Westinghouse

Vertical Water Wheel Synchronous Generators

GENERAL INFORMATION AND CONSTRUCTION

Installation

Operation **Maintenance**

INSTRUCTION BOOK

Westinghouse Electric & Manufacturing Company
East Pittsburgh, Pa.

I. B. 7240

COMMUNICATIONS

When communicating regarding a product covered by this Instruction Book, replies will be greatly facilitated by citing COMPLETE NAME PLATE READINGS of the involved products. Also, should particular information be desired, please be very careful to clearly and fully STATE THE PROBLEMS AND ATTENDANT CONDITIONS.

PURPOSE

The purpose of this instruction book is to give the reader the maximum of useful information and suggestions concerning construction, installation, operation and maintenance of Westinghouse Vertical Water Wheel Generators.

The material contained herein has been assembled with a view toward facilitating installation and operation of the equipment and this book is intended to serve as a guide to installation and operating personnel so that the maximum useful life of the apparatus can be obtained.

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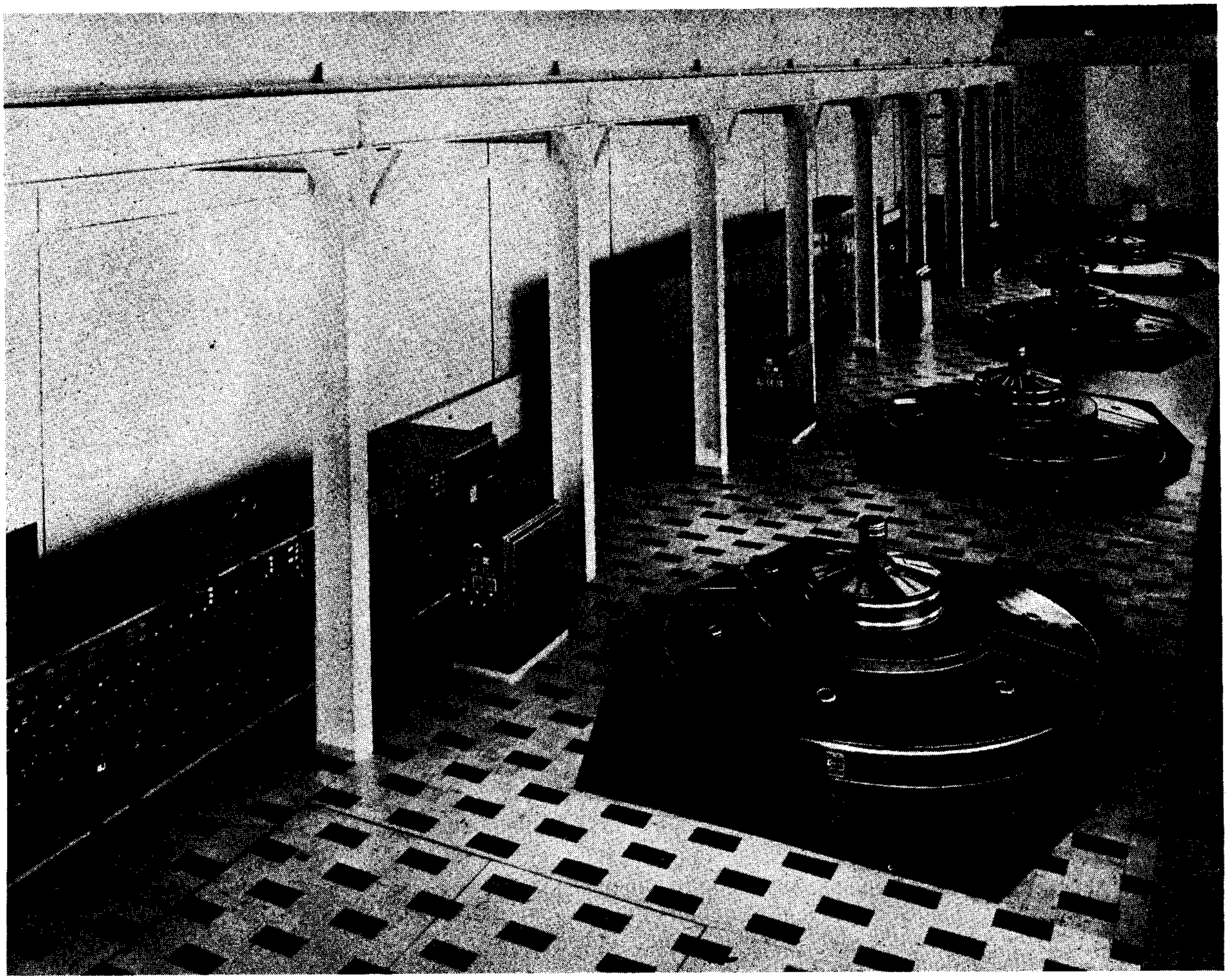

FIG. 1—INSTALLATION VIEW OF A MODERN HYDRO-STATION

Westinghouse

Vertical Water Wheel Synchronous Generators

PART I

GENERAL INFORMATION

Waterwheel driven, synchronous generators are standardized for a wide range of capacities and speeds, to meet the varying hydraulic conditions of flow and head which are encountered in this country and throughout the world. (Westinghouse generators are installed in many foreign countries).

The capacities vary from 62½ Kv-a. at 1200 RPM to 125,000 Kv-a. at 60 RPM, on the basis of 60 cycle frequency.

With such a wide range of speeds and capacities, it logically follows that there are differences in the type of design, construction of the major parts, and in the proportions of the units. In general, the high speed units are axially longer in proportion to the overall diameter than the slower speed units.

There are two primary structural types of waterwheel generators, viz: (1) the **conventional two-guide bearing type** having the thrust bearing above the rotor and a guide bearing above and below the rotor, and (2) the **umbrella or single-guide bearing type** having a combined thrust and guide bearing located below the rotor. Note Figs. 21 and 22 which show a cross section of each type of construction.

Each type has its own field of application.

The two-bearing machines are those in the higher speed class, having comparatively small diameters and comparatively long core lengths.

The umbrella type, on the other hand, are those slower speed units with comparatively large diameters and short core lengths.

The major limiting factor in the design of Umbrella type machines is the ratio of the vertical distance between centers of the rotor and guide bearing to the radial distance to the center of the guide bearing. Umbrella construction is not used where this ratio exceeds the value required for mechanical stability.

Direct connected exciters are commonly used to provide excitation for the generator. The smaller generators are usually provided with a main exciter only, whereas the larger units are furnished with both a main and a pilot exciter. In most installations the larger units are connected to long transmission lines or are a part of a large network system where a high speed of exciter voltage response is desirable. This high rate of exciter voltage response can best be obtained by the use of a fixed voltage, pilot exciter.

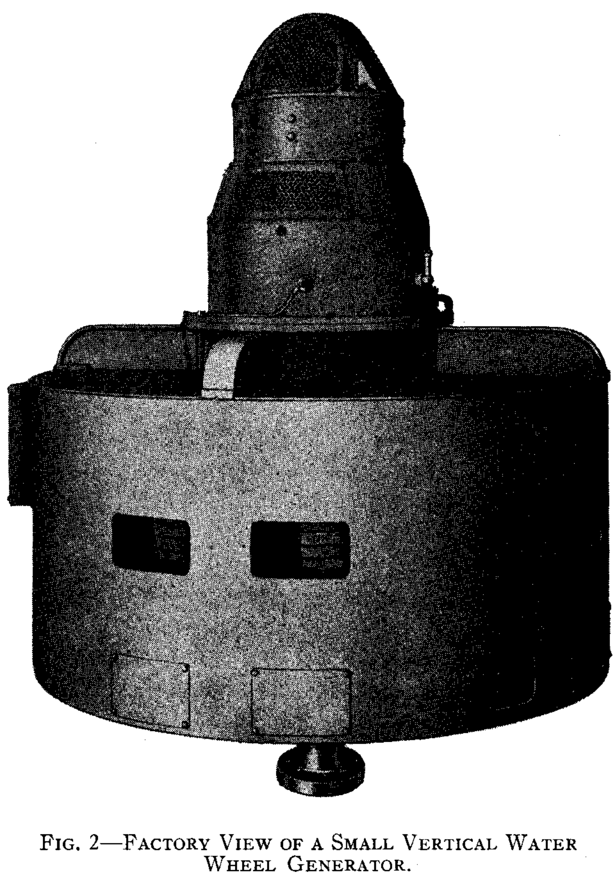

FIG. 2—FACTORY VIEW OF A SMALL VERTICAL WATER WHEEL GENERATOR.

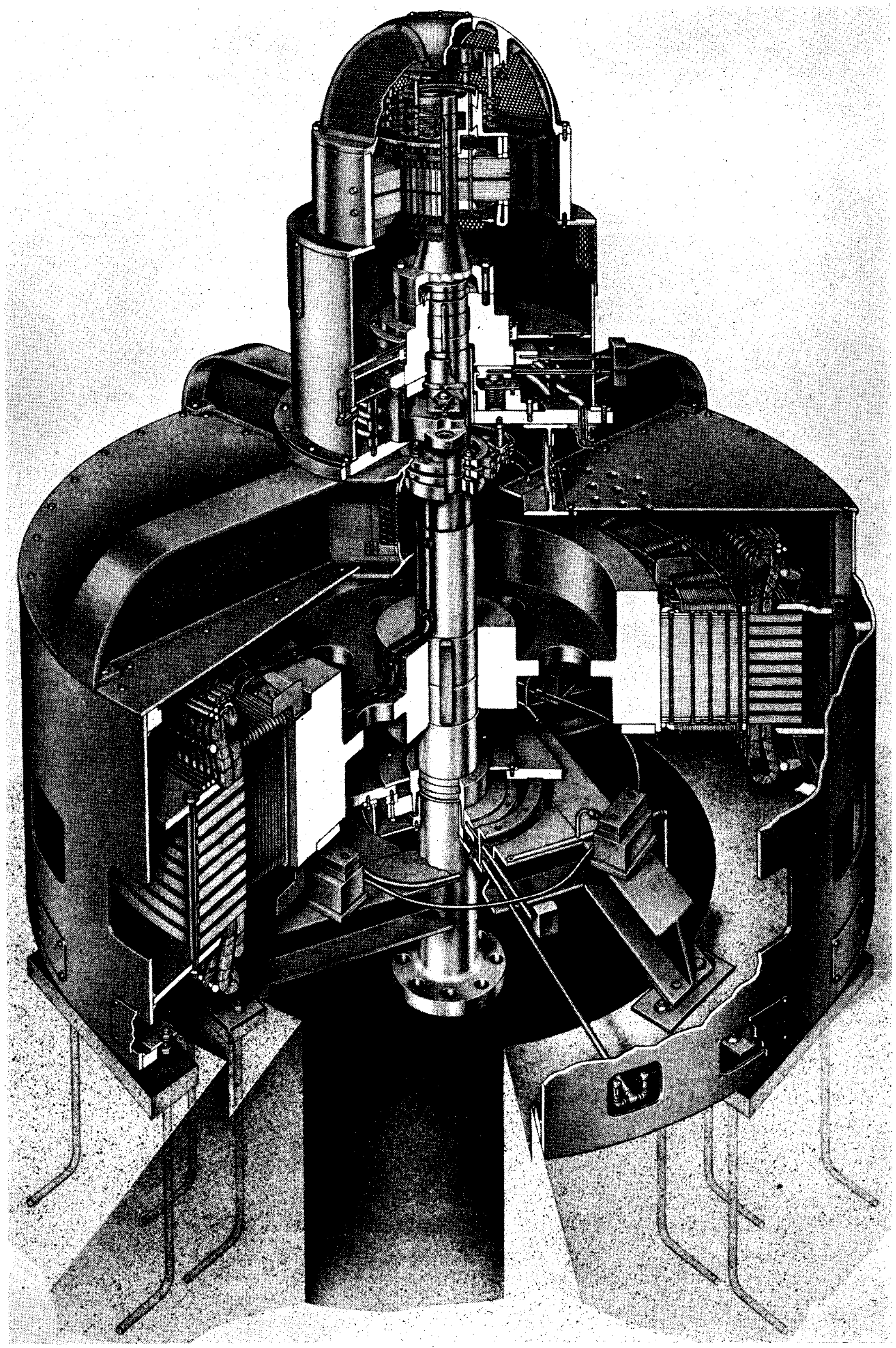

FIG. 3—CUTAWAY VIEW OF A SMALL VERTICAL WATER WHEEL GENERATOR.

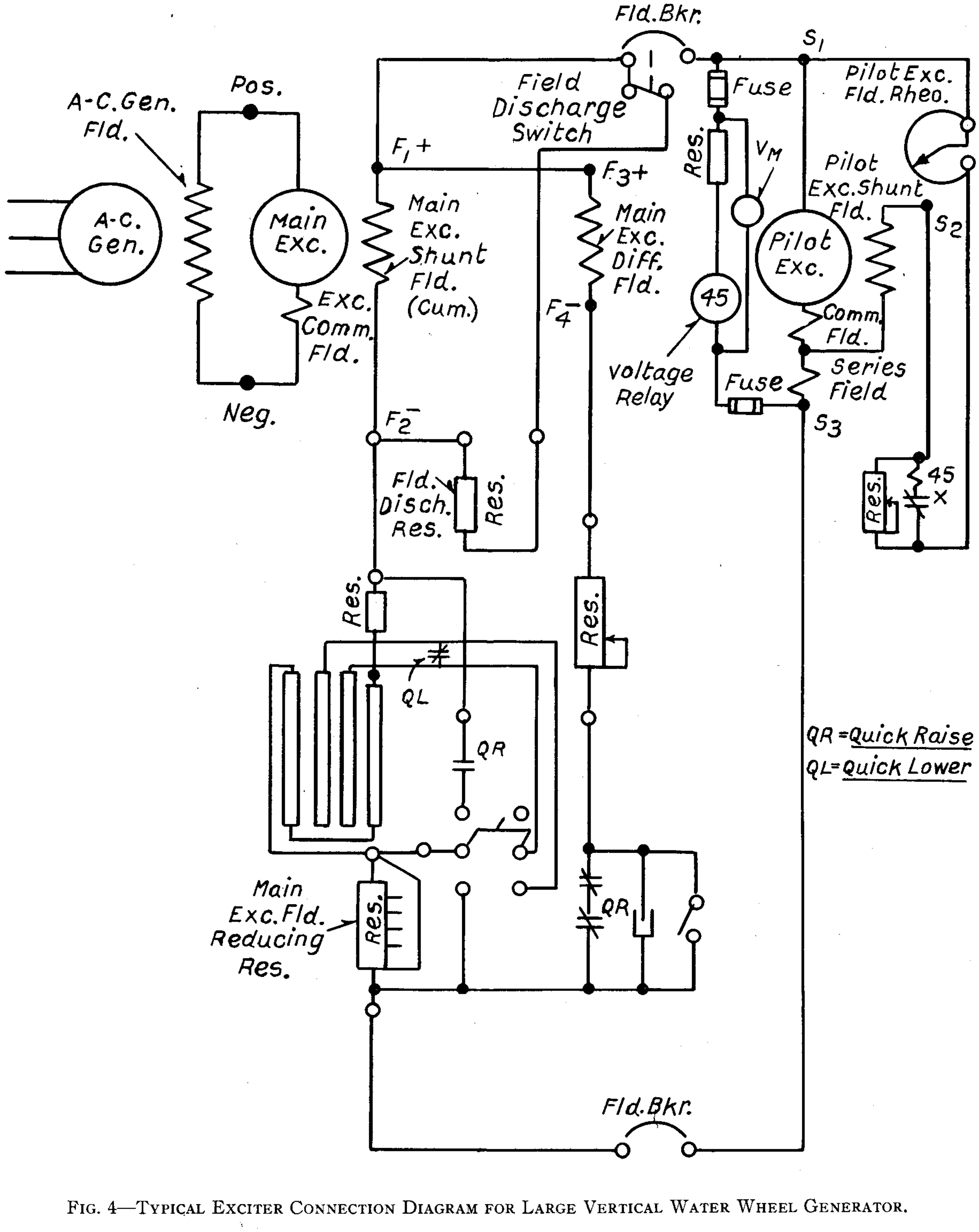

FIG. 4—TYPICAL EXCITER CONNECTION DIAGRAM FOR LARGE VERTICAL WATER WHEEL GENERATOR.

The excitation circuit varies with individual installations and therefore it would not be possible to include all the schematic connection diagrams which might be used. Fig. 4 shows a typical excitation diagram for the large generators.

An instruction book is furnished with all direct connected exciters and the operator should refer to this book for more specific information on operation and maintenance.

PART II

CONSTRUCTION

CONSTRUCTION

A general understanding of the construction of the apparatus is necessary in order that the succeeding chapters on installation, operation and maintenance be the most helpful. Figs. 3, 21 and 22 respectively show typical cross section views of the small two-bearing units, the large two-bearing units and the large umbrella or single guide bearing units.

It is recommended that the reader study the illustrations in conjunction with the following descriptive matter.

STATOR

(A) Frame

The stator frame is fabricated from electrically welded steel plates to form a rigid box section. The frames are solid for the small machines and the larger machines are sectionalized in either 2, 3, or 4 sections to meet shipping limitations. The stator core is assembled on bolts which span the length of the frame. Openings are provided around the periphery of the frame wrapper plate for discharge of the ventilating air. Suitable lifting holes are provided in the frame to permit handling during assembly. Note Figs. 5 and 6.

(B) Stator Core

The stator core is built up of segmental, high grade, non-aging silicon steel laminations. Both

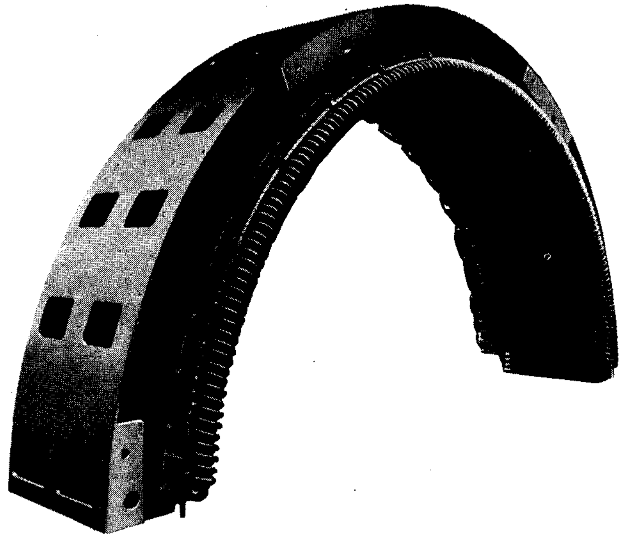

FIG. 6—ONE SECTION OF A TWO SECTION STATOR HAVING ALL COILS WOUND EXCEPT THOSE NEAR THE SPLITS.

FIG. 5—TYPICAL FABRICATED STATOR WITH INTEGRAL LOWER GUIDE BEARING BRACKET FOR SMALL VERTICAL WATER WHEEL GENERATOR.

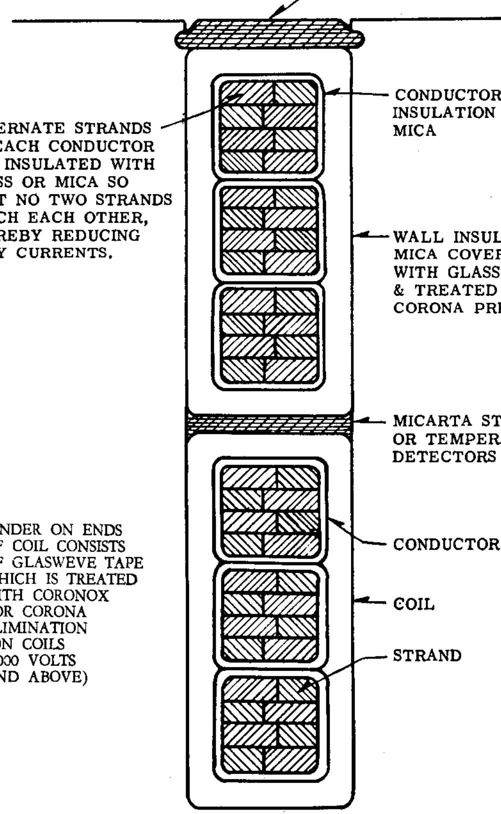

FIG. 7—A CROSS SECTION VIEW SHOWING TYPICAL CONSTRUCTION OF ARMATURE COIL WITH CLASS B INSULATION (6900 VOLTS AND ABOVE).

CONSTRUCTION—Continued.

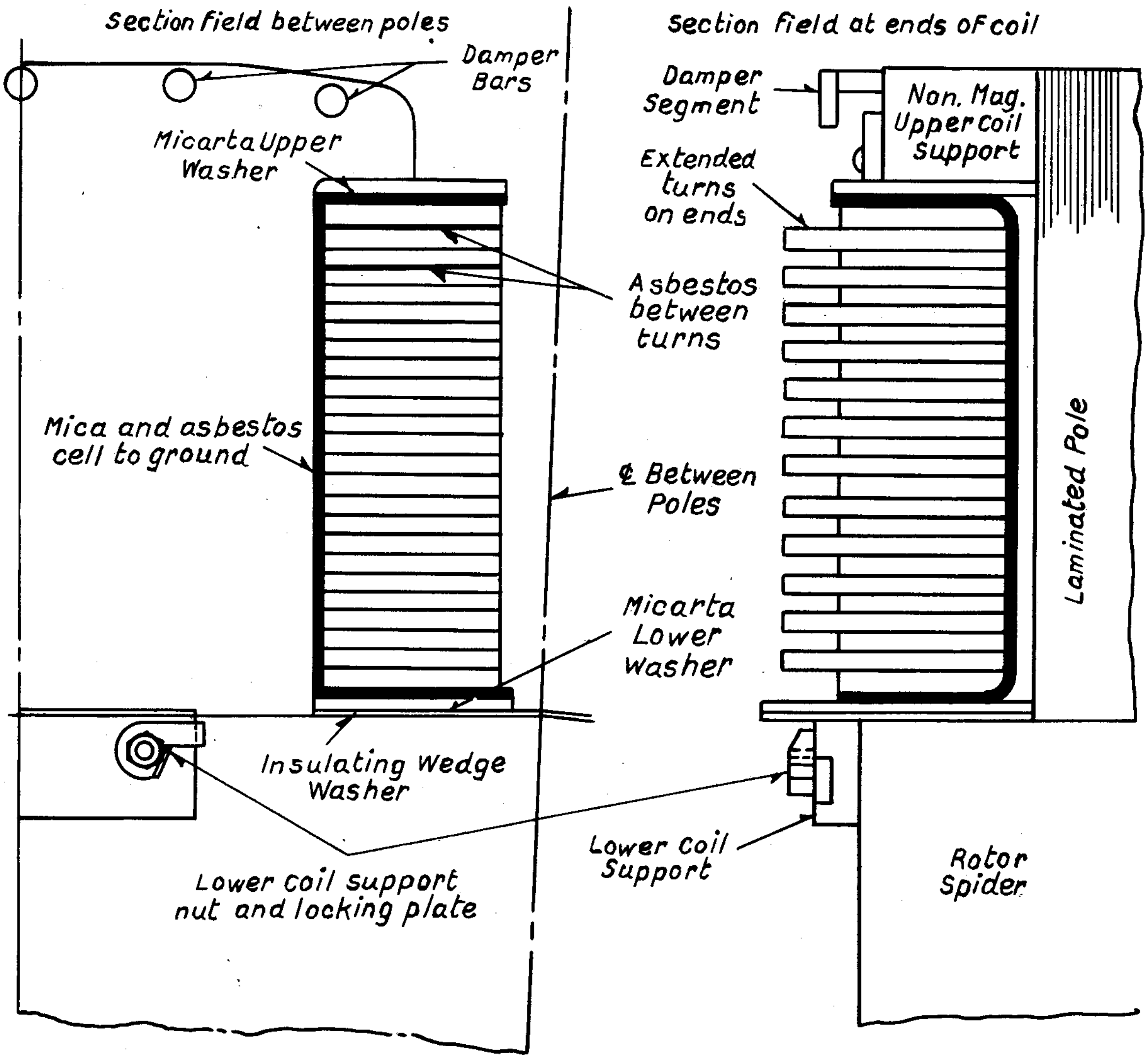

FIG. 8—TYPICAL SIDE AND END SECTION OF STRAP FIELD COIL ASSEMBLY FOR SLOW SPEED GENERATORS.

sides of the laminations are treated with a suitable insulating material to prevent short circuiting the laminations. Adequate pressure is applied at intervals during the stacking operation to produce a tight core. The core laminations are kept tight by means of heavy fingerplates and end plates which maintain adequate pressure on the core at all times. This construction lessens the possibility of loose iron and core vibration. Note Fig. 6.

(C) Stator Winding

The stator windings of all standard vertical water wheel generators consist of form wound, pulled type, interchangeable coils. Standard waterwheel generators below 6250 Kv-a. have class "A" insulation regardless of voltage. For 5000 volts and below, class "A" insulation is standard regardless of capacity. Above 6250 Kv-a. and 5000 volts all standard machines have stator coils insulated with class "B" insulation.

Class A insulation is identified by A.S.A. and N.E.M.A. Codes ABAV, ABAVX, ABBVX.

Class B insulation is identified by A.S.A. and N.E.M.A. Code BBBVX. A cross-section view of a typical stator coil is shown in Fig. 7. Note Figs. 6 and 28 for partially wound stators.

(D) Temperature Detectors

Six embedded temperature detectors are standard and are provided in the stator winding of all generators above 1500 Kv-a. capacity to obtain a measurement of the operating temperature. The detectors are located at the center of the core and between the top and bottom coil sides in a slot. Note Fig. 7 for location. The detectors consist of a flat copper wire coil having a resistance of 10 ohms at 25°C.

CONSTRUCTION—Continued.

The temperature coefficient of resistance of these detectors is .00427 ohms per degree C. The detector leads are brought to a terminal board which is arranged so that one lead of the detectors can be grounded to protect the operator. The terminal board is usually mounted on the generator frame in an accessible location to permit connection to Purchaser's measuring devices.

ROTOR

(A) Poles

The field poles are built up of steel laminations riveted or bolted together under high pressure. The poles of the small slow speed machines are usually bolted to the rim of the rotor spider. Note Figs. 10 and 14 for typical rotor construction of small machines. This construction is used when the stresses permit. The rotor illustrated in Fig. 14 is typical of the type of construction employed in the smaller machines except that the poles are dovetailed to the steel rim because of the high speed requirement for this particular unit.

The higher speed machines as well as the larger capacity machines requiring a "shrunk-on" laminated rim have the poles dovetailed to the rim. Note Fig. 9 and 11.

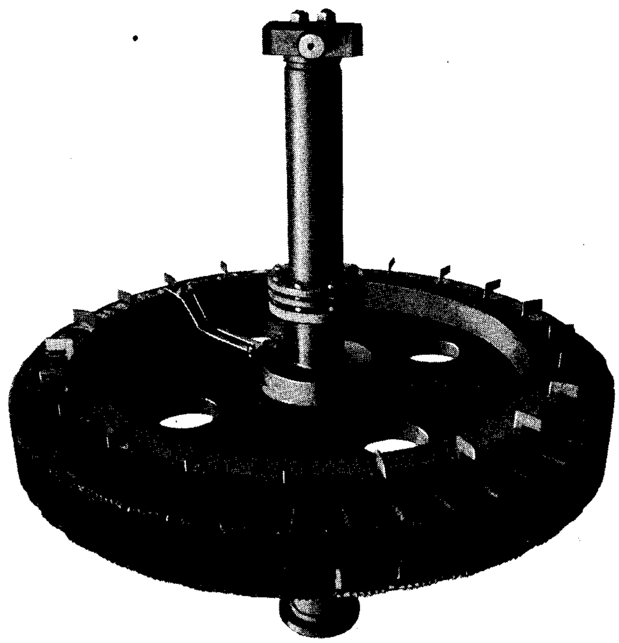

Fig. 10—View of Rotor and Shaft of Small Water Wheel Generator.

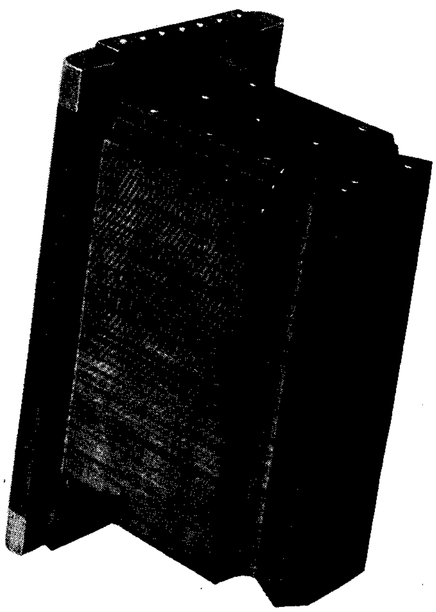

Fig. 9—Typical Field Pole for High Speed Vertical Water Wheel Generators Showing Dovetail.

In these cases, dovetail projections on the pole engage the dovetail slots in the spider rim and the pole is held in position in the spider slot by tapered keys or wedges. Note Fig. 11. In assembly, tapered keys are driven in from each side of the rotor. The taper is so slight (.005) inches per inch) that there is no tendency for the keys to slip after once being set.

The taper key assembly consists of a thick key, a thin key and a liner. The thick key is proportioned to withstand driving without damage.

(B) Field Winding

The field winding consists of coils wound from strap copper for the large generators and either strap or wire for the smaller generators.

Where strap is used, it is wound on edge. The copper strap is formed into the shape of the coil and then strips of asbestos, soaked in shellac, are placed between the turns. The partially completed coil is heated and pressed to expel all the solvents.

After finishing, the outer edges of the copper strap are practically bare, being covered only with

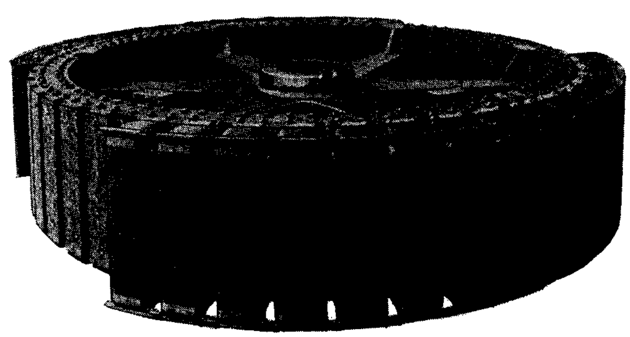

Fig. 11—View of Large Laminated Rim Rotor with Part of Poles and Coils Installed.

CONSTRUCTION—Continued.

a coat of insulating varnish. This allows the heat to be dissipated effectively from the exposed edges. Strap field coils are insulated from the pole by a cell of either treated rope cement paper (Class A) or mica and asbestos (Class B). Micarta washers at the top and bottom (in addition to the cell) insulate the coil from the pole tip and spider respectively. Note Fig. 8 for typical field coil construction.

Where wire is used, it is generally wound on a separate former, but in some of the smaller machines having a narrow core the wire is wound directly on the pole. During the winding process the wire is brushed with a bakelizing varnish. The completed coil is pressed in the direction of the turns and layers while being baked at high temperatures. This procedure produces a compact coil, which is mechanically adequate.

(C) Damper Windings

Damper windings are supplied in the pole faces of vertical waterwheel generators only when specifically required by the contract. They are frequently specified on the larger machines as such units are generally connected to long transmission lines which may have values of inductance, capacitance and resistance that will produce a resonant circuit and thus impress high voltages on the winding or protective devices, in the event of a line to ground fault, if dampers are not provided.

Except for occasional automatic stations, dampers are seldom specified on the smaller ratings.

When dampers are supplied they may or may not be connected in the interpolar space, depending upon the desired relation of the sub-transient reactances on the direct and quadrature axes. Note Fig. 11.

(D) Ventilation—Fans

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

Westinghouse synchronous generators are designed and proportioned so that the cooling air is uniformly directed to all sources of heat generation. The fans or blowers, which are mounted on the rotor, are liberally designed; the ventilating ducts in the stator core are liberal in number and so distributed that uniform temperatures exist throughout the entire length of the machine.

The blowers or fans provided on the rotors of the large machines are usually of the inclined blade, centrifugal type, When the fans are properly assembled on the rotor, the inner edge of the blades lead the outer edge in the direction of the mechanical rotation. If the fans are incorrectly assembled, they will not deliver the normal amount of air and the machine will operate at higher than normal and possibly at dangerous temperatures.

It is therefore important that the blower mounting be checked before the assembly has progressed too far. If the blowers are found to be incorrectly mounted with respect to the mechanical rotation, then they must be reversed end for end if possible.

BEARINGS

(A) Thrust Bearings

All Westinghouse vertical waterwheel generators are supplied with a flat adjustable Kingsbury type thrust bearing. Each of the individual shoes is supported on an adjustable jack screw which makes it possible to distribute the load equally between the individual shoes. Note Figs. 12-13. The individual shoes are made of steel plate, finished on the surface so that the babbitt may be tinned directly to the surface of the shoes. The bearing assembly operates in a bath of oil, which insures that the surfaces will be separated by a wedge shaped oil film as illustrated by Fig. 15.

The loaded plate shown in the illustration is constrained to move horizontally. It rests on several shoes which can tilt on the ends of pivots and allow the oil film to assume the desired wedge form. The principle is the same whether the supporting shoes tilt or the load plate does; also whether the shoe pivots are fixed and the load plate moves, or the latter is fixed and the shoes move.

In the practical application of the principle, illustrated by Fig. 15, the loaded plate is the runner plate which is attached to the shaft and rotates in a bath of oil at shaft speed. The jack screws under the shoes are the supports or pivots and they are in the center of the shoe (circumferentially).

NOTE:—Fig. 16 which illustrates the care with which the runner surface is finished.

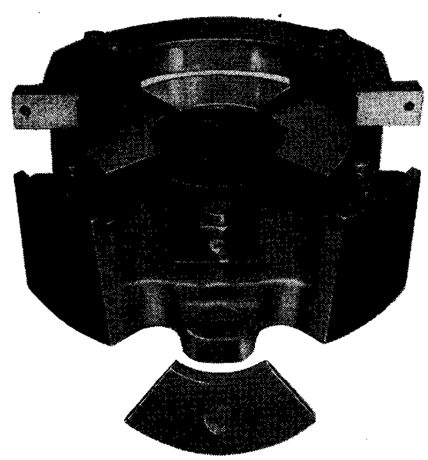

FIG. 12—TYPICAL COMBINED GUIDE AND THRUST BEARING FOR SMALL WATER WHEEL GENERATORS (ONE SHOE AND ONE-HALF OF GUIDE BEARING REMOVED).

CONSTRUCTION—Continued.

(B) Guide Bearings

There are three types of guide bearing designs supplied with Westinghouse vertical waterwheel generators. Each has its own field of application. These types are:

(1) Conventional sleeve type which bears against the surface of the shaft. This type is used on the high speed two-bearing generators.

(2) Segmental shoe type with adjustable jack screws similar to the thrust bearing design. This type is used on the umbrella design generators and the slow speed two-bearing generators. Note Fig. 19.

(3) Split type sleeve bearing, used with the small generators. Note Fig. 12.

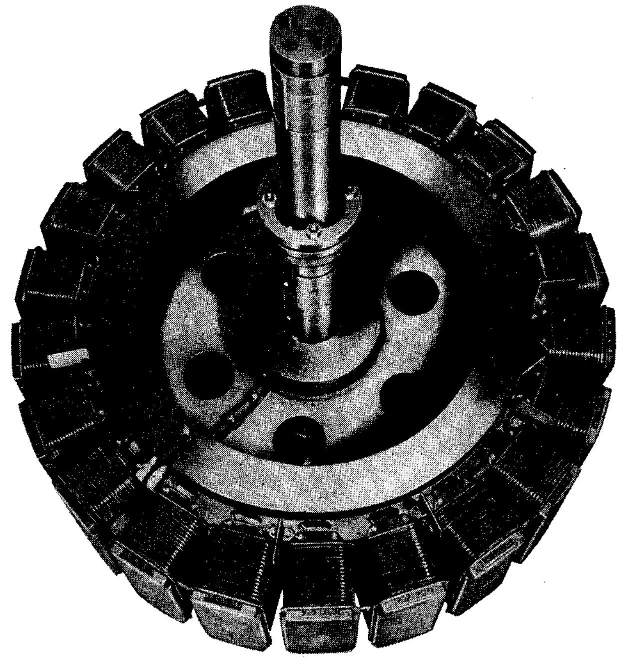

FIG. 14—ROTOR FOR SMALL HIGH SPEED WATER WHEEL GENERATOR.

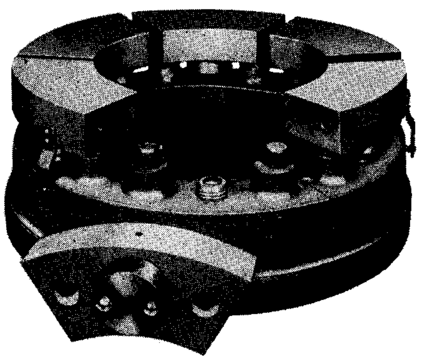

FIG. 13—TYPICAL THRUST BEARING FOR LARGE WATER WHEEL GENERATORS (ONE SHOE REMOVED).

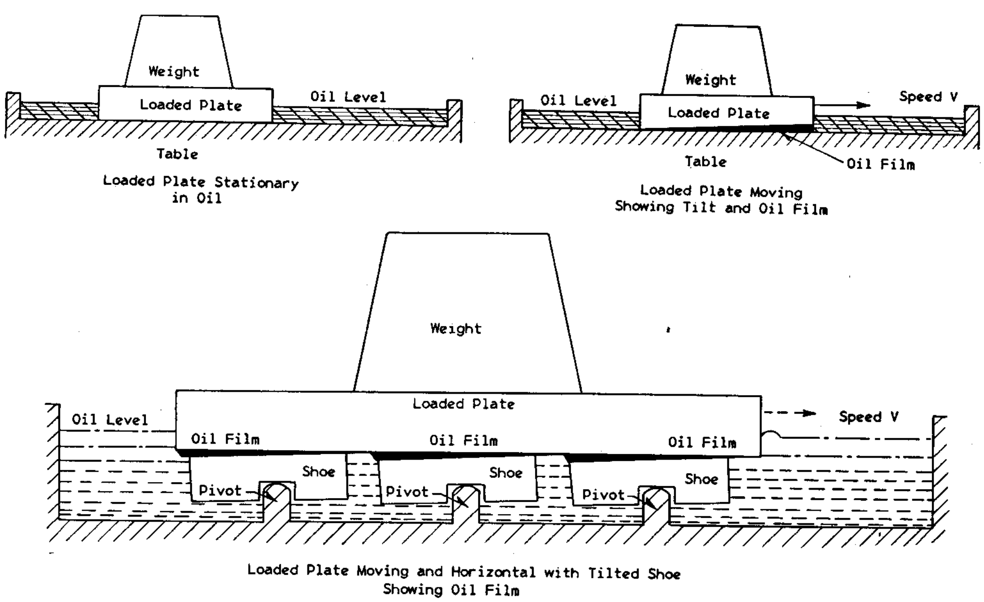

FIG. 15—LOADED PLATE MOVING AND HORIZONTAL WITH TILTED SHOE SHOWING OIL FILM.

CONSTRUCTION—Continued.

BEARING INSULATION

Variations in reluctance in the magnetic circuit of an alternating current machine may cause periodic changes in the amount of flux which links the shaft. This change in flux may generate sufficient voltage to circulate current through the circuit consisting of shaft, bearings, brackets and frame. This condition is encountered only in machines having two guide bearings and if precautions are not taken to prevent its flow this circulating current soon has a destructive effect upon the shaft journals and the bearings. Small pits are usually formed on the surface of the shaft and runner plate. These pits are sufficiently rough to score the surface of the bearings and in some instances, the bearing babbitt actually shows evidence of having been eaten away by the current.

As it is not practical to provide control of the generation of shaft voltages and currents, it becomes necessary to insulate one or more of the bearings from their supporting members. This insulation interrupts the path for circulating currents. The insulation consists of a suitable thickness of micarta or vellumoid placed between the bearing shell or bearing support and the bearing brackets. To avoid short circuiting the insulation, all water and oil piping and detector bulbs must also be insulated.

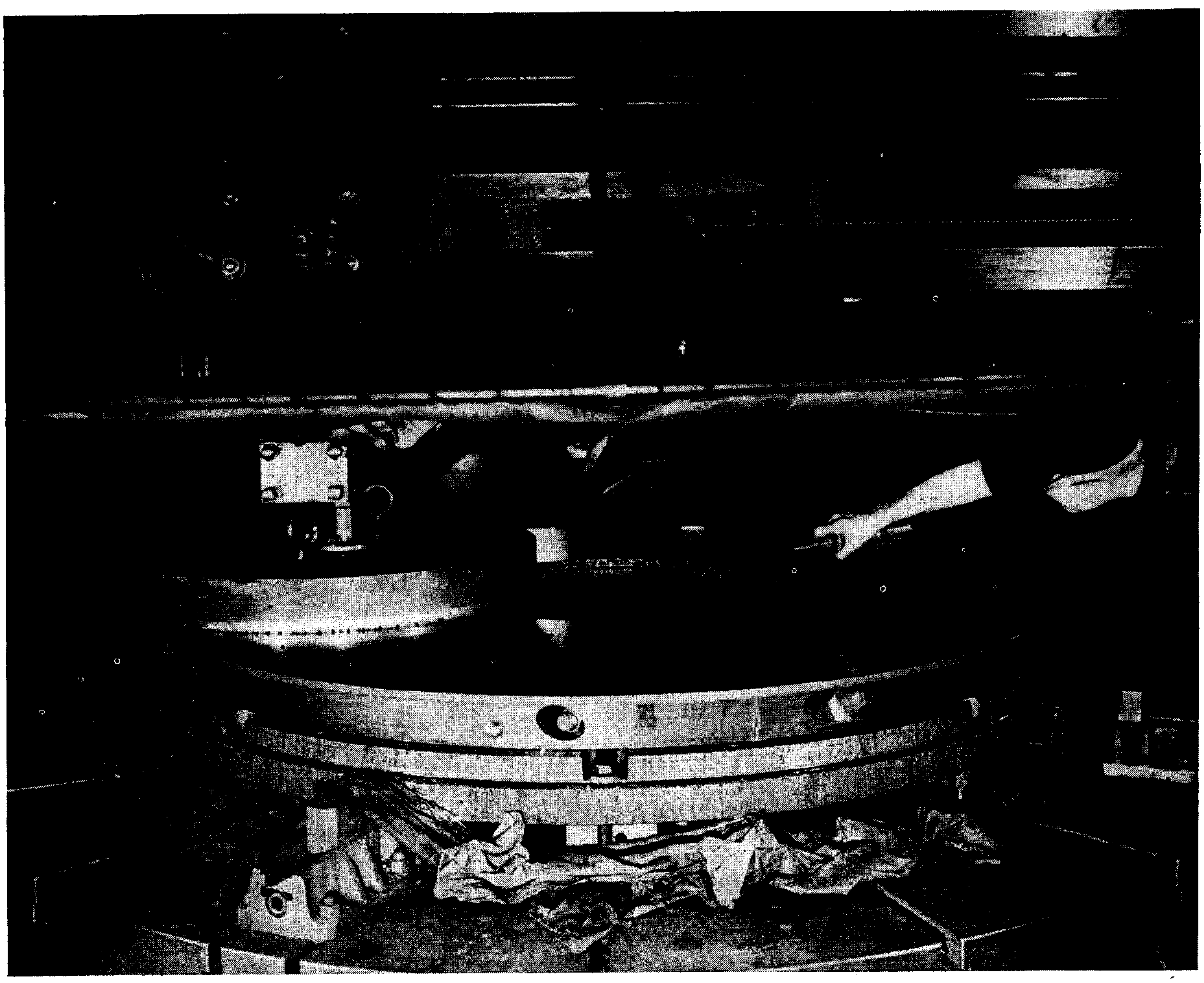

FIG. 16—FACTORY VIEW ILLUSTRATING THE METHOD OF POLISHING A THRUST BEARING RUNNER.

CONSTRUCTION—Continued.

BRAKES AND JACKS

Vertical waterwheel generators may be provided with either hand, air, or oil operated brakes. The former is applicable only to the small slow speed machines, while one of the latter two types are used on all large vertical generators. When the brakes are air or oil operated, they may also be used to lift the rotor and so expedite the assembly. When so used, they are termed jacks. Note Fig. 18.

BEARING BRACKETS

The bearing brackets for all types of Westinghouse generators are fabricated from structural steel members. They are proportioned to support the loads imposed on them, with minimum deflection. Two of the various types of brackets are shown in Figs. 17 and 18. On the Umbrella type the lower bracket must be designed to support the entire rotating load since the thrust bearing is carried by this member.

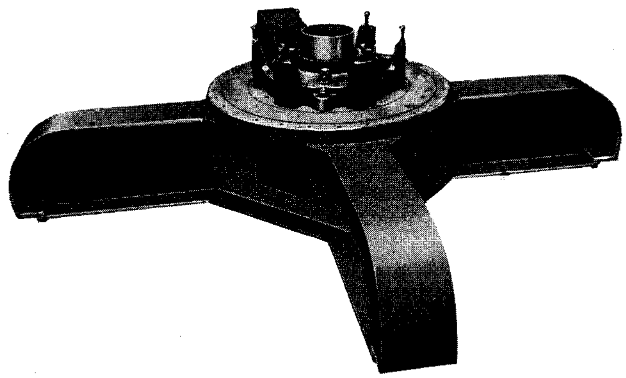

FIG. 17—UPPER BRACKET FOR SMALL WATER WHEEL GENERATOR.

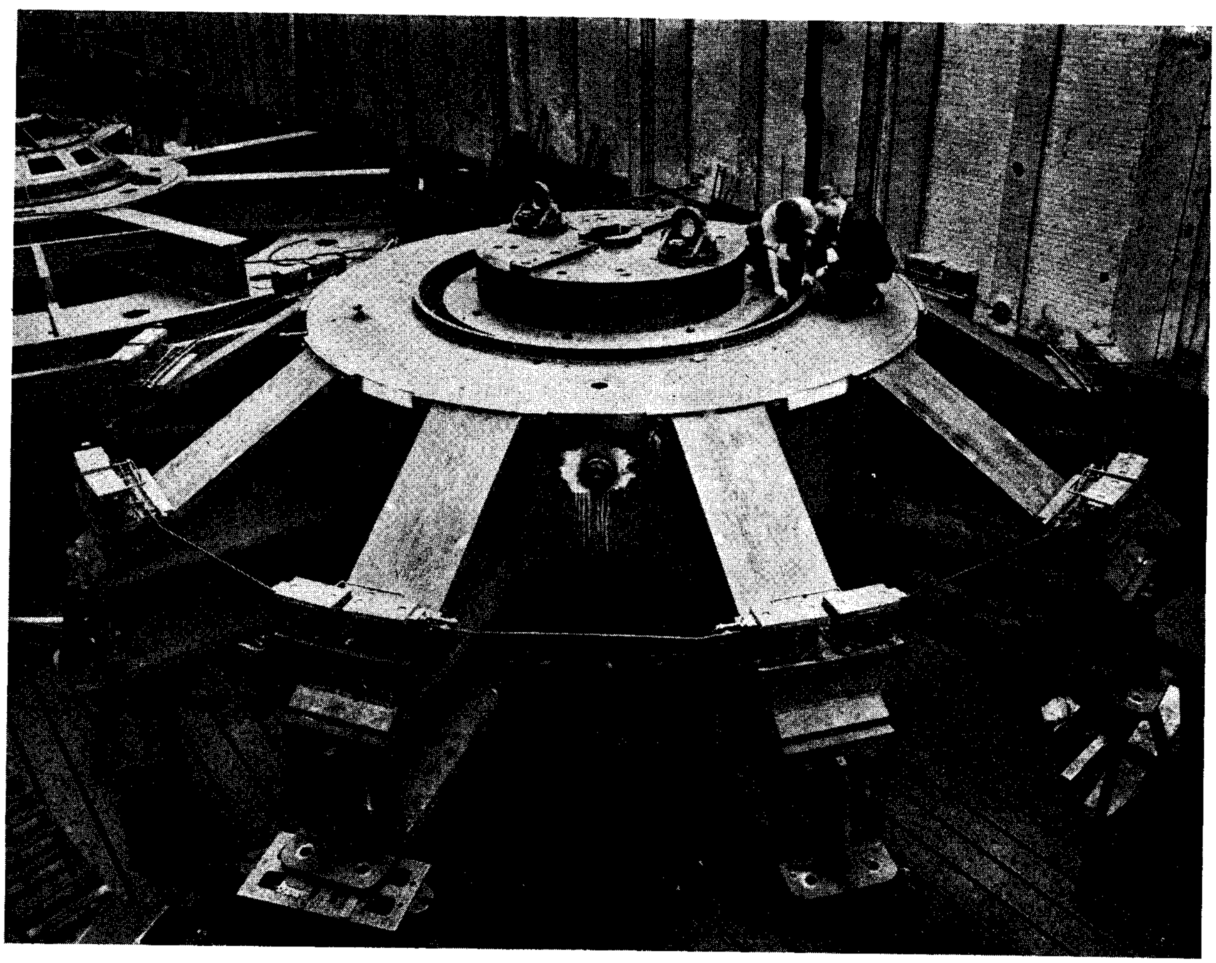

FIG. 18—TYPICAL BEARING BRACKET OF AN UMBRELLA GENERATOR SHOWING THE SHAFT IN POSITION AND THE BRAKES MOUNTED ON THE BRACKET ARMS.

Part III

INSTALLATION

GENERAL

The small generators are usually completely assembled at the factory and given a running test. In those cases where shipping limits permit, the unit is shipped completely assembled and therefore there is very little to be done in the field.

When the unit cannot be shipped assembled, or it is not desirable to ship it completely assembled, it is dismantled into its major parts such as (1) complete stator including integral lower bracket; (2) complete rotor with shaft, spider, poles and coils and thrust bearing runner in position; (3) upper bracket; (4) thrust and guide bearing parts; (5) exciter and exciter support (if any). All parts are match marked to expedite the reassembly of the parts at the site of installation.

There is no real problem associated with the assembly of these small units on their foundation, and therefore this book will not deal with such units as a special subject.

The large units are partially assembled at the factory but only to the extent necessary to match mark the parts to insure that they will fit together properly when reassembled in the field. The machine is then completely dismantled for shipment.

This instruction book deals primarily with the erection of the large units, but will contain suggestions and procedures which will be common to all vertical generators and hence the assembly of the smaller units can be considered as a special case of the general procedure for the large units.

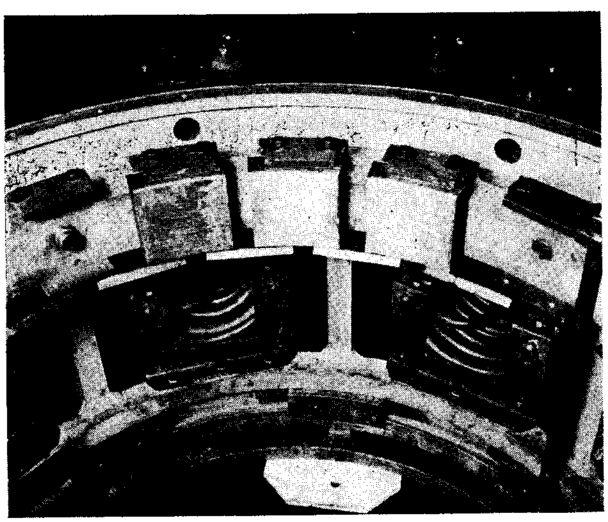

FIG. 19—INSIDE VIEW OF OIL POT OF UMBRELLA GENERATOR SHOWING SEGMENTAL GUIDE BEARING SHOES AND COOLING COILS.

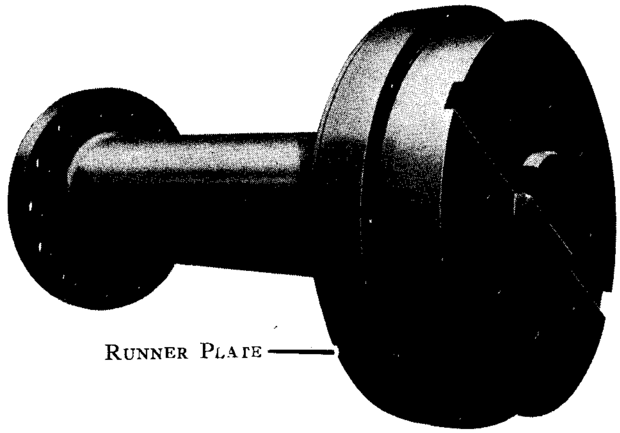

FIG. 20—TYPICAL SHAFT AND RUNNER FOR UMBRELLA GENERATOR.

CHECKING SHIPPING LISTS

Make a careful check of the shipping reports before beginning the assembly of the machine.

The parts which will be required for the first operations should be removed from the crates or packing boxes and carefully examined. Check each piece against the shipping report and report any shortages or damaged pieces immediately. It is very important to arrange the various parts so they will be readily accessible and available at the proper time in the sequence of assembly.

Those parts which are not immediately required in the assembly should be carefully stored and protected with tarpaulins, if necessary, to keep them clean and dry.

Arranging the parts in the order in which they will be used, and being sure that the material list is complete, will greatly expedite the assembly and will result in a minimum of wasted time of the erecting personnel.

FOUNDATIONS

Satisfactory performance of the completely assembled machine requires that the foundation be adequately designed. The foundation should rest on rock or very firm sub-soil, and be adequately reinforced. At the time of the erection of the generator it is too late to do anything about the foundation design and the erector can only assume that it is entirely adequate.

The foundation details, such as pit diameter, location of foundation holding down bolts or bolt holes, cable or piping ducts, cooler trenches, elevations, etc. should be carefully checked against the outline drawing of the machine to be sure there has not been a mistake in the foundation layout.

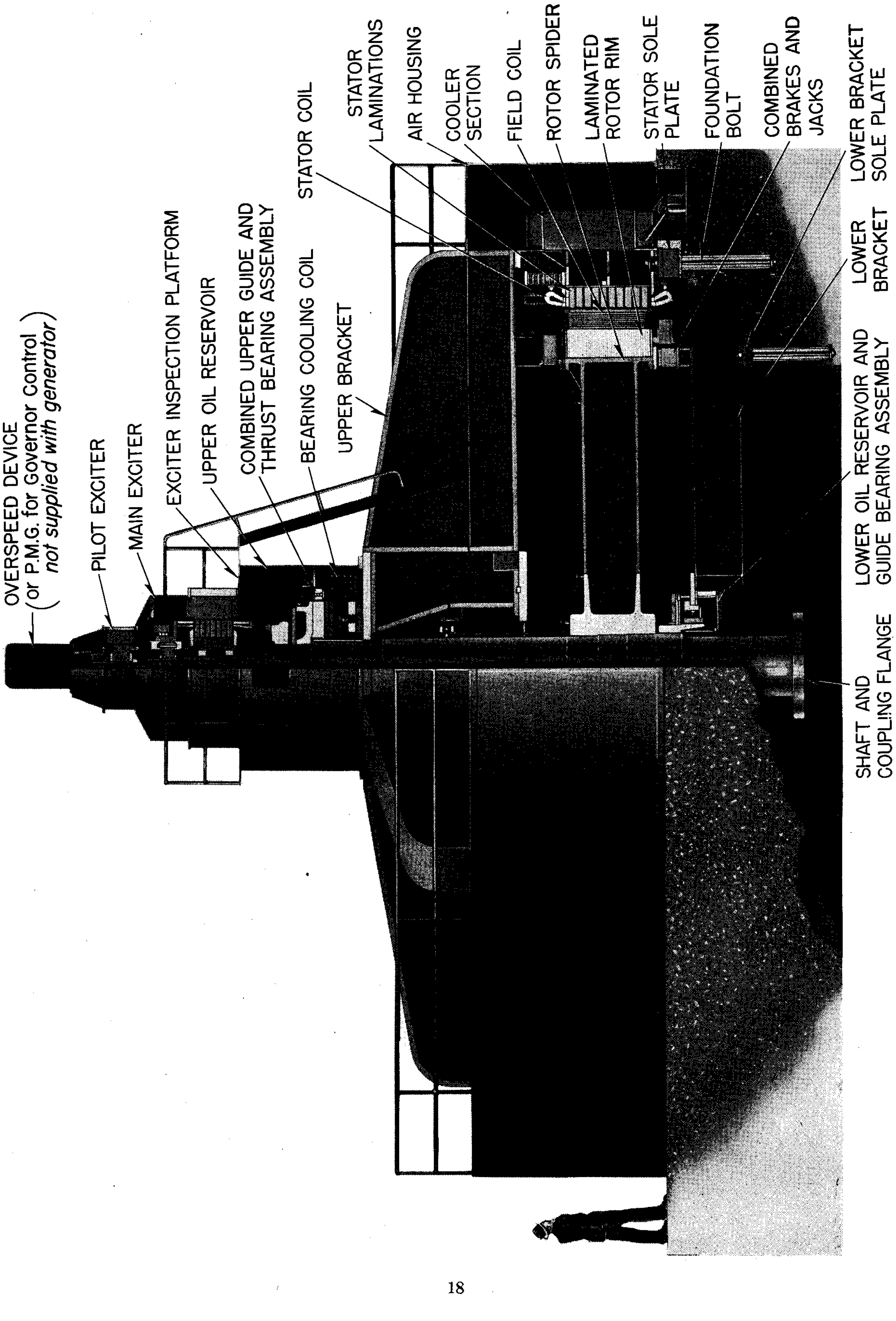

FIG. 21—CROSS SECTION VIEW OF CONVENTIONAL TWO-GUIDE BEARING GENERATOR.

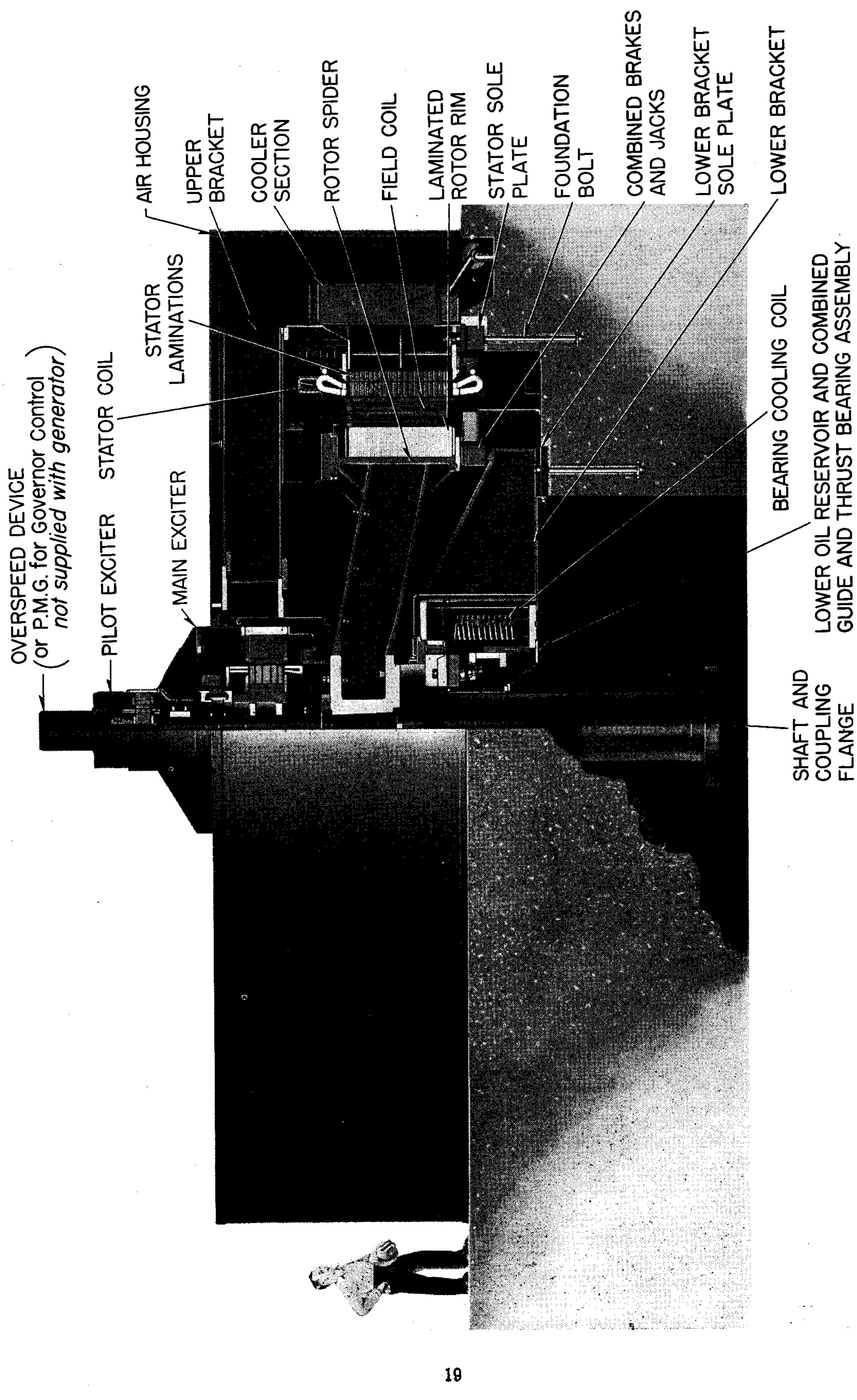

FIG. 22—CROSS SECTION VIEW OF UMBRELLA GENERATOR.

INSTALLATION—Continued.

FOUNDATION BOLTS

Prior to the beginning of erection, the foundation should have provisions for properly installing the bolts which secure the generator base plate or sole plates to the foundation. It is the general practice to install foundation bolts of sufficient length to permit considerable distortion of the bolts if the lower end is imbedded in the concrete. The shank of the bolt should have clearance as the upper end requires greater adjustment than permitted by the clearance in the holes in the base plate or sole plates.

The following types of foundation bolts are in general use:

(1) Threaded rods with a nut on each end. These rods are used in clearance (pipe lined) holes, usually with the bottom nut of each bolt in a pocket provided with an opening to the outside of the concrete foundation wall. A "blind" pocket may be used if a thick, drilled and tapped plate is used instead of the retaining washer.

Removable bolts (bolts that need not be installed until the base plate or sole plates is placed on the foundation) have several advantages. The holes in the foundation should be tightly plugged, particularly when "blind" pockets are used.

(2) Bolts in clearance holes, but with the bolt head "grouted" in the foundation. This arrangement permits bending or distorting the bolt to take care of adjustment of base plate or soleplates if necessary.

(3) Standard type machine bolts or (L) shaped rods grouted in the foundation at the time the concrete is poured. This type requires very accurate aligning when being installed.

(4) Standard or special bolts or rods to be located in large clearance holes in the foundation and grouted in with the base plate or sole plates.

PROVISIONS FOR ASSEMBLY AND ERECTION (GENERAL)

Provisions for the major assembly operations to be carried out before erection is started, such as building the laminated rim of the rotor, insertion of the shaft in the spider (if machine is conventional two-bearing design) and the assembly of the stator sections should be studied before the actual work is begun. The procedure to be followed will depend to a great extent on the conditions at the "site" or power station and on the facilities and equipment available for handling the apparatus.

When time is an important factor (and it usually is), it may be desirable and necessary, where space permits, to carry on the assembling of the rotor, the assembling of the stator and other preliminary erecting operations simultaneously. This also requires that the hydraulic turbine or waterwheel runner be satisfactorily located to establish the elevation and the vertical, horizontal and concentric alignment of the unit.

When several large vertical waterwheel generators are to be installed in one station, it has become the general practice to provide a level, rigidly supported and conveniently located floor space for use in assembling the generator and turbine parts. These erection spaces are frequently referred to as erection bays. It is also common for the purchaser's specifications to require that special devices such as erection sole plates and pedestals be supplied (at extra cost) with the generator.

(A) Provisions for Assembly of Rotor

If a "conventional 2-guide bearing type" vertical waterwheel generator is to be assembled, it will usually be advantageous to have a trap opening in a section of the assembly floor that is constructed to support the spider rim, and the material that will make up the rim. The trap opening must be large enough in diameter to clear the coupling flange on the shaft, since the shaft will be lowered and raised through this opening. There should be ample clearance for the crane operator to guide these operations by signals from men standing on the floor at a safe distance away from the rotor assembly.

The trap opening should be located where there will be sufficient space on the floor around it for assembling the spider on the shaft; for building the rotor rim and for installing the field pole-coil assemblies. A clear space or path of about three feet wide all around the rim will be required for workmen during the rim building operation. Boxes containing rim punchings will be piled outside this path, therefore a circular space approximately twelve feet larger in diameter than the assembled rim, with the opening in the floor at its center, should be available for building the rotor rim. Note Figs. 23 and 25.

Radial floor plates on which to mount the leveling supports or "fixtures" for the rim, during the building operation, and to act as an anchorage during the rim pressing operations, should be imbedded in the assembly room floor. These plates should be laid out and located to the dimensions shown on the rim punching and the rim assembly drawings. The plates should be set level and they should be firmly anchored in the floor, as there may be a very large upward pull during the rim pressing operations.

(B) Provisions for Handling and Assembly of the Stator Sections.

The sections of the stator with windings installed may be shipped with the core vertical (the operating position) or it may have been necessary to load them with the core horizontal to keep within transportation limits and clearances. Extreme care must be taken when assembling these heavy pieces,

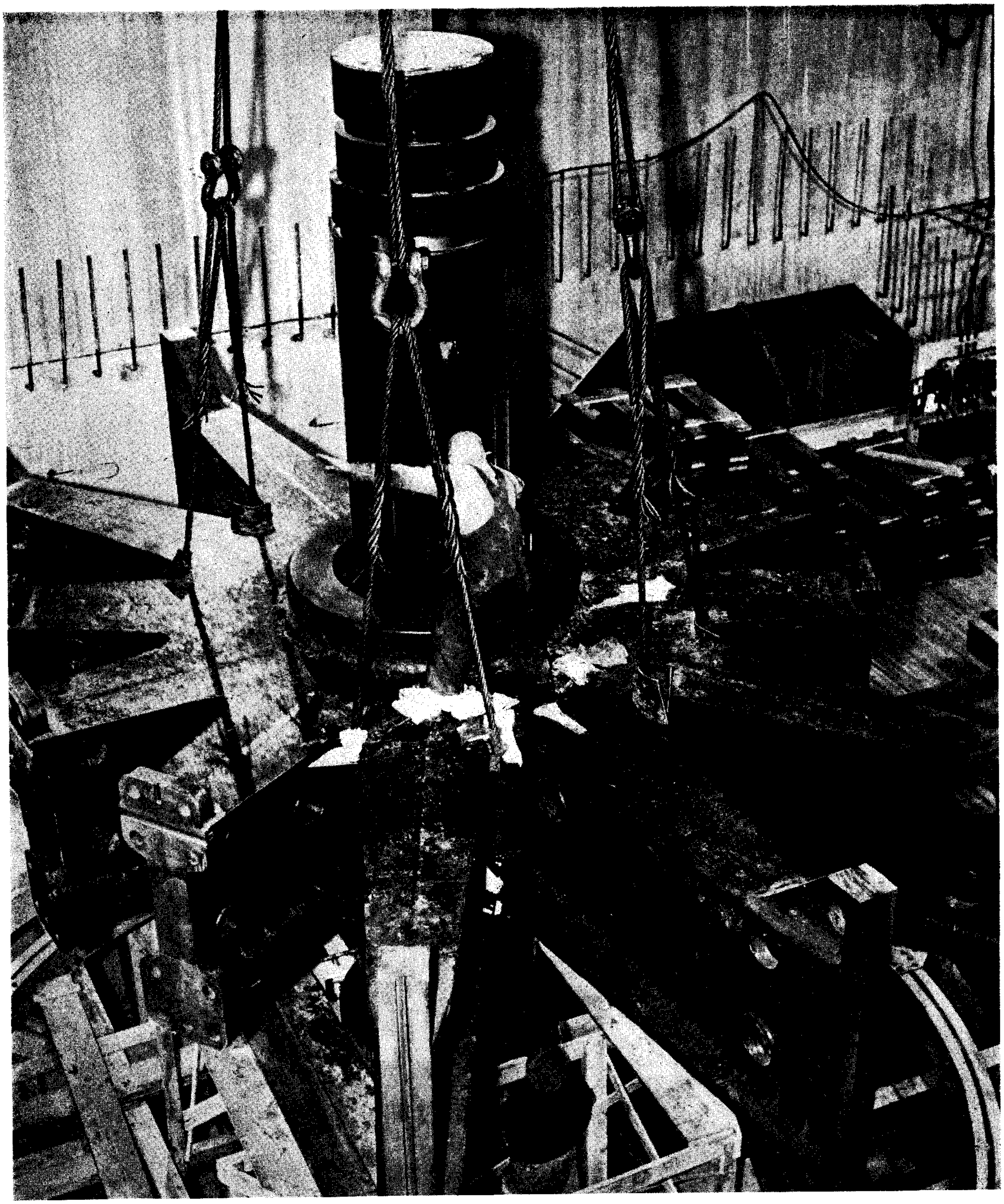

Fig. 23—Power House View of a Large Spider Being Lowered to Position on its Shaft.

FIG. 24—TYPICAL SPIDER FOR LARGE UMBRELLA GENERATOR.

INSTALLATION—Continued.

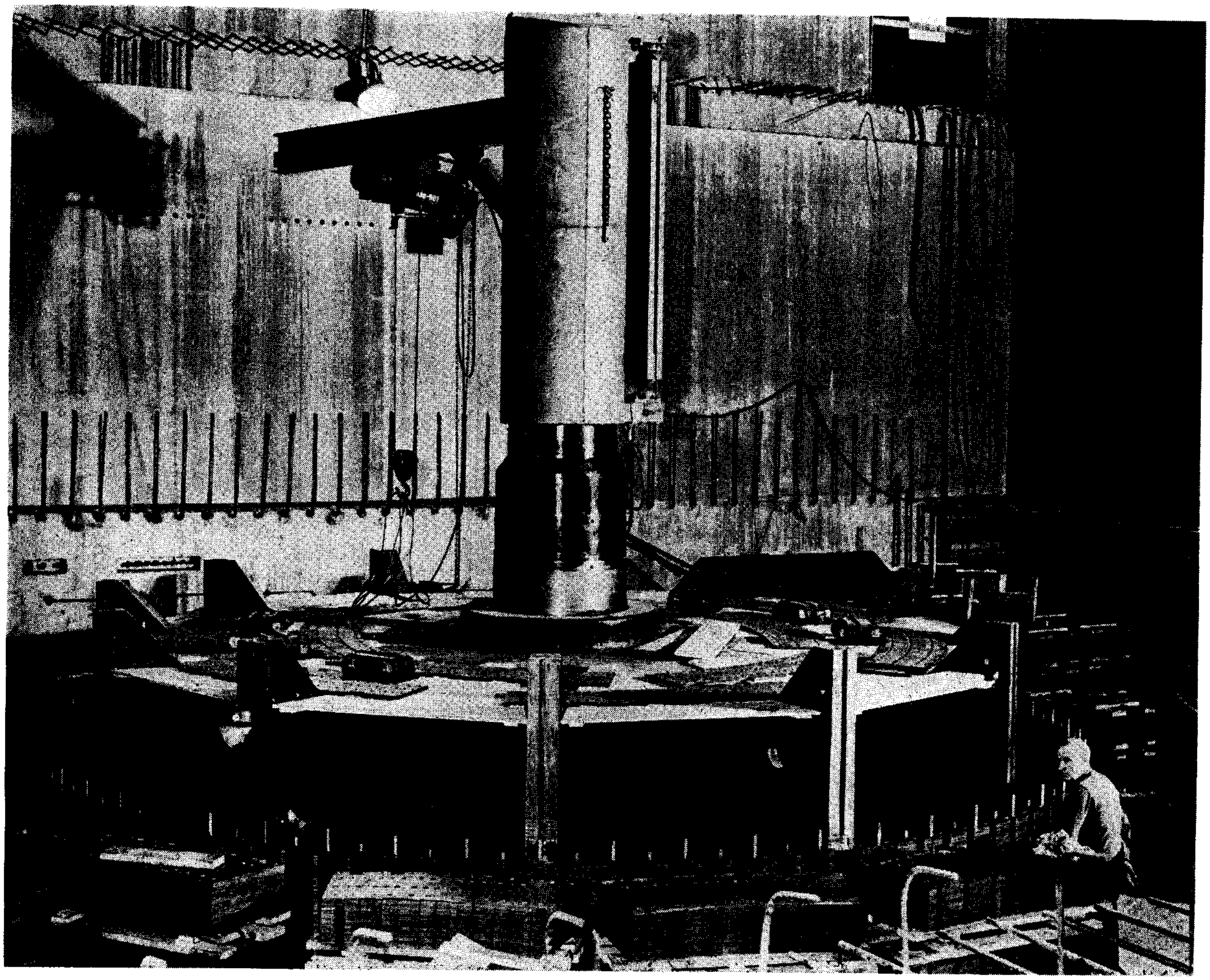

FIG. 25—POWER HOUSE VIEW SHOWING STACKING OF THE PUNCHINGS OF A LAMINATED RIM ROTOR.

particularly sections that require turning to an upright position. The location of lifting slings is very important, to avoid distortion of the structure. If the completely wound stator is moved from the assembly floor to the generator foundation, special precautions should be taken to prevent distortion. Two cranes, each with two main hoists provide almost ideal handling equipment for large vertical waterwheel generators, as straight slings may be used at four points around the frame. For very large stators, eight points of support can be had which will reduce the deflection and cause but slight compression stresses at the top of the frame. With two cranes, each with one hoist; or with one crane with two hoists, two lifting beams should be used to insure safe handling of the stator, particularly if the upper bracket can be used to prevent distortion. It is difficult to avoid serious stresses if a large stator is lifted with one hoist unless an elaborate combination of lifting beams is used. When the construction is such that the upper bracket can be installed to re-inforce the frame (2-bearing type generators) satisfactory lifts can be made. Note Fig. 33.

The floor space allocated to the stator should not encroach on that provided for the rotor assembly, if it is intended to set up both parts on the floor at the same time, or if the complete disassembly of a unit is necessary for repairs or changes to the hydraulic turbine. If a separate space is not available for assembling the stator sections, they may be assembled on the generator foundation after the vertical, horizontal and concentric alignments have been established and the generator frame sole plates and the lower bracket sole plates have been aligned and "grouted-in." This requires that the assembling and erecting of large and heavy sections of the hydraulic apparatus be completed;

INSTALLATION—Continued.

that the turbine shaft be aligned and that the half-coupling be located to establish the elevation and the concentric alignment of the generator.

If the stator is assembled on its foundation, it is necessary that scaffolds be built inside the stator assembly over the pit for use in completing the armature winding. Further work on the turbine will be prevented or greatly hindered until the armature winding has been completed. With the stator in this location, the windings will be exposed to injury if work is done on the turbine, or if apparatus or equipment is lowered into the pit through the assembled armature, particularly while the winding operation is in progress. It is therefore necessary to take special care to avoid damage to the generator stator.

MAJOR ASSEMBLY OPERATIONS PRIOR TO FINAL ERECTION

(A) Expanding the spider hub bore and inserting the shaft in the hub (2 guide bearing machines only, unnecessary on Umbrella units).

(B) Building the laminated rim around the rotor spider.

(C) Expanding the assembled rim and keying it in place on the spider.

(D) Mounting the field pole and coil assembly on the rim; connecting the field coils together and to the collector rings.

(E) Joining the Sections of the stator frame.

(F) Installing and connecting the stator coils across the splits of the stator sections.

(A) Expanding the Spider Hub Bore and Inserting the Shaft in the Hub (Two Guide Bearing Machines only, Unnecessary on Umbrella Units

A "solid" hub is standard construction for rotors of Westinghouse vertical waterwheel generators. When shipping limitations require separate handling of the spider and the shaft, the shaft must be inserted into the rotor bore at the site of erection as part of the rotor assembly operations. Before this assembly operation is begun, the protecting compound should be removed from the surfaces of the shaft and the hub bore, and these parts should be thoroughly cleaned. Any rust or burrs should be removed with emery cloth. The "fit" dimensions of both shaft and bore should be carefully checked with micrometer instruments. Turn the shaft to its normal vertical position, lower the coupling end through the opening in the floor, accurately adjust the shaft to a vertical line and secure the coupling flange to an adequate support. Note Fig. 23.

Two general classifications are applied to shaft-hub bore assemblies: (1) Press fits vary from a maximum of .0005 inch for ½ inch diameter shafts, to .008 inch for 40 inch diameter shafts. (2) Shrink fits vary from a maximum of .002 inch for ½ inch diameter shafts, to .030 inch for 40 inch diameter shafts. These fits are the amounts by which the diameter of the shaft is greater than that of the hub bore.

Three methods of inserting shafts into large hub bores are in more or less general use for power plant assembly operations.

(1) The shaft may be forced into the hub bore by pressure. This method is seldom used as it is difficult to obtain the equipment required, and the cost usually is relatively high.

(2) The shaft diameter may be reduced by lowering its temperature. This method is particularly applicable to small shafts which can be submerged in a bath of acetone and dry ice. It also may be used when large, hollow shafts are involved. Generally it is difficult to apply. In many remote localities dry ice cannot be obtained.

(3) The rotor may be expanded by heat. Some variation of this method usually is employed when the shaft is inserted into the bore of a large vertical waterwheel generator spider, or the spider lowered to position on the shaft at the site of erection.

In deciding on the method to be used to expand the rotor by heat, the following factors must be considered:

(1) The size and weight of the shaft and the spider.

(2) The type of spider construction (open arm or integral rim).

(3) The shrink fit allowance.

(4) The facilities available, such as working space, crane service, power supply at suitable voltage, etc.

(5) The equipment available; such as electric heaters, wiring details, asbestos paper, etc.

Usually electric strip heaters will provide the most satisfactory source of heat for expanding the bore of a vertical waterwheel generator spider hub.

The direct application of electric strip heaters, in intimate contact with the spider hub is recommended. If the spider is of "open arm" construction, electric heaters will be required on the hub section only. If the spider has an integral rim, that also must be heated, or compression stresses will be set up in the arms and affect the expansion of the bore. Suitable heater units should be secured against the hub, within the bore of the spider and on the rim (if there is a rim). These heaters should be connected in several circuits to permit satisfactory temperature control and to insure uniform expansion. From a few simple calculations the approximate capacity in electric heaters can be determined.

INSTALLATION—Continued.

The temperature required to produce the desired expansion may be calculated, with sufficient accuracy, from the following formula:

$$T = \frac{E}{.000012\ B}$$

Where B = Bore diameter in inches.
E = Expansion desired in inches.
T = Temperature required in degrees C.
.000012 = Inches Per Inch Per °C.

The approximate heater capacity necessary to obtain the required theoretical temperature will be indicated by the formula:

$$H = \frac{.207\ WT}{3413} = .0000607\ WT$$

Where W = Weight in pounds of spider hub, or section to be heated.
T = Temperature required in degrees C.
H = Kw. hours required.
.207 = Specific heat of steel in B.t.u. per pound per degrees C.
3413 = B.t.u. per Kw. hour.
.0000607 = Kilowatt hours per pound of steel per degree C. rise.

This formula does not include an allowance for radiation. An accurate radiation factor cannot be pre-determined for an electrical heating operation of this kind as the work must usually be carried on in a power plant undergoing construction. The heat loss depends on (1) effectiveness of the enclosure, or covering for the apparatus being heated; (2) on the air currents around, and particularly under, the apparatus; (3) on the method of applying the heaters; (4) on the control of the heat, etc. Experience indicates that with reasonably good conditions, the heat loss should not exceed 50 per cent, but to be safe it is advisable to select the heating equipment on the basis of a kilowatt hour consumption of **twice** the value obtained from the formula.

The elapsed time most satisfactory for expanding any spider hub bore a pre-determined amount with a given Kw.-hour consumption of electric energy and without undue distortion, depends upon the section of the structure to be heated; the method of applying and controlling the heat; the radiation loss, etc. The experience and judgment of an experienced supervisor always will be valuable. It is important that the temperature be raised gradually and that the heat be uniformly applied so that objectionable stresses do not develop in any part of the structure. Heating periods of from five to eight hours will be sufficient for most rotors. The kw. capacity of heaters to be applied is determined by dividing the total energy requirement in Kw-hours (including the radiation loss), by the estimated hours required. The length of the spider bore, and possibly the width of the rim, will dictate the size of the heaters most applicable.

The electric strip heaters should be located so as to give a reasonably even distribution of heat throughout the structure to be heated. The circuit should be arranged to control the distribution of heat to restore the best balance in case it is disturbed by external conditions such as air currents or air pockets. The 36 inch, 1000 watt or the 43 inch, 1250 watt strip heaters with both terminals at one end generally are the most convenient to use. These heaters are available for either 230 volts or 115 volt service.

With a uniform application of heaters throughout the bore, the upper part of the hub will become much hotter than the lower part, consequently it is the practice to apply more heat at the bottom than at the top of such a structure, and also to arrange the heater wiring so that the top and the bottom section circuits may be controlled independently. When possible, it is good practice to lay out the heater groups for the hub so that they may be used for heating certain sections of the rim without re-wiring.

Various devices may be used to "fix" the strip heaters around the bore of the hub. The method is left to the discretion of the supervising erector.

Be sure the method used permits speedy removal of heaters.

After the heaters have been mounted, connected and energized, use thermometers or thermocouples to indicate the temperature of the various parts of the hub. Cover the spider with asbestos paper to prevent excess radiation of heat and arrange the covering to permit access to the thermometers and to permit pin-gauge measurements without interfering with the heating operation. Attach slings to the spider to permit quick handling after the bore has been expanded. Note Fig. 23.

The following procedure is usual:

(1) Check the temperature and the hub bore expansion at frequent intervals.

(2) Regulate the expansion of the various bore sections by temperature control, secured by "cutting-out" and "cutting-in" heater circuits as required.

(3) When the desired bore expansion has been obtained, attach the crane hook to the slings which were previously attached to the spider.

(4) Open the heater circuits.

(5) Remove the asbestos covering.

(6) Remove the strip heaters and wiring from the hub bore.

(7) Wipe out the bore with clean cloths.

(8) Brush the bore fits with graphite and oil; also brush the shaft fits with the same compound.

Do not use white lead as it will cake on the heated surfaces.

(9) Lift the spider with the crane and lower it down on the shaft. Note Fig. 23. Many of these

INSTALLATION—Continued.

operations can be done simultaneously and usually the entire operation can be completed in a comparatively short time after the heating is discontinued.

(B) Building the Laminated Rim Around the Rotor Spider

Building the spider rim usually is the longest assembly operation. The number of workers is limited by the distance around the periphery of the rim. When the most efficient number of competent workers is being used, the work can be expedited only by increasing the number of hours worked per day. The assembled layers of laminations are overlapped and confusion will result unless the workmen act in unison. The slowest workman controls the speed of building a rotor rim.

With the spider mounted on the vertical shaft and located at a pre-determined height above the floor proceed as follows:

(1) Clean the machined ends of the short arms and also the matching ends of the detached sections (if any) and assemble the parts.

(2) Clean the ends of all spider arms.

(3) Arrange the rim supports or fixtures around the spider and bolt them to the floor plates.

(4) Place the lower end plate segments on the supports and carefully adjust them to the correct elevation.

(5) Level them accurately by placing shims between the supports and the floor plates.

(6) Stack the rim punchings with the building pins as guides. Keep the punchings in positive contact with the ends of the spider arms. Note Fig. 25.

(7) Refer to the manufacturer's drawings for details of construction and carefully follow any Process Specifications or any special instructions indicated on the drawings.

(8) Press the assembled punchings, or laminations, after each section or package of approximately twelve inches has been stacked. Generally the permanent end plates can be used as pressing plates.

(9) After the final pressing operation has been completed, make any adjustments that may be necessary and install the permanent bolts.

The rotor rim assembly is next to be heated to expand the bore to a predetermined value so that the torque keys can be inserted between the rim and the spider arms. The torque keys are made larger than the key-slot between the spider and the rim so that a definite shrink fit will exist between the two members.

(C) Expanding the Assembled Rim and Keying It In Place On The Spider

Arrange electric heaters around the periphery of the rim and secure them in positive contact with the assembled structure. It is usual practice to

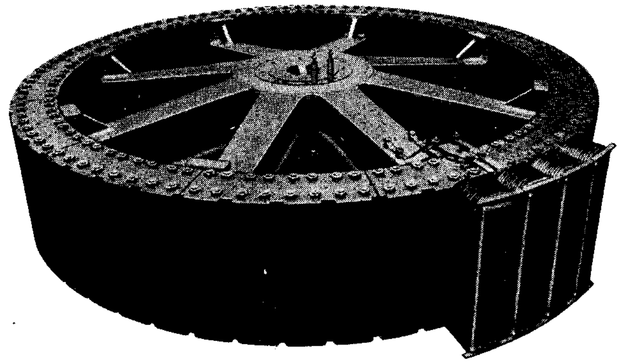

FIG. 26—VIEW OF LAMINATED RIM ROTOR WITH SOME POLES AND COILS IN POSITION

suspend the heaters with a soft steel wire passed through the mounting hole at the end of the heater and looped around the nut on the top of a rim bolt. Usually it is most convenient to connect the heaters when both terminals are at the lower end. The heaters in the dovetail slots can be held in satisfactory contact with the laminated structure by two or three bricks placed edgewise against each heater and held in place by small metal wedges forced between them and the overhang of the dovetail slot. A flattened nail may be sufficient for this purpose. The heaters located between dovetail slots may be held against the laminated structure by three single-turn wire bands around the rim. These should be located about three inches from each end and at the center of the heaters. They should be put on loose and tightened with a tourniquet. It is good practice to cover the heater terminals with a strip of asbestos.

The total capacity of heaters required for expanding the rim can be determined from the formula on page 25. The size and capacity of individual heaters, and their arrangement will be governed by the construction of the rim. It is usual practice to locate from one to four heaters in each dovetail slot, and from two to eight between slots, depending on the size of the rim.

Locate thermometers or thermocouples on various parts of the rim and the spider arms to indicate the difference in temperature of these parts during the rim heating operation. Also locate thermometers in the air where they will not be affected by the heat of the rim. Cover the rim with 36 inch wide asbestos paper, but do not extend the covering over the spider arms. The pieces of asbestos paper should extend completely over the rim (except at the spider arms) in a radial direction and each end should be held down on the floor by bricks or other means. If the air temperature is low and if there is a considerable difference in temperature between the inside and the outside of the covering or if there are strong air currents, it may be necessary to place bricks on the top of the rim to hold the asbestos paper in

INSTALLATION—Continued.

place and to prevent its tearing. The half sections of asbestos paper at the spider arms should be held in place by bricks on top of the rim. Spread the pieces in the first layer and cover the gaps with a second layer. This will permit easy access to thermometers and also facilitate inspection of the rim during the heating operation.

The rim should be expanded until there is a clearance between all the spider arms and the rim punchings, after which the asbestos covering should be removed and the nuts on the inner circle of rim bolts tightened.

After tightening these rim bolt nuts, re-cover the rim and continue heating until the "shrink keys" can be easily driven into the slots with a hand hammer.

Thermometer readings should be checked and gauge measurements should be made every half hour, or more often if erratic conditions prevail. Frequent adjustments of the various heater circuits may be necessary to maintain uniform expansion in all sections of the rim.

When the keys are in place, discontinue the heating, remove the asbestos covering, and allow the rim to cool slowly. Check the nuts on the rim bolts for tightness and tighten any that are loose. The heaters should be removed after the assembly has been checked.

(D) Mounting the Field Poles and Coils Assembly on the Rim and Connecting the Field Coils Together and to the Collector Rings

Each field pole and coil assembly is shipped in its own individual box. The boxes are substantially made and usually banded with steel when necessary. If they are broken apart to remove the assembly there is danger of damaging the coils. It is therefore suggested that the box cover be removed and the **assembly of pole and coil be lifted out** with a sling and a suitable lifting device, attached to the pole dovetail projection. An experienced erector should have no difficulty in making a device from steel plates.

The number of the pole assembly is marked on each box and stamped on each pole. There will be small differences in the weight of the various poles and coils and for this reason they should be as-

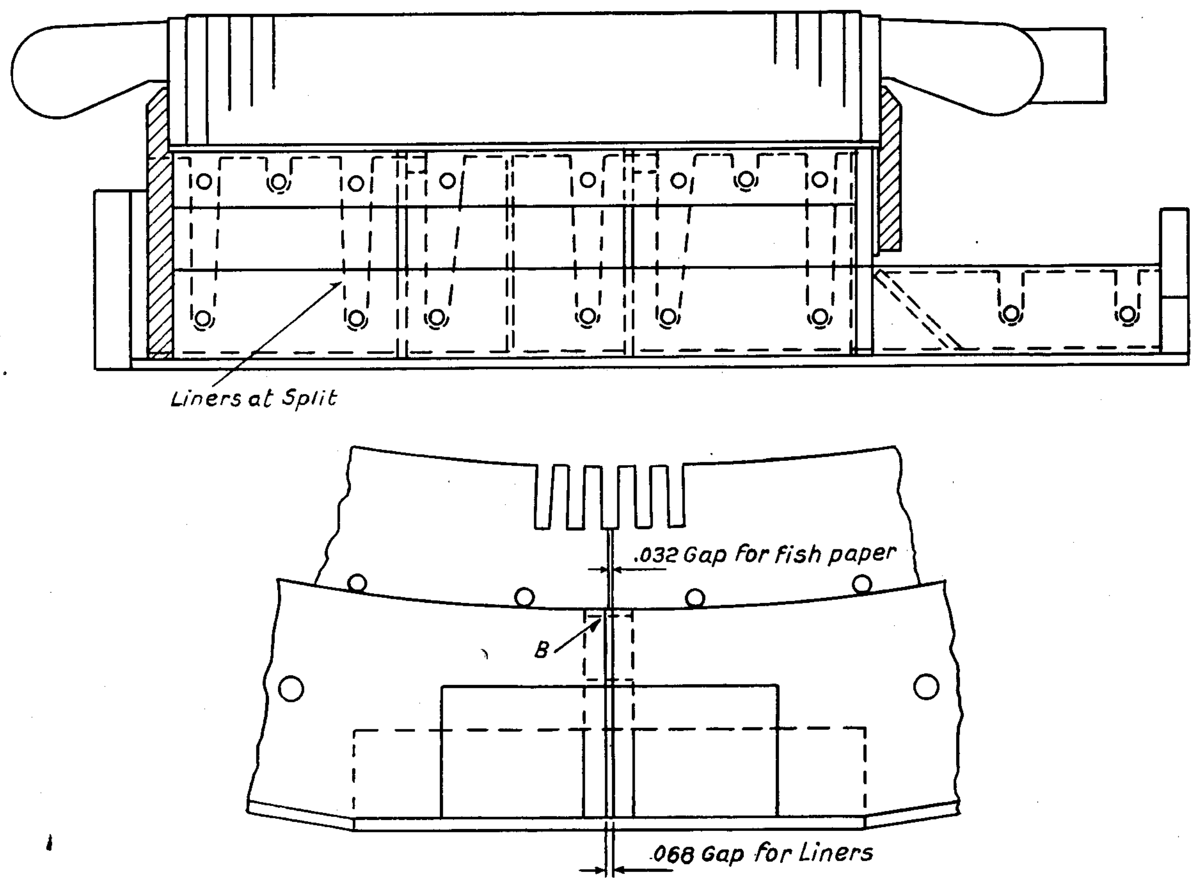

FIG. 27—SKETCH SHOWING PROVISION FOR PACKING STATOR SECTIONS AT THE SPLITS OF THE IRON.

INSTALLATION—Continued.

sembled on the spider as marked, in order to obtain the best initial rotor balance.

After the assemblies have been removed from the boxes, they should be placed horizontally on blocks about four inches high and located so that there is a clear space of at least two feet at the lower end of the coil to permit raising the assembly to the vertical position.

If the field coils have extended end turns for increased radiation, wood strips should be placed between the extended turns to protect them from damage before attempting to lift the coils with a crane.

By means of slings fastened around the pole and coil assembly, it can be lifted by the crane and lowered so that the pole dovetail engages the dovetail slot in the rotor rim. The pole is then adjusted to its correct position and secured by means of the dovetail keys.

After the poles and coils are permanently secured in position the connections should be made between field coils and to the collector rings.

(E) Joining the Sections of the Stator Frame

The stator sections should be mounted on carefully leveled supports at the time the sections are bolted together. If necessary, shims should be used under the sections to level them to the same elevation.

In some cases the erection of the hydraulic turbine may have progressed far enough so that the stator sections can be assembled on the foundation in their final position.

Generally however, it will be necessary to assemble the stator sections on beams temporarily located on the power house floor. Such temporary beams must of course be adequate to support the sections without objectionable distortion.

When the stator frame was "bored" at the factory, the sections were bolted together with .068 inch liners located at the joints of the sections. Note Fig. 27. The stator core is designed with approximately .032 inch gap at each split in the core to permit the insertion of fish paper.

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 fish paper 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. 27, to be sure that the fish paper is tight.

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

(F) Installing and Connecting the Stator Coils Across the Splits of the Stator Sections

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 winder and under the supervision of 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 will depend 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. Note Figs. 28 and 29.

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 the insulation will not crack and eventually 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 can be used.

Note Figures 28 and 29 which illustrate a method of holding the coils in the raised position in the case of a horizontal machine.

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.

GENERATOR ALIGNMENT

It is very important to obtain the best possible alignment of the generator and turbine parts to assure satisfactory operation of the combined unit.

It is usually the responsibility of the hydraulic erection engineer to establish the vertical centerline and the elevation of the unit.

Before proceeding with the final generator alignment the following conditions must be checked and satisfied:

(1) That the turbine shaft has been aligned to an established vertical centerline.

(2) That the face of the turbine half-coupling has been machined within allowable tolerances and is level and at right angles to the shaft.

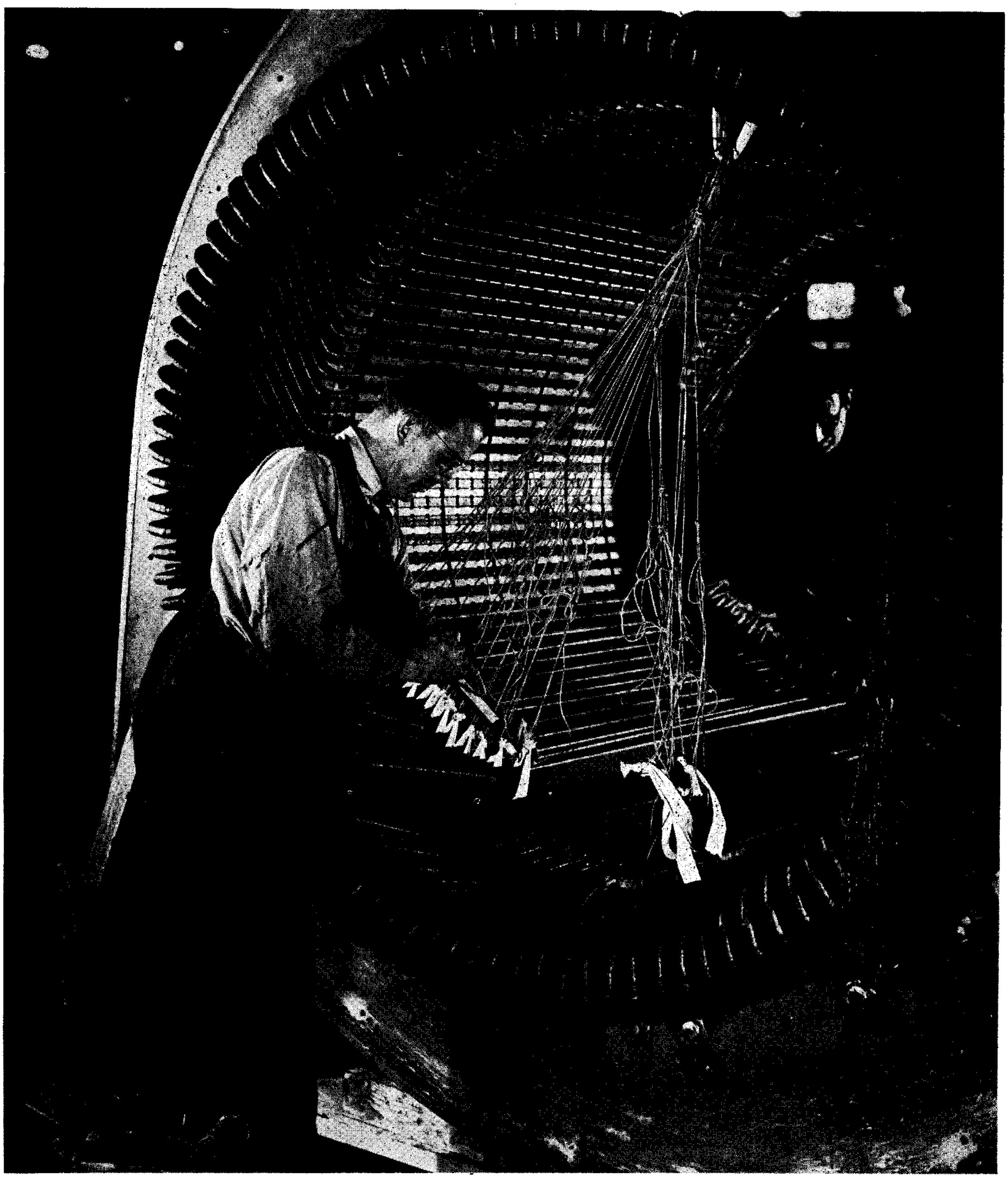

FIG. 28—FACTORY VIEW SHOWING WORKMEN COMPLETING THE WINDING OF A HORIZONTAL GENERATOR. CLOSING THE SPLITS OF A SECTIONALIZED STATOR. (VERTICAL MACHINE WOULD BE DONE IN A SIMILAR MANNER).

INSTALLATION—Continued.

(3) That the diameter of the turbine half-coupling is correct and that the flange outer surface is machined at right angles with its face.

(4) That the spigot is machined to the correct diameter and its height is within the limits of the vertical adjustment of the turbine runner.

(5) That the elevation of the turbine half-coupling face, with the runner lowered, centered and blocked into position, is a definite distance below the operating elevation and so located that the coupling halves will be separated sufficiently to clear the spigot fit when the runner is in this position and when the generator rotor is in its raised position. This is very important as the final check of the alignment of the rotor is made by taking measurements at the separated halves of the coupling.

When these conditions have been found to be satisfactory, the generator shaft will be aligned to the turbine shaft and the face of the generator half-coupling will be adjusted to the correct elevation.

Final Generator Alignment

The rotating element of all vertical generators is supported by a Kingsbury type thrust bearing. In the case of the conventional two-guide bearing type generator construction, the thrust bearing is supported by the upper bracket of the generator which in turn is supported by the frame of the stator. The frame of the stator in turn rests on sole plates which are mounted on leveling plates to facilitate aligning operations.

In the case of the umbrella type of construction the rotating element is supported by a Kingsbury type thrust bearing which in turn is supported by the lower bracket. The lower bracket rests directly on the foundation and on sole plates which in turn are mounted on leveling plates.

It has become the accepted practice to locate the leveling plates (small steel plates firmly secured in cement grout) on the weight bearing surfaces of the foundation to provide adequate support for the shims or wedges which are inserted under the sole plates during the aligning opera-

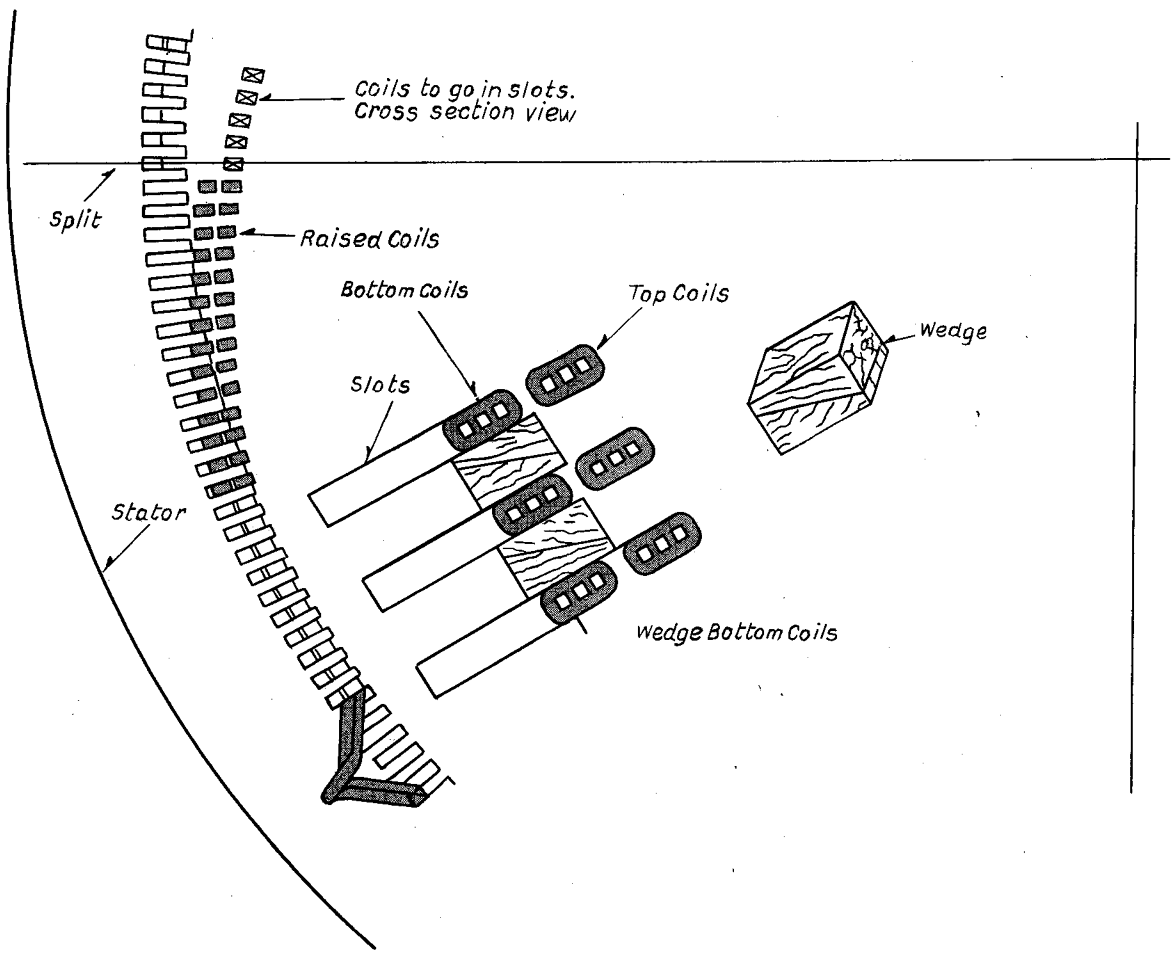

FIG. 29—SKETCH ILLUSTRATING THE METHOD OF BLOCKING THE THROW COILS TO COMPLETE THE WINDING AT THE SPLITS.

INSTALLATION—Continued.

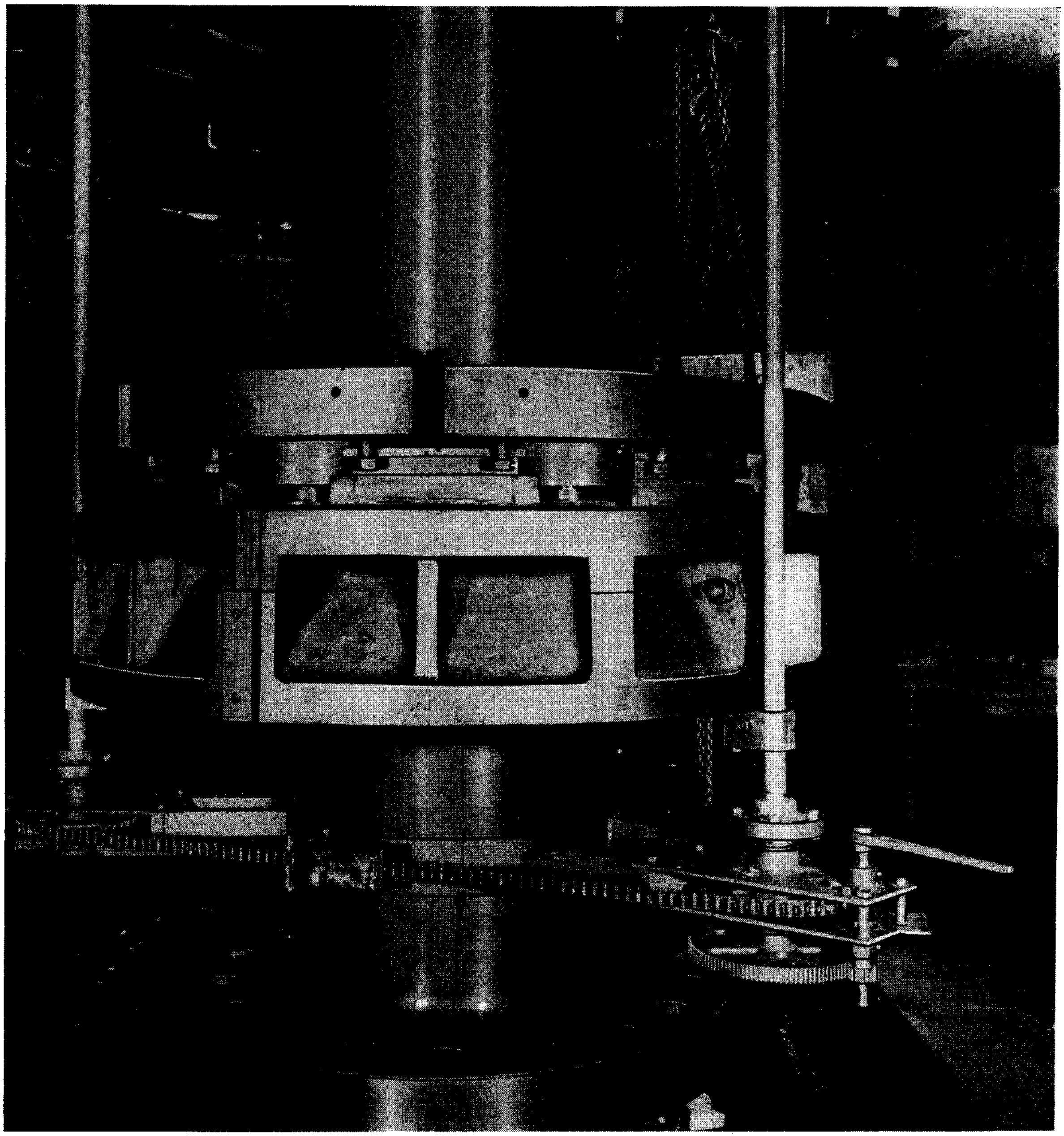

FIG. 30—FACTORY VIEW SHOWING THE THRUST BEARING ASSEMBLY OF AN UMBRELLA GENERATOR IN THE LOWERED POSITION. ALSO ILLUSTRATES THE USE OF THE SPECIAL THRUST BEARING LOWERING DEVICE.

tions. Plates made of flat, smooth steel about four inches wide and one-half inch thick usually are satisfactory. The length should be at least two inches greater than the width of the sole plates. Two or more leveling plates should be provided for each sole plate.

Since the soleplates are not initially grouted in place, it is recommended that they be aligned with the apparatus mounted on them (either frame or lower bracket) by using a sufficient number of leveling plates correctly located to prevent distortion of the soleplates, the generator frame, or the brackets.

Horizontal alignment, or "level," is obtained by adjusting the shims or wedges which are placed between the leveling plates and the sole plates. Allowance must be made for the thickness, or height, of these shims when determining the

INSTALLATION—Continued.

elevation at which the leveling plates must be located.

The three general methods of aligning, and particularly of leveling, large vertical waterwheel generators are as follows:

(1) The "plumb line," "pin gauge," "straight edge," and "spirit level" method.

(2) The "leveling beam" method.

(3) The "engineers level and micrometer target" method.

Combinations of these methods and tools may also be used. Special tools, such as an accurate spirit level; an inside micrometer, or length gauge, and thickness gauges, or feelers are always useful and should be available for any method of alignment which may be used. A summary of the sequence of operations is given below:

(1) Align and "grout-in" the leveling plates in line with the following:

(a) With the face of the turbine half-coupling located at a pre-determined elevation below the operating position, place a straight-edge with one end supported on the coupling, or supported at a definite height above the coupling and with the other end extended radially and supported in any convenient way over a leveling plate location.

(b) Carefully level the straight edge with a spirit level.

(c) Place a leveling plate on the foundation at a position corresponding to the location of a sole plate, as shown on the outline drawing furnished with each machine.

(d) With a pin gauge, adjust the plate to the shaft and to the straight-edge by referring to drawing dimensions, making allowances for the coupling elevation and the height of alignment details to be used between the leveling plate and the sole plate.

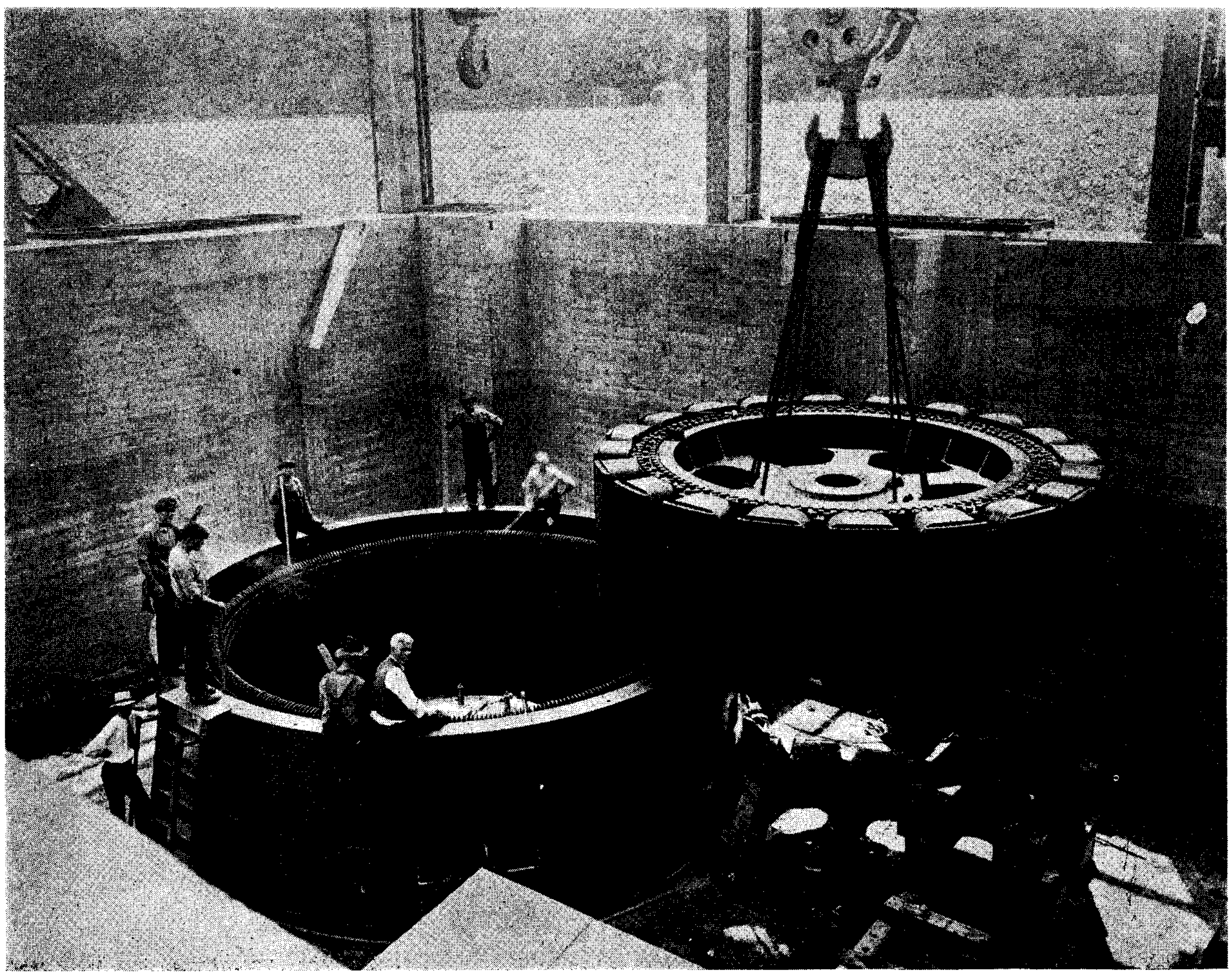

FIG. 31—POWER HOUSE VIEW OF A LARGE ROTOR SUSPENDED BY THE POWER HOUSE CRANE.

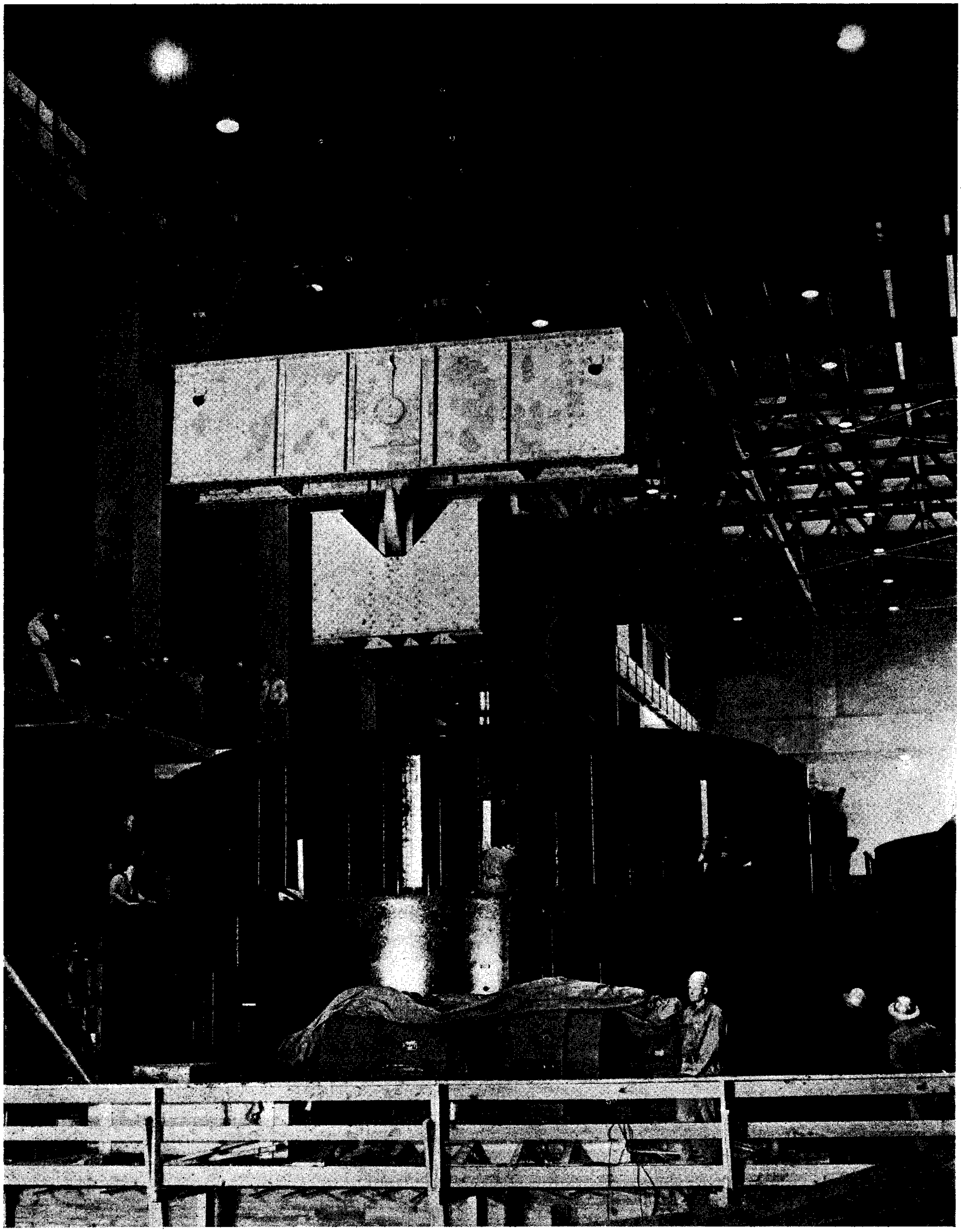

Fig. 32—Power House View Showing a Large Rotor Being Lowered to its Final Position in the Stator.

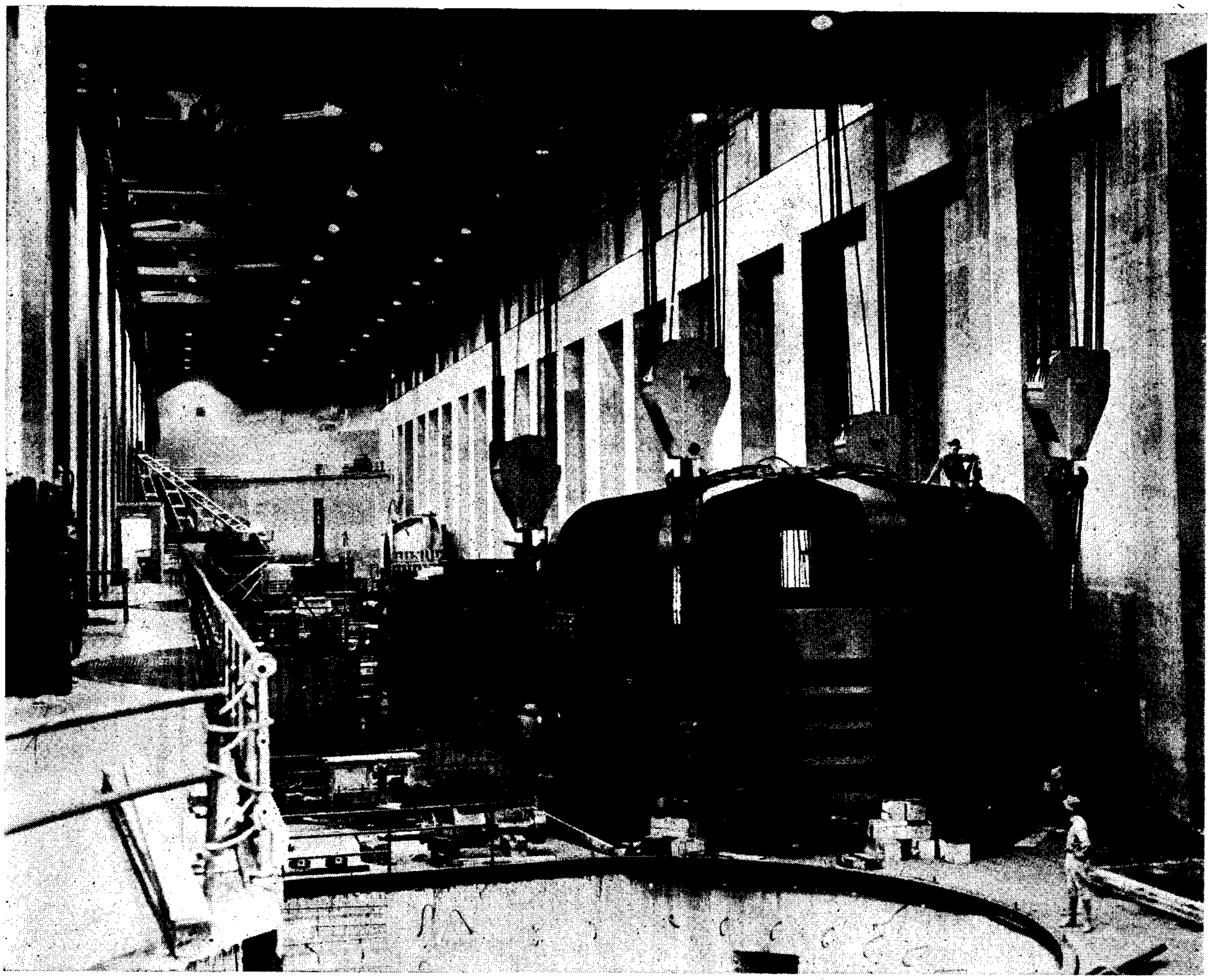

FIG. 33—POWER HOUSE VIEW SHOWING HOW THE UPPER BRACKET IS USED TO BRACE STATOR DURING HANDLING OPERATIONS.

(e) Carefully level the plate and secure it in place.

(f) Align and level all other plates in a similar way.

(g) Check the elevation of the various plates by "chording" from plate to plate across sections of the foundation by means of a straight-edge and level.

(h) After all the leveling plates have been correctly located and adjusted to the same elevation, they should be grouted to the foundation.

(i) When the grout has hardened, the sole plates for the frame and for the lower bracket can be placed on the leveling plates.

PLACING FRAME AND BRACKETS IN POSITION ON FOUNDATION AND LOWERING ROTOR TO POSITION

(A) Conventional Type Generator

After the sole plates are located in their correct positions as outlined above, the major machine parts are assembled in the following order:

(1) Place the lower bracket in position on its sole plates and level and align it by means of the shims between the sole plates and the leveling plates, and the aligning jack screws which are provided on the bracket for this purpose.

(2) Place the stator frame on its sole plates as close to its final position as possible. It should be

INSTALLATION—Continued.

adjusted to the required elevation and carefully centered and leveled. The frame is provided with jack screws to provide concentric adjustment.

(3) Lower the rotor into the stator and support it by the jacks mounted on the arms of the lower bracket. The rotor should be raised to an elevation which will result in clearance beteeen the shaft flanges. Note Fig. 32.

(4) Place the upper bracket in position on the stator frame.

(5) Install and adjust the thrust bearing parts on or in the upper bracket as the case may be.

(B) Umbrella Type Generator

The sequence of assembly is the same for the umbrella unit with the exception that the thrust bearing parts are assembled in the pit around the shaft, above the coupling, and the bearing parts are raised to position by means of a special device. Note Fig. 30. This device is supplied as standard equipment with the umbrella generators and is designed for manual operation or for operation from a portable motor.

When the preceding operations have been completed, the final adjustments of the frame, lower bracket, bearing jack screws, etc. should be made as required to bring the coupling faces into exact alignment and to obtain a uniform air gap.

After the shafts and couplings have been aligned by one of the several recognized methods previously discussed, the generator rotor should be lowered to its normal position, the turbine shaft raised to match the generator coupling and the permanent coupling bolts installed and tightened.

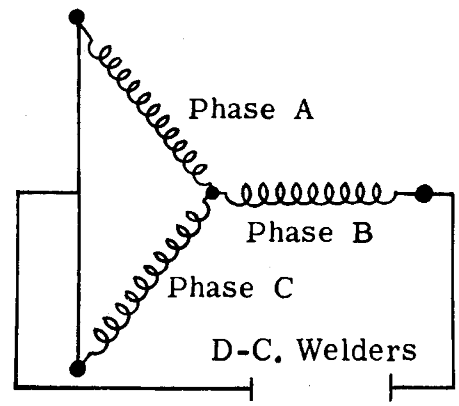

Fig. 34—Connection Diagram Using D-C. Welders.

When all parts are properly aligned, the frame and lower bracket holding down bolts should be tightened and the parts secured in position by driving in the dowels which are supplied with the generator.

The final operations to complete the erection include the installation of gauges, fittings, piping, auxiliary leads and any other details covered by the manufacturer's drawings.

After the entire assembly has been checked, and the oil reservoirs filled with oil, the generator can be turned over by the prime mover and is ready for the routine operations of drying-out and phasing-out which are necessary before the generator can be placed in commercial operation.

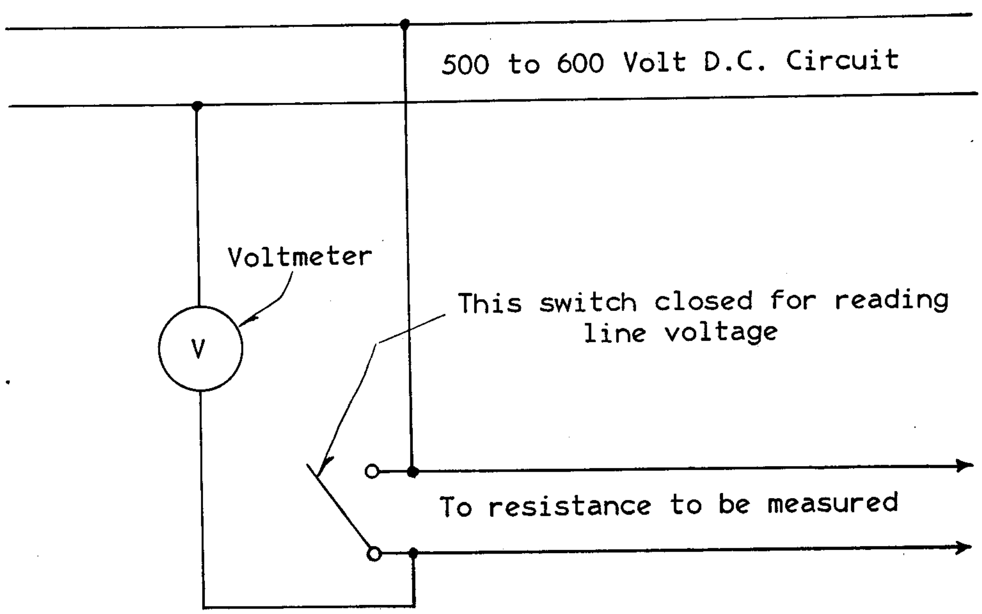

Fig. 35—Diagram of Connections for Measuring Insulation Resistance.

INSTALLATION—Continued.

DRYING OUT WINDINGS PRIOR TO INITIAL OPERATION

Most generators absorb sufficient moisture during the shipping and erection period to require drying-out before they can be placed in operation. Many of the modern large units and some small units are provided with space heaters mounted on the arms of the lower bracket or on the foundation for the specific purpose of keeping the machine dry during shut down periods, when condensation might otherwise take place.

These heaters can also be used to aid in drying out the windings after erection.

The most generally used methods are:

(1) Drive the generator at reduced speed, short circuit the stator and excite the field so about 25 per cent rated current is circulated, the exact value of current to be determined by temperature measurements.

(2) Circulate current through the windings by means of D-C welders if such are available. The welders can be connected as shown in Fig. 34. Usually two large welders will be sufficient to dry out a medium size generator.

The field winding can be dried-out by connecting the welders to copper clamps attached to the collector rings. The copper clamps will prevent burning of the collector rings.

In general, the drying should proceed slowly at first, with the heating gradually increased as the insulation dries. The temperature of the insulation as measured by thermometer should not exceed 65°C. If embedded temperature detectors are used to read temperature, the permissible temperature is 80°C.

Insulation Resistance Measurements

Insulation resistance measurements should be taken periodically throughout the drying-out period. It will usually be noted that the resistance will decrease at the start of the dry-out but will finally increase until the values are reasonably constant. When constant and if equal to or above the minimum as determined by formula below, the generator can be placed in service.

Insulation resistance measurements are made to determine the condition of the insulation on the windings and should be checked in a similar manner at regular intervals during the life of the machine.

The resistance may be measured by a megger or by using a 500 volt direct current circuit and a 500 volt direct current voltmeter. Fig. 35 shows a diagram of connections for the latter method of measuring insulation resistance.

Referring to the diagram, Fig. 35, the insulation resistance can be calculated from the following formula:

$$R^1 = \frac{R(V - V^1)}{V^1\ 10^6}$$

Where V = Line voltage.
V^1 = Voltage reading with the insulation in series with voltmeter.
R = Resistance of voltmeter.
R^1 = Resistance of the insulation—in megohms.

The insulation resistance of a machine at the operating temperature should not be less than that given by the following formula:

$$R\ (\text{Megohms}) = \frac{\text{Terminal Voltage}}{\frac{\text{Rating in Kv-a}}{100} + 1000}$$

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

PART IV

OPERATION

STARTING A NEW GENERATOR

Before starting a vertical waterwheel generator, the entire assembly should be checked very carefully to be sure that all details are complete and in operating condition. **BE SURE OF THE FOLLOWING:**

(1) That the bearing oil reservoirs are filled to their proper levels with the quality of oil recommended by the manufacturer. See page 46.

(2) That the gauges, meters and other auxiliaries are all in good operating condition and that all alarm circuits have been checked.

(3) That adequate synchronizing equipment is available to check the phase rotation of the machine with respect to the line.

(4) That the valves in the water lines are open so cooling water is available for cooling the bearing oil where water cooled bearings are furnished.

(5) That the windings have been adequately dried out and meggered so full voltage can be generated without hazard of an insulation failure.

(6) That the brake system is operating properly to stop the unit when necessary.

The bearings of all Westinghouse vertical waterwheel generators have been carefully finished at the factory and unless damaged during transportation or assembly will have a satisfactory finish for normal running conditions.

The starting and stopping of vertical bearings, some of which are loaded about as heavily at rest as when running, is their severest treatment.

When the rotor is at standstill the continuous oil film is not present and the relative coefficient of friction, with respect to running conditions, is high. At the instant of starting there is some rubbing between the metals. This rubbing may result in more or less noise, like a "grunt" or "groan," but this is normal and not an indication of trouble. The rubbing noise usually lasts only a brief time (about a quarter of a turn of the shaft), as the oil film begins to form soon after the runner has moved a small distance, and increases in extent and thickness as the speed increases.

With properly finished runners, the minute high spots on the runner are gradually worn down without wiping the bearing babbitt.

In general, it should be remembered that vertical thrust bearings are heavily loaded and should therefore receive more care and attention at first than ordinary horizontal or vertical shaft type bearings.

A conservative procedure which is followed by many customers and recommended by the manufacturer, is to wet the bearing surfaces before starting by raising the rotor to provide lubrication at the instant of starting. This procedure should be followed during the early operation (1st ten starts) of the machine especially in the case of large machines with thrust bearings greater than 32 inches in diameter, and can then usually be dispensed with, as the bearing surfaces will have worn in and taken on a satisfactory finish.

The ordinary installation will show a temperature rise of the oil in the thrust bearing pot of about 15°C. to 20°C. An anbormal or rapid rise means trouble and the unit should be shut down quickly and the bearings inspected.

PHASE SEQUENCE DETERMINATION

Before paralleling polyphase machines, it is not only necessary that one phase be in synchronism with one phase of 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. There are various methods of "phasing-out" but only the three most commonly used methods will be described here.

(a) Probably the most widely used method for determining correct phase sequence is the use of incandescent lamps connected as shown in Fig. 37a for two 3-phase generators. The same connection can also be employed for synchronizing which will be described in subsequent paragraphs.

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.

Now 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 connections again, interchanging two other leads if necessary so that both sets of lights are dark at the same time indicating proper phase sequence. The lamps thus being properly connected, to pulsate together, the generator may be thrown in parallel at the proper indication of synchronism. Synchronizing apparatus in one phase only is sufficient for paralleling

OPERATION—Continued.

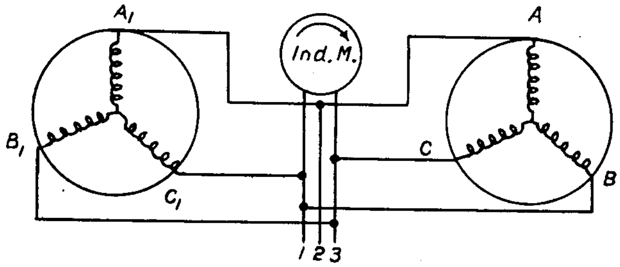

FIG. 36—SCHEMATIC CONNECTION FOR CHECKING PHASE ROTATION USING SMALL INDUCTION MOTOR.

the generators after the proper phase sequence has thus been established.

The procedure in "phasing-out" 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 proper phase-sequence of two-phase generators is determined in a similar manner. In case of incorrect rotation the two leads belonging to the same phase must be reversed instead of any two leads.

(b) There may be certain cases where it is not advantageous or even possible, at a particular time during the erection program, to resort to the use of lamps (or a synchroscope) for phasing out a generator. If this is the case and if a small induction motor is available, the phase rotation of the machine with respect to the system can be determined as follows: Note Fig. 36 for schematic connections.

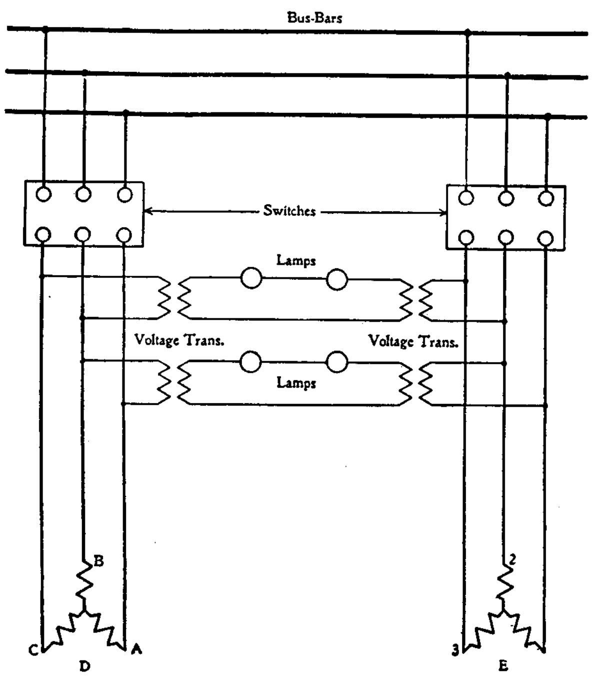

FIG. 37A—CONNECTIONS FOR SYNCHRONIZING THREE-PHASE GENERATORS.

(1) Connect the induction motor terminals to the system and note the direction of rotation of the motor rotor.

(2) Connect similarly marked terminals of incoming machine to the same motor terminals and note direction of rotation of motor rotor.

(3) If direction of rotation of motor is the same for each connection (1 and 2), the similarly marked terminals of incoming machine and system can be connected together as the machines will be in phase.

If the similarly marked terminals result in opposite mechanical rotation of the motor as would be for the case shown in Fig. 36 the similarly marked terminals cannot be connected together as the phase rotation is not correct. In the case illustrated in Fig. 36, the following terminals would be connected together: (A^1 to A)–(C^1 to B)–(B^1 to C.)

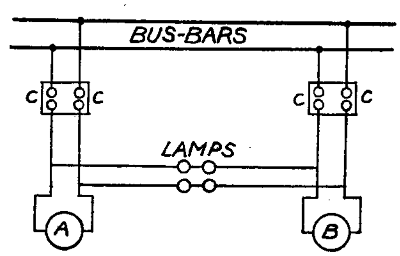

FIG. 37B—CONNECTION FOR SYNCHRONIZING LOW VOLTAGE SINGLE-PHASE GENERATORS.

(c) A further alternative method for insuring proper phase sequence is by use of the synchroscope. If a synchroscope is used for the synchronizing operation as described in the following paragraphs, the foregoing methods of "phasing-out" are not necessary.

SYNCHRONIZING A.C. GENERATORS

After the proper phase-sequence has been established as discussed above there is only one other condition to be fulfilled before paralleling two alternating current systems. The electromotive force of the incoming machine and of the system to which it is connected must be approximately the same at each instant. This requires that the frequencies be the same and the two voltages equal, as indicated by a voltmeter.

The fundamental principle employed in determining when generators are at the same frequency and in phase is illustrated by Fig. 37b 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.

OPERATION—Continued.

It will be noted that this scheme is basically the same as that employed for determining phase-sequence, however, once proper phase sequence has been established, synchronizing can be accomplished by inserting lamps in one phase only. When the voltage of the system is too high for the lamps available, potential transformers should of course be employed between the main bus and the synchronizing circuits as shown in Fig. 37a.

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.

If the connections of either the primary or secondary of either transformer are 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.

SYNCHROSCOPE

A synchroscope, Fig. 38, 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 synchroscope 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.

FIG. 38—SYNCHROSCOPE.

In order to check the synchroscope 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 synchroscope 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.

ADJUSTMENT OF FIELD CURRENT

(A) 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.

(B) Generator Operated in Parallel

A generator operated in parallel with one or more other generators may require that its excitation vary 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 to suit 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 the governor of the prime mover.

Operation with field current lower than the value which gives 100 per cent power factor should generally be avoided since this imposes additional load

OPERATION—Continued.

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 the generator pulling out of step during periods of heavy load or rapidly fluctuating loads. A generator pulls 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.

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 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. 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 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.

Machines which are not designed for single-phase operation, can deliver 20 per cent of the normal polyphase current as a single-phase generator. Higher values may be permissible if the machine has a damper winding liberally designed. 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 5 per cent at full load, it is advisable to watch the temperatures of all parts closely.

In addition to excessive heating of the damper winding or an increase in field current, the machine may vibrate seriously if the single phase load current is in excess of 20 per cent of the normal polyphase value.

LINE CHARGING

The larger generators usually transmit power over long transmission lines. A transmission line is, in effect, a condenser and the charging kv-a. can be very appreciable. The effect of the charging current is to magnetize the generator so that very low values of excitation are required to maintain rated voltage. Note Fig. 39. The line charging capacity of a generator varies with the short circuit ratio (*) which in turn (for standard designs) varies with the machine power factor rating. A standard 80 per cent power factor generator is designed for unity short circuit ratio and can charge a line, requiring not more than 80 per cent of the name plate kv-a. rating at rated voltage. A standard 90 per cent power factor generator is designed for a short circuit ratio of 1.10 and can charge a line not requiring more than 88 per cent of the name plate kv-a. rating. A standard 100 per cent power factor generator is designed for a short circuit ratio of 1.25 and can deliver charging kv-a. to a transmission line up to its full name-plate kv-a. rating.

***The short circuit ratio as defined by the American Standards Association is the ratio of I_{FNL} to I_{FSI}, Fig. 39.**

It is important that the generator line charging capacity limitations be known and not exceeded as the excitation may be so low as to result in unstable operation and ultimate "pull-out".

To permit operation at low values of field excitation, the excitation system must be specially designed for the minimum value of field current required.

All large standard generators are provided with exciters having a differential field which reduces the residual exciter armature voltage to zero. The smaller units require a main generator field rheostat to reduce the excitation voltage. A typical diagram, showing the connection of the differential shunt field is shown in Fig. 4.

CONDENSER CAPACITY

During periods of low water, when it would be uneconomical to operate all machines at fractional load, it may be desired to operate some of the generators as synchronous condensers. If the gen-

OPERATION—Continued.

erators are operated as condensers, the turbine should be de-watered by means of compressed air to reduce the water friction losses.

The permissible condenser capacity or over-excited capacity, varies with the field strength which is a function of the rated power factor for which the generator is designed.

A standard 80 per cent power factor machine can be operated as a condenser at rated voltage up to 65 per cent of its name plate kv-a. rating, a standard 90 per cent power factor generator up to 55 per cent of its rating, and a standard 100 per cent power factor generator up to 35 per cent of its name plate rating,

The usual method of starting a generator which is to operate as a condenser is to bring it up to speed by connecting it electrically to another unit and bringing both units up to speed together. After it has been brought up to rated speed or near to rated speed, the unit can be thrown on the line without field and then the field applied, after the generator pulls into step with the system. There will be an initial "bump" or disturbance on the system but it will be of short duration and usually not serious.

If the generator is provided with an adequate damper winding, it can be started as an induction motor by applying reduced voltage to the terminals of the machine.

The manufacturer should be consulted if this method of starting is contemplated.

OVER-VOLTAGE

The life of the stator winding insulation will be considerably shortened if a generator is operated for extended periods of time at an appreciable over-voltage.

In addition to the increase in dielectric stress and dielectric loss due to over-voltage operation, there is an additional excitation loss and iron loss due to the increased flux in the iron parts. If the operating power factor is not increased at the over-voltage, the field heating may increase to excessive values.

While the performance and temperature rise guarantees are always based on rated voltage, it is safe to operate a standard machine over a range of voltage from 95% to 105% at rated kv-a. and power factor without exceeding safe temperature rises, and without seriously reducing the life of the insulation.

When it becomes desirable or necessary to operate a generator at voltages above its name plate rating, the manufacturer should be consulted. **DO NOT PROMISCUOUSLY OPERATE AT OVER-VOLTAGES.**

Many generators are connected to long or exposed transmission lines and are therefore frequently subjected to lightning surges. These surges impress voltages so many times in excess of that for which the insulation is designed, that breakdown will occur if **LIGHTNING PROTECTIVE EQUIPMENT IS NOT USED. ADEQUATE INSULATION STRENGTH CANNOT BE BUILT INTO THE MACHINE TO WITHSTAND SUCH SURGES.**

SHORT CIRCUITS AND SYNCHRONIZING OUT OF PHASE

The stator windings of all standard generators are adequately braced to withstand the torques resulting from a polyphase short circuit at the machine terminals. If the relation of the positive, negative, and zero sequence reactances are such that a single phase short circuit will result in currents and torques in excess of the polyphase value, it is necessary to use external reactance or resistance to limit the short circuit current and torque to the polyphase value.

Particular care should always be exercised in supporting and bracing the bus structure and in making the joints external to the machine.

As previously stated, all generators are braced to withstand a polyphase short circuit but **DO NOT SHORT CIRCUIT A MACHINE TO PROVE IT,** as a short circuit always takes something out of the machine.

The short circuit current, resulting from a short circuit at the machine, without any external reactance can be calculated as follows:

	R.M.S.	PEAK ASSYMMETRICAL
3 Phase	$L\text{–}L = I''_i = \frac{E''}{X''d}$	$\cong 2\sqrt{2}\ I''_i$
1 Phase	$L\text{–}L = I''_{iL} = \frac{\sqrt{3}\,E''}{X''_d + X_2}$	$\cong 2\sqrt{2}\ I''_{iL}$
1 Phase	$L\text{–}N = I''_{iN} = \frac{3\,E''}{X''_d + X_2 + X_0}$	$\cong 2\sqrt{2}\ I''_{iN}$

Where:

E'' (from load) $\cong E_o + X''_d \sin \varnothing$

$\varnothing$ =power factor angle.

X''_d =subtransient reactance

X_2 =negative sequence reactance

X_o =zero sequence reactance

The above reactance values can be obtained for any particular unit by referring to headquarters and giving the serial number of the machine in question.

Care should be taken to avoid synchronizing a generator out of phase, as the results can be as severe as a short circuit. The magnitude of cur-

PART V

MAINTENANCE—Continued.

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 is necessary. It is suggested that insulation resistance readings be taken every six months, preferably summer and winter, and over a period of years. Any sudden trend of the insulation resistance values will indicate that maintenance steps need be taken. A method of making insulation resistance measurements is discussed on page 36.

The procedure employed for taking insulation resistance measurements should be carefully controlled. The following routine is suggested:

(1) Adopt a definite time of application for taking readings, preferably after 1 minute of voltage application.

(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 factor varies from 1 at 75°C. to about 14 at 25°C. Note Fig. 4.

(4) Take readings at machine terminals, being sure other cable, 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.

ROTOR

(A) Pole Dovetail Keys or Pole Bolts

The small vertical water wheel synchronous generators have the poles bolted to the spider rim. The bolts are tightened at the factory but they should be checked at intervals during the life of the machine.

The larger units which have the poles dovetailed to the spider laminated rim should periodically be checked for loose dovetail keys.

During the operation of the generator it is periodically started and stopped and in so doing may be subjected to "bumps". Also it may be operating single phase during fault conditions and be subjected to vibration. In addition there may be necessary to drive out the old keys and replace them with new keys. This is quite improbable if the unit is regularly inspected and properly maintained.

(B) Field Coil Braces

Due to the proportions and speeds of vertical waterwheel synchronous generators, it is usually not necessary to brace the field coils against the action of centrifugal forces, however there are some high speed units which require coil braces bearing against the sides of the coils. These braces are insulated from ground by micarta spacers located between the braces and the coil sides. The braces are kept in position by means of bolts tapped into the rotor spider.

After the generator has been in service for some time, the insulating spacers may shrink to some extent and may compress slightly due to the forces acting upon them. This action may result in the braces becoming loose. Therefore, the braces should be checked periodically and tightened if necessary. Failure to keep the coil braces tight will result in unbalance and may lead to more serious trouble.

RE-INSULATION OF FIELD COILS

After some period of operation, the generator rotor may develop short circuited turns or grounds. **Such developments do not mean that the material or workmanship was inferior at the time of manufacture.** Abnormal operation; failure to keep machine parts clean; failure to keep field coil braces and dovetail keys or pole bolts tight; can all be instrumental in causing such troubles.

When such troubles develop, **the repair work should not be undertaken by the Purchaser.** The ground insulation between the field coil and the pole consists of mica and asbestos which is built up on the entire inside surface of the coil. The operation requires tools and baking processes which are usually not available to the Purchaser or to the local service shops. Also the turn insulation is a specific material which is subjected to a variable but pre-determined pressure under large hydraulic presses.

It is therefore recommended that field coils needing re-insulation be returned to the manufacturer's headquarters.

MAINTENANCE—Continued.

The Westinghouse Electric & Manufacturing Company recommends the return of the coils when any major field coil repairs are necessary.

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 to do the work.

ORDERING INSTRUCTIONS

When ordering renewal parts, give the complete nameplate reading. Always give the name and style number (if known) of the part wanted, also the serial 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 shut-downs 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 (Recommended Renewal Parts Stock)

Generators in use up to and including......		1	5
Name of Part	No. Per Generator	Recommended For Stock	
Armature Coil—Stationary	1 Set	1–3 Set	1 Set
Cut Winding Insulation	1 Set	1–3 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	1–3 Set	1 Set
Thrust Bearing Shoe	1 Set	0	1 Set
Guide Bearing Lining	1 Set	0	1 Set

EXCITERS

See the Exciter Instruction Book for Maintenance Data.

MEMORANDA

MEMORANDA

WESTINGHOUSE BUSINESS ADDRESSES

Headquarters—306 4th Ave., Pittsburgh 30, Pa., P.O. Box 1017

*AKRON 8, OHIO, 106 South Main St.
*ALBANY 4, N. Y., 456 No. Pearl St.
*ALLENTOWN, PA., 522 Maple St.
*APPLETON, WISC., 340 W. College Ave., P.O. Box 206
*ASBURY PARK, N. J., 601 Bangs Ave., Room 708, Electric Bldg.
¶#†*ATLANTA 2, GA., 1299 Northside Drive, N.W., P.O. Box 4808
xATTICA, N. Y.
*†AUGUSTA, MAINE, 9 Bowman St.
*BAKERSFIELD, CALIF., 2224 San Emedio St.
¶*BALTIMORE 2, MD., 118 E. Lombard St.
†BALTIMORE 24, MD., 4015 Foster Ave.
xBALTIMORE 3, MD., 2519 Wilkens Ave.
†BATON ROUGE, LA., 555 Choctaw St.
*BEAUMONT, TEXAS, 1213 American National Bank Bldg.
*BINGHAMTON 62, N. Y., Suite 704, Marine Midland Bldg., 86 Court St.
*BIRMINGHAM 2, ALA., 1407 Comer Bldg.
①¶*BLUEFIELD, W. VA., Appalachian Elec. Power Co. Bldg., P.O. Box 848
¶*BOSTON 10, MASS., 10 High St.
†#BOSTON 27, MASS., 235 Old Colony Ave., So. Boston, Mass.
¶*†BRIDGEPORT 8, CONN., 540 Grant St.
¶*BUFFALO 3, N. Y., 814 Ellicott Square
#BUFFALO 13, N. Y., 960 Busti Ave.
†BUFFALO 10, N. Y., 1132 Seneca St.
*BURLINGTON, VT., 208 Flynn Ave.
*BUTTE, MONTANA, 52 East Broadway
#BUTTE, MONTANA, 50 East Broadway
*CANTON 2, OHIO, 901 First National Bank Bldg., 120 W. Tuscarawas
xCANTON 4, OHIO, Canton Ordnance Division, P.O. Box 710
*CEDAR RAPIDS, IOWA, 361 21st St., S. E., P.O. Box 148
①xCENTER LINE, Mich., 23500 Mound Road
*CHARLESTON, S. C., 89 G. Smith St., P.O. Box 303
*CHARLESTON 23, W. VA., 610 Union Bldg., P.O. Box 911
*†#CHARLOTTE 1, N. C., 210 East Sixth St.
*CHATTANOOGA 2, TENN., Volunteer State Life Bldg., Georgia Ave. & East Ninth St.
¶*CHICAGO 6, ILL., 20 N. Wacker Drive, P.O. Box B
①†CHICAGO 9, ILL., 2211 W. Pershing Road, P.O. Box 1103
#CHICAGO 23, ILLINOIS, 3201 S. Kedzie Ave.
¶*†CINCINNATI 2, OHIO, 207 West Third St.
¶*xCLEVELAND 1, OHIO, 1216 W. Fifty-Eighth St.
†CLEVELAND 2, OHIO, 5901 Breakwater Avenue, Station A
#CLEVELAND 14, OHIO, 1748 E. 22 Street
*COLUMBUS 15, OHIO, 85 E. Gay St.
*DALLAS 1, TEXAS, 209 Browder St.
#DALLAS 2, TEXAS, 1712 Laws St.
*DAVENPORT, IOWA, 206 E. Second St., P.O. Box 55
*DAYTON 2, OHIO, 30 North Main St.
¶*DENVER 2, COLORADO, 910 Fifteenth St.
#DENVER 2, COLORADO, 1700 Sixteenth St.
†DENVER 4, COLORADO, 988 Cherokee St.
xDERRY, PA.
*DES MOINES 8, IOWA, 1400 Walnut St.
¶*†#DETROIT 31, MICH., 5757 Trumbull Ave., P.O. Box 828
¶*DULUTH 2, MINN., 10 East Superior St.
x#EAST PITTSBURGH, PA.
*EL PASO, TEXAS, Oregon and Mills St.
#EL PASO, TEXAS, 450 Canal St.
†*EMERYVILLE 8, CALIF., 5915 Green St.
①#EMERYVILLE 8, CALIF., 6101 Green St.
*ERIE, PA., 1003 State St.
*EVANSVILLE 8, IND., 201 N. W. First St.
#*†FAIRMONT, W. VA., 10th and Beltline, P.O. Box 1147
*FORT WAYNE 6, IND., 1010 Packard Ave.
*GARY, IND., 846 Broadway
*GRAND RAPIDS 2, MICH., 148 Monroe Ave., N.W.
*GREENSBORO, N. C., Apartment I-7, Country Club Apartments, P.O. Box 1828
*GREENVILLE, S. C., 106 W. Tallulah Drive, P.O. Box 1591
*HAMMOND, IND., 235 Locust St.
*HARTFORD 3, CONN., 36 Pearl St.
*HONOLULU, T. H., Hawaiian Elec. Co., Agt.
¶*HOUSTON 2, TEXAS, 1314 Texas Ave.
#HOUSTON 2, TEXAS, 2301 Commerce Ave.
†HOUSTON 2, TEXAS, 2315 Commerce Ave.
¶†*#HUNTINGTON, W. VA., 1029 Seventh Ave., P.O. Box 1150
¶*INDIANAPOLIS 9, IND., 137 S. Penna. St.
†INDIANAPOLIS 2, IND., 551 West Merrill St.
*JACKSON, MICH., 212 West Michigan Ave.
*JACKSONVILLE 3, FLA., 37 South Hogan St., P.O. Drawer K
#*†JOHNSTOWN, PA., 107 Station St.
¶*KANSAS CITY 6, MO., 101 W. Eleventh St.
#KANSAS CITY 8, MO., 2020-2024 Walnut Street, c/o Walnut Warehouse, Inc.
*KNOXVILLE 8, TENN., Gay & Clinch St.
LESTER 13, PA., Merchant Marine Plant, P.O. Box 9177, Phila., Pa.
xLIMA, OHIO
¶*†#LOS ANGELES 13, CALIF., 420 So. San Pedro St.
*LOUISVILLE 2, KY., 332 West Broadway
①xLOUISVILLE 1, KY., P.O. Box 1860
*MADISON 3, WISC., 1022 E. Washington Ave.
xMANOR, PA., Benolite Corporation
xMANSFIELD, OHIO, 246 E. Fourth St.
*MEMPHIS 3, TENN., 130 Madison Ave.
*MIAMI 4, FLA., 11 N. E. Sixth St., P O. Box 590
¶*MILWAUKEE 2, WISC., 538 N. Broadway
†MILWAUKEE 3, WISC., 424 North Fourth St.
¶†*#MINNEAPOLIS 13, MINN., 2303 Kennedy St., N.E.
*MONROE, LA., 1107 N. 2nd St., P.O. Box 1851
*NASHVILLE 3, TENN., 219 Second Ave., N.
*NEWARK 2, N. J., 1180 Raymond Blvd.
①#NEWARK N. J., 123-7 Plane St.
xNEWARK 1, N. J., Plane & Orange Sts.
†NEWARK 1, N. J., Haynes Ave. & Lincoln Hwy.
*NEW HAVEN 8, CONN., 42 Church St., P.O. Box 1817
¶*NEW ORLEANS 12, LA., 333 St. Charles St.
xNEW PHILADELPHIA, OHIO, Power Train Div., 406 Mill Ave., Drawer 912
¶*NEW YORK 5, N. Y., 40 Wall St.
*NIAGARA FALLS, N. Y., 253 Second St.
*NORFOLK 1, VA., 2600 Hampton Boulevard, P.O. Box 2120
#NORWOOD, OHIO, Mentor & Houston Aves.
*OKLAHOMA CITY 2, OKLA., 120 N. Robinson Street
*OMAHA 2, NEB., 409 South Seventeenth St.
*PEORIA 2, ILL., 418 S. Washington St.
¶*†#PHILADELPHIA 4, PA., 3001 Walnut St.
*PHOENIX, ARIZONA, 11 West Jefferson St.
xPITTSBURGH, PA., Nuttall Work, 200 McCandless Ave.
¶‡*PITTSBURGH 30, PA., 306 4th Ave., Box 1017
†PITTSBURGH 8, PA., 543 N. Lang Ave.
#PITTSBURGH 6, PA., 6526 Hamilton Ave.
¶*PORTLAND 4, OREGON, 309 S.W. Sixth Ave.
†PORTLAND 12, ORE., 626 North Tillamook St.
#PORTLAND 9, ORE., 1518 N.W. Marshall St.
¶*†PROVIDENCE 3, R. I., 16 Elbow St.
*RALEIGH, N. C., 803 North Person St., P.O. Box 2146
*RICHMOND 19, VA., 301 S. Fifth St.
*ROCHESTER 7, N. Y., 1048 University Ave.
*ROCKFORD, ILL., 130 South Second St.
*SACRAMENTO 14, CALIF., Rooms 411 & 412 Ochsner Building, 719 K St.
¶*ST. LOUIS 1, MO., 411 North Seventh St.
†ST. LOUIS 2, MO., 717 South Twelfth St.
①#ST. LOUIS 2, MO., 815 South Eleventh St.
§*SALT LAKE CITY 1, UTAH, 10 West First South St.
†SALT LAKE CITY 7, UTAH, 346A Pierpont Ave.
#SALT LAKE CITY 11, UTAH, 235 West South Temple St.
*SAN ANTONIO 5, TEXAS, 115 W. Travis St.
*SAN DIEGO 1, CALIF., 861 Sixth Ave.
¶*SAN FRANCISCO 4, CALIF., 1 Montgomery St.
#SAN FRANCISCO 3, CALIF., 1355 Market St.
¶#†*SEATTLE 4, WASH., 3451 East Marginal Way
§SEATTLE 4, WASH., 1051 First Ave., So.
xSHARON, PA., 469 Sharpsville Ave.
*SIOUX CITY 17, IOWA, 2307 Kennedy Drive
*SOUTH BEND 4, IND., 216 East Wayne St.
xSOUTH PHILA. WKS., Essington 13, Pa. First-class mail, P.O. Box 7348, Phila. 1, Pa.
*SPOKANE 1, WASH., 158 S. Monroe St., Box 2130
*SPRINGFIELD, ILL., 601 E. Adams St., Box 37
¶*†SPRINGFIELD 1, MASS., 395 Liberty St.
xSPRINGFIELD 2, MASS., 653 Page Boulevard
xSUNBURY, PA., 1354 Susquehanna Ave.
*SYRACUSE 4, N. Y., 420 N. Geddes St.
†SYRACUSE, N. Y., 961 Genesee St.
*TACOMA 2, WASH., 1115 "A" St.
*TAMPA 1, FLA., 417 Ellamae Ave., Box 230
*TOLEDO 4, OHIO, 245 Summit St.
xTRAFFORD, PA.
*TULSA 3, OKLA., 303 East Brady St.
¶*†#UTICA 1 N. Y., 113 N. Genesee St.
¶*WASHINGTON 6, D. C., 1625 K Street, N.W.
*WICHITA 2, KANSAS, 233 S. St. Francis Ave.
†¶*WILKES-BARRE, PA., 267 N. Pennsylvania Ave.
*WILLIAMSPORT 1, PA., 348 W. Fourth St.
*WORCESTER 8, MASS., 507 Main St.
*YORK, PA., 137 So. George St.
*YOUNGSTOWN 3, OHIO, 25 E. Boardman St.

Where address and P.O. box are both given, send mail to P.O. box, telegrams to address indicated.

WESTINGHOUSE AGENT JOBBERS

Westinghouse Electric Supply Company—Headquarters—40 Wall St., Wall St. Station, P.O. Box 25

Fully equipped sales offices and warehouses are maintained at all addresses.

ALBANY 4, N. Y., 454 No. Pearl St.
ALLENTOWN, PA., 522 Maple St.
ATLANTA 2, GA., 1299 Northside Drive, N.W.
AUGUSTA, MAINE, 90 Water St.
BALTIMORE 2, MD., 40 South Calvert St.
BANGOR, MAINE, 175 Broad St.
BINGHAMTON 60F, N. Y., 87 Chenango St.
BOSTON 10, MASS., 88 Pearl St.
BURLINGTON, VT., 208 Flynn Ave.
BUTTE, MONTANA, 50 East Broadway
CHARLOTTE 1, N. C., 210 East Sixth St.
CHICAGO 7, ILL., 113 North May St.
§CINCINNATI 6, OHIO, 2329-2331 Gilbert Ave.
CLEVELAND 3, OHIO, 6545 Carnegie Ave.
COLUMBIA A, S. C., 915 Lady St.
CORPUS CHRISTI, TEXAS, North end of Mesquite St.
DALLAS 2, TEXAS, 405 No Griffin St.
DAVENPORT, IOWA, 402 E Fourth St.
DES MOINES 8, IOWA, 1400 Walnut St.
DETROIT 2, MICH., 547 Harper Ave.
DULUTH 2, MINN., 308 W Michigan St.
ERIE, PA., 1013 State St.
EVANSVILLE 8, IND., 201 B W First St.
FORT WAYNE 2, IND., 612 S. Harrison St.
FORT WORTH, TEXAS, 210 Jones St.
GRAND RAPIDS 2, MICH., 511 Monroe Ave., N.W.
GREENVILLE, S. C., 226 Pendleton
HOUSTON 2, TEXAS, 1903 Ruiz St.
INDIANAPOLIS 9, IND., 137 S. Pennsylvania St.
JACKSONVILLE 3, FLA., 37 South Hogan St.
LOS ANGELES 54, CALIF., 905 East Second St.
MADISON 3, WISC., 1022 E. Washington Ave.
MEMPHIS 1, TENN., 366 Madison Ave., Box 157
MIAMI 4, FLA., 11 N. E. Sixth St.
MILWAUKEE 2, WISC., 546 N. Broadway
MINNEAPOLIS 1, MINN., 215 South Fourth St.
NEWARK 5, N. J., 49 Liberty St.
NEW HAVEN 8, CONN., 240 Cedar St.
①NEW ORLEANS 6, LA., 420 South Peters St.
‡NEW YORK 5, N. Y., 40 Wall St., Wall St. Sta., P.O. Box 25
*#NEW YORK 13, N. Y., 150 Varick St.
NORFOLK 1, VA., 2600 Hampton Blvd., P.O. Box 2120
OAKLAND 7, CALIF., Tenth & Alice Sts.
OKLAHOMA CITY 2, OKLA., 850 N. W. 2nd St.
OMAHA 2, NEB., 117 North Thirteenth St.
PEORIA 2, ILL., 412 S. Washington St.
PHILADELPHIA 7, PA., 141 North Eleven St.
PHOENIX, ARIZONA, 315 West Jackson St.
PITTSBURGH 19, PA., 575 Sixth Ave.
PORTLAND 9, OREGON, 134 N. W. Eighth St.
PROVIDENCE 1, R. I., 66 Ship St.
RALEIGH, N. C., 319 W Martin St.
READING, PA., 4th and Elm Sts.
RICHMOND 19, VA., 301 South Fifth St.
ROANOKE, VA., 726 First St., S. E.
ROCHESTER 7, N. Y., 1048 University Ave.
SACRAMENTO 14, CALIF., Room 413 Ochsner Building, 719 K St.
ST LOUIS 2, MO., 1011 Spruce St.
ST PAUL 1, MINN., 253 E. Fourth St.
SALT LAKE CITY 11, UTAH, 235 West South Temple St.
SAN ANTONIO 6, TEXAS, 1211 E. Houston St., P O Box 1700
SAN FRANCISCO 1, CALIF., 260 Fifth St.
SEATTLE 4, WASH., 1051 First Ave., So.
SIOUX CITY 4, IOWA, 1005 Dace St.
SPOKANE 8, WASH., 152 So Monroe St.
SPRINGFIELD 3, MASS., 46 Hampden St.
SYRACUSE 4, N. Y., 961 W. Genesee St
TACOMA 2, WASH., 1115 "A" St
TAMPA 1, FLA., 417 Ellamae St.
TOLEDO 2, OHIO, 1920 N Thirteenth St.
TRENTON 10, N J., 444 S Broad St.
TULSA 3, OKLA., 307 East Brady St.
UTICA 1, N. Y., 113 N Genesee St.
WASHINGTON, D. C., 1216 "K" St., N.W.
WATERLOO, IOWA, 328 Jefferson St.
WHEELING, W VA., 1117 Main St.
WICHITA 2, KANSAS, 233 So St. Francis Ave.
WILLIAMSPORT 1, PA., 348 W Fourth St.
WILMINGTON, DEL., 216 E Second St.
WORCESTER 4, MASS., 17 Mulberry St.
YORK 2, PA., 143 S. George St

Other Than Westinghouse Supply Company

AKRON 8, OHIO, The Moock Electric Supply Co.
BIRMINGHAM 2, ALA., Moore Handley Hdw. Co.
BLUEFIELD, W. VA., Superior-Sterling Co.
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CANTON 2, OHIO, The Moock Electric Supply Co.
‡CHATTANOOGA, TENN., Mills & Lupton Supply Co.
CHICAGO 6, ILL., Hyland Electrical Supply Co.
COLUMBUS 16, OHIO, Pixley Electric Supply Co
†DENVER 17, COL., The Mine & Smelter Supply Co
†EL PASO, TEX., The Mine and Smelter Supply Co.
HUNTINGTON, W. VA., Banks Miller Supply Co.
KANSAS CITY 8, MO., Columbian Elec'l. Co.
KANSAS CITY 8, MO., Continental Elec. Co
LEXINGTON 31, KY., Tafel Elec. & Supply Co.
LOUISVILLE 2, KY., Tafel Electric & Supply Co.
NASHVILLE 2, TENN., Tafel Electric Supply Co.
§NEW YORK 10, N. Y., Times Appliance Co., Inc.
①RENO, NEV., Saviers Electrical Products Corp
SAN DIEGO, CALIF, The Electric Supplies Distributing Co
SCRANTON 9, PA., Penn Electrical Eng'nrg Co.
YOUNGSTOWN 1, OHIO, The Moock Electric Supply Co.

* Sales Office   † Mfg. and Repair Shop   x Works   # Warehouse   § Merchandising Products Only   ‡ Headquarters   ¶ District Eng. and Service Dept.

①Changed or added since previous issue.

September, 1944
Supersedes Issue dated May, 1944