Westinghouse

Alternating-Current Generators and Synchronous Condensers

INSTRUCTION BOOK

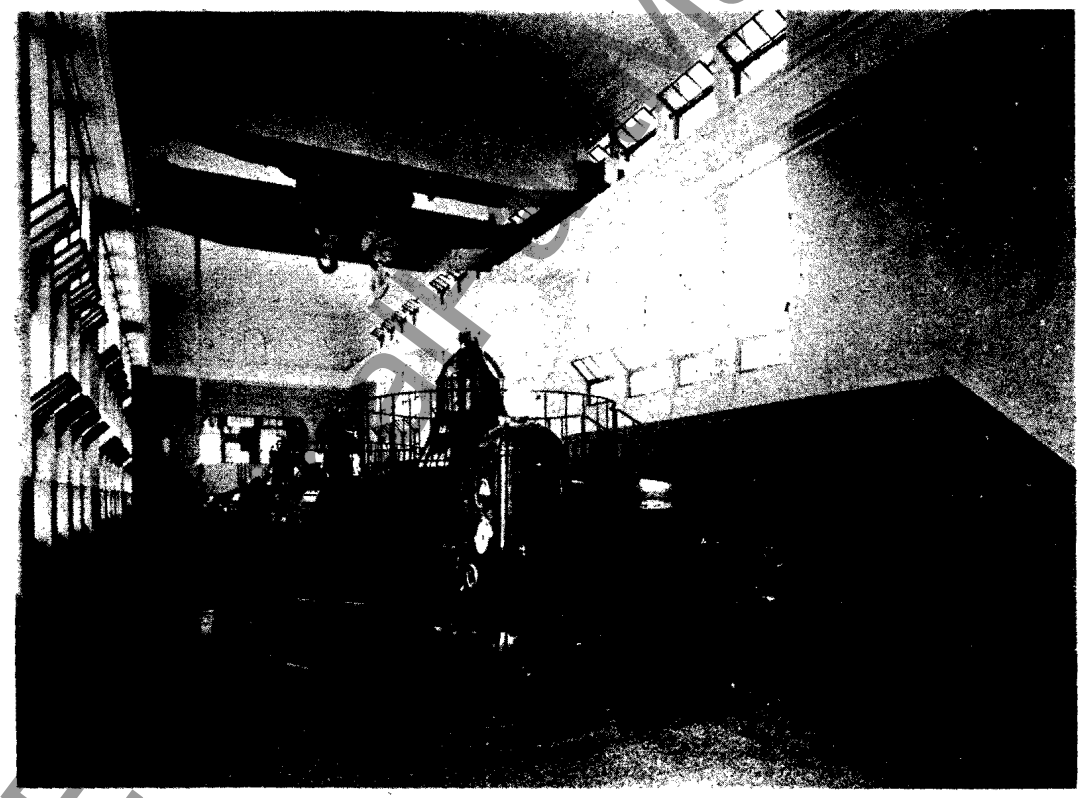


FIG. 1—THREE—4000 KV-A., 225 RPM. UMBRELLA TYPE WATERWHEEL GENERATORS WITH DIRECT-CONNECTED EXCITERS INSTALLED IN EAGLE PASS GENERATING STATION, CENTRAL POWER AND LIGHT COMPANY

Westinghouse Electric & Manufacturing Company
East Pittsburgh, Pa.

I. B. 5442-F

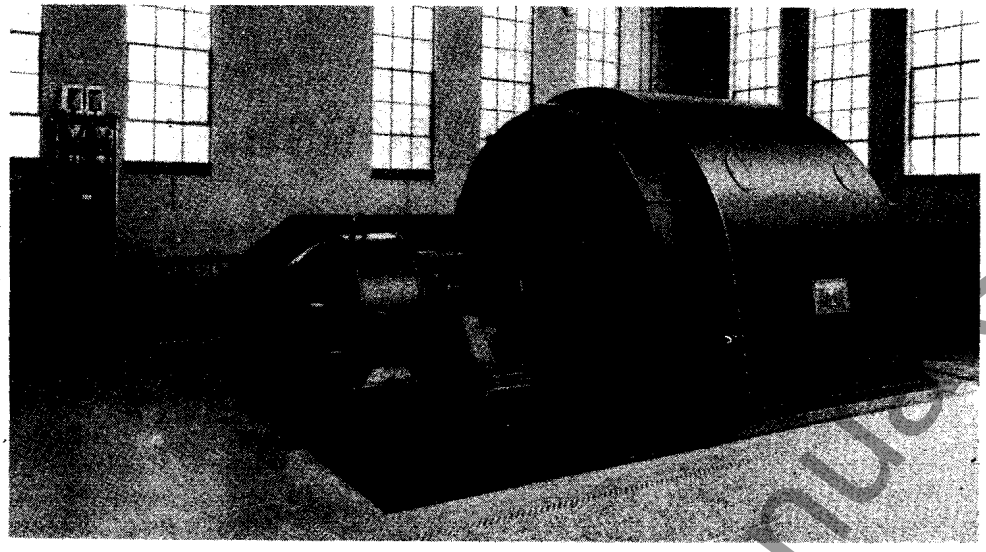


FIG. 2—TYPICAL HORIZONTAL SYNCHRONOUS CONDENSER INSTALLATION

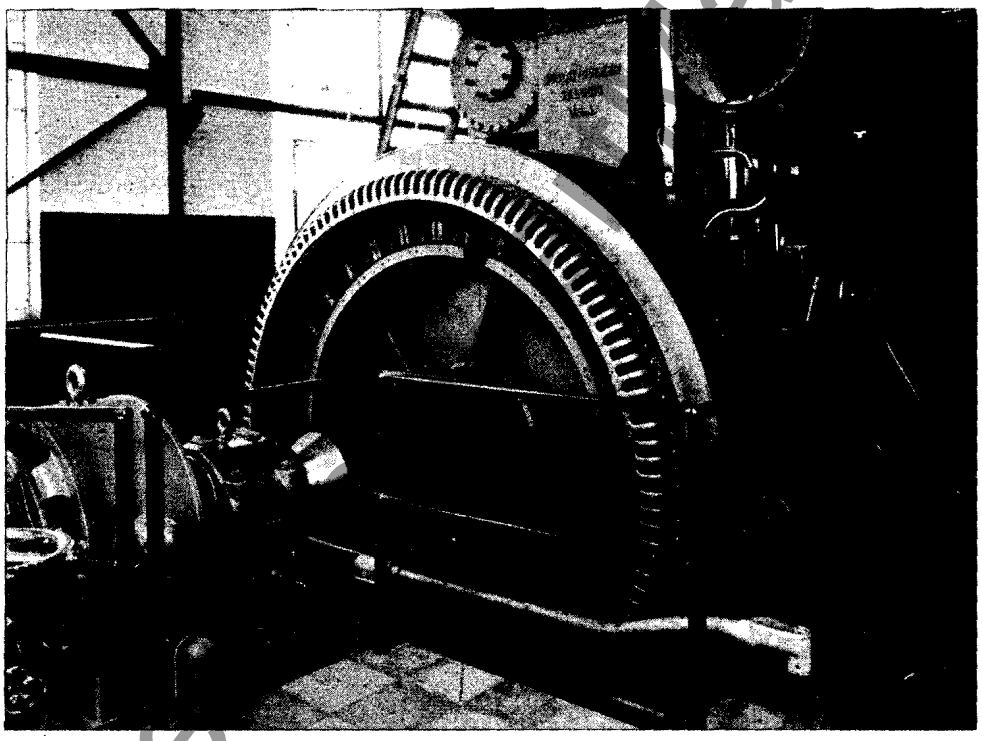


FIG. 3—TYPICAL DIESEL ENGINE TYPE ES GENERATOR INSTALLATION

SPECIAL NOTICE

Personal safety should be the first consideration when electrical apparatus is adjusted, reconditioned or repaired. One man should not be permitted to work alone, as in case of accident help should be available. The practice of using one hand only when working on "live" circuits should be followed. Damp clothing should not come in contact with "live" parts of apparatus or wiring. The wearing of damp shoes is particularly dangerous. Extreme care should be used when adjusting the brushes on commutators or collectors of operating machines. Under no circumstances should all of the brushes of one polarity be raised while rotating apparatus is in operation, as a very high voltage "kick" will occur when the exciting circuit is broken. Machines a e connected with the field excited direct from the D-C. generator. Make sure that the field circuit is opened before the brushes a e raised.

Westinghouse
A-C. Generators and Synchronous Condensers

General Information

The instructions given in this book apply to salient pole a-c. generators, both horizontal and vertical type and synchronous condensers. The latter are similar in structure to horizontal generators and will be referred to specifically only where special operating instructions are required.

Construction

Types of Generators and Condensers

Engine Type Generators have no shaft, bearings or bedplate. The stator is mounted on soleplates on the foundation or on the engine bedplate. The rotor is pressed or clamped on the shaft of the engine.

Coupled Type Generators have bedplate, shaft and bearings and, usually, a half coupling on the driving end.

Belted Generators are made with two bearings and a shaft extension for a pulley in small sizes and with three bearings with a pulley between two of the bearings for larger sizes. There are rails under the bedplate and a jacking device which permits movement of the bedplate along the rails so as to tighten the belt.

Vertical Generators for connection to vertical shaft, hydraulic turbines have a Kingsbury thrust bearing for supporting the weight of the rotating parts of the water wheel and generator. There are either one or two guide bearings for steadying the rotor. The stator rests on soleplates, or in some cases on a continuous base ring.

Synchronous Condensers have two bearings and a bedplate but have no shaft extension beyond the bearings.

Exciters

An exciter may be mounted on one end of the machine. The exciter frame is usually supported by a stand which is bolted to an extension of the bedplate. This allows the stand and the exciter stator to be removed in case it becomes necessary to remove the main rotor for repairs. The exciter armature may be mounted on an extension of the main shaft or on a small shaft coupled to the end of the main shaft. Vertical machines have the exciter mounted at the top.

Ventilation

Small machines are usually constructed so that ventilating air is drawn in directly from the room and, after passing through the machine, is discharged back into the room. For larger machines, the incoming air may be drawn through enclosing end bells which extend into the pit beneath the floor and are connected to ducts leading to a source of cool air. After passing through the machine the air is discharged through a single opening in the frame, either at the top or the bottom, to which a duct may be attached for carrying the air out of the building. In some large machines a closed ventilating system is used in which the air is taken from the discharge and is passed through a cooler and then returned to the machine intake.

The ventilating air for vertical machines is drawn partly from the pit beneath the generator and partly from the generator room through the upper bracket arms. In some special cases the upper part of the machine is closed and all the air is taken from the pit.

Fans

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 each of which is bolted to the rotor. For other machines a completely assembled blower having inclined blades is bolted to each side of the rotor. The blades are inclined in such a way that they are not radial, the edge of the blade nearest the shaft being in advance of the outer edge in the direction of rotation. It is 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.

Bedplates

The bedplates are fabricated from structural steel beams. For very large machines the bedplate may consist of separate side rails and end rails which are not joined at the corners but which are mounted separately on the foundation.

Bearings

The bearings of horizontal machines are lubricated by means of oil rings. There are openings at the top of the bearing cap which permit inspection of the rings. The oil level can be determined by raising the spring cover on the sight hole which is provided on the pedestal, or, in some cases, by a sight gauge. There is a drain plug which allows all of the oil in the reservoir to be removed. 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 and recommended method is to circulate oil through the bearings and through external coolers. Water coolers, such as the multiwhirl type, are generally used. 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 system when required. Large condensers are provided with a high pressure oil system for lubricating the bearings during starting. A small inlet pipe and a larger return or suction pipe are furnished with the bearing when this system is used. Thrust bearings for vertical generators are described on page 6.

Insulated Pedestals

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

To avoid this trouble in horizontal machines, one of the pedestals is insulated from the bedplate so as to prevent the flow of current. A sheet of insulation about $\frac{1}{16}$ inch thick is placed between the bottom of the

pedestal and the bedplate and insulating tubes and washers are used around the bolts and dowels. If water or oil 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: Piping which touches both the pedestal and bedplate and which has no insulated union; guard rail; metal ladder set against the pedestal; tools left in contact with both pedestal and bedplate; pump or other device geared to the main shaft. A break in the insulation may occur during erection due to careless handling and it is well to test for this with a bell and battery or with a test lamp. 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 this by placing one end of a copper wire on the pedestal and by touching the other end on the shaft from which sparks can be drawn. The wire simply shunts part of the current which otherwise flows through the bearing surfaces.

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

Conventional type vertical generators of the older designs had the bracket insulated from the frame. Later designs have insulation under the thrust bearing support. This may be tested by raising the rotor so the bearing shoes are not in contact with the runner. Umbrella type generators seldom require shaft current insulation.

Oil Pressure for Starting

The use of oil under high pressure in the bearings of large synchronous condensers **during starting** reduces the friction and permits the use of lower starting voltages and currents. The equipment consists of a pump, driven by a small motor and the necessary piping.

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

If any of the bearings are insulated from the bedplate the piping connected to them should be equipped with insulated unions.

Leads

The arrangement of leads for various types of windings is shown in Fig. 3. The leads of horizontal machines are brought out normally at the bottom of the frame on the collector end of the machine and are equipped with terminals into which the purchaser's cables may be inserted.

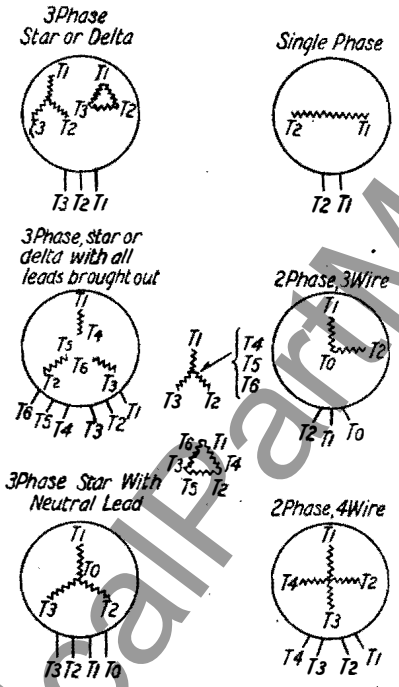


FIG. 4—STANDARD ARRANGEMENT OF LEADS FOR VARIOUS WINDINGS

Important Notice

Exciter Adjustment

In order to minimize main field rheostat losses, synchronous condensers having **individual** exciters either direct-connected or separately motor driven, should have their exciters adjusted so that the exciter voltage, after installation, is just sufficient to provide the condenser field current, required at rated load, **with the main field rheostat in the all-resistance-out position.**

Phase Sequence

The phase sequence, or phase rotation as it is sometimes called, is in the order of T_1-T_2-T_3, etc., when the mechanical rotation is in a clockwise direction viewed from the collector end of the machine. When the rotation is counter-clockwise, viewed from the collector end, the phase sequence is in the reverse order.

Installation

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

Foundations

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

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

Erection

The erection of **small machines** which are shipped assembled on the bedplate is fairly simple. The machine should be placed on the foundation with the bedplate resting on steel plates or wedges. These wedges should be of sufficient height to facilitate grouting and should be so located that they will carry the weight of the machine without distorting the bedplate. The machine should be brought into alignment with and also leveled to the elevation of the connected apparatus. Before the bedplate is grouted in, the shaft alignment should be carefully checked by the use of thickness gauges between the coupling faces if a solid coupling is used or by the method recommended by the coupling manufacturer if a flexible coupling is used. When the shaft alignment is satisfactorily adjusted, the foundation bolts should be pulled tight and the alignment rechecked before any grout

ing is done. The grouting should be in line with the recommended procedures shown in figure (5).

Larger machines are generally shipped dismantled and the extent of the dismantling depends on the physical size of the machine. In certain cases the poles and 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.

The following operations of the remainder of the erection are of vital importance and should be carefully performed.

1. Alignment of Bedplate

The bedplate should be placed on the foundation and be set by the use of wedges or shims and an accurate spirit level so that its top surface is level and in such position that when the machine is assembled on it, the shaft and coupling will be in sufficiently close alignment with any coupled apparatus that the final correction can be made without the necessity of shifting the bedplate. In certain 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. After the bedplate is properly set the foundation bolts should be pulled tight and the surface again checked.

2. Grouting the Bedplate

The benefit expected from a heavy solid foundation will not be obtained if a poor job of grouting on the bedplate is done. The grout should fill all the spaces in the structural steel bedplate and should be carried flush with the top so that a solid tie between the bedplate and the foundation is obtained. See Figure 5.

3. Alignment of Shafts

When solid couplings are used on coupled type generators, the bolts should be loosened and the faces of the coupling checked for parallelism by the use of thickness gauges between them. If the generator has but 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 and 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 pedestals shifted to bring them in line. The maximum variation in the measured distance between the coupling faces should be less than .002" across the diameter for any size of coupling. The alignment of the "Fast" flexible coupling (when used) should be checked by the method recommended by the Bartlett Hayward Company.

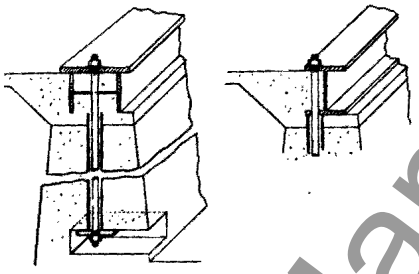


FIG. 5—SETTING OF STRUCTURAL STEEL BEDPLATES

5. Adjust stator for uniform air gap.

6. Bolt the end bells in place.

7. Connect all leads and piping and fill the bearings with oil.

The various parts of the machine that must be disassembled for shipment are marked at several points so as to facilitate assembly. The marking consists of numbers stamped near the junction of two parts and so arranged that when the parts are assembled correctly, a number on one part is adjacent to the same number on the other part.

Assembling Engine Type Generator Rotors on Engine Shafts

A—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 facilitate mounting a solid generator rotor on an engine shaft, such as:

1. Engine shaft can be forced in generator rotor by pressure.
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.)

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 sometimes be satisfactory. Experience has shown that the proper degree of expansion can generally be obtained by heating the rotor to a total temperature of 150°C.

If poles and coils are mounted on spider, the enclosure should be made to confine only the rotor center. Poles and coils should be kept outside of 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.

B—Split Rotors

Engine type generators where the rotor cannot be shipped directly on the shaft, may be designed with a split spider to facilitate assembly in the field. The split type is fastened together with bolts, through the hub, and the rim is fastened by means of links. The links are tightened and the two edges of the rim are drawn together with steel wedges, driven in from both the inside and outside of the rim. A steel plate holds the wedges in place on the inside, while the pole is bolted over them on the outside.

On some of the completely split spiders, it is necessary to disconnect and remove two or more of the poles, before assembling on the shaft. Care-

fully disconnect the coils and damper segments, and after removing the pole bolts, lay the poles aside where they will not be injured. Split collector rings are provided, and the bolts at the split of the ring must be removed when assembling the completely split spider, while with the spider having a solid rim and split hub, they may be loosened without being removed.

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 or bolts may then be inserted and tightened.

The collector rings on split rotors are of necessity also split and although they are turned and ground true in the factory, require care in their assembly to ensure that they run true. 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. There should be no sharp "jump" of the brushes at the collector ring split and the rings should not run out of true more than .004" at full speed. Eccentricities greater than this amount can be tolerated on slow speed machines but if trouble is encountered with the operation of the brushes, the rings should be ground true.

Adjustment of the Air-Gap

In setting up any machine in which the bearings are independent of the frame, great care must be exercised in adjustment of the air-gap between the armature core and the pole faces, as any inequality in the gap will result in an unbalanced magnetic pull which will cause unnecessary friction and heating of the bearings and unequal heating of the armature iron. During these adjustments gauge the air-gap at different points from each side of the machine. Gauges for this purpose should extend to the center of the core. They may be made from thickness or "feeler" gauge stock that can be procured in various micrometer thicknesses and any suitable length.

Bearings

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

Bearings may be operated safely with temperature from 90° to 100°C. if they are in good condition. Usual recommended continuous operating temperature is 80°C. (176°F.). It should be remembered that a bearing may be below this temperature even though it is hot enough to burn the hand when held against the outside.

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

The cause of overheating may be any of the following:

Insufficient oil in the reservoir.
Dirty oil or oil of poor quality.
Failure of oil rings to revolve.
Excessive pressure or end thrust caused by poor alignment of the machine.
Bent shaft.
Shaft currents.
Rough bearing surface, which may have been the result of careless handling.

Kingsbury Thrust Bearings

Packing and Rust Prevention—The bearing faces of the thrust collars (or runners) and shoes must be carefully protected against rust, corrosion or other injury, because any roughness may make the bearing run hot or burn out. In shipment or storage, these surfaces must be protected by some kind of neutral water-proof coating. Wood or damp packing material of any kind must not be placed in contact with them.

The best method of packing a collar (or runner) for shipment or storage is to bolt it into the box in such a way that the bearing faces are in no danger of touching the inside of the box. Very slight rusting of the bearing face may be removed by stoning with a fine oil stone, but if deep rusting occurs the surface must be refinished.

Babbitt faces of shoes are very sensitive to acid. Hence to avoid pitting they must not be packed in contact with paper, even if it is oiled. It is best to paint them all over with neutral protective coating, placing two babbitt faces together and then wrap up the pair of shoes in weatherproof paper or case lining to keep out dirt and moisture.

Cleaning—Bearings and housings should be thoroughly cleaned before assembling bearing in place. Remove all anti-rust coatings with gasoline or kerosene. Use rags or cloth for cleaning, as waste always leaves lint, which may cause trouble in the bearing, or oiling system.

Bearing Faces—As the working faces of shoes and collars are fitted to a surface plate, they will fit each other very closely when assembled in the bearing. This accurate fit is essential to the formation of the continuous thin oil film on which the working of the Kingsbury thrust bearing depends. Burrs, bruises and rust, caused by handling, shipment or storage, should be removed from all parts.

In order to detect and remove all small defects, the bearing face of the thrust collar (or runner) should be stoned lightly all over with a clean, flat face of a fine emery of carborundum stone and kerosene rubbing back and forth in the radial direction (not circumferentially). Do not use a coarse-grained stone, nor scraper, nor file on the bearing face of the runner. The fine side of a number 121 carborundum oil stone is satisfactory.

Bruises on the wearing faces of the shoes may be removed with a scraper. The high spots may be found by testing them with Prussian blue on a surface plate or on the bearing face of the collar. Remove any chips or grit that may be found embedded in the faces of the shoes.

Freedom for Self-Adjustment—Good operation of the bearing requires that the shoes and their supporting parts be free to adjust themselves to the collar position so as to overcome the effects of misalignment or springing of parts. Clearances for this purpose are provided in the designs. Before putting into service, the bearings should be inspected to see that all parts are free as described above.

Keys, Dowels and Bolts—Special care should be taken to see that keys, dowels or bolts, used to fasten a thrust bearing collar or other parts to the shaft or housing, do not bottom or bind, as this will throw the parts out of true.

Thrust Collar or Runner—The runner, or rotating part of the bearing, is secured to the top of the main shaft. On large vertical and all umbrella type generators,

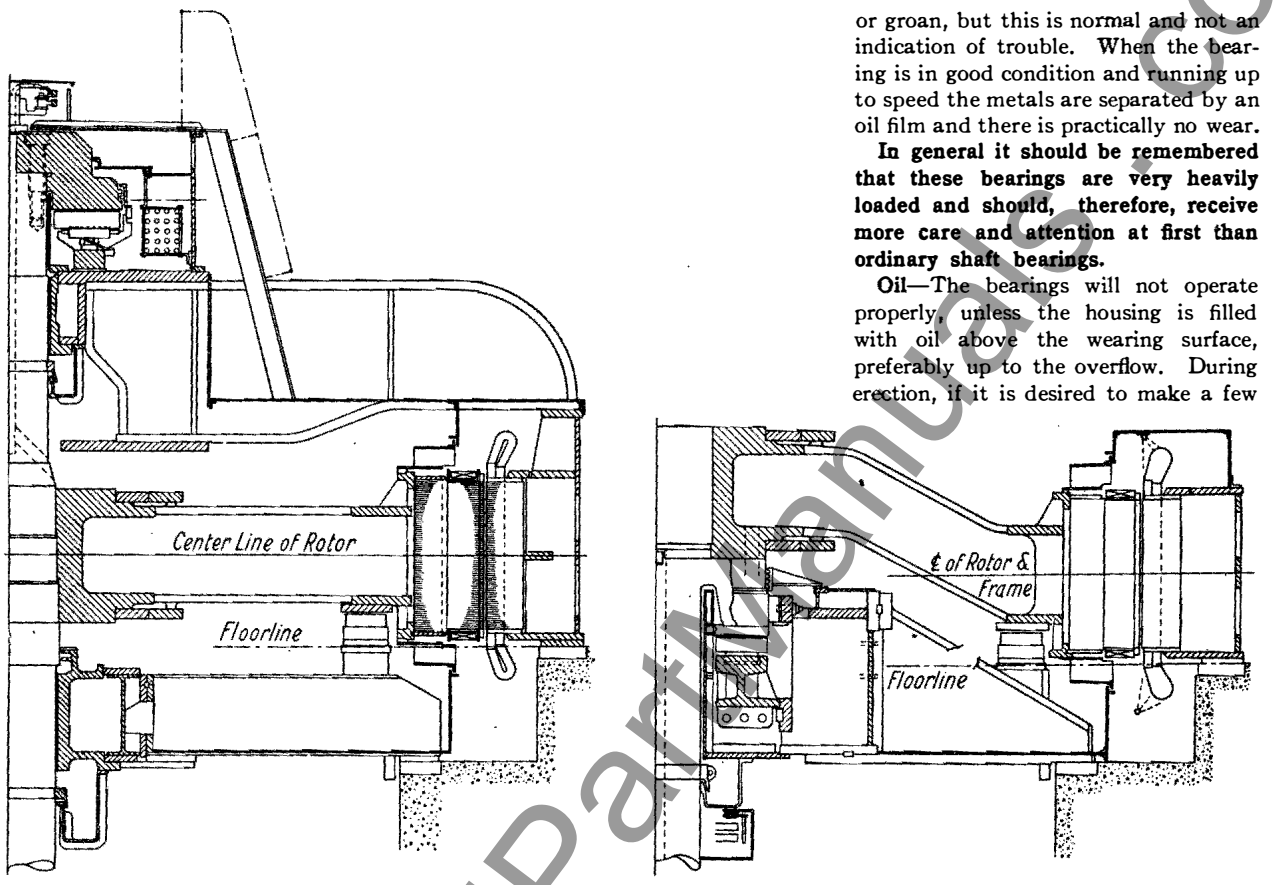


FIG. 6—TYPICAL SECTIONS OF CONVENTIONAL AND UMBRELLA TYPE VERTICAL WATERWHEEL GENERATORS OF SAME CAPACITY, SHOWING RELATIVE HEIGHT AND HEAD-ROOM REQUIREMENTS

the thrust bearing runner plate is bolted to the thrust bearing runner support so as to be easily removable.

Adjustable Shoes—The babbitted shoes forming the stationary part of the bearing are supported by jack screws which permit each one to be adjusted in a vertical direction.

Starting Up New Bearings—When shipped separately from the generator, the bearings are carefully finished and boxed at the factory in the manner described above, but they are liable to injury thereafter from handling, improper reboxing, dirt and bruises during shipment; hence, careful final inspection is necessary to be sure each bearing is in proper condition for operation.

After being run a short time, or after being turned slowly a few times, the bearing should again be inspected. If rubbing marks show excessive bearing pressures at any part of the bearing surfaces, the high spots should be removed by scraping. This process should be repeated until a good fit is secured. Streaks in the faces of the shoes may be caused by bruises or rough spots on the collar. Fine scratches may be due to dirt in the oil.

The ordinary installation will show a temperature rise of the oil in the thrust pot of about 15°C. to 20°C. If any appreciable rise above normal temperature occurs, the machine should be shut down as quickly as possible and the cause of the trouble removed. If the trouble is detected early, it can be corrected by scraping the babbitt to a new fit and stoning the collar, but if allowed to continue, the babbitt will be dragged off and more extensive repairs will be required.

In vertical thrust bearings, subject to practically full load at all speeds, repeated starts and stops may be made to improve the polish of the runner and the fit of the shoes. Practically no wear occurs except at the instants of starting and stopping; that is, when the oil film is not fully formed and the metals rub together. At these times the bearings when not rigidly mounted make more or less noise, like a grunt or groan, but this is normal and not an indication of trouble. When the bearing is in good condition and running up to speed the metals are separated by an oil film and there is practically no wear.

In general it should be remembered that these bearings are very heavily loaded and should, therefore, receive more care and attention at first than ordinary shaft bearings.

Oil—The bearings will not operate properly, unless the housing is filled with oil above the wearing surface, preferably up to the overflow. During erection, if it is desired to make a few turns of shaft for adjustment, apply a coating of heavy cylinder oil to the shoes. The service oil, unless otherwise specified, should be a good grade of dynamo or engine oil, free from acid and having a viscosity of approximately 250-300 seconds at 100°F. (Saybolt test). It should be kept clean and free from grit or other injurious substances, and where a station oiling system is used, should be returned to the bearing at a temperature not exceeding 35°C.

Re-Babbitting Shoes—In case of necessity shoes may be re-babbitted, using genuine hard babbitt, preferably of the composition 85 per cent tin, 10 per cent antimony, 5 per cent copper, with proper care to prevent overheating in melting. Allow about 1/8 inch to machine off the face. Do not peen the babbitt. Face carefully and scrape to the collar face or to a surface plate.

Umbrella Type Vertical Generators

This type of construction differs from the conventional or two guide bearing

construction, chiefly by the use of only one guide bearing on the generator. The single guide bearing and the Kingsbury thrust bearing are combined and the combination is located below the rotor. The guide bearing is placed near the center line of the rotating parts in order to obtain full benefit of the umbrella type construction. The greatest advantages of this construction are obtained on relatively slow-speed units.

With this type of construction it is not necessary to remove major parts at the top of the unit in order to get to and remove the thrust and guide bearing parts. Neither is it necessary to disturb the shaft alignment or to disturb thrust or guide bearing adjustments when removing the rotor, because the rotor can be unbolted from the shaft and the shaft left in place. This requires a minimum of labor and time, and crane height, to dismantle and to erect the machine. This guide bearing can be very easily adjusted by means of adjusting screws back of each shoe. The waterwheel-generator shaft alignment is not a difficult operation with this type of construction. The thrust bearing runner support is forged integral with the main shaft.

Alignment
Vertical Generators

It is the responsibility of the hydraulic turbine, or waterwheel erector to establish the vertical center line and the elevation of the waterwheel-generator unit. This implies that the waterwheel shaft, if one is provided, will be placed in accurate vertical and concentric alignment by the hydraulic apparatus erector, and that the waterwheel shaft coupling face will be machined within established tolerances and will be level. If no shaft is provided with the hydraulic element, and the generator shaft connects direct to the waterwheel runner, the elevation, and the vertical and concentric alignment of the generator will be established by machined surfaces of the stationary part of the hydraulic equipment.

In the erection of large vertical waterwheel-generator units, spirit level-pin gauge methods of alignment have been largely superseded by the pivoted leveling beam method which establishes elevation, also vertical and concentric alignment in one operation. A somewhat special "close range" engineer's telescopic level with micrometer target has also been used very satisfactorily.

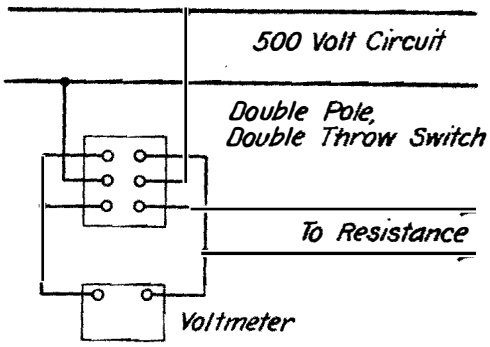


FIG. 7—CONNECTION FOR MEASURING INSULATION RESISTANCE

Protection

The machine should be protected carefully against moisture both before and after erection. Water or steam from leaking pipes, rain, snow or condensation from the atmosphere should be excluded. It is particularly important to keep the windings dry since moisture lowers the insulation resistance and increases the likelihood of a breakdown. If a machine is brought from cold surroundings into a warm room, it should be kept covered until its temperature has risen to room temperature so as to prevent condensation on the windings and other parts. (See page 9 for methods of drying out windings.)

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

Lifting of the machine by cranes should be done with the greatest care. The stator is usually provided with lifting holes into which the crane hooks may be inserted. The rotor should be lifted preferably with rope slings looped around the shafts. In no case should the ropes or chains be allowed to exert pressure on the windings or collector rings.

Use kerosene to remove paint on the journals. In cases where rust is present use an oil stone or emery cloth and finish with an oil stone, depending upon the amount of rust to be removed.

Do not mar or scratch the journals, as any roughness may cut the bearings and cause them to run hot.

Insulation Resistance

The insulation resistance of windings is measured, usually, with an instrument called a megger.

In case a "megger" is not available, insulation resistance measurements may be easily made using a 500-volt direct-current circuit and a 500-volt direct-current voltmeter. The method of measurement is first to read the voltage of the line, then to connect the resistance to be measured in series with the voltmeter and take a second reading.

The measured resistance is then calculated by using the following formula:

$$R = \frac{r\,(V - v)}{v\,(1{,}000{,}000)}$$ in which

V = voltage of the line.

v = voltage reading with insulation in series with voltmeter.

r = resistance of voltmeter in ohms (generally marked on label inside the instrument cover).

R = resistance of insulation in megohms (1 million ohms).

The method of connecting the apparatus is shown in the diagram Fig. 6:

If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified since $r = 1$ and the above formula becomes

$$R = \frac{V}{v} - 1$$

A safe general rule is that insulation resistance should be approximately 1 megohm for each 1000 volts of operating voltage with a minimum of 1 megohm.

No new machine should have an insulation resistance of less than 1 megohm.

Insulation resistance of machines in service should be checked periodically to determine possible deterioration of the windings.

This measurement gives an indication of the condition of the insulation particularly with regard to moisture and dirt. The actual value of resistance varies greatly in different machines depending on the size and voltage. The chief value of the measurement therefore, is in the relative values of resistance of the

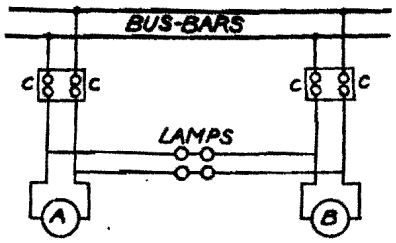


FIG. 8—CONNECTION FOR SYNCHRONIZING LOW VOLTAGE SINGLE-PHASE GENERATORS

same machine taken at various times. During a drying out run, for example, the insulation resistance rises as the winding dries out although it may fall appreciably at first. When measurements are made at regular intervals, with the machine at the same temperature, as part of the maintenance routine, it is thus possible to detect an abnormal condition of the insulation and take steps to remedy it before a failure occurs.

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

$$\text{Insulation Resistance (in megohms)} = \frac{\text{machine voltage}}{\frac{\text{Rated Kv-a.}}{100} + 1000}$$

Drying Out Windings

Winding insulation should be kept warm and dry during the erection of the apparatus. The end bells may be placed temporarily in position, or a tarpaulin may be used to cover the machine. Electric heaters should be located within the enclosure below the windings. When the machine has a closed ventilating system, the heaters may be located in the incoming air stream. Electric space heaters are convenient for this purpose. If the windings have been exposed to moisture during shipment the insulation may be dried by this method while the machine is being erected. This saves the time and expense required for a "drying out run".

The insulation may also be dried by circulating current through the windings. One way of circulating current through the windings, without subjecting them to full voltage, is to short-circuit the armature and drive the machine, applying enough field excitation to give somewhat less than full load armature current. This method, usually called the short-circuit method, is generally impracticable for drying synchronous condensers.

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

In all cases of drying by means of current in the windings, the temperature measured by thermometer should not be allowed to exceed 65°C. If the temperature is measured by imbedded temperature detectors 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. It is well to take readings of insulation resistance by means of a megger at intervals as this gives a good indication of the state of the insulation.

In many cases, it is impracticable to dry the windings by heat generated within the machine and external heat must be used. A tarpaulin should be used to cover the machine and some source of heat, preferably electric heaters, placed within the enclosure. In the case of a machine having a closed ventilating system, the heaters can be placed in the incoming air stream.

Precautions against fire should always be taken when drying insulation. Inflammable material should not come in contact with electric heaters. Wiring connections should be substantially made. Fire extinguishers should be at hand.

Synchronizing A-C. Generators

The condition to be fulfilled in order that synchronous apparatus may be connected to a system already in operation, is that the electromotive forces of the incoming machine and of the system to which it is connected shall be approximately the same at each instant. This requires that the frequencies be the same, that the two voltages be equal, as indicated by a voltmeter, and that the two voltages be in phase.

The elementary principle employed in determining when generators are at the same frequency and in phase is illustrated by Fig. 8 in which A and B represent two single-phase generators, the leads of which are connected to the bus-bars by switches C and two series of incandescent lamps which are connected as shown. As the electromotive forces change from the condition of phase coincidence to that of phase opposition, the flow of current through the lamps varies from a minimum to a maximum.

When the electromotive forces of the two machines are exactly equal and in phase, the current through the lamps is zero. As the difference in phase increases, the lamps light up and increase to a maximum brilliancy when corresponding phases are in exact opposition. From this condition the lamps will decrease in brilliancy until completely dark, indicating that the machines are again in phase. The rate of pulsation of the lamps depends upon the difference in frequency, i. e., upon the relative speeds of the machines.

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 to reduce the voltage at the switchboard to safe limits, as shown in Fig. 9.

If the connections of either the primary or secondary of either transformer be now reversed from those shown in the diagram, the indications of the lamps will be reversed, i.e., when the generators are in phase, the lamps will burn at maximum brilliancy and vice versa.

In order to make certain that the lamps will be dark instead of bright when the machines are in phase, disconnect the main leads of the first generator at the generator and throw in the main switches of both generators with full voltage on the second generator. Since both machine circuits are then connected to one machine, the lamp indication will be the same as when the main or paralleling switches are open and both machines are in phase. If the lamps burn brightly and it is desired that they be dark for an indication of synchronism, the connections of one of the voltage transformer primaries or one of the secondaries should be reversed. **Dark lamps as an indication of synchronism are recommended.** The lamps should be adapted for the highest voltage which they will receive, i.e., double the normal voltage.

Phase Sequence

In the case of polyphase machines, it is not only necessary that one phase be in synchronism with one phase of

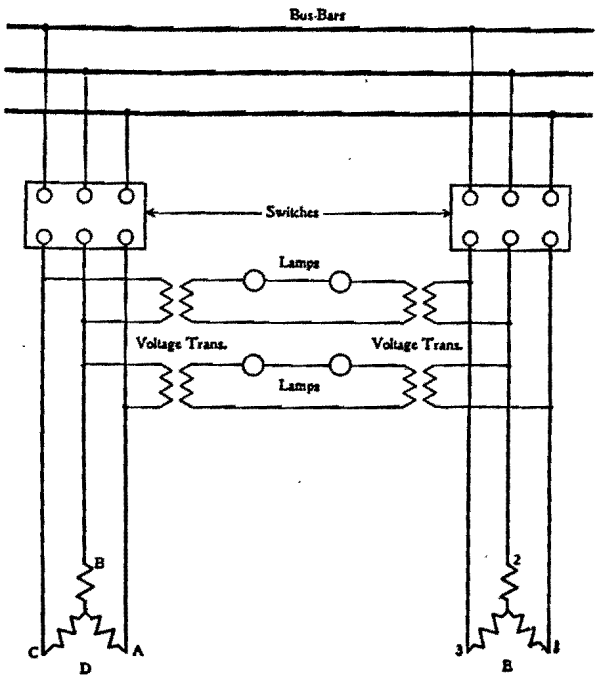


FIG. 9—CONNECTIONS FOR SYNCHRONIZING THREE-PHASE GENERATORS

another generator but the sequence of maximum values of voltage in the several phases must be the same. The phase sequence must therefore be checked. The necessary connections for two three-phase generators are shown in Fig. 9.

Connect the generators temporarily to their switches, but with the switches open, so that the phases of D will be in parallel with those of E. Connect synchronizing apparatus in any two phases. Test out the synchronizing connections with machine D running at normal speed and voltage, the leads disconnected from E at the generator and the paralleling switches closed. Having changed the synchronizing connections, if necessary, so that both sets of lamps will be the same when indicating synchronism, open the paralleling switches, re-connect the leads of machine E and bring it up to normal speed and voltage. Then observe the two sets of synchronizing lamps. If their pulsations come together, i.e., if both sets are dark and both are bright at the same time, the phase rotation of the two generators is the same, and the connections are correct for paralleling the generators when the lamps are dark. If, however the pulsations of the lamps alternate, i.e., if one is dark when the other is bright, reverse any two leads of one machine and test out the synchronizing connections again, changing them if necessary so that they are the same when indicating synchronism. The lamps will now be found to pulsate together and the generators may be thrown in parallel at the proper indication. Synchronizing apparatus in one phase only is sufficient for paralleling the generators after the first time.

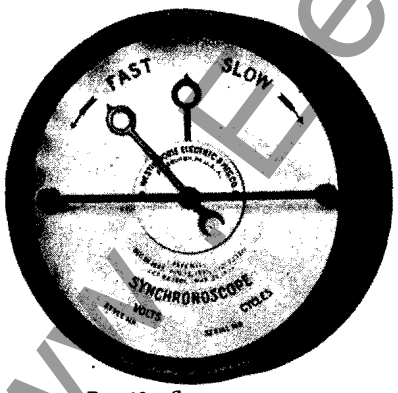


FIG. 10— SYNCHRONOSCOPE

The procedure in synchronizing a generator with an existing power system is the same, the phase rotation of the generator being changed, if necessary, to agree with that of the system.

The paralleling of two-phase generators is accomplished in a similar manner. In case of incorrect rotation the two leads belonging to either phase must be reversed instead of any two leads.

Synchronoscope

A synchronoscope, Fig. 10 is an instrument that indicates the difference in phase between two electromotive forces at every instant. By its aid the operator can see whether the incoming machine is running fast or slow, what the difference in speed is, and the exact instant when it is in synchronism. These conditions cannot be observed with certainty by the use of lamps alone.

The synchronoscope has a pointer which shows the phase angle between the incoming and running machines. This angle is always equal to the angle between the pointer and the vertical position marked on the dial of the instrument. When the frequencies of the two machines are equal, the pointer stops at some position on the scale and when the machines are in phase, the pointer coincides with the marker at the top of the scale.

In order to check the synchronoscope connections, proceed in the same manner as previously described for determining whether lamps will be bright or dark for a given synchronizing connection. If the synchronoscope pointer stops at the bottom, reverse the leads at the upper terminals. If it stops in the same position, the connections to the upper terminals are made to the wrong phase.

Operation

Starting an A-C. Generator

Bring the generator up to speed and synchronize it with the line according to instructions in previous paragraphs.

Adjust the prime mover so that it tends to speed up, thus causing the generator to take part of the kilowatt load of the system.

Adjust the field current so as to give the desired power factor.

Starting Synchronous Condensers

Synchronous condensers are started by means of auto-transformers which supply a voltage of from 20 to 30 per cent. The exact procedure for starting is as follows:

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

Close the starting switch applying reduced voltage from the starting transformers to the stator windings. During this time, the field winding should be closed through a short-circuiting switch,

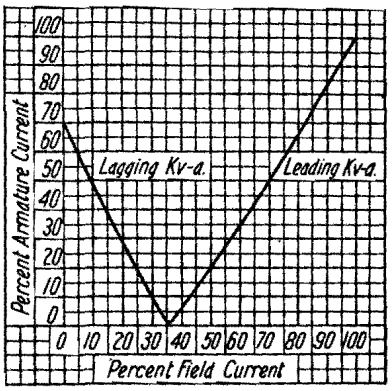


FIG. 11—EFFECT OF VARIATION OF FIELD CURRENT OF A SYNCHRONOUS CONDENSER

or, if the condenser has a direct-connected exciter, it may be connected across the exciter terminals. A rheostat may or may not be in the circuit with the field in either case. In no case should direct-current be applied to the field when the machine is to be started, nor should the field be left open-circuited.

When the machine has begun to turn freely the oil pump should be shut down. It should not be allowed to run longer than necessary.

When approximately full speed has been attained, the field winding should be excited. If the field is connected directly to the terminals of the direct-connected exciter, the excitation is applied automatically.

The starting switch can then be opened and the running switch closed, transferring the machine from the starting voltage to full voltage.

The alternative method of switching to full voltage first and then applying the exciting current, is sometimes used. Should the switching arrangement be such that the circuit must be opened for an appreciable interval during the transfer from starting to running, there may be less line disturbance if this method is employed.

Adjustment of Field Current

Single Generator—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.

Generator Operated in Parallel—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 kv-a. If the field current is increased, the generator furnishes reactive kv-a. 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 per cent power factor should usually be avoided since this imposes additional load in reactive kv-a. 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.

Condenser—The reactive kv-a. of a condenser is proportional to the field current. To get the maximum kv-a. at all times, the field current should be set at the rated value given on the name plate. A voltage regulator is used on some installations to vary the field current, and thus the reactive kv-a., so as to maintain constant voltage on the system. At times of light load on the system, it may be desirable to operate the condenser at low values of excitation so as to produce lagging reactive kv-a. and thus keep the voltage of the system from rising above normal. The curve in Fig. 11 shows how the kv-a. of a condenser varies with changes in field current.

Parallel Operation

The requirements for successful parallel operation are:

1. The speed regulation of the prime movers should be alike. That is, the per cent drop in speed for a given per cent 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 per cent 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 machines.

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 voltage or, in the extreme case, to operate single-phase, depends largely on the design of the amortisseur or damper winding. Single-phase operation produces heavy currents in the damper winding, 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 in a less degree.

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

Maintenance

CAUTION

Keep the machines clean. The finest machines and the most expensive plant may be shut down by accident if they do not have the proper protection and care. The insulation must be kept clean and dry. Oil and dirt in the insulation are as much out of place as grit or sand in a cylinder or bearing. In a direct-connected unit, oil may splash from the driving machine or work along the shaft to the insulation and cause a burn-out, unless the attendant provides the necessary protection.

Cleaning†

"Electrical equipment should be kept reasonably free from accumulations of dirt in order that ventilating ducts may function and that low resistance paths may not be formed between live parts. Various methods and solvents are used in the cleaning.

"**Compressed Air** is the most convenient method of removing an accumulation of dirt not too firmly fixed to be blown out. The only precautions to be observed are that the air line must be free from moisture, and that the dirt must be blown out and not compacted into some inner recess in the equipment where it will be difficult to remove and where it may close ventilating ducts. The air should be at 50 pounds pressure.

"**Water**—When the dirt is water soluble, warm water can be used effectively. The washing should be rapid and the apparatus should be immediately wiped with a dry cloth and then dried in an oven or with a jet of hot air in order to minimize the chance for water to soak into the windings. Where laminated iron, such as the fields or armatures of motors, have been wetted the drying should be especially thorough,

"**Solvents**—Where the accumulation of dirt contains grease or oil, there are three solvents in general use for its removal: petroleum distillates such as benzine or gasoline; carbon tetrachloride; and a mixture of the two. Of these, the carbon tetrachloride is the most active, with a mixture second, and the benzine or gasoline last. Any o them, however, are sufficiently powerful for most cases, so that the choice depends upon the degree of fire risk involved and also upon the ventilation available to protect the operator.

"Benzine and gasoline are petroleum distillates and are of course highly inflammable when their vapors form mixtures with air. They are therefore permissible only where damage from fire would not be excessive, and where there is sufficient ventilation to remove the fumes rapidly enough to prevent them ever reaching explosive concentrations with air. The cleaning should be done by sponging the parts with rags wetted by the solvents. The apparatus should then be dried thoroughly to remove all traces of the solvents. Their continued presence might soften the varnish.

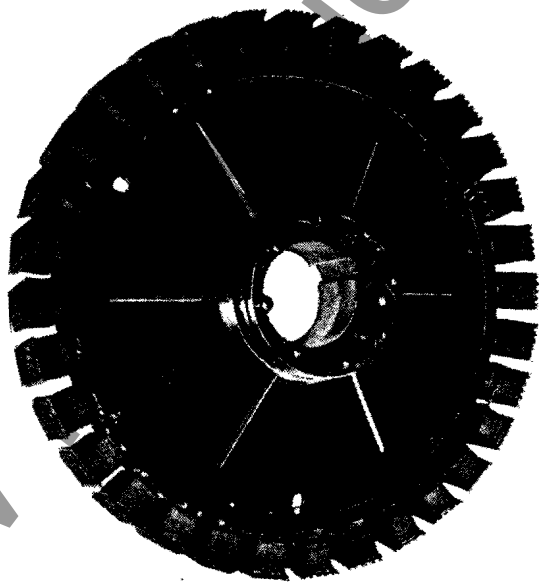


FIG. 12—PLATE TYPE SPIDER FOR LARGE DIESEL GENERATOR

"Carbon tetrachloride is a non-inflammable compound but is to some extent toxic. The chief danger in its use is that the vapor is heavier than air and will accumulate in pits or confined spaces and cause suffocation and poisoning of anyone working. It should never be used without complete ventilation, preferably a forced draft of air to carry the fumes away and then only when the fire hazard with other solvents makes it necessary. Carbon tetrachloride is an active solvent, 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.

"A mixture of 50-50 carbon tetrachloride and benzine, or 60-40 carbon tetrachloride and gasoline, is non-inflammable but the vapors mixed with right proportions of air are explosive. This hazard is greatly reduced, however, as compared with the use of the petroleum solvents alone.

"Two types of commercial solvents or cleaning fluids are sold by the oil companies. One of them conforms to the specifications covering Stoddard solvent*, which is safer than gasoline because it has a higher flash point. It does not catch fire so easily as benzine or gasoline, but it cannot be considered non-inflammable. This material costs about the same as gasoline. The other type is a mixture of a petroleum distillate like Stoddard solvent and carbon tetrachloride. It is similar to the carbon tetrachloride and petroleum solvent mixture referred to and should be used with he same precautions. The cost is between that of gasoline and carbon tetrachloride.

"**Precautions**—It is advisable to remember the precautions already inferred. Carbon tetrachloride alone or in any mixture in addition to being relatively expensive, is dangerous to life if one is subjected to prolonged or concentrated exposure to its fumes and should never be used unless the fire risk from the petroleum solvents is too great. In no case should solvent cleaning be attempted unless the ventilation is sufficient to prevent accumulation of the vapors or a gas mask is worn by the operator. A Mine Safety Appliance Company, special nose mask is recommended for this service. Furthermore

†*Reprinted from Electric Journal, November 1933, Vol. 30, No. 11.*

**A petroleum distillate prepared especially for dry cleaning — Bureau of Standards "Commercial Standard CS3-28."*

it is dangerous to have an operator working alone, particularly where carbon tetrachloride is being used. With two operators, it is not likely that both would be affected simultaneously, and if one is overcome the other can help him to fresh air."

The dirt which clings to the field coil washers should be removed carefully since it may accumulate and form a conducting path from coil to ground. A coat of insulating varnish applied to the armature and field coils after they have been cleaned will protect the insulation. An air hose should be applied to the air ducts through the stator punchings since an accumulation of dirt at this point will impede the free flow of cooling air.

Oil

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

Only the very best grade of oil—having a viscosity of from 200 to 220 seconds, Saybolt, at 100°F., should be used for horizontal machines and oil with a viscosity of 250 to 300 seconds, Saybolt, at 100°F., should be used for vertical machines. It always proves a false economy to use cheap oil. If the oil is to be used a second time, it should be filtered and if warm, allowed to cool before the bearings are refilled. Even new oil should be examined carefully and filtered or rejected if it is found to be gritty

Collector Rings and Brushes.

a. Sparking.

If sparking between the brushes and the collector rings occur, the following points should be checked:

1. Brush pressure.
   It may be that the pressure on the brushes is insufficient to make them follow the ring surface.
2. Brush holder vibration.
3. Brush chatter.
4. Oil vapor.
5. Collector ring truth.
6. Spotted rings.
   This has been cured in certain cases by the use of a more abrasive brush.

b. Selective action between brushes.

This is generally aggravated by any of the causes of sparking at the brushes and if the same remedies are applied, it can generally be improved.

Since there is always an electrolytic action on the surface of an iron ring, the collector operation is improved by occasionally reversing the polarity of the rings. Sometimes trouble will occur on one ring only and by reversing the polarity every day or so, the trouble will entirely disappear.

Occasionally ring trouble will arise from a ring not being of uniform hardness, so that it wears unevenly. Such a ring should be replaced. Small pin holes in the surface of a cast iron ring will not cause trouble.

Collector ring trouble is seldom due to high current density as the maximum current density, 40 amperes per square inch or less, is well below the maximum density specified for the brushes.

The brushes used should be light in weight, with a fairly high current capacity and should contain a slight amount of abrasive material. A suitable grade is furnished with the machine, and for best results this grade should always be used.

Renewal Parts

Repairing

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

Ordering Instructions

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

RECOMMENDED STOCK OF RENEWAL PARTS

The following is a list of the Renewal Parts and the quantities of each that we recommend should be stocked by the user of this apparatus to minimize interrupted operation caused by breakdowns. The parts recommended are those most subject to wear in normal operation or those subject to damage or breakage due to possible abnormal conditions.

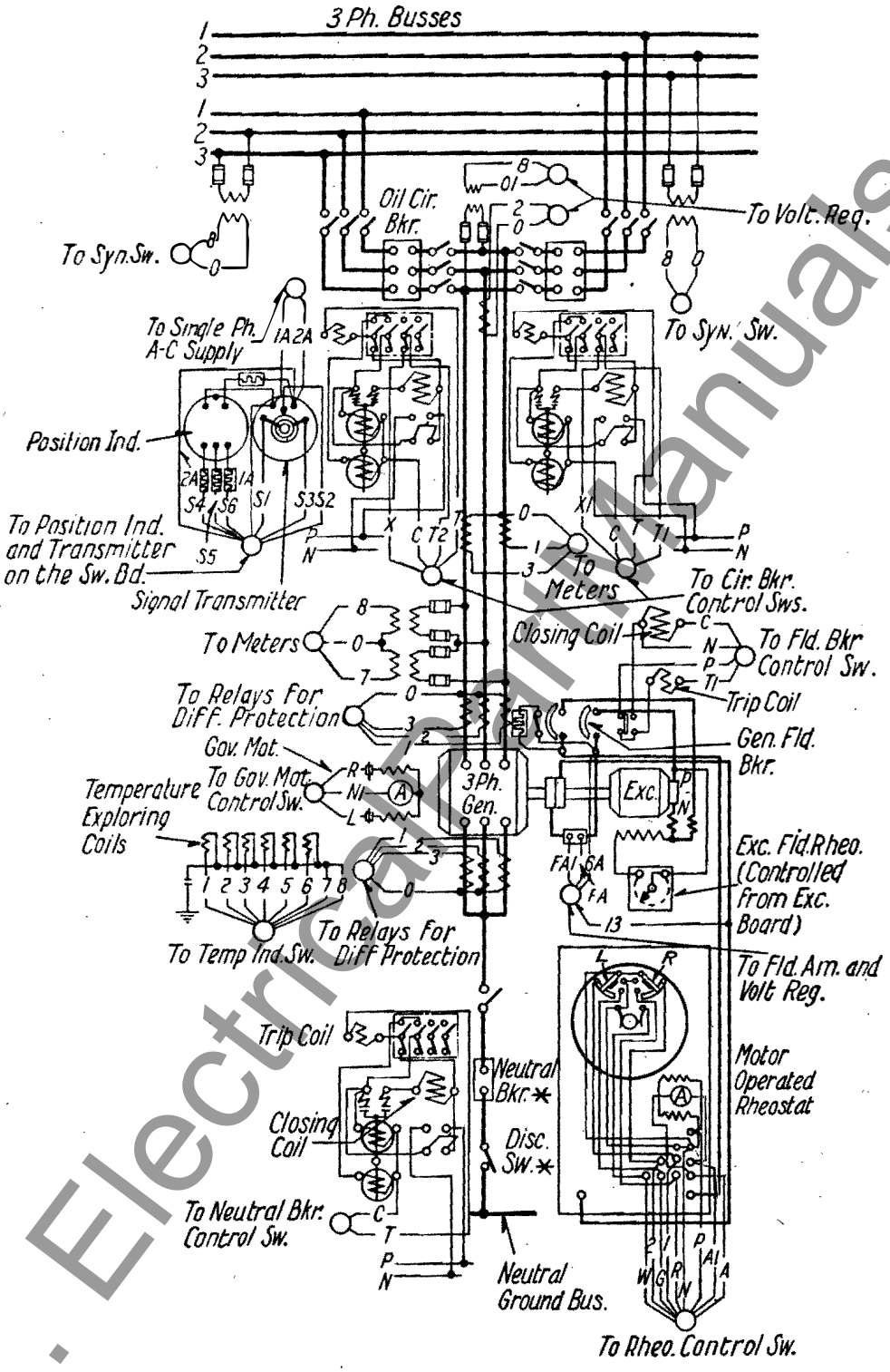
This list of Renewal Parts is given only as a guide. When continuous operation is a primary consideration, additional insurance against shutdowns is desirable. Under such conditions more renewal parts should be carried, the amount depending upon the severity of the service and the time required to secure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

VERTICAL TYPE GENERATORS

Generators in use up to and including		1	5
Name of Part	No. Per Generator	Recommended For Stock	
Armature Coil—Stationary	1 Set	⅓ Set	1 Set
Cut Winding Insulation	1 Set	⅓ Set	1 Set
Revolving Field Coil—Open	1 Set	1	1
Revolving Field Coil—Crossed	1 Set	1	1
Brush	1 Set	1 Set	2 Sets
Brushholder	1 Set	⅓ Set	1 Set
Thrust Bearing Shoe	1 Set	0	1 Set
Guide Bearing Lining	1 Set	0	1 Set

HORIZONTAL GENERATORS AND SYNCHRONOUS CONDENSERS

Generators or Condensers in use up to and including		1	5
Name of Part	No. Per Unit	Recommended For Stock	
Armature Coil—Stationary	1 Set	⅓ Set	1 Set
Cut Winding Insulation	1 Set	⅓ Set	1 Set
Revolving Field Coil—Open	1 Set	1	1
Revolving Field Coil—Crossed	1 Set	1	1
Brush	1 Set	1 Set	2 Sets
Brushholder	1 Set	⅓ Set	1 Set
Bearing Lining—Front	1	1	1
Bearing Lining—Rear	1	1	1
Oil Ring—Front	1 Set	0	1
Oil Ring—Rear	1 Set	0	1



*Note: Neutral bkr. and one disc. sw. are optional equipment.

FIG. 13—TYPICAL DIAGRAM OF CONNECTIONS FOR GENERATOR CONTROL FOR A DOUBLE-BUS SYSTEM

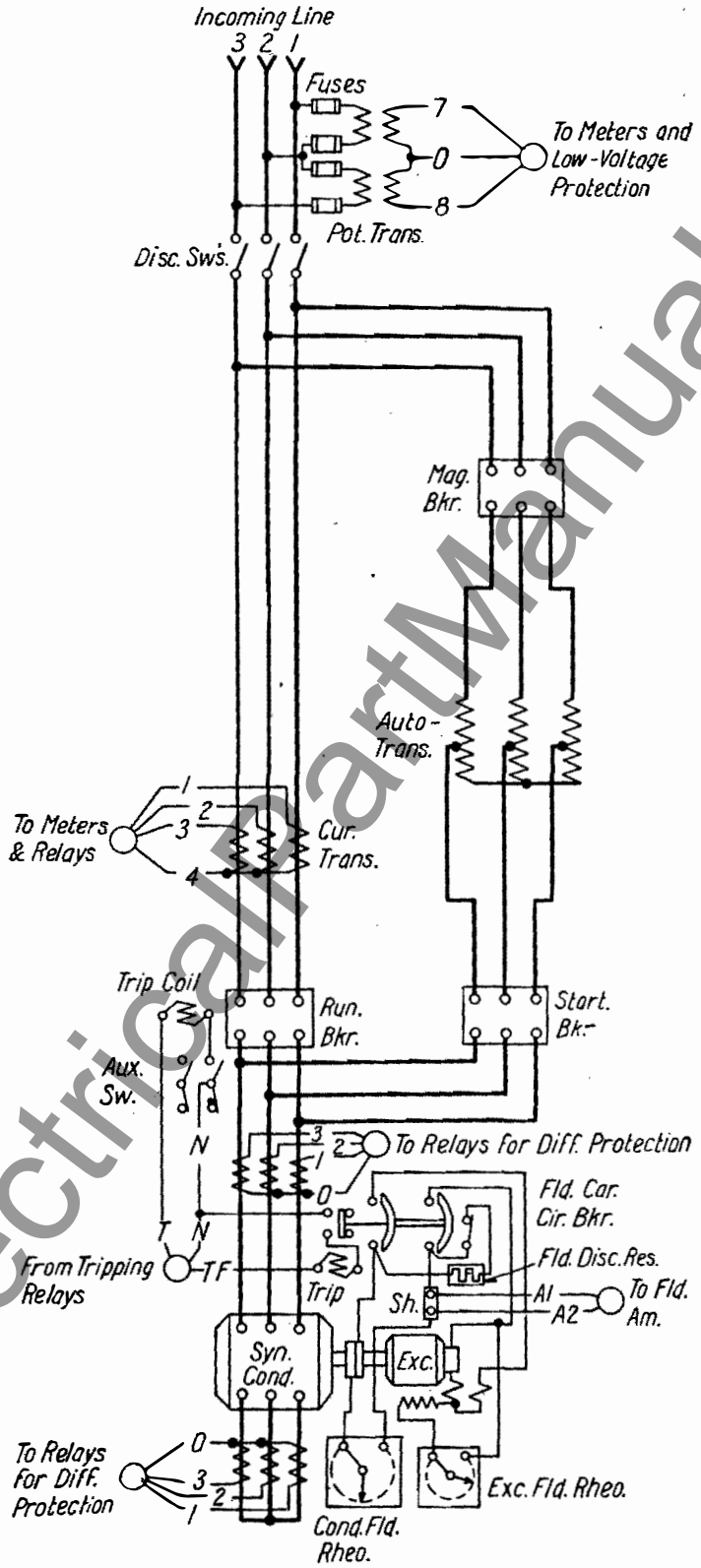


FIG. 14—TYPICAL DIAGRAM OF CONNECTIONS FOR MANUALLY-CONTROLLED A-C. SELF-STARTING SYNCHRONOUS CONDENSER