.

Before fitting any type of spider on the shaft, remove all protecting coats of paint and oil with kerosene or other solvent. If rust is present on the journal or the part of the shaft that rests in the bearing, it must be removed. The rust may be removed with a piece of emery cloth, but the journal should then be polished with a fine oil stone. Do not mar or scratch the journal, as any roughness will cut the bearings causing them to run hot.

Methods of applying heat depend to a large extent on the facilities available. Whatever means of applying heat is used, it is important that the temperature of the spider be raised gradually, and that the heat be uniformly applied so that objectionable stresses do not occur in any part of the structure. The best results can ordinarily be obtained by enclosing the entire spider in a temporary housing. Sometimes it may be necessary to cover only the hub. When electric or steam heat is used, a tarpaulin will usually be satisfactory. Experience has shown that the proper degree of expansion can usually be obtained by heating the rotor to a total temperature of 150°C.

If poles and coils are mounted on the spider, the enclosure should be made to confine only the rotor center, and the rotor rim temperature should not exceed 100°C for Class A insulated rotor or 130°C for Class B rotor. Poles and coils should be kept outside the enclosure. After the rotor has been located on the engine shaft, the whole mass should be allowed to cool gradually to avoid any serious contraction stresses.

SPLIT ROTORS

Engine type generators, on which the rotor cannot be pressed on the shaft at the factory, may be designed with a split spider.

On the larger split spiders, the rim is secured at the matched surfaces by dovetailed shrink links. The centerline of two diametrically opposite poles correspond to the splits in the spider rim and thereby usually 3 poles on each side need be removed to assemble or remove the rotor from the shaft.

To remove shrink links they should be heated with a torch. Generally 100°C to 150°C, above the rim temperature will expand the links sufficiently to be lifted out. Two 1/2" tapped holes in the link are provided for lifting and handling. These holes can also be used to exert some pulling force.

The links are heat treated, therefore reasonable care and judgement should be used in applying heat. The torch flame should be applied to the link evenly; first on the outside and then on the inside until the link can be removed. Blue spots on the link would indicate that the surface of the metal had been heated to an excessive temperature and the heat treatment properties had been destroyed. Care must also be exercised to prevent the flame from striking the field coils. Protect the coils with asbestos if necessary.

When assembling any type of spider, first place the key in the shaft key-way. The two halves of the completely split spider may then be placed in position around the shaft. Tightening the bolts at the hub will bring the edges of the rim together and the links may then be inserted after heating to approximately 150°C.

The collector rings on split rotors are of necessity also split and, although they are turned and ground true in the factory they require care in their assembly to insure that they run true.

Caution: Do not remove rings from the rotor; only loosen bolts to open the splits. The splits can generally be realigned by light tapping with a rawhide hammer but there are cases where this does not give a satisfactory job and then the rings should be ground true. For other collector ring information, see page 30.

ENGINE DRIVEN GENERATORS

Special Design Considerations. Engine-driven generators are designed with special allowance made in their rotors for torsional vibrations set up by reciprocating engine prime movers. The total WR^2 or inertia of the generator is so adjusted to avoid resonance with any engine mechanical parts and also to avoid resonance with the electrical system from any impulse either in the engine driving the generator or from other engines in the station at the time of its installation. This entire torsional study is handled by the engine builder who supplies a flywheel of proper design for elimination of torsional vibration insofar as practicable and for avoidance of undesirable resonances. Therefore, when changing generators from one engine or location to another, it will be necessary to contact the engine builder to make sure that such problems are avoided.

OPERATION

Caution: Before starting the unit make absolutely certain there is no foreign or loose material in or on the rotor or air gap spaces. Also check to make sure all ventilating ducts in the stator and interpolar spaces are clean to preclude any interference with the ventilation of the unit. Any time spent to eliminate foreign material is well spent since any hindrance to the flow of air within the machine may cause overheating and great damage.

Keep the area adjacent to the machine free of all small iron items as they may be drawn magnetically into the air gap spaces of the machine while it is running and cause serious damage.

MECHANICAL TEST

Before the machine is turned over for a mechanical test run, the following items should be checked:

1. Oil level.

2. Oil circulating system.

3. Cooling water system (if supplied).

If these are satisfactory, the machine should be jacked over by hand to see that everything is free to rotate.

Before starting the prime mover, go over the generator thoroughly, testing for loose bolts and nuts that may have been overlooked. Check blower paddle bolts, pole keys, damper winding segment bolts, coupling bolts, exciter coupling bolts or belting, foundation bolts and dowels. In short, make absolutely certain that all parts are in their correct places and are properly tightened down.

Make reference to the drawings. Compare drawings and assembled machine point by point. Check first before it is too late. Then start the machine on a slow roll and gradually bring up to speed. Check operation of oil rings at frequent intervals. The oil rings should revolve freely and smoothly and should carry oil to the tops of the journals.

Bearing Temperatures. During this first run, the temperature of the bearings must be watched closely. A thermometer should be placed with its bulb in the shallow hole filled with oil in the top of the bearing shell (inside the sight cover on pedestal type bearings) to observe the temperature.

Most small and medium sized generators have bearings which are designed for a low temperature rise. With a moderate ambient temperature these bearings should operate below 70°C. For these bearings and for some larger bearings which are supplied with an oil circulating pump, a good industrial type mineral oil with a viscosity of approximately 250 SSU at 100°F (SAE 20) is recommended.

In some cases where a higher ambient temperature or other special condition exists bearings may operate at temperatures as high as 80°C to 85°C. For these bearings a heavier oil having a viscosity of 350 to 400 SSU at 100°F (SAE 30) will be required.

Bearings can be operated safely at temperatures as high as 100°C if sufficient oil viscosity can be maintained at this temperature. This would be difficult and would require a very heavy oil which would not be efficient and convenient to use.

Of more significance than the actual temperature of the bearing is the change and the rate of change of the temperature as the machine is started and run. In general the temperature of a bearing should not rise faster than 1°C per minute. When bearings are operated for the first time, their temperature should be periodically checked and should level off at the normal temperature as given above.

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

The causes of overheating of sleeve bearings are given on page 29 under "Bearing Maintenance."

ELECTRICAL TEST

If the machine runs satisfactorily on the mechanical test, it is ready to be checked through electrically and placed on the line. The insulation should be dried out and checked in accordance with the following instructions.

To Dry Out Windings. All insulation should have been kept warm and dry during storage and erection of the machine. If, however, the machine has been subjected to wet weather or high humidity conditions in transit or storage, it will be advisable to dry out the windings at this time. If any doubt exists as to the moisture content of the insulation, the machine should be dried out by one of the following methods. The method used will depend on the facilities available at the erection site:

1. Use of Space Heaters. This is the preferred method. The heaters are located beneath the windings on machines that have no enclosed ventilating system. On machines with an enclosed ventilating system, the heaters should be located in the incoming air stream as the generator is rotated without load by the prime mover.

2. Circulating Current Through the Windings. One way of circulating current through the windings without subjecting them to full voltage is to short-circuit the stator and drive the machine with the prime mover, applying enough field excitation to give somewhat less than full load armature current. This method, usually called the short-circuit method, is somewhat more expensive than the preceding method.

A second way of drying out the machine by circulating current is to apply a low d-c voltage from an external source to the armature winding, keeping the current down to less than full load. Frequently d-c welder sets are available and can be used to circulate current through the stator winding. Circulate approximately 75% of rated current through the windings. The field winding may also be energized from another welder by connecting the welder to clamps attached to the collector rings. This will preclude burning of the rings which would be the case if the voltage were applied to the field leads. The machine cannot be rotated when using this method of dry-out.

In all cases of drying by means of current in the windings, the temperature measured by thermometer fastened to the windings should not be allowed to exceed 65°C. If the temperature is measured by means of embedded temperature indicators, it may be allowed to go as high as 80°C. In general, the drying should proceed slowly at first and the heating gradually increased as the insulation dries. The reason for this is that if vapor is formed from the moisture in the windings more rapidly than it is allowed to escape, the insulation is liable to damage from being ruptured by escaping steam. The moisture should not be expelled from the windings a great deal faster than it was absorbed.

It is well to keep a check on the temperature of the windings frequently and to take readings of insulation resistance by means of a "megger" at intervals as this gives a good indication of the state of the insulation. In general, it will be found that the insulation resistance will fall at first during the dry out and then rise and level off at some much higher value than when the dry-out began. See page 31 for information on taking insulation resistance.

Caution: Precautions against fire should always be taken when drying insulation. Flammable material should not come in contact with the heaters. Wiring connections should be substantially made and well checked. Fire extinguishers of the CO_2 type should be at hand.

STARTING

In order that synchronous generators may be connected to a system already in operation, the voltage of the incoming machine and that of the system must be approximately the same at each instant. This requires that the two voltages be of the same frequency, have the same magnitude and phase sequence, and be in phase with each other.

Voltmeters indicate whether the magnitudes of the voltages are the same, and frequency meters or tachometers indicate whether the frequencies are approximately the same. Whether the voltages are exactly in phase and of exactly the same frequency is indicated either by a synchroscope or by a synchronizing lamp circuit.

USE OF SYNCHRONIZING LAMPS

Although the indication of synchronism given by a synchronizing lamp circuit is less precise than the indication given by a synchroscope, the frequent use of the lamp circuit justifies an explanation of its operation.

Lamps should be connected between the leads which will be joined together when the generators are synchronized. The lamps should be adapted for the highest voltage which they will receive. This voltage will be twice the normal value and will occur when the machine voltages are in phase opposition. When the voltage of the system is too high for the synchronizing apparatus, it is usual to place voltage transformers between the main circuits and the synchronizing circuits so as to reduce the voltage at the switchboard to safe value. Fig. 13 shows such connections between two of the phases of two 3-phase generators. One generator may be considered as representing a system which is already in operation.

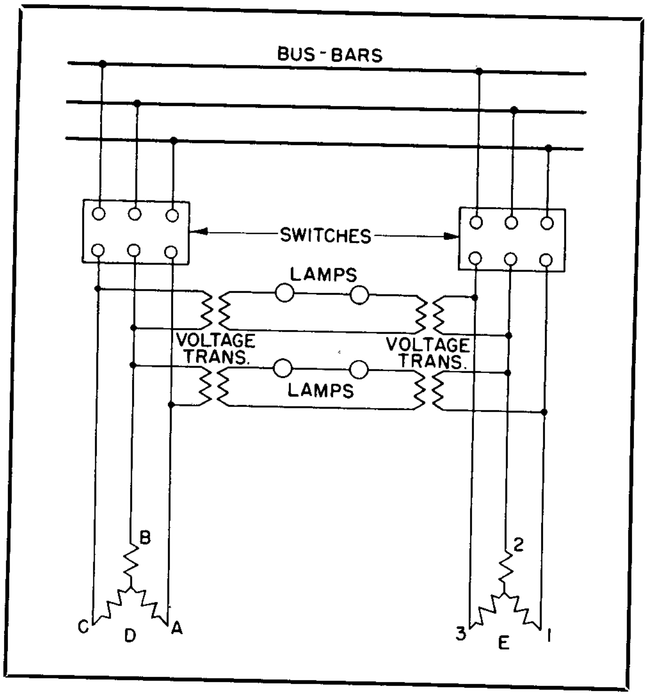


FIG. 13. Connections for Synchronizing Three-Phase Generators

As the voltage of the incoming generator and the voltage of the system change from a condition of phase-coincidence to one of phase-opposition, the flow of current through the lamps changes from a minimum to a maximum. When the voltages are exactly equal and in phase, the current through the lamps is zero. A phase-difference between the voltages causes current to flow through the lamp circuit and illuminate the lamps.

If there is a small difference between the frequency of the incoming generator and that of the system, the lamps will increase in brilliancy until the voltages of the machine and that of the system are in exact opposition. From this condition, the lamps decrease in brilliancy until they are completely dark (if the voltages are equal in magnitude), indicating that the voltages are again in phase. The frequency with which the lamps alternate between the bright and dim condition is equal to the difference between the generator and system frequencies.

When the frequencies of the incoming generator and the system are equal and the voltages are equal but out-of-phase, the lamps glow with a steady brilliancy. The degree of brilliancy depends upon the amount of phase displacement between the two voltages.

When voltage transformers are required in the lamp circuit because of high line voltages, it is possible for the transformer connections to be made in such a manner that the lamps burn with maximum brilliancy when the two voltages in question are ***in-phase*** rather than ***out-of-phase.*** It is preferable to ***use dark lamps to indicate synchronism*** instead.

The following check can be used to make certain that the lamps will be dark when the voltages are in phase: Disconnect the main leads of the incoming generator at the generator, and throw in the main switch of this generator so that its bus work will be energized from the system. Both voltage transformers will then be energized from the same voltage source, and the lamps will be dark if the transformer connections are correct. If the lamps burn brightly under these conditions, the two connections to one of the primaries or to one of the secondaries of the voltage transformers should be reversed.

When a generator is to be synchronized with a system already in operation, the phase sequence of the generator must be the same as that of the system. To check the phase sequence, the following procedure is recommended: Refer to Fig. 13 and assume that generator "D" is to be synchronized with the system represented by generator "E". Note that synchronizing equipment is required in two phases when the phase sequence is to be checked. Check the two lamp circuits separately, as described in the preceding paragraph, to be sure that the lamps in each circuit are dark when the voltages being compared are equal and in phase. Once the circuits have been checked, the proper phase sequence for the incoming generator may be determined.

To check the phase sequence, observe both sets of lamps when the voltage and frequency of the incoming generator have been made approximately equal to those of the system. If both sets of lamps become bright and dark in unison, when the frequency of the incoming generator is slightly different from that of the system, the phase rotation of the generator is the same as that of the system.

If one set of lamps is bright while the other is dark, the phase sequence of the incoming generator is opposite to that of the system. To make the phase sequence of the generator agree with that of the system, interchange any two of the three line connectors between the generator and the bus. It is well to make a confirming check on the phase sequence after changing the connections, but first the lamps should again be checked to be sure that they will be dark when the corresponding voltages are equal and in phase.

Synchronizing lamps are recommended for use as a check on the operation of the synchroscope and for emergency use in case the synchroscope is inoperative. Separate voltage transformers should be used for the synchroscope and lamps. If the phase sequence of the incoming machine is known to be correct, lamps need to be connected between only one phase of the generator and one phase of the system. The lamps should be connected so as to be dark at synchronism and to be at maximum brilliancy when the generator and system voltages are 180 degrees out of phase. Zero potential is applied to the lamps at synchronism. However, an incandescent lamp appears dark even though a considerable potential is applied. For this reason, lamps do not give as definite and accurate an indication of synchronism as is obtained with a synchroscope. Nevertheless, they may be used satisfactorily if proper care is exercised.

With the generator frequency slightly greater than that of the system, adjust the speed of the generator so that the bright and dim sequence of the lamps becomes slow and constant. Anticipate the time required for the breaker to close its contacts, and throw the breaker so that its contacts will close at the middle of the dark period.

USE OF SYNCHROSCOPE

A synchroscope is an instrument which is used to indicate the instantaneous difference in phase between the voltage of the incoming generator and the voltage of the system with which the generator is to be synchronized. Refer to Fig. 14.

The voltage of the system is used as a reference, and its voltage vector can be represented as a stationary pointer in the "twelve o'clock" position on the dial of the instrument. The voltage vector of the incoming generator is represented by the movable pointer. The number of mechanical degrees between these "vectors" on the synchroscope dial is the number of electrical degrees by which the generator and system voltages are out of phase.

When the pointer is in either of the two left-hand quadrants of the dial, the voltage of the incoming generator is considered to be lagging the voltage of the system. When the pointer is in either of the two right-hand quadrants of the dial, the voltage of the incoming generator is considered to be leading the voltage of the system.

The speed of rotation of the pointer is proportional to the difference between the frequency of the generator and that of the system. If the generator frequency is higher than the system frequency, the pointer will rotate in the "FAST" (clockwise) direction, indicating that the generator is running too fast. If the generator frequency is less than the system frequency, the pointer will rotate in the "SLOW" (counterclockwise) direction, indicating that the generator is running too slow.

FIG. 14. Synchroscope

Before the incoming generator is connected to the system, a check should be made on the synchroscope to be sure that the pointer of the instrument rotates when the generator frequency is known to be somewhat different from the system frequency.

When the incoming generator and the system are in exact synchronism, the following conditions exist:

1. The voltage of the generator is equal to the voltage of the system. When this condition exists, the generator and system voltmeter readings are equal.

2. The frequency of the generator is equal to the frequency of the system. When this condition exists, the pointer of the synchroscope remains stationary.

3. The voltage of the generator is in phase with the voltage of the system. When this condition exists, the pointer of the synchroscope is in the "twelve o'clock" position.

In practice, the best results in synchronizing a generator with a system, are obtained by closing the line breaker when the pointer is rotating slowly in the "FAST" direction and approaching the "twelve o'clock" position. By observing the synchroscope carefully and timing the closing operation properly, the circuit may be completed at the exact point of synchronism, or at least within a very few degrees of it.

Faulty synchronizing will cause a disturbance on the power system and may result in automatic tripping of the circuit breakers.

ADJUSTMENT OF FIELD CURRENT

The final section of this book on "Exciters" should be studied in conjunction with this section. (See page 32). When a generator operates alone, without being paralleled with other generators, the field current is adjusted for each change in load so as to maintain rated voltage. The adjustment can be made by hand, but it is preferable to use a voltage regulator which can keep the voltage constant even though the load varies rapidly.

A generator operated in parallel with one or more other generators may have its excitation varied through a fairly wide range while delivering the same kilowatt output at rated voltage. A change in field current under these conditions changes the power factor of the generator. The field current may be set at its rated full load value for all loads or it may be varied depending upon the need for reactive kva. If the field current is increased, the generator furnishes reactive kva to the system and thus relieves the other generators of part of their burden. No change in kilowatt output can be effected by variation of the field current. This can be accomplished only by a change of governor of the prime mover.

Operation with field current lower than the value which gives 100 percent power factor should usually be avoided since this imposes additional reactive load on the other generators. In addition it reduces the ability of the machine to stay in step with the system and may result in its being pulled out during periods of heavy load. A generator is pulled out of step with other machines and is forced above synchronous speed when its prime mover attempts to deliver more power than the generator is capable of delivering to the electrical system.

In the case of a generator connected to a long transmission line which is lightly loaded, it may be necessary to operate with very low values of field current in order to prevent a rise in terminal voltage due to the charging current of the line. This is more fully discussed in the exciter section of this book.

PARALLEL OPERATION

The requirements for parallel operation are:

1. The speed regulation of the prime movers should be alike. That is, the percent drop in speed for a given percent increase in load should be the same on both, or all, units. The drop in speed from no-load to full-load may be only 2 percent or less, but if it is the same on all units which are in parallel, the total load will divide between them in proportion to their ratings.

2. The governors of the engines or turbines should be free from hunting and should bring the machines to a steady speed without delay. Any oscillation of the governors will result in a transfer of load back and forth between machines and a fluctuation of the voltages.

3. Engine driven machines should have sufficient flywheel effect to prevent wide fluctuations in speed which arise from the regular pulsations in torque inherent in reciprocating engines.

4. The wave form of the generators should be alike. If this condition is not fulfilled, there will be harmonics in the current wave which produce additional losses in the machines. In modern machines, the wave forms are usually close enough to sine waves to prevent any trouble from this source.

UNBALANCED VOLTAGE AND SINGLE-PHASE OPERATION

The ability of a generator to operate on unbalanced voltages or, in the extreme case, to operate single-phase, depends largely on the design of the amortisseur or damper winding. Single-phase operation produces heavy currents in the damper winding, if there is one, which may cause overheating in a machine not designed for such operation. If there is no damper winding, the field current required for a given load is increased to such an extent that the output is seriously limited. Operation with unbalanced load has the same effect as single-phase operation but is not as severe.

For machines not designed for single-phase operation, 20 to 30 percent of normal current single-phase is usually safe. Higher values may be permissible if the damper winding is liberal.

The degree of unbalanced polyphase operation that is permissible depends likewise on the design of the individual machine. In any case of unbalancing of more than five percent at full load, it is advisable to watch the temperatures of all parts closely. If unbalanced operation is contemplated for any length of time, it is best to consult the manufacturer giving all pertinent data such as complete machine nameplate identification and the degree and kind of unbalanced operation.

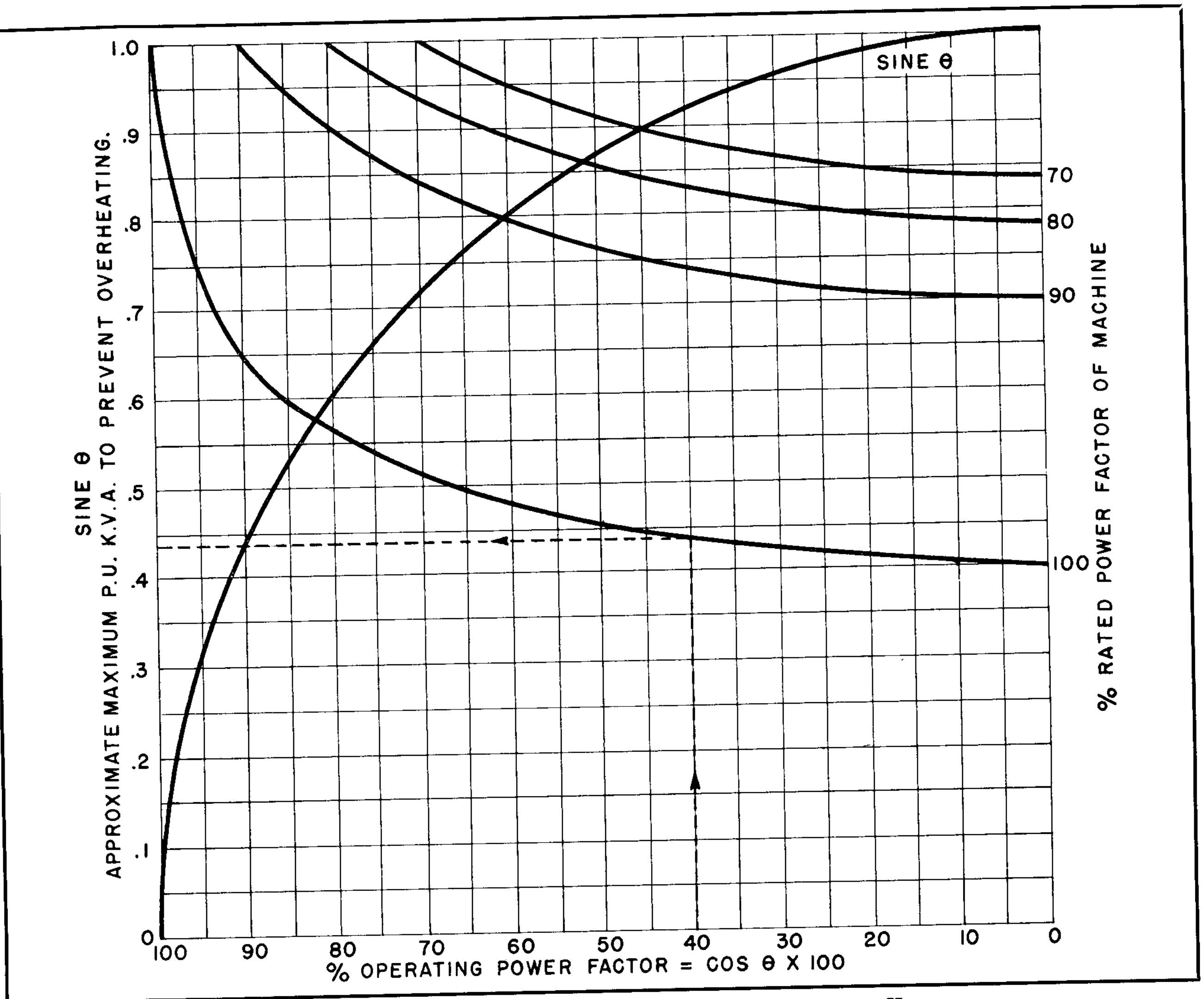


FIG. 15. Reactive Capability Curve—Power Factor versus Kva

OPERATION BELOW RATED POWER FACTOR

As noted before, as the ratio of reactive load to kilowatt load increases, field current increases also, provided the kva output remains constant.

Another way of stating this is to say that field current is a minimum, at rated kva output, when the power factor of the load is a maximum or 100% since we are considering lagging power factors only. As the power factor is reduced, the field current must be increased to maintain rated kva output. Marked on the nameplate of the machine is the lowest power factor at which the machine will operate and deliver rated kva without excessive field heating. However, the machine may be operated at any other power factor lower than that marked on the nameplate provided the kva output of the machine be reduced in accordance with the curve shown in Fig. 15 called the "Reactive Capability Curve".

Reactive Capability Curve. The curve is used as follows: Find the curve corresponding to the rated power factor of the machine. Then determine the power factor at which it is desired to operate the machine, and find this on the abcissa. Follow up to the curve from this point and read the factor by which to multiply the rated output kva of the machine on the left. This gives reduced rating of the machine at the new power factor.

As an example, say we have a 1000 kva machine rated at 100% power factor, but we want to know its capability at 40% power factor. Following up from 40 on the abcissa to the 100% power factor curve and following across to the left margin, we find a factor of approximately .44. Multiplying this by 1000 kva, we find the machine capable of delivering 440 kva at a power factor of 40%.

The data plotted on these curves are typical and adequate for estimating reactive capability of any machine for all practical purposes.

PART FOUR

MAINTENANCE

Important. Keep your machine clean! If the ventilating ducts become clogged with dirt and foreign material the machine will operate at increased and possibly dangerous temperatures. Remember that a generator is only as good as its insulation and that insulation damage can result from poor ventilation and consequent overheating.

Remember also that in some locations such things as oil vapor, carbon dust and other conducting materials can condense and settle on the windings. When these collect in sufficient quantities, they provide paths for surface discharges which may seriously reduce the life of the coil insulation and non-metallic structural material such as string, spacers, and blocking. Any time spent in cleaning these generators will be well repaid by years of trouble-free service and avoidance of costly repairs.

INSPECTION

Do not permit the machine to operate for extended periods of time without a thorough inspection. After the machine is first installed, very frequent inspections are recommended to determine the length of time for subsequent periodic inspections. Periodic inspections will reveal the condition of cleanliness prevailing in the machine. Inspections will reveal any minor troubles as they occur and permit their remedying before serious harm has been done. Some of the things to look for are movement of the stator coils due to loose coil end bracing, presence of dirt or oil on the windings, looseness of the stator iron, condition of rotor wedges and bolts, etc. (Be sure to inspect the pole bolts and tighten them, if necessary). Any of these conditions, if neglected, may result in machine outage and costly repair bills. Do not allow the inspections to become perfunctory!! Use a flashlight and a small mirror fastened to the end of a rod so that the entire machine can be inspected—not just the easily observed places.

CLEANING METHODS

Several methods are commonly used to clean the windings of electrical apparatus. The most effective method will depend upon the type and degree of dirtiness of the apparatus to be cleaned.

Compressed Air. This is the most convenient method of removing an accumulation of dirt which is not too firmly fixed to be blown out. The only precautions to be observed are that the air line be free from moisture, and that the dirt be blown out and not compacted or embedded into some inner recess within the machine where it will be difficult to remove and where it may close some of the ventilating ducts. The air pressure should be about 50 lb. per square inch. Excessive pressure is capable of weakening insulation and windings.

Warm Water. This is used effectively when the dirt is soluble in water. The washing should be rapid and the parts which are washed should be wiped immediately with a dry cloth and then dried. A jet of hot air, if available, may be used or the apparatus can be covered with a tarpaulin and some source of heat used to dry out the water.

Solvents. Solvents should be used where the accumulation of dirt contains grease or oil. There are several solvents which can be used to remove grease and oil from machine parts but the one generally recommended and used is carbon tetrachloride.

Carbon tetrachloride is an active solvent and somewhat corrosive in its action. It should be applied sparingly with sponges or rags. Thorough drying afterwards is essential to avoid damage to the insulation.

Caution: Carbon tetrachloride is a non-inflammable compound, but is toxic and must be used intelligently. The chief danger in its use is that the vapor is heavier than air and will accumulate in pits or confined spaces. It should be used only in locations which are adequately ventilated, as prolonged or concentrated exposure to the fumes is dangerous to life and respiratory membranes.

The Mine Safety Appliance Company makes a special nose mask which is recommended as a protection against overexposure to such fumes. As an additional safety measure it is suggested that any cleaning work be done by more than one workman.

After the windings have been cleaned it is recommended that a coat of recommended insulating varnish be applied to protect the insulation.

BEARING MAINTENANCE

Sleeve Bearings. The design of Westinghouse bearings has a background of many years of operating experience and with reasonable maintenance and attention they should give long and trouble-free service. Periodic inspections should be made to be sure the oil level in the bearing pedestal is up to the normal mark on the gauge. The oil should be sampled at intervals to check its viscosity and purity and to be sure it is acid-free. Openings are provided in the bearing cap over the oil rings for the purpose of adding fresh oil and inspection of the oil rings.

The bearings of synchronous generators may be provided with temperature detectors or indicating thermometers embedded in the bearing shell close to the bearing surface. These are specified as accessory apparatus.

The temperature of the bearing should be observed regularly by the operator so that a sudden change or an unusual rise in temperature can be detected. If bearing thermostats are supplied with the generator, they are usually set to sound an alarm or trip off the machine at a temperature of 96°C.

If external oil coolers are required to cool the bearing oil, such coolers should be inspected regularly to be sure they are clean and operating efficiently.

The cause of overheating of a bearing may be any one, or a combination of the following:

1. Insufficient oil in the reservoir to cover the bottom of the oil rings.

2. Dirty oil or oil of poor quality.

3. Failure of oil rings to revolve.

4. Excess end thrust resulting from an installation with the bedplate badly out of level or from the axial magnetic pull resulting from the magnetic centers of rotor and stator being out of line.

5. Poor alignment of the machine.

6. Pitting due to bearing currents.

7. Bent shaft.

8. Rough bearing surface due to corrosion or careless handling.

9. Bearing overload due to unequal air gap.

Caution: Bearing currents may flow if tools or other miscellaneous objects fall across the pedestal insulation.

Anti-Friction Bearings. Ball and roller bearings are frequently used with industrial generators. These bearings are used where the generator must be able to withstand end thrust or when their use has been requested by the purchaser.

The anti-friction bearings in large horizontal generators are usually grease-lubricated. They are packed with grease when assembled at the factory and require only the addition of a small quantity of grease every three months. At intervals of approximately two years, depending upon the application, the bearing should be cleaned thoroughly with kerosene and then dried and repacked with grease. When repacking, the bearing and seal cavities beside it should be filled approximately two-thirds full of a good quality sodium base grease of the channeling type.

Grease. The greases listed below are satisfactory for the lubrication of ball and roller bearings. One of these greases or an equivalent should be used for any grease-lubricated bearing supplied with Westinghouse generators:

Lubriko M-6
Lubriko M-21—(Master Lubricants Corp.)
Starfak Regal No. 2—(Texas Company)

Lubricating Oil. Keep the oil in the bearings clean! The frequency of oil changing depends to such an extent on local conditions, such as severity and continuity of the service, the room temperature, the state of cleanliness, etc., that no definite instructions can be given. A conservative recommendation would be to clean and refill the bearing pedestals with fresh oil every six months. Refer to page 22 for the type of oil recommended for various conditions of operation.

ROTOR WINDINGS

Maintenance of the rotor should begin by measurement of the insulation resistance prior to placing the unit in service. Following this, a thorough check-up of all parts of the rotor should be made at the end of a year's operation and annual inspections thereafter should include the following steps:

1. Check damper winding for loose bars in the iron, connections of each bar to the ring segment, and joints in ring segments between poles.

2. Check clearance between blowers and coils.

3. Check for movement or shifting of field coils.

4. Check for dirt on winding, and if necessary, clean as instructed on page 28.

5. Inspect strap field coils for condition of turn-to-turn insulation.

6. Check condition of ground insulation and washers or collars.

7. Check connections between field coils and the collector rings.

8. Measure insulation resistance to ground of field winding, including the collector, using a device which applies not more than 500 volts d-c from the winding to ground.

9. If necessary, after cleaning, refinish with suitable recommended varnish as instructed below.

10. For refinishing use black varnish #2227 flowed or sprayed on, or spray with red enamel #7340 as required.

STATOR WINDINGS

Maintenance should begin with operation of the unit and therefore, before the unit is started, measurements should be made of the stator insulation resistance. It is desirable to take this reading immediately after the dry-out run at the elevated temperature as this would provide a more nearly correct "bench-mark" for future reference. Take these readings in line with rules outlined on pages 23 and 31.

Inspection. Annual inspections are recommended unless unusual service conditions require more frequent inspection. The first annual inspection should include a thorough check-up of all parts of the stator windings as listed below, as well as a general cleanup of the winding, by blowing with dry air or by wiping with dry rags. If the winding is dirty, take necessary cleaning steps with solvents as described on page 28.

Procedure. After the first annual inspection, subsequent inspections should include the following steps along with proper cleaning as necessitated by service conditions.

1. Check for broken, damaged, loose or missing wedges.

2. Check end wedges for movement at the end of the core and check position of all other wedges.

3. Check coil ends for distortion.

4. Check security of all lashing and spacers.

5. Check tightness of coil support brackets, if any.

6. Check for loose coils in the slots.

7. Check coil ends for cracks in the insulation or other mechanical damage.

8. Check all connections between coils and connections around frame.

9. Measure insulation resistance of winding to ground, from the machine terminals.

10. Thoroughly clean where required.

11. Protect the finish by revarnishing as needed. For machines rated up to 6600 volts, use Varnish M#2227 flowed or sprayed on. For machines rated above 6600 volts, use enamel M#7340 sprayed on. Always clean the windings before revarnishing.

12. Check collector rings for burning or corrosion.

13. Check brushes for freedom to move in holders.

14. Check brush tension (should be about 2½ lbs. per sq. in).

CARE OF COLLECTOR RINGS AND BRUSHES

Sparking is the principal indication of improper brush and collector performance. It is caused by imperfect contact between the brushes and collector rings, which may be due to any of the following causes:

1. Presence of Dirt or Dust Particles Between a Brush and the Ring. The alignment of the brushes on the ring should be checked occasionally to be sure that a brush does not overhang the edge of the ring. If the brush is allowed to overhang, the over-hanging part develops a thin edge which breaks off.

The collector rings, brushes, and brushholders should be kept clean and free from dirt, carbon dust, and oil. Best results are obtained when all brushes are clean and move free in their holders. If there is a tendency for brushes to stick, remove and rub side of brush with fine-grade sandpaper. Clean brushholders thoroughly. The collectors, also, should be well cleaned. A piece of canvas dipped in a grease solvent is recommended for cleaning the brush rigging and collector parts.

2. Presence of Dust Between the Brush and Holder. This dust may conduct sufficient current to fuse the brush to the holder. Frequent cleaning of the brush rigging will prevent this difficulty.

3. Improper Brushes. Brushes of the proper grade are furnished with the generator. Sparking and improper service may occur if other types of brushes are used.

If the brush is too large, it will stick in the holder. If it is too small, it is likely to cramp at an angle in the holder.

4. Vibration of the Brush Rigging. Any loose parts of the brush rigging should be tightened.

5. Improper Spring Tension. The spring tension should be sufficient to maintain contact between the brush and the ring in spite of small vibrations of the brush rigging and collector rings.

However, the pressure should not be such as to cause undue mechanical wear. It has been found that a brush pressure of 2½ lbs. per square inch of brush area gives the best brush performance in the case of most generators discussed in this book.

As the brushes become shorter from wear, the springs should be tightened so as to maintain the proper brush pressure. Brushes should be replaced before they reach the limit of their travel.

Sparking may result from an unequal distribution of current between the brushes on any one ring. The spring tension should be relieved temporarily on the brush carrying the excessive current. Readjustment of the spring tension may be necessary for the other brush on the ring to cause each brush to carry its proper share of the current.

6. Rough or Marked Rings. Any black spots that appear on the surface of the collector should be removed by polishing lightly with fine sandpaper and crocus cloth. It is very important that this be done; for while these spots are not serious in themselves, they will lead to pitting of the rings and the necessity for regrinding. However, no harm is done to the rings if the condition is corrected at once. If the rings are very rough, they should be ground and polished with the unit running at full speed. This should be attempted only if the collector assembly is tight. Hand grinding or turning is not advised because the eccentricity may actually be increased by this method.

7. Eccentricity of the Rings. A slight unbalance in the rotor or eccentricity of the collector rings can cause the brushes to leave the ring and draw an arc once every revolution. This repeated arcing at the same place on the ring in time burns the imprint of the brush on the rings. Brush imprints due to eccentricity always occur at the same place on the rings.

The trueness of the rings can be checked with a dial indicator on the back of a brush while the unit is running at low speed. The rings should be ground and polished as previously described. Replacement collector rings may be slightly eccentric after assembly on the shaft. They should be checked and trued if necessary.

8. Uneven Hardness of a Ring. Occasionally ring trouble arises when a ring is not of uniform hardness. Uneven wear results, and such a ring should be replaced.

9. Unusual Operating Conditions. Excessive current densities due to overloads: The mechanical contact between the brush and the ring is never perfect, and high current density at the contact surface can cause sparking with brush fits that would be sufficiently accurate for normal current densities.

Extended operation with low values of brush current: Brush "chatter," accompanied by sparking, has been found to result from a long period of operation with an unusually low value of field current, as when a stand-by generator is kept running without load.

10. Electrolytic Action. Since there is always an electrolytic action at the surface of the rings, their operation is improved by reversing the polarity of the rings occasionally.

INSULATION RESISTANCE

Insulation resistance is useful in determining the presence of moisture or dirt upon the winding surface, and a complete record kept of insulation resistance is useful in determining when cleaning or drying of the windings are necessary. It is suggested that insulation resistance readings be taken every six months, preferably summer and winter, over a period of years. Any sudden downward trend of the insulation resistance values will indicate that maintenance steps need be taken.

Procedure. The method of taking insulation resistance should be definitely controlled, and the following routine is suggested:

1. Adopt a definite time of application for taking readings, preferably after 1 minute of voltage application. Make tests immediately after a shutdown when machine is relatively free from moisture.

2. Always use the same voltage instrument.

3. Keep a complete record of date, temperature of winding and ambient temperature, relative humidity and condition of winding. Insulation resistance will vary inversely with the temperature. That is, the insulation resistance will decrease with increase in temperature. Roughly the resistance will be doubled for each 15° drop in temperature. For example, if a certain insulation has a known resistance at 75°C, then at 60°C the resistance should be approximately doubled and at 25°C it should be in the neighborhood of 10 times as great. It must be emphasized that these figures are only approximations and that the rate for individual machines will usually vary.

4. Take readings at machine terminals, being sure other cables, switches, etc., are isolated.

5. Whenever motor driven or electronic instruments are used to take readings over a period of time longer than 1 minute, as in the case of dielectric absorption curves, it is essential that, before a repeat reading of the same part is taken, that the winding be discharged to ground for a time at least equal to the total time of voltage application when readings were first taken.

PART FIVE

EXCITERS

Westinghouse horizontal, salient pole a-c generators usually receive their excitation from a belt driven or a shaft connected d-c generator. The performance of synchronous generators in general and their voltage regulation in particular is largely dependent on the performance of their exciters.

When a synchronous generator is operated alone on the line, its voltage is a function of the exciter voltage and the consequent main generator field current.

When a synchronous generator is operated in parallel with other units, its voltage remains constant, within limits, no matter what the excitation voltage and main field current. Changing the main field current by changing the exciter voltage changes the share of the reactive load carried by the particular generator when it is operated in parallel with other units.

Thus if the exciter voltage is increased in one machine, that machine will take more of the reactive component of the load while its terminal voltage remains the same. From the foregoing considerations, the importance of rapid and accurate exciter voltage control can be appreciated.

EXCITER OPERATION

The voltage of most synchronous generators may be regulated either manually or automatically. The provisions for manual operation are made for synchronizing purposes or in case of failure of the automatic voltage regulating equipment.

Under voltage regulator control, the main field rheostat, if supplied, should be in the "all out" position and the exciter voltage will then be varied by the regulator to suit the excitation requirements of the machine. This type of operation reduces both the exciter loss and the rheostat loss to a minimum and provides the maximum field forcing capability for momentary overload conditions.

Machines with small exciters (below approximately 30 kw) are normally supplied with silverstat regulators and the exciters are operated as self-excited shunt wound machines. The silverstat regulator varies the field current in the exciter by varying the resistance in series with the exciter field, thus changing the exciter terminal voltage and consequently changing the field current in the main generator.

Large exciters are controlled by the BJ direct-acting rheostatic type regulator in conjunction with a pilot exciter or other type of separate control voltage.

If the regulator should be out of service for any reason, the a-c generator voltage may be controlled by a hand control. Two types of rheostat and exciter combinations are commonly furnished:

1. Ordinary exciter with a main generator field rheostat and exciter field rheostat.

2. A stabilized exciter with exciter field rheostat and without the main generator rheostat.

With the former equipment, it is often necessary to use the main generator field rheostat to reduce the excitation voltage to the generator low enough for control of the voltage when synchronizing, or for continuous operation at light loads, or for operation over long transmission lines of high capacitance. The reason for being unable to reduce the voltage of the exciter low enough by insertion of resistance in the field is that the residual magnetism of the exciter causes it to produce a voltage at very light load even with no field current at all.

If the second group of equipment is supplied, then the exciter field rheostat has a large number of steps and the exciter itself can be adjusted to operate down to 30 or 35 volts with good stability. This type of exciter has a stabilizing winding which is merely a very small shunt field connected in such a direction that it "bucks" the main exciter field, thus reducing the residual magnetism of the machine at light loads to such a value that the output voltage can be maintained very low with good stability. This is normally low enough to provide control of the a-c generator voltage during synchronizing and under light load conditions. Even with the stabilized exciter, however, there is a possibility that for a period of 15 minutes to an hour, depending on the load conditions on the a-c machine and below normal temperature in both the exciter and the a-c generator fields, that the generator voltage will be higher than its rated value. Therefore, when operating manually, it is well to keep a closer watch on the line voltage during the first hour of operation than is necessary subsequently.

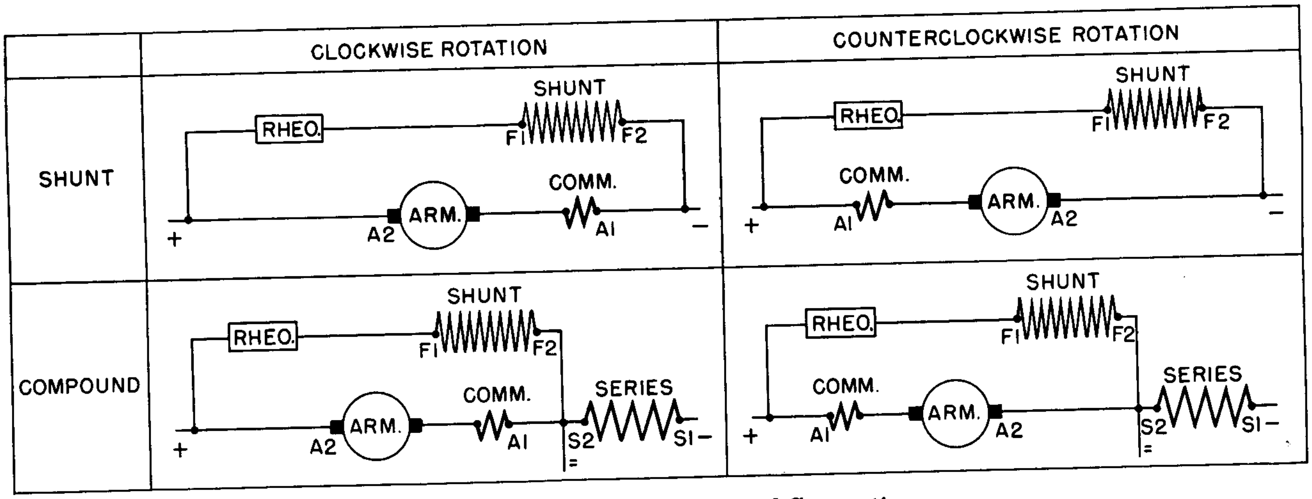


FIG. 16. Diagram of Exciter Lead Connections

Sometimes it is found that a main generator field rheostat is ordered when no room is provided by the customer for mounting the equipment. In such cases, the exciter field rheostat may not have a sufficient number of steps and fineness of control of the a-c generator voltage at very light loads. Usually, a satisfactory combination for synchronizing may be obtained by using an exciter field rheostat with a large number of steps or a vernier plate so that a larger number of variations of resistance may be obtained. When operating under these conditions, a drift in voltage may be expected larger than that with a stabilized exciter, but with an operator constantly observing the voltage satisfactory operation may be obtained for short periods while synchronizing.

The connections for the exciter leads are shown in Fig. 16, for a clockwise and counterclockwise rotation as viewed from the commutator end of the exciter. Sometimes a series field is supplied with the exciters, but when a silverstat or BJ regulator is used, this field should be ***left out*** of the circuit by ***taping up the terminals.***

V-BELT DRIVEN EXCITERS

V-Belt driven exciters are operated the same as any other exciter, except that attention must be paid to belt tension. The belts should be adjusted just tight enough to pull the load with the machine operating at maximum overload and minimum power factor expected. This keeps the pull on the exciter bearings at a minimum and prevents them from overheating.

If the belts should be looser than necessary, the maximum exciter load would cause the belts to slip and the exciter to drop in speed when a momentary overload on the a-c generator occurs. If the belts are too loose the exciter speed will drop to such an extent that the exciter voltage cannot be maintained and the main generator voltage regulator will not be at its full capabilities.

DIRECT CONNECTED EXCITERS

Direct connected exciters may be divided into two types, the stub shaft type exciters and the quill type exciters. These exciters differ only in the manner of securing the armature to the shaft of the main machine.

Stub Shaft Type. The stub shaft type of exciter has its armature built on a small shaft which has a forged coupling flange on one end, for bolting directly to the generator shaft. The exciter armature may be removed from the main shaft for handling or maintenance by removing the coupling bolts, and may be replaced by replacing the coupling bolts.

Quill Type. The quill type exciter has its armature built on a quill. The quill resembles a large cup with a threaded hole in the bottom. The armature is built around the quill and then fitted over the end of the main shaft with a very light press fit. This construction eliminates the stub shaft and coupling. The quill is held in place on the main shaft by a bolt which is threaded into a hole in the end of the shaft. The armature and quill is removed by taking out the small bolt and washer and inserting a larger bolt which fits the threaded hole in the bottom of the quill and bears against the end of the shaft.

Turning this large bolt causes it to exert a pulling force on the quill and a pushing force against the end of the shaft thus removing the quill from the shaft. To replace the quill, turn a stud into the threaded hole in the end of the shaft. The stud should be long enough to extend through the hole in the quill when it is held in place at the end of the shaft. Then place a larger washer and nut on the stud and turn the nut up against the end of the quill, thus forcing it on the shaft. When the quill has been forced onto the shaft to its proper place, remove the long stud and nut and insert the small bolt which holds it in place on the generator shaft.

EXCITER MAINTENANCE

Since the same principles for maintenance of the exciter are outlined under maintenance in an earlier section of this book for the main generator, they will not be repeated here. It is recommended that the exciter be given the same careful treatment and cleaning as the main machine. The following discussion applies to maintenance of the commutator and brushes. Because of the presence of a commutator, there is apt to be more carbon and copper dust in the windings of the exciter than of the main machine.

Keep the commutator clean. Oil is especially harmful as it will damage the mica and may cause bar-to-bar short circuit and consequent burn-outs in the armature.

Minor roughness or unevenness of the commutator may be corrected by placing a piece of sandpaper over a block of wood and holding it against the commutator surface while the machine is rotating. Coarse sandpaper should be used first and the job finished up with "000" paper. ***Never*** use emery cloth on a commutator as the particles of emery are conductors of electricity and will cause insulation breakdown if they get imbedded in the windings. After sanding the commutator smooth, it may be polished by holding a piece of canvas against it with the same block of wood. The brushes must be lifted during the sanding and polishing operation.

If the commutator is too rough for correction by sanding or by using a commutator stone, it may be trued up with a cutting tool mounted on the machine or the armature may be removed and a cut taken on the commutator in a lathe. However, this work should be done only by experienced personnel. After grinding or cutting the commutator, it must be checked to see that the mica is not too high. If it is, it must be undercut to a depth of $1/64$ inch below the bar surface.

Old brushes which are not seating properly and new brushes being installed may have the correct curvature put on their seating surfaces by inserting a strip of sandpaper between the brush and the commutator surface, the cutting side next to the brush, and sliding the sandpaper back and forth. The brush should be lifted on each stroke, the cut being taken only in the direction of rotation of the machine. The sandpaper strip should be held snugly against the commutator during the cutting operation in order to give the proper curvature to the seating surface of the brush. A coarse grade of sandpaper may be used first, and a fine grade used to finish the seating.

SPARKING AT THE BRUSHES

Some sparking under the brushes on modern exciters 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,".

Causes of Sparking. Sparking may be due to either mechanical or electrical causes. The usual causes of sparking are:

1. Overloaded machine.
2. Rough commutator due to high or loose bars, flat spots, or imperfect undercutting.
3. High commutator bar mica.
4. Dirty, oily, or worn out commutator.
5. Brushes not set on neutral.
6. Brushes unequally spaced around the periphery of the commutator.
7. Brushholders set too far away from the commutator.
8. Brushes which may be sticking in the brushholders or have reached the end of their travel.
9. Brushes not fitted to the circumference of the commutator.
10. Brushes not bearing on the commutator with proper pressure.
11. Brushes having extra pressure and taking more than their share of the current.
12. Unsuitable grade of carbon brushes.
13. Burned faces on the brushes.
14. Vibration of the brushes.
15. Incorrect brush angle.
16. Non-uniformity of commutator pole air gaps.

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 the 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.

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.