IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications

Circuits and Devices

Communications Technology

Computer

Electromagnetics and Radiation

Energy and Power

Sponsored by the
Energy Development and Power Generation Committee
of the IEEE Power Engineering Society

Industrial Applications

Signals and Applications

IEEE Std 1095-1989

Published by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017, USA.

February 16, 1990

SH13086

THIS PAGE WAS
BLANK IN THE ORIGINAL

IEEE
Std 1095-1989

IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications

Sponsor

Energy Development and Power Generation Committee of the IEEE Power Engineering Society

Approved December 6, 1989

IEEE Standards Board

IEEE Std 1095-1989, *IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications,* describes installation procedures for synchronous generators and generator/motors rated 5000 kVA and above to be coupled to hydraulic turbines having vertical shafts.

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Foreword

(This Foreword is not part of IEEE Std 1095, IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.)

Large hydraulic turbine-driven generators are shipped as components and completely assembled and installed at the site. The installation, therefore, becomes a continuation of the manufacturing process, and many of the operations involved are those that are normally performed in the factory on smaller generators. Close tolerances must be maintained in the fit and alignment of the various parts. The use of proper installation procedures is essential to achieve satisfactory operation of the unit.

This Guide incorporates much of the information previously found in the National Electrical Manufacturers Association (NEMA) publication MG 5.2, Installation of Vertical Hydraulic-Turbine-Driven Generators and Reversible Generator/Motors for Pumped Storage Installations. MG 5.2 was originally issued in 1972 and revised in 1975 and 1977. NEMA sponsorship was withdrawn and MG 5.2 was rescinded in September, 1982.

In 1985 the Energy Development and Power Generation Committee of the IEEE Power Engineering Society agreed to sponsor the Guide, and the Hydroelectric Power Subcommittee undertook the task of reviewing, revising, and reissuing it.

The IEEE Std 1095, IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications Working Group wishes to acknowledge the contributions made to the guide by R. D. Handel and J. M. Quigley.

At the time this Guide was approved, the members of the Working Group were as follows:

David J. Parker, *Chairman*

F. L. Brennan
D. L. Evans
P. S. Johrde
D. G. McLaren
M. S. Pierce
D. H. Thomas

The Energy Development and Power Generation Balloting Committee, which approved this guide for submission to the IEEE Standards Board, had the following membership:

M. S. Baldwin
I. B. Berezowsky
L. D. Boydstun
S. R. Brockschink
R. W. Cantrell
R. L. Castleberry
E. F. Chelotti
R. S. Coleman
R. E. Cotta
M. L. Crenshaw
D. J. Damsker
H. R. Davis
D. Diamant
G. Engmann
A. H. Ferber
N. R. Friedman
D. I. Gorden
R. K. Gupta
M. E. Jackowski
J. H. Jones
P. R. H. Landrieu
J. E. LeClair
G. L. Luri
J. T. Madill
O. S. Mazzoni
D. R. McCabe
F. R. Meloy
M. W. Migliaro
J. L. Mills
C. R. Pope
R. J. Reiman
D. E. Roberts
E. P. Rothong
J. E. Stoner, Jr.
T. R. Whittemore

When the IEEE Standards Board approved this standard on December 6, 1989, it had the following membership:

Dennis Bodson, *Chairman* **Marco W. Migliaro,** *Vice Chairman*
Andrew G. Salem, *Secretary*

Arthur A. Blaisdell
Fletcher J. Buckley
Allen L. Clapp
James M. Daly
Stephen R. Dillon
Donald C. Fleckenstein
Eugene P. Fogarty
Jay Forster*
Thomas L. Hannan
Kenneth D. Hendrix
Theodore W. Hissey, Jr.
John W. Horch
David W. Hutchins
Frank D. Kirschner
Frank C. Kitzantides
Joseph L. Koepfinger*
Michael Lawler
Edward Lohse
John E. May, Jr.
Lawrence V. McCall
L. Bruce McClung
Donald T. Michael*
Richard E. Mosher
Stig Nilsson
L. John Rankine
Gary S. Robinson
Donald W. Zipse

*Member Emeritus

Contents

SECTION PAGE

FIGURES

TABLE

IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications

1. Introduction and Scope

The procedures for installation, described in this Guide, apply to all types of synchronous generators and generator/motors rated 5000 kVA and above to be coupled to hydraulic turbines or hydraulic pump/turbines having vertical shafts. All references made in this Guide to "generators" apply equally to "generator/motors."

2. References

Definitions, characteristics, and test methods not specifically covered in this Guide should comply with the following documents insofar as they are applicable:

[1] ANSI C50.5-1955, Rotating Exciters for Synchronous Machines.

[2] ANSI C50.10-1977, American National Standard General Requirements for Synchronous Machines.[1]

[3] ANSI C50.12-1982, American National Standard Requirements for Salient-Pole Synchronous Generators and Generator/ Motors for Hydraulic Turbine Applications.

[4] ANSI/IEEE Std 113-1985, Guide on Test Procedures for DC Machines.

[5] ANSI/IEEE Std 115-1983, IEEE Guide: Test Procedures for Synchronous Machines.[2]

[6] ANSI/IEEE Std 810-1987, Standard for Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances.

[7] IEEE Std 43-1974, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

3. Tools and Facilities

3.1 General. In general, the erector should have the complement of necessary tools and materials ready for use prior to the start of installation. Considerable time and money can be lost if these items are not ready when needed. The responsibility for the supply of erection tools and materials falls into the following main categories:

(1) Those supplied by the erector
(2) Those supplied by the manufacturer
(3) Those supplied by the customer

The following subsections will briefly describe these categories and will act as a guide for a typical installation. It is not intended that the lists be all-inclusive.

3.2 Erection Contractor-Supplied Tools. The tools and erection materials required for erection of a hydro unit are varied and numerous. The list below is indicative of the required items to be supplied by the erector.

(1) Portable power tools
(2) Stationary power tools
(3) Sets of large wrenches, ratchets, slugging, and impact wrenches
(4) Jacks and hydraulic rams
(5) Sledgehammers and air hammers
(6) Pipe bending and threading equipment
(7) Welding and burning equipment
(8) Soldering and brazing equipment
(9) Manual and small power hoists
(10) Jib crane for building the rotor rim and positioning the field pole assemblies
(11) Light rigging equipment
(12) Miscellaneous consumable items

[1] ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[2] ANSI/IEEE publications can be obtained from ANSI or the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

(13) Stator winding tools
(14) Precision measuring tools
(15) Electrical test equipment, including high-potential test sets, kelvin bridge, ohmmeter, megger (500, 1000, 2500 V ranges), voltmeters and ammeters

Craft labor groups are to have personal hand tools available.

3.3 Manufacturer-Supplied Tools. Certain tools will be called for in the customer specification and will be supplied as part of the contract. To be sure of the supply of these tools, the erector should contact the manufacturer and the customer. In most cases, these tools become the property of the customer and are left in good condition after the installation is complete:

(1) Shaft, rotor, and stator lifting devices
(2) Slings of proper length and size for the major lifting operations
(3) Rotor erection pedestal
(4) A plate for supporting the shaft in a vertical position. The plate is anchored in the assembly area concrete floor or in a pit of the proper depth to bring the rotor to a convenient distance above the floor.
(5) Pole and coil lifting device
(6) Thrust-bearing removal equipment
(7) A set of special wrenches and tools

The manufacturer will, in some instances, supply the erector with special erection tools. These tools are to be agreed upon with the customer prior to the start of erection, preferably during contract negotiations, and are not usually considered as part of the normal erection equipment.

3.4 Customer-Supplied Materials, Services, and Facilities. The customer often supplies various erection materials, services, and facilities for the erector. The customer specification will often spell out definite items that will be furnished. The specific responsibilities of each party should be checked for every job. Some typical items are as follows:

(1) Use of powerhouse cranes and crane-lifting beams
(2) Supply of a crane operator
(3) Compressed air
(4) Water
(5) Electric power
(6) Office space and administrative areas
(7) First-aid equipment
(8) Living accommodations for certain people
(9) Oil and oil filtering equipment for bearings
(10) Storage space for erection tools and equipment
(11) Grout
(12) Certain instrumentation
(13) Erection pedestal soleplates
(14) Assembly areas
(15) Security clearance for power plant access

4. Personnel

It is essential to have a crew of skilled workers with sufficient helpers and a supervisor experienced in the installation of vertical hydraulic turbine-driven generators. In addition to electricians and mechanics, workers skilled in pipe fitting, welding, rigging, and coil winding are usually needed.

In cases where the generator manufacturer is given the job of installing the equipment that he furnishes, he will provide a supervisor and all other personnel needed. Otherwise, it is recommended that one of the generator manufacturer's field representatives be employed to provide technical direction of the installation. The representative's familiarity with the construction of the generator and experience in the installation of similar machines are valuable assets.

Close cooperation between the purchaser, the generator manufacturer, exciter manufacturer, turbine manufacturer, governor manufacturer, and any installation contractors involved is necessary to assure proper installation in the most efficient manner. Agreement of the general procedures to be followed should be reached before actual erection begins.

5. Generator Construction

The following paragraphs give a brief description of the construction features of vertical hydraulic turbine-driven generators that have an important bearing on their installation.

5.1 General Arrangement. The basic elements of the generator are the stator (frame, magnetic core, and windings), rotor (shaft, thrust block, spider, rim, and poles with windings), thrust bearing, one or two guide bearings, upper and lower brackets (for the support of bearings and other parts), and soleplates, which are bolted to the foundation and form supports for the stationary parts of the machines. Other components may include a direct-connected exciter or starting motor, rotor brakes or combined brakes and jacks, foundation bolts, platform, stairway and handrails, and an air-discharge housing or a totally enclosed ventilating system with surface air coolers.

The thrust bearing can be located above or below the rotor. When only one guide bearing is utilized, it is normally located near the thrust bearing. When two guide bearings are used, one is located above and one below the rotor. A generator with the thrust bearing located above the rotor is referred to as a suspended generator (see Fig 1). A generator with the thrust bearing and a single guide bearing below the rotor is referred to as an umbrella generator (see Fig 2). An umbrella generator with a second guide bearing is referred to as a modified umbrella generator (see Fig 3).

The upper bracket is supported from the stator frame and occasionally requires radial restraint by the generator enclosure. On small generators with their thrust bearing above the rotor, the lower bracket may be integral with or bolted to the stator frame. Otherwise, the lower bracket is supported on its own set of soleplates.

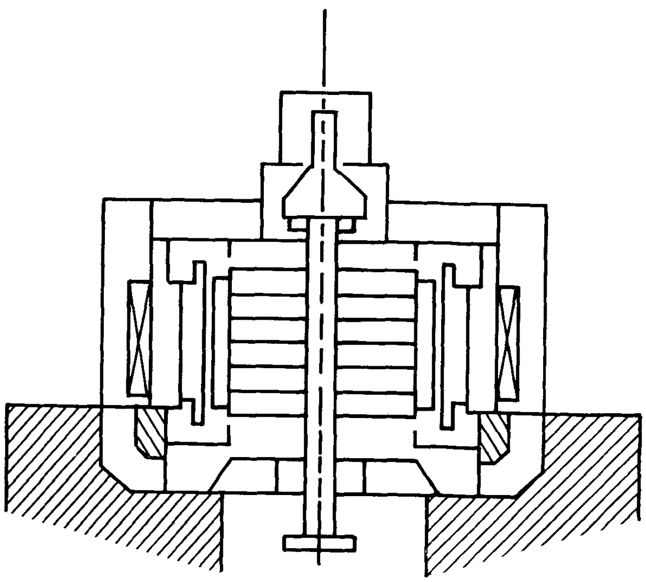
5.2 Stator Construction. The stator frame is usually fabricated from steel plate. Small-diameter stators can be shipped in one piece with the core stacked and the winding installed at the factory. Larger-diameter stators are sectionalized for shipping purposes, the number of sections depending upon shipping limitations, and the sections bolted or welded together at the site.

The sections may be stacked and wound at the factory or at the site, depending on preference or site requirements. If wound at the factory, the coils or bars adjacent to the splits may be shipped separately and the winding completed at the site.

Soleplates, which may have provision for levelling and centering, are grouted into the foundation. On larger diameters, provision is made to permit radial movement between the frame and the soleplates to accommodate thermal effects.

The stator core is composed of electrical grade steel laminations treated with

Fig 1
Suspended Generator



insulating enamel and stacked on keybars or core studs attached to the frame. The laminations are clamped in place by means of finger and flange assemblies, with the required clamping pressure applied and maintained with core studs.

The stator winding may consist of single- or multi-turn coils or half-turn bars. Double-layer windings, having two coil sides per slot, are most commonly used. The coils or bars are secured in the stator slots by wedges driven in grooves located at the top of the slots and by side-packing provided separately or integrally with the coil or bar. End windings are braced to restrain movement due to short circuits and to prevent possible downward movement of the stator coils or bars. Temperature detectors are generally installed between coils in a selected number of slots to indicate the temperature of the winding during operation.

5.3 Rotor Construction. The rotor of a small low- or medium-speed generator has a spider, which is generally shrunk on and keyed to the shaft. This spider is usually fabricated such that the hub, web, and rim are a single piece. The rim is a solid steel ring to which the poles are attached by bolts, studs, or dovetails.

Large low- and medium-speed machines have a fabricated spider with a separate rim, which is built up of segmental steel laminations bolted together to form one or several homogeneous rings. This rim is free to expand without constraint from the spider, but it is keyed to the spider periphery for torque transmission and centering. Often the rim is shrunk onto the spider to minimize the differential radial movement between the two structures at some level above rated speed. The field poles are held by dovetails to the laminated rim.

The spider design will vary considerably depending upon the configuration of the shaft and bearing system, the type of ventilation, the machine speed, and the ratio of rotor diameter to axial length.

Large low-speed machines with the thrust bearing above the rotor usually have a continuous shaft through the rotor. In this case, the spider is either shrunk on and keyed to the shaft, or bolted to one or two flanges forged integral with the shaft. Some medium-speed machines may also have this construction.

Large low-speed machines with the thrust bearing below the rotor usually have the main shaft terminating at the underside of the spider hub. The spider hub must be designed for this attachment, which will utilize one or more of the following: fitted bolts, bolts and torque pins, radial keys, or radial dowels.

Large medium-speed machines with large axial length compared to rotor diameter often are built with the spider hub serving as a section of the total shaft system. This construction is most common where the thrust bearing and a guide bearing are below the rotor, and there is need for a second guide bearing above the rotor. The main shaft terminates at the underside of the spider hub. An upper shaft is bolted to the top of the spider hub, thus completing the shaft system between guide bearings.

High-speed generators generally require a rotor spider, which is built up of circular steel laminations, plates, or forgings. The poles are attached to the outer periphery of the spider by dovetails. The spider is shrunk on and keyed to the shaft.

5.4 Shaft and Coupling. The generator coupling is often forged integrally with the shaft. The thrust block or collar, which transmits all vertical forces from the shaft to the thrust bearing, is often forged integrally with the shaft if the thrust bearing is below the rotor. If the thrust bearing is above the rotor, a separate collar is shrunk on and keyed to the shaft.

If the turbine is of the adjustable-blade propeller (Kaplan) type, a hollow generator shaft is required so that oil pipes can be carried through the shaft from the oil head at the top of the generator to the turbine servomotor.

5.5 Thrust Bearing. The thrust bearing carries the combined weight of the rotating parts of the generator and the turbine plus the hydraulic thrust imposed on the turbine runner. Thrust bearings used are the flat-type having segmental, stationary, babbitt-lined shoes.

5.5.1 Thrust Surface. The rotating thrust surface, which transfers load to the shoes, may be any of the following:

(1) A smooth surface on the underside of the integral thrust collar of the main shaft
(2) A smooth surface on the underside of a one-piece thrust collar or ring which is separate from the shaft

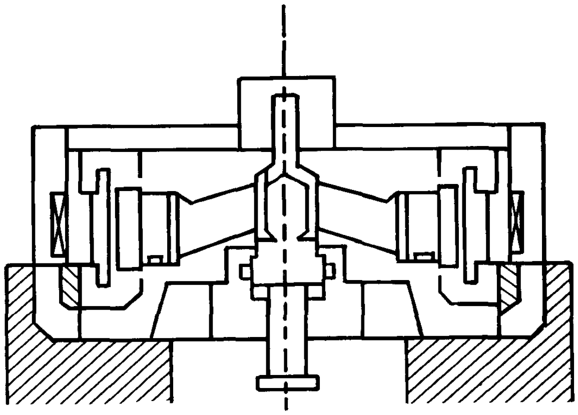


Fig 2
Umbrella Generator

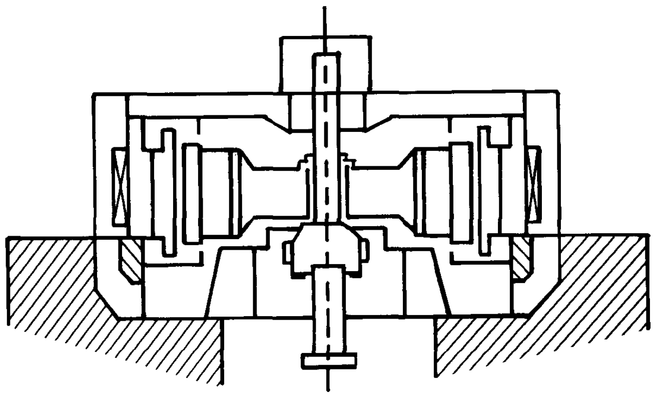


Fig 3
Modified Umbrella Generator

(3) The smooth surface may be on the underside of a circular flat plate or runner which has been precisely machined to have uniform thickness. This runner, which may be one or two pieces, is attached to the underside of the thrust collar or ring and transfers the load to the shoes.

5.5.2 Thrust-Shoe Support. The babbitt-faced thrust shoes are supported in a manner that is designed to equalize the loading between shoes and to allow each shoe to assume the proper position (slight tilt) with respect to the rotating thrust surface to establish and maintain a thin wedge-shaped oil film. The following four different forms of thrust-segment support systems are in general use:

(1) The rigid support, or adjustable-shoe type, in which the shoes are restrained so they do not rotate, but each is free to pivot on the spherical end of a jackscrew that supports it. The jackscrews provide a means of adjusting the height of each shoe individually to obtain equal loading of all shoes. They are also used to adjust the elevation of the rotor and to plumb the shaft. In some cases, measuring devices are permanently located in each jackscrew assembly for direct measurement of the load on the shoe.

(2) The semi-rigid support, or self-equalizing type. These bearings are also designed so that each shoe can pivot on its

support. In most self-equalizing types, these supports consist of systems of interlocking levers that allow small vertical movements of the shoes in order to maintain uniformity of shoe loading.

(3) The semi-flexible support, or spring type. These bearings have relatively thin and flexible babbitted segments, each supported on a bed of closely spaced precompressed springs, or pieces of specially formed metal. This allows each segment to adjust itself to the proper position with respect to the runner while a uniform pressure is maintained on all segments.

(4) Flexible-support type, in which the segments are positioned or restrained by a suitable structure and are mounted for load support on interconnected hydraulic bellows or cylinder devices. The hydraulic interconnection maintains uniformity of shoe load sharing. It should be noted, however, that this type of flexible bearing support has insufficient angular rigidity to maintain a horizontal thrust surface plane. This fact requires that bearings with flexible support mechanisms and, in some cases, even semi-flexible supports, need to have special consideration given to shaft support during erection and when alignment checks are made.

5.5.3 Bearing Lubrication. Thrust bearings operate immersed in a reservoir of lubricating oil. Oil circulates across the bearing by the pumping action of the rotating thrust surface and provides a continually changing oil film between the shoes and the thrust surface. The heat generated in the oil film may be removed by one of the following methods:

(1) For small bearings, the heat may be removed by the flow of machine-ventilating air over the walls of the bearing housing.

(2) In the larger sizes, it is usual to circulate water through cooling coils submerged in the oil in the bearing housing.

(3) The oil may be circulated by a motor-driven pump or by pumping action of the bearing from the bearing housing to an external heat exchanger.

Thrust bearings with high loss density in the oil film, the result of necessary high load pressure or high peripheral speed, may need more cooling than can be obtained by the above methods. Supplementary cooling may be obtained by either of the following methods:

(4) Circulating water through passages located in each shoe. This system requires careful assembly to ensure that there are no leaks in the piping and hoses inside the bearing housing.

(5) Circulating the lubricating oil through passages in the shoes. Either external pump or the self-pumping action of the bearing can be used to force the oil through the passages.

5.5.4 High-Pressure Oil-Lift System. Most large thrust bearings are equipped with a high-pressure oil-lift system. This usually is a packaged unit consisting of one or more motor-driven pumps, motor controls, pressure switches and gauges, strainers, filters, and check valves. Oil is pumped from the bearing reservoir and supplied at high pressure to a special port in each shoe, which is connected to a shaped groove in the central part of the babbitt surface. Before starting the machine, the high-pressure oil is forced between the babbitt and the rotating thrust surface, thereby establishing an oil film. This protects the bearing from possible damage upon initial start and ensures an oil film until the speed is sufficient to maintain the film. Similarly, during unit shutdown the high-pressure oil system is used to prevent damage due to low rotational speeds.

5.5.5 Bearing Insulation. A thrust bearing located above the rotor is usually insulated from its supporting structure to prevent the flow of shaft currents. The latter result from permeance variations in the stator core and tend to flow lengthwise along the shaft, flow out through a bearing on one end of the rotor, and return through the frame and the bearing at the other end of the rotor. Such current flow can be prevented by opening the circuit at any point. It is most convenient to open the circuit above the rotor, which requires insulation of the bearings and all other metallic parts that make contact with the shaft above the rotor. Either a single layer of insulation or a double layer with a metallic component between the two layers may be used. The latter is used to test the dielectric strength of the insulation by applying a voltage between the inner metallic component and the outer metallic parts.

5.6 Guide Bearings. If the thrust bearing is located above the rotor, the upper guide bearing may be combined with the thrust bearing, with the outer cylindrical surface of the thrust block or runner acting as the guide-bearing journal. Both bearings operate in the same oil reservoir. In some large machines, however, the guide bearing may be located below the thrust bearing in a separate oil reservoir. If the thrust bearing is located below the rotor, the lower guide bearing is usually combined with the thrust bearing and shares a common reservoir.

Most guide bearings are self-oiled and are designed to pump oil to the upper portion when the lower portion is immersed in oil. The bearings may be of the sleeve type, either solid or split, or of the segmental type. The latter are made up of a number of segments that are independently adjustable in a radial direction to permit convenient adjustment of the bearing clearance.

A guide bearing that is located above the rotor is usually insulated in the manner described in 5.5 for the thrust bearings.

5.7 Brakes and Jacks. The function of the brakes is to bring the rotor to rest after the turbine gates have been closed and to hold it at rest against a small amount of gate leakage. Subject to agreement of the manufacturers, brakes should normally be applied in the range of 15% to 50% of rated speed. Brakes are usually operated by compressed air at a pressure of about 100 lb/in^2.

Brakes may also be used as jacks. When jacking, they are usually operated by oil at a pressure of 1000 to 3500 lb/in^2 by means of a motor-driven or hand-operated oil pump used solely for this purpose. In this case, the header is so arranged that air may be admitted to and released from one end, and oil admitted to and released from the other end. As a safety measure, a blocking device is generally used so that the rotor can be held in the raised position without depending upon the maintenance of oil pressure.

If the turbine is a Kaplan type and flange couplings are used to connect the oil supply pipes to the servomotor, it may be necessary to raise the generator rotor an extra amount by special jacks or other means during assembly to connect the pipe couplings.

The brakes and jacks are usually supported on the lower bracket but, in some cases, the relation between the turbine pit diameter and generator rotor diameter is such that the brakes and jacks can be supported on their own soleplates. If the rotor has a rim of solid metal, this rim may form the braking surface; otherwise, separate segmental brake plates are used.

5.8 Field Assembly Requirements. Most hydraulic turbine-driven generators must be shipped disassembled to keep within the size and weight limitations of transportation and handling facilities. Even when these limitations can be met by an assembled generator, the generator may be shipped disassembled to reduce the possibility of damage during shipment and to facilitate final inspection and cleaning of the unit before operation.

Machines of moderate size may be shipped with the stator, rotor, and bearing brackets separate but with each of these parts completely assembled. With larger machines, however, some or all of these components should be shipped in two or more parts to meet the limitations of transportation facilities. The stator may be shipped in two or more sections.

The sections are bolted or welded together and the windings completed across the joints during installation. For very large machines, stator frames may be assembled at site along with core stacking and winding installation. The rotor may be shipped complete except for the shaft. In this case, the rotor is shrunk on or otherwise attached to the shaft in the field.

The rotors of low-speed machines having cast or rolled steel rims may be split into two parts, which are joined by shrink links during installation. Large machines with laminated rims will have the rim stacked on the spider and the field poles attached at the destination. On large high-speed machines, the spider itself, if built up of laminations or steel plates, may be assembled in the field. If the spider is of fabricated steel construction, it may be shipped in several parts, which must be bolted or welded together during installation.

The bearing brackets, too, may be of such a size that they must be shipped in several pieces, which are bolted or welded together at the destination. In all cases where the machines are not shipped completely assembled, such components as exciters, bearing parts, air coolers, air baffles, air housings, etc., are packed separately.

Because it is impractical to duplicate in the factory all of the conditions that will exist at the installation site, it is usually necessary to perform certain machining and fabrication operations in the field in order to assure proper fit and positioning of all parts. This will also correct any minor distortions that occur during shipment or fabrication. Typical of the operations that may be required at site are the following:

(1) Reaming or finish boring of holes for bolts holding a rotor spider to the shaft flanges
(2) Machining of chocks to fit between soleplates and the parts they support
(3) Drilling and reaming of dowel holes
(4) Reaming or finish boring of shaft-coupling bolt holes
(5) Drilling and tapping of holes and welding for mounting of accessories, conduit, piping, etc.

6. Preparation of Generator and Turbine Shafts in Factory

6.1 Factory Preassembly and Alignment. Preassembly and alignment of the combined turbine or generator shafts may be carried out at the factory of either the turbine or generator manufacturer. This procedure requires fitting the coupling bolts and checking the runout. It provides a convenient opportunity to remachine any of the parts or to take other corrective measures to reduce the runout, should this prove necessary.

The method of making the runout check and the recommended runout tolerances are given in 4.1 of ANSI/IEEE Std 810-1987 [6][3].

When the best relative position of the two couplings has been determined, each is matchmarked so that the same relative position can be obtained in field assembly.

It is preferred that the manufacturer making the factory alignment check also provide the coupling bolts, and the manufacturer's representative supervise the closing of the coupling in the field to assure correct assembly.

[3]The numbers in brackets correspond to those of the references listed in Section 2.

6.2 Field Alignment. When factory alignment of the combined shafts is not performed, runout checks are made on the individual shafts at the plants of the respective manufacturers. The method of making the runout check and the recommended runout tolerances are given in 4.2 and 4.3 of ANSI/IEEE Std 810-1987 [6]. The coupling bolt holes are drilled undersize for final reaming and fitting of the coupling bolts in the field.

7. Installation Precautions

7.1 Position References. When the unit is properly installed, the turbine runner should be supported in the center of the head cover and bottom ring, and at the proper elevation with respect to the water seal surfaces of these stationary parts. Since the positions of the turbine head cover and bottom ring are fixed before installation of the generator can begin, the resultant position of the turbine coupling must be used as the reference for the location of the generator, irrespective of any previously established center line or elevation.

Prior to erection of the generator, the turbine runner and shaft must be centered properly and supported in a position at a specified elevation (usually 1/4 in to 3/4 in) below the correct operating position. The turbine coupling can then be used to locate the soleplates and other parts of the generator.

7.2 Handling of Generator Parts. Generator components shall be handled carefully to prevent damage to windings and other parts.

When lifting stator frames, the slings should be arranged so that the weight is supported by the lifting bars and not by the reinforcing members of the frame.

Shafts should never be supported on the journal surfaces. With the shaft vertical, rotors may be handled by slings through the spider. Tapped holes in the end of the shaft should not be used to lift a complete rotor, but they are sometimes used to attach a device for handling the shaft only. A lifting trunnion may be used for handling the complete rotor. For machines furnished with a separate thrust collar, the trunnion may fit on the shaft in place of the collar.

7.3 Matching of Parts. When assembling machines in the field, attention should be paid to all matchmarks. Where more than one unit is being furnished, each machine should be assembled from parts having the same serial number or otherwise identified by the manufacturer as being parts of the same machine.

7.4 Use of Plumb Lines. A plumb line should consist of a steel piano wire attached to a heavy plumb bob. A 0.016 in diameter wire and a plumb bob weighing not less than 35 lb are satisfactory.

Providing fins on the plumb bob and allowing it to hang in a pail of heavy oil will dampen its swings and expedite the work. In use, the plumb line should be protected from all strong air currents.

7.5 Precautions in Welding. A serious hazard to bearings is electric welding on any part of the generator or turbine. A bearing can be damaged very quickly if welding current passes through it.

Whenever possible, all electric welding, especially on the rotating elements or bearing support brackets, should be done before the bearings are assembled. If welding must be done after assembly of the bearings, the following precautions should be observed:

(1) Ensure that the part being welded is connected to station ground grid.

(2) Connect the ground cable from the welder directly to the part being welded and to no other part of the machine.

(3) In the case of uninsulated bearings, separate the stationary and rotating parts. For solid guide bearings, the bearings must be removed. For segmental guide bearings, the segments must be backed off and paper inserted between the journal and the babbitt. For thrust bearings, the rotor should be jacked up. In some designs, if necessary to ensure complete separation, the driving dowels between runner and thrust block can be removed. A solid ground to the generator shaft should be maintained during assembly.

(4) If there is any possibility that a bearing, particularly a thrust bearing, has been subjected to any flow of welding current, it should be inspected before being restored to service.

7.6 Cleanliness. At all times, bearing parts, generator coils, ventilating ducts, exciter commutators, and collector rings should be shielded from dirt and other extraneous material. A special effort should be made to exclude metal chips, filings, weld spatter, or other conducting material from the windings and the rotor.

If construction work is being done, all parts of the generator should be covered where necessary to exclude dust and dirt. In all cases, the generator assembly area must be protected from the weather. In no case should construction work be carried on above the generator without adequate protection to the equipment and workers.

Experience has shown that dirt, small pieces of metal, and other extraneous materials will be left in any area of a hydro machine that is accessible to man. Therefore, the following procedures are recommended:

(1) Machine components should be inspected thoroughly before they are moved into the generator erection area.

(2) Workers should wear coveralls.

(3) Tools and assembly materials should be checked in and out at the appropriate time to ensure nothing has been left in the machine.

(4) Workers in generator erection areas should carry as few personal items as possible in their pockets and, when necessary, should declare personal items upon entry and exit.

(5) Generator erection areas should be cleaned daily.

7.7 Keeping Records. Permanent records should be kept of all settings, clearances, and tolerances established during erection of the generator. Such records are particularly useful if, at a later date, it appears that a change in alignment has occurred. Without adequate records it is difficult to determine the magnitude and cause of the change in alignment and the most suitable remedy.

To retain accurate alignment records, permanent reference plugs should be inserted in the concrete foundation.

8. Receiving, Storing, and Unpacking

8.1 Receiving. Upon receipt of shipment, all materials should be checked against the packing lists and assembly drawings for loss or shortage and inspected for damage during transit. Any loss or damage discovered should be reported at once to the carrier, and the carrier's agent should be given an opportunity to make an appropriate investigation. In all cases, copies of reports of damage or loss made to the carrier should be sent to the generator manufacturer. If concealed damage is found after the parts are unpacked, this should be reported in a similar manner.

A thorough inspection for damage to component's packing and protective coatings should be performed. All damaged protective coatings and covers should be repaired. All damaged crates should be opened, inspected, and resealed. All remaining crates should be inspected in sufficient time to obtain replacement parts in the event of shortage or damage. All piping end coverings must be intact.

All material should be placed under adequate cover immediately upon its receipt. Packing cases are not suitable for unprotected storage.

Machines in storage should be inspected and the insulation resistance of windings measured at periodic intervals. Records should be kept and any significant drop in resistance should be investigated. It may prove necessary to increase the heat input to limit the moisture absorption. Such precautions during storage will avoid costly deterioration of parts and an abnormally long dry-out time after installation.

It is important that all parts be stored properly or much time and expense will be incurred due to cleaning and refinishing parts during erection.

8.2 Storing. The following information should enable field personnel to protect the equipment from the time of arrival until the time the machine is assembled. Such protection will increase the chance of a long, reliable service life based on the best possible initial condition when the unit is first placed in service.

In storing generator components, considerations should be given to the following factors:

(1) Protecting from the elements
(2) Preventing moisture condensation
(3) Protecting from dust and dirt
(4) Safeguarding against mechanical damage
(5) Protecting from rodents, insects, and other species that may be able to penetrate the packing

The recommended conditions of storage of parts and the frequency of inspection and extent of testing are given in Table 1. The list of parts is not all-inclusive.

8.2.1 Outdoor Storage. In general, the following practices should be followed for the parts recommended to be stored outdoors:

(1) Storage site selected should be in a well drained area that is not subject to flooding.
(2) Components should rest on timbers at least 6 in above the ground.
(3) No machined surfaces should rest on the blocking. That is, all machined surfaces should be exposed. If this requirement cannot be met, machined surfaces must rest on oil-impregnated paper at the points of contact.
(4) Metal housings should be stored with concave surfaces facing down so that water cannot collect.
(5) All items should be covered with waterproof material (plastic, canvas, etc.) that allows space for air circulation and room for inspection.

Before storing in these conditions, a thorough inspection for damage to components' packing and protective coatings should be performed. All damaged protective coatings and covers must be repaired. Any marks on the finish due to handling and shipping must be repainted. All machined surfaces must be given an additional coat of slushing compound for added protection while in storage.

Parts on which final alignment and running clearances depend are machined to close tolerances. Consequently, adequate blocking must be provided when storing such parts to prevent distortion of their machined surfaces. Large parts such as rotor spiders must be supported to distribute their weight uniformly and thus avoid any permanent deformation.

8.2.2 Indoor Storage. If a well ventilated warehouse is used, the temperature should be maintained at about 15 °F above exterior temperature to prevent moisture condensation. Space heaters used inside the shelter should be kept at least 3 in away from metal and at least 6 in from combustible materials.

Table 1
Recommended Storage Location and Maintenance Schedule

Type of Equipment	Storage: Outdoor	Storage: Indoor
Spider, spider arms, thrust bracket, thrust-bracket arms, upper bracket top plate, upper bracket oil pot, upper bracket arms, air-housing deck, spider baffles, air-housing walls		
Recoat machined surfaces (if necessary)	3*	6
Inspect (general)	1	2
Thrust-bearing shoes, lower guide-bearing shoes, upper guide-bearing shoes, endbell assemblies, thrust-bearing base ring, rim punchings–rotor, misc., hardware, misc. instruments, special tools		
Recoat machined surfaces (if necessary)	N/R†	6
Inspect (general)	N/R	1
Stator frame sections		
Recoat machined surfaces (if necessary)	N/R	6
Megger winding	N/R	2
Inspect (rodent activity–general)	N/R	Weekly
Generator shaft		
Recoat machined surfaces (if necessary)	2	3
Inspect (general)	1	1
Field poles and coils		
Inspect coils (general)	N/R	1
Inspect (rodent activity–general)	N/R	1
Thrust-bearing runner		
Inspect (general)	N/R	2
Transformers, inverter, converter, cyclo-converter, switchgear assemblies, excitation system, reactor assembly, starting motors		
Inspect (general)	N/R	1

* Numbers represent intervals in months between activities.
†N/R indicates location not recommended.

Ventilation is important to proper drying, and heat alone is useful in preventing condensation. A useful guide is to provide 40 W of heat per 1000 lb of material to be kept warm. No heated part should exceed a total temperature of 150 °F.

Machined surfaces are coated with a rust-preventive material before shipment. If there are signs of damage to such surfaces, the protective compound should be removed, the rust and moisture eliminated, and the coating reapplied. Where thrust-bearing runners, bearing, and other highly polished surfaces are involved, the manufacturer should be consulted before any action is taken. As with parts stored outdoors, adequate blocking must be provided when storing parts having close tolerances to prevent distortion of their machined surfaces. All machine surfaces should be given an additional coat of slushing compound for added protection while in storage.

All electric equipment and instrumentation is susceptible to deterioration if allowed to become damp or if exposed to corrosive atmosphere. The equipment should be kept sealed in a packing box with an active desiccant, surrounded by a plastic bag, until it is ready for installation.

The field coils mounted on poles may be stacked two or three high in their packing crates, provided proper precautions are taken to prevent mechanical damage. Space should be available between stacks for air circulation.

It is recommended that the wound stator sections be stored in a manner to protect against moisture and dust. The stator sections should be properly supported off the floor and completely enclosed. All insulated windings should be protected against sweating and freezing by a safe and reliable heating system, which will keep the temperature of the windings above the dewpoint of the surrounding air. About 40 W/1000 lb may be sufficient if the heat is applied inside the enclosure. If the storage area ambient temperature has a variance of more than 5 °F in one day, additional heating may be needed.

The electrical condition of the stator sections should be monitored using a 2500 Vdc megger. The insulation resistance should be measured for a period of 10 min. Records should be kept and any significant drop in resistance should be investigated. The polarization index of the stator insulation should not be allowed to fall below two (2).

The generator shaft should be inspected to determine that the bearing journal and thrust face are free from moisture. Following the inspection of this area, the rust-preventive compound should be reapplied if necessary. It is also recommended that the shaft be lifted after three months of storage, the support area inspected, and rust preventive reapplied if necessary.

Since the shaft is machined to very close tolerances, adequate blocking shall be provided to prevent distortion. Supports should not be placed under journal surfaces, nor should wood supports be in direct contact with the shaft. Protection should be provided with oil-impregnated paper at the points of contact.

8.3 Unpacking. Upon unpacking, the contents of all boxes should be checked against the manufacturer's packing list. If windings or parts with machined surfaces have been exposed to low temperature, their coverings should not be removed until they have been warmed to approximately the temperature of the room where they will be unpacked.

Rust-preventive coatings on machined surfaces should not be removed until the parts are to be installed. The solvent used should be one specified by the generator manufacturer. In no case should any abrasive material, such as sandpaper or metallic scrapers, be used to remove the rust-preventive coatings.

After the finished surfaces have been thoroughly cleaned, any burrs or bumps received in shipping or handling should be removed with a fine file, scraper or stone, except where highly polished runners, bearing journals, etc., are involved. In the latter case, the manufacturer should be consulted for specific instructions.

9. Erection Procedures

9.1 General. The erection procedures described herein are those that will generally prove most satisfactory. Special circumstances, however, may arise in any installation that make it desirable to depart somewhat from these procedures.

The erection procedure for generators which are shipped completely assembled differ from that for machines which are assembled in the field. Furthermore, field-assembled generators require a somewhat different erection procedure if the thrust bearing is located above the rotor than they do if it is located below the rotor. Finally, the procedure for field-assembled machines having a spring-type or self-equalizing-type thrust bearing differs from that for machines having an adjustable-shoe-type thrust bearing. Hence, the five cases for which this section is applicable are as follows:

(1) Generator shipped completely assembled (see 9.2)
(2) Generator assembled in the field, thrust bearing above the rotor, spring-type or self-equalizing-type thrust bearing (see 9.3)
(3) Generator assembled in the field, thrust bearing above the rotor, adjustable-shoe-type thrust bearing (see 9.4)
(4) Generator assembled in the field, thrust bearing below the rotor, spring-type or self-equalizing-type thrust bearing (see 9.5)
(5) Generator assembled in the field, thrust bearing below the rotor, adjustable-shoe-type thrust bearing (see 9.6)

The step-by-step erection procedures for these five cases are outlined in 9.2 through 9.6. More detailed information on certain steps in the erection procedures is given in Section 10. Some generator components must be assembled in the erection bay before they are incorporated into the final assembly in the generator pit. Such subassembly work should be scheduled properly so that it will fit into the final erection procedure, which is outlined in 9.2 through 9.6. Ample time should be allowed for major operations, such as the field assembly of a generator rotor and stator stacking and winding.

In all cases, the foundation bolts are placed in position while the forms for the concrete foundations are being built (see 10.1).

9.2 Generator Shipped Completely Assembled

(1) Lift the generator into place on the foundation with the soleplates bolted to the bottom of the machine.

(2) Center the shaft in guide bearings and stator bore; check air gap; and temporarily lock in place.

(3) Adjust elevation and horizontal position of soleplates (see 10.2) until the generator coupling is in alignment with the turbine coupling and at the correct elevation. Tighten foundation bolts.

(4) Close the generator-turbine coupling (see 10.10) and check the elevation of the turbine runner.

(5) Make shaft-plumb and straightness check (see 10.11) where the design of the machine permits, and recheck centering of shaft in guide bearings.

(6) Grout the soleplates (see 10.2).

(7) Dowel generator to soleplates (unless predoweled).

9.3 Generator Assembled in the Field, Thrust Bearing Above the Rotor, Spring-Type or Self-Equalizing-Type Thrust Bearing

(1) Place the soleplates for the stator frame and for the lower bracket (if it is not integral with or bolted to the stator frame) in position over the foundation bolts, and adjust them to a level position (perpendicular to the stator plumb) at approximately the correct elevation. Temporarily tighten foundation bolts. (For grouting, see 10.2.)

(2) Place the assembled lower bracket into position on its soleplates and install hold-down bolts.

(3) Place the stator on its soleplates and install hold-down bolts; if the stator is sectionalized, close the joints in the frame and complete the stator winding across the joints (see 10.3).

(4) Adjust the elevation of soleplates (see 10.2) until the top surface of the stator frame is level and at the correct elevation. Also, check to see that the stator forms a true circle and make any necessary adjustments. Assembly of air coolers and any internal wiring and piping (see 10.7) can usually start at this time.

(5) Place the assembled upper bracket on the stator frame and shim under ends of arms until the thrust-bearing supporting surface is level and at the correct elevation.

(6) Suspend a plumb line from the upper bracket to the turbine shaft, centering the line with respect to the upper guide bearing fits. Shift the bracket on the stator to center the plumb line in the stator core, and temporarily dowel the bracket to the frame to facilitate reassembly.

(7) Center the assembly of the stator and upper bracket to the turbine shaft and recheck roundness.

(8) Adjust the elevation and position of soleplates supporting the lower bracket (see 10.2) until the guide-bearing support is at the proper elevation and is centered with respect to the turbine shaft; then tighten the lower bracket foundation bolts (omit this step when lower bracket is integral with or bolted to the stator frame).

(9) Remove the upper bracket and lower the assembled rotor (see 10.4) into the stator, resting the rotor on the jacks or, where they are provided, on special blocks.

(10) Replace the upper bracket and assemble the thrust bearing (see 10.5) and thrust block.

(11) Lower the rotor so that the weight of the rotor is transferred to the thrust bearing and check thrust-bearing insulation (see 10.9).

(12) Check to see that the rotor is approximately centered axially with respect to the stator core. Allowance should be made for deflection in the bearing bracket, which will result from the weight of turbine rotating parts and hydraulic thrust.

(13) Check the elevation and alignment of the generator coupling with the turbine coupling and make adjustments, if necessary. Allow for deflection of the bearing bracket.

(14) Close the generator-turbine coupling (see 10.10) and check the elevation of the turbine runner.

(15) Perform shaft-plumb and straightness check (see 10.11) and make necessary adjustments.

(16) Center the turbine runner and establish trammel points at all guide bearings (including the turbine guide bearing) in cooperation with the turbine erector.

(17) Check the shaft runout by rotation check method 1 (15.1) if this method is selected and is applicable (see 10.13). In this case, the upper guide bearing should first be installed or other provision made to prevent excessive side slip during rotation of the shaft.

(18) Check the axial position and centering of the lower guide bearing support and make necessary adjustments in the position and elevation of the lower bracket. (Omit this step when the lower bracket is integral with or bolted to the stator frame.)

(19) The thrust-bearing oil coolers may be installed at this time following final inspection (see 11.2) depending on the generator manufacturer's recommendations.

(20) Install the upper guide bearing (unless already installed) and then the lower guide bearing (see 10.6). (The turbine guide bearing should now be installed.) If the bearings are of the sleeve type, check the clearances all around the journal and, if necessary, re-center the bearing support or bracket or both. If segmental-type bearings are used, adjust each segment to the correct clearance. Check the trammel points at the turbine guide bearing after installing each bearing to make sure that the shaft has not shifted. Also, check the insulation of the upper guide bearing (see 10.9).

(21) Install rotating exciters (if provided), collector rings, and brush rigging (see 10.14), and complete the internal wiring to these devices.

(22) Check air gap for uniformity (see 10.8).

(23) Dowel the upper bracket to the stator frame and dowel the stator frame (and lower bracket, when not integral with or bolted to the stator frame) to the soleplates. This doweling must not prevent thermal differential expansion of components.

(24) If not done previously, grout the soleplates (see 10.2).

(25) Install enclosing air shrouds, covers, stairs, handrails, etc., if provided.

(26) After complete assembly of all parts (including turbine and governor parts) that are located above the generator rotor, check the insulation of all possible paths for shaft current (see 10.9).

9.4 Generator Assembled in the Field, Thrust Bearing Above the Rotor, Adjustable-Shoe-Type Thrust Bearing

(1) Place the assembled lower bracket in position on the foundation with the bracket arms bolted to the soleplates. Bring the bracket to the correct elevation and center the bracket to the turbine shaft with a plumb line. For grouting of the lower bracket soleplates, see 10.2. Final centering of the bracket will be done later by removing the pipe spacers from around the bracket hold-down bolts and moving the bracket on its soleplates. (Omit this step when lower bracket is integral with or bolted to the stator frame.)

(2) Place the stator soleplates in position and set them to the correct elevation, angle, and radius. (For grouting, see 10.2.) The lower bracket is a working platform for this operation.

(3) Place the stator on its soleplates and install hold-down bolts; if the stator is sectionalized, close the joints in the frame and complete the stator winding across the joints (see 10.3).

(4) Adjust the elevation of soleplates (see 10.2) until the top surface of the stator frame is level and at the correct elevation. Also, check to see that the stator forms a true circle and make any necessary adjustments. Assembly of air coolers and any internal wiring and piping (see 10.7) can usually start at this time.

(5) Place the upper bracket on the stator. Center the stator and upper guide bearing fit to the turbine shaft. Install temporary dowels in the upper bracket arms.

(6) Remove the upper bracket and lower the assembled rotor (see 10.4) into the stator, resting the rotor on the jacks or, where they are provided, on special blocks.

(7) Replace the upper bracket and assemble the thrust bearing (see 10.5) and thrust block.

(8) Lower the rotor so that the weight of the rotor is transferred to the thrust bearing and check thrust-bearing insulation (see 10.9).

(9) Check to see that the rotor is approximately centered axially with respect to the stator core.

(10) Adjust the thrust-bearing jackscrews until the generator coupling face is at the correct elevation and parallel with the turbine-coupling face. Shift the generator rotor horizontally until the two couplings are in alignment.

(11) Close the generator-turbine coupling (see 10.10) and check the elevation of the turbine runner.

(12) Perform shaft-plumb and straightness check (see 10.11), and make necessary adjustments.

(13) Center the turbine runner and establish trammel points at all guide bearings (including the turbine guide bearing) in cooperation with the turbine erector.

(14) Check the thrust-bearing shoes for uniformity of loading and make necessary adjustments (see 10.12).

(15) Check the shaft runout by rotation check method 1 (15.1.1.1) if this method is selected and is applicable (see 10.13). In this case, the upper guide bearing should first be installed or other provision made to prevent excessive side slip during rotation of the shaft.

(16) Check the axial position and centering of the lower guide-bearing support and make necessary adjustments in the position and elevation of the lower bracket. (Omit this step when lower bracket is integral with or bolted to the stator frame.)

(17) The thrust-bearing oil coolers may be installed at this time following final inspection (see 11.2) depending on the generator manufacturer's recommendations.

(18) Install the upper guide bearing (unless already installed) and then the lower guide bearing (see 10.6). (The turbine guide bearing should be installed.) If the bearings are of the sleeve type, check the clearances all around the journal and, if necessary, re-center the bearing support or bracket or both. If segmental-type bearings are used, adjust each segment to the correct clearance. Check the trammel points at the turbine guide bearing after installing each bearing to make sure that the shaft has not shifted. Also, check the insulation of the upper guide bearing (see 10.9).

(19) Install rotating exciters (if provided), collector rings, and brush rigging (see 10.14), and complete the internal wiring to these devices.

(20) Check air gap for uniformity (see 10.8).

(21) Dowel the upper bracket to the stator frame and dowel the stator frame (and lower bracket when it is not integral with or bolted to the stator frame) to the soleplates. This doweling must not prevent thermal differential expansion of components.

(22) If not done previously, grout the soleplates (see 10.2).

(23) Install enclosing air shrouds, covers, stairs, handrails, etc., if provided.

(24) After complete assembly of all parts (including turbine and governor parts) that are located above the generator rotor, check the insulation of all possible paths for shaft current (see 10.9).

9.5 Generator Assembled in the Field, Thrust Bearing Below the Rotor, Spring-Type or Self-Equalizing-Type Thrust Bearing

(1) Place the soleplates for the stator frame in position over the foundation bolts, and adjust them to a level position at approximately the correct elevation. Temporarily tighten foundation bolts. (For grouting, see 10.2.)

(2) Place the soleplates for the lower bracket in position over the foundation bolts, and adjust them to a level position at approximately the correct elevation. Tighten foundation bolts. (For grouting, see 10.2.) (This step in the erection procedure does not apply, of course, if the soleplates are embedded in the foundation.)

(3) In the erection area, assemble together the lower bracket, shaft, thrust bearing, and lower guide bearing (see 10.5 and 10.6). If the guide bearing is of the

segmental type, tighten four segments against the journal to keep the shaft in position. Perform the necessary fitting of any thermal devices in the bearings and oil reservoir (see 10.15).

(4) Place the lower bracket assembly in its approximately correct location on the soleplates. If the soleplates were not grouted (step 2) or embedded in the foundation, install the lower bracket hold-down bolts.

(5) Place the stator on its soleplates and install hold-down bolts; if the stator is sectionalized, close the joints in the frame and complete the stator winding across the joints (see 10.3).

(6) Adjust the elevation of the lower bracket and shift its position until the generator coupling is at the correct elevation and is in alignment with the turbine coupling.

(7) Close the generator-turbine coupling (see 10.10) and check the elevation of the turbine runner.

(8) Perform shaft-plumb and straightness check (see 10.11) and make necessary adjustments.

(9) Center the turbine runner and establish trammel points at the generator lower guide bearing and at the turbine guide bearing (in cooperation with the turbine erector).

(10) If the lower bracket soleplates were grouted (step 2) or embedded in the foundation, fit and install chocks between the bracket arms and soleplates when they are required, and install hold-down bolts. Otherwise, tighten the foundation bolts and grout the lower bracket soleplates (see 10.2).

(11) Recheck the shaft plumbness and centering of the turbine runner and make any necessary adjustments.

(12) Adjust the elevation of the stator soleplates (see 10.2) until the top surface of the frame is level and at the correct elevation. Also, check to see that the stator forms a true circle and make any necessary adjustments. Center the stator around the shaft and tighten stator foundation bolts. Assembly of air coolers and any internal wiring and piping (see 10.7) can usually start at this time.

(13) Install the assembly of rotor spider, rim, and poles on the shaft (see 10.4).

(14) Replumb the shaft with the rotor weight supported by the thrust bearing.

(15) Check the shaft runout by rotation check method 1 (15.1.1.1), if this method is selected and is applicable (see 10.13).

(16) Check to see that the rotor is approximately centered axially with respect to the stator core and, if not done previously, grout the stator soleplates (see 10.2).

(17) Install the assembled upper bracket and center it to the shaft.

(18) If an upper guide bearing is provided, align and axially locate its support. Also, establish trammel points at the upper guide bearing.

(19) Adjust the clearance of the lower guide bearing, then install any thermal devices in the thrust bearing and oil reservoir. The thrust-bearing oil coolers may be installed at this time or following final inspection (see 11.2), depending on the generator manufacturer's instructions.

(20) Install and adjust clearance of the upper guide bearing, if an upper guide bearing is provided. (The turbine guide bearing should also be installed at this time and its clearance adjusted.) Recheck the trammel points to be sure the shaft has not shifted.

(21) Check the insulation of the upper guide bearing, if provided (see 10.9).

(22) Install rotating exciters (if provided), collector rings, and brush rigging (see 10.14), and complete the internal wiring to these devices.

(23) Check air gap for uniformity (see 10.8).

(24) Dowel the upper bracket to the stator frame, the stator frame to the soleplates, and the lower bracket to the soleplates. This doweling must not prevent thermal differential expansion of components.

(25) Install enclosing air shrouds, covers, stairs, handrails, etc., if provided.

(26) After complete assembly of all parts (including turbine and governor parts) that are located above the generator rotor, check the insulation of all possible paths for shaft current (see 10.9).

9.6 Generator Assembled in the Field, Thrust Bearing Below the Rotor, Adjustable-Shoe-Type Thrust Bearing

(1) Some of the generators of this type are designed so that the shaft and thrust-bearing assembly can be placed through the top of the lower bracket after the bracket has been set on the foundation. For machines of this type, the procedure for setting the lower bracket and stator can be identical to the method used on adjustable shoe bearings with the thrust bearing above the rotor.

(2) Place the assembled lower bracket in position on the foundation with its soleplates bolted to the bracket arms. Bring the bracket to the correct elevation and center the bracket to the turbine shaft with a plumb line. (For grouting of the lower bracket soleplates, see 10.2.) Final centering of the bracket will be done later by removing the pipe spacers from around the bracket hold-down bolts and moving the bracket on its soleplates.

(3) Place the stator soleplates in position and set them to the correct elevation, angle, and radius. (For grouting, see 10.2.) The lower bracket is a working platform for this operation.

(4) Place the stator on its soleplates and install hold-down bolts; if the stator is sectionalized, close the joints in the frame and complete the stator winding across the joints (see 10.3).

(5) Thrust-bearing parts can be preassembled around the shaft and this assembly can be placed in the lower bracket.

(6) On machines where the shaft and thrust bearing cannot be assembled through the top of the lower bracket, it will be necessary to preassemble the shaft and bearing in the bracket and place this as a unit on its foundation; otherwise, the procedure is as outlined in steps 2 to 5, inclusive.

(7) Adjust the elevation of the lower bracket and shift its position until the generator coupling is at the correct elevation and is in alignment with the turbine coupling. Fine elevation adjustment may be accomplished by use of the thrust-bearing jackscrews.

(8) Close the generator-turbine coupling (see 10.10) and check the elevation of the turbine runner.

(9) Perform shaft-plumb and straightness check (see 10.11), and make necessary adjustments.

(10) Center the turbine runner and establish trammel points at all guide bearings (including the turbine guide bearings) in cooperation with the turbine erector. If not done previously, grout the lower bracket soleplates (see 10.2).

(11) Adjust the elevation of the stator until the top surface of the frame is level and at the correct elevation. Also, check to see that the stator forms a true circle and make any necessary adjustments. Center the stator around the shaft and tighten the stator foundation bolts. Assembly of air coolers and any internal wiring and piping (see 10.7) can usually start at this time.

(12) Install the assembly of rotor spider, rim, and poles on the shaft (see 10.4).

(13) Replumb the shaft with the rotor weight supported by the thrust bearing.

(14) Check the thrust shoes for uniformity of loading and make necessary adjustments (see 10.12).

(15) Check the shaft runout by rotation check method 1 (15.1.1.1) if this method is applicable (see 10.13).

(16) Check to see that the rotor is approximately centered axially with respect to the stator core and, if not done previously, grout the stator soleplates (see 10.2).

(17) Install the assembled upper bracket and center it to the shaft.

(18) If an upper guide bearing is provided, align and axially locate its support. Also, establish trammel points at the upper guide bearing.

(19) Adjust the clearance of the lower guide bearing. The thrust-bearing oil coolers may be installed at this time or following final inspection (see 11.2) depending on the generator manufacturer's recommendations.

(20) Install and adjust clearance of the upper guide bearing, if an upper guide bearing is provided. (The turbine guide bearing should also be installed at this time and its clearance adjusted.)

Recheck the trammel points to be sure the shaft has not shifted.

(21) Check the insulation of the upper guide bearing, if provided (see 10.9).

(22) Install rotating exciters (if provided), collector rings, and brush rigging (see 10.14), and complete the internal wiring to these devices.

(23) Check air gap for uniformity (see 10.8).

(24) Dowel the upper bracket to the stator frame, the stator frame to the soleplates, and the lower bracket to the soleplates. This doweling must not prevent thermal differential expansion of components.

(25) Install enclosing air shrouds, covers, stairs, handrails, etc., if provided.

(26) After complete assembly of all parts (including turbine and governor parts) that are located above the generator rotor, check the insulation of all possible paths for shaft current (see 10.9).

10. Details of Erection Procedures

10.1 Placing of Foundation Bolts. The proper size and the location of the foundation bolts are shown on the generator outline drawing. Most foundation bolts are coaxial assembly of a long rod threaded at both ends and a pipe sleeve 1 or 2 in larger in diameter than the rod. A nut at the lower end supports a square plate, which in turn supports the pipe sleeve. The sleeve is welded to the plate, and the nut is welded to both the plate and the rod (bolt).

A metal template or jig should be used to assure accurate positioning of the bolt assemblies while the foundation is being poured. Until the soleplates are grouted, concrete and other foreign matter should not be allowed in the space between the sleeve and the bolt because this would prevent the small lateral movement of the bolt often necessary when the soleplates and machine parts are finally positioned.

Alternatively, tapered rectangular pockets, which are larger at the lower end, may be formed in the foundation at the foundation bolt locations. Later the foundation bolts can be grouted into these pockets, after the soleplates are positioned. The foundation bolt assemblies should be left unpainted to provide a better bond with the concrete.

10.2 Positioning and Grouting of Soleplates. Soleplates are often positioned by being bolted to the part that they support (stator frame or lower bracket) before being grouted so that proper positioning of the part brings the soleplates to the correct location. The holes for the hold-down bolts are usually drilled oversize to allow some adjustment of the position of the supported part after the soleplates have been grouted. Initially, the bolts should be centered in the holes. This is conveniently accomplished by placing sleeves of proper dimensions in the bolt holes. Sometimes, it is advantageous to locate accurately and grout the soleplates before the supported part is brought into position.

The elevation of the soleplates may be adjusted by means of jackscrews, sliding parallels, or double parallel wedges. In the case of the stators of large machines, convenient adjustment of the elevation is possible if provision is made in the foundation so that a jack can be placed alongside each soleplate to raise and lower the stator with the soleplates attached. After a soleplate has been brought to the correct elevation, it can be supported in this position by flat plates or shims. In all cases, the soleplates must rest on a support that is substantial enough to carry the total vertical loading until the soleplates are grouted.

After final positioning, chocks, if required, are machined to fit accurately into the space between each soleplate and supported part.

During the erection procedure, grouting of the soleplates should be done at the time specified by the generator manufacturer. Before grouting soleplates, the base mass of concrete should be thoroughly cleaned. The surface should be roughed up by chipping, then wetted and slurried. A stiff, fine grout should then be forced into the space around and under the soleplate, making sure that every crevice is filled. The use of vibrators for distributing the grout is not recommended, since their use may disturb the alignment of the soleplates.

Sufficient space must be allowed for installing any radial dowels as shown on the generator outline drawing or in accordance with the generator manufacturer's instructions.

10.3 Assembly of Stator. If the stator that has been stacked and wound at the factory is shipped in two or more sections, each section of the stator is placed in position on the soleplates and bolted to the adjacent section. The sections are then carefully aligned so that the cores match at each split. The manufacturer should specify the procedure to use and the tolerances required in making up the splits.

Stators that are to be stacked and wound at the site generally have had the core studs and the keybars on which the core laminations are stacked installed at the factory.

Each stator frame section is placed in position on the soleplates and bolted to the adjacent section. On stators equipped with radial keying systems, care should be taken to ensure that the frames are not welded to the soleplates as this will defeat the purpose of the keying system, which is to permit radial freedom of the stator. On stators equipped with radial support rods, care should be taken that the frame is free to expand and contract along the clearance provided by the connecting structures and the rods are positioned to allow equal in and out movement after the stator and rotor centers have been adjusted. The frame is then centered by measurements taken from a center wire, referenced to the center line of the turbine, to the keybars. Centering screws are usually provided to facilitate the line-up.

The frame should be checked to ensure that it is level, at the correct elevation, and round within tolerances specified by the generator manufacturer. Keybars should be checked for verticality, and those adjacent to the joints should have their chordal dimensions checked against the chords of the remaining keybars.

When the stator frame has been thus set up and assembled, it is made ready for the stacking of the core and the assembly of the winding. Both operations are intricate in nature and should be carried out under close supervision by the generator manufacturer's erection supervisor. Close attention must be paid to cleanliness and every effort made to provide and maintain the proper working conditions.

If stacking and winding are performed in the erection bay instead of in the generator pit, the finished stator should be positioned in the pit with level, elevation, verticality and concentricity referenced to the stator core by several measurements around the periphery.

The installation and connection of the stator coils at the joints can start as soon as the joints are aligned and can continue while other work is being done, until the rotor is placed in the machine. In some cases, the lower bracket may be placed temporarily in position and used as a base for the winding platform. The procedures recommended by the generator manufacturer should be followed. The work should be done, under the technical direction of the manufacturer's representative, by winders who have had experience in winding large generators.

After the coils are in the slots but before connections are made, the newly installed coils and those that have been disturbed should be given a high-potential test in accordance with the recommendation of the generator manufacturer, or as agreed upon with the customer.

Coil connections should be made in accordance with the connection diagram furnished by the generator manufacturer. The materials and methods used to complete the insulation of the machine should also be in accordance with instructions provided by the generator manufacturer.

10.4 Assembly of Rotor. The procedure to be followed in the assembly of a generator rotor will vary considerably for the different designs and should be specified by the generator manufacturer. However, the following suggestions are generally applicable:

10.4.1 Shrinking of Rotor Spider on Shaft.[4] The spider bore and the shaft diameter should be compared at the same temperature to make sure that the proper interference fit will be provided. The key dimensions should be checked and all burrs and sharp corners removed. Both keyways should be checked for straightness and parallelism. Finally, it is desirable to lubricate the keys and keyway with a mixture of graphite and machine oil before assembly.

The shaft should be in a vertical position when the spider is shrunk onto it to minimize the shaft distortion due to uneven cooling. The spider should be heated in an oven or temporary enclosure by suitable heaters. The heating should be done slowly and evenly to

[4]In heat shrinking a rotor spider to a shaft, the possibility exists that the shaft may be distorted. It is recommended that, whenever possible, this assembly procedure be done at the factory so that heat straightening and machining of the thrust collar and bearing journal surfaces may be performed as required.

prevent distortion. The oven temperature should not exceed 250 °C for a rotor without poles. The shrinking operation should be performed before the poles are attached; otherwise, the temperature should not exceed 100 °C. With an interference fit of 1/2 mil/in of diameter, a temperature difference between the spider and shaft of approximately 75° to 150 °C is required.

To determine that the correct clearance has been obtained, the hot rotor bore should be checked with a micrometer or pin gauge that is at the same temperature as the shaft. After the rotor spider has been properly positioned on the shaft, air should be blown against the side of the spider that is next to the shaft shoulder so that the spider will cool and seize on this side first and not pull away from the shoulder as it cools.

If the spider consists of more than one axial section, the sections may be shrunk on one at a time. Alternatively, the sections may be lined up when cold and the heat applied while they are supported in a position around the shaft above the fit.

After the oven has been removed and without disturbing the spider, the shaft is pulled up through the spider bore by the crane to the correct position. The shaft-lifting device provided must be suitable for lifting the total weight of the shaft and spider. With either method of assembly, it is essential that the dovetail slots to the poles on the periphery of the spider be kept in alignment. This can be accomplished by the use of several aligning bars in these slots.

There is always some danger of the rotor seizing on the shaft before it reaches the proper location. Therefore, arrangements should be made beforehand for quick disassembly if it should prove necessary. A trial lift with the spider cold is also desirable to mark the final crane position for quicker action with the hot spider.

10.4.2 Assembly of Laminated Rim. If the thrust bearing is above the rotor, the rotor and shaft are usually assembled together in the erection area and handled as a unit. Hence, provision must be made to support the shaft from the coupling in a vertical position for assembly of the spider and laminated rim. On the other hand, if the thrust bearing is below the rotor, the rotor and shaft are usually handled separately, the rotor being assembled independently of the shaft. This means that steel blocking (or an erection pedestal) should be provided in the erection area for the support of the rotor at its center.

In any case, the central support should be capable of carrying the weight of the completed assembly. The height should be such that the bottom of the spider assembly is about 2 ft from the floor. The floor at the ends of the arms must be able to support the full weight of the rim and poles.

The rotor spider, generally of fabricated construction, is installed on the shaft or attached to the central support. If it was shipped in several parts, the parts should be assembled in accordance with the generator manufacturer's instructions.

The rotor spider with the brake plates attached should be leveled, and blocking should be installed for supporting the ends of the spider arms and the rim at the correct elevation. A check should be made after each pressing of the punchings to make sure that the rim is being assembled in a horizontal plane and at right angles to the axis of the shaft.

Accurate positioning and alignment of the rim laminations must be maintained as they are stacked. This may involve the use of temporary keys, assembly pins, or shims as recommended by the generator manufacturer. Each layer of laminations should be seated by tapping with a heavy mallet, and the stack may be pressed at intervals of 12 to 20 in as the rim is assembled.

After the stacking is complete, the rim studs should be tightened in the pattern and to the tension specified by the generator manufacturer. After final tightening, the stud nuts are locked by welding.

The method of installing the rim drive keys varies with the design and should be specified by the generator manufacturer.

In designs requiring the rim to be shrunk onto the spider, the procedure should be in accordance with the generator manufacturer's instructions.

10.4.3 Field Pole Assembly. All poles should be located so that their centers are in the same plane at right angles to the shaft and coinciding, as nearly as possible, with a plane through the center of the stator core. Proper axial location of the poles can be checked by measurements taken from a machined surface on the shaft, such as a shoulder or flange. Either a tram mounted to the shaft or a wye level may be used.

It is important that iron-to-iron contact be obtained between the pole core and the spider rim for the full length of the pole; otherwise, the pole may loosen after a short period of operation and cause fatigue failure of the pole fastening. Hence, before the poles are installed, the spider surface and the base of the pole should be cleaned and deburred. If the poles are attached by means of dovetails, the bearing surface of the dovetails, the spider slots, and the keys should also be cleaned and deburred. The corners of the keys should be inspected and filed, if necessary, to make sure they will fit within the radius of corners of the dovetails and rim slots. Finally, each pole should be checked for correct seating on the rim of the generator rotor. The field pole bottom (base) collar should not interfere with the seating of the pole on the rim. If there is any question, the pole can be installed without the bottom collar and a measurement taken to the top of the pole from the shaft or rim surface. The pole is then removed and reinstalled with the collar in place and the same measurement taken. The dimension should be the same. Another method for checking the correct seating of a pole is to fully tighten the pole and then heat the coil by passing current through it. If the pole was loose, it can be tightened further after it has cooled. A loose pole must be removed or the bottom collar trimmed until the pole seats firmly.

For the mounting of dovetail poles, the generator manufacturer's instructions for installing the keys should be followed with respect to the use of proper lubricant, designation of drive-in and drive-out keys, necessity for redriving keys, ultimate tightness of pole, removal of excess key length, and installation of locking plates over the dovetail slots.

For poles that are held in place by radial bolts or studs (bolted poles), the bolts should be tightened in accordance with the generator manufacturer's instructions.

After the poles are installed, the field winding should be checked for correct polarity, uniformity of field-coil impedance or ac voltage drop, grounds, open circuits, resistance, and high-resistance joints.

10.4.4 Bolting of Rotor Spider to Shaft. Rotor spiders, which are bolted to the end of the generator shaft or to shaft flanges, are generally held by circles of close-fitting bolts or dowels. The bolt holes in the spider and shaft may be drilled undersize in the factory. During assembly, after the rotor is lowered onto the shaft, the bolt holes are reamed or finish-bored to the proper size. The details of the procedure to be followed in this assembly operation should be specified by the generator manufacturer.

10.5 Assembly of Thrust Bearings. Each of the different designs of thrust bearings requires a somewhat different assembly procedure, which should be specified by the generator manufacturer. In all cases, however, cleanliness and careful workmanship are extremely important.

A bearing can easily be ruined by even a little lint or dirt. Consequently, precautions should be taken during assembly of the bearing to avoid the presence of dust and dirt by eliminating other construction work above and in the vicinity of the generator.

Finally, before assembly, all parts of the bearing, bearing housing, and oil reservoir should be inspected to ensure absolute freedom from dirt, lint, or other foreign matter. Any rags used around a bearing should be free of lint (never use cotton waste). Lint-free paper towels are an excellent choice. The bearing oil coolers should be given a hydrostatic test.

After assembly, the thrust bearing should be kept covered to exclude dust and dirt. The oil reservoir should be filled with clean filtered lubricating oil, or the bearing otherwise protected in accordance with the generator manufacturer's recommendations to prevent corrosion.

10.6 Assembly of Guide Bearings. The precautions outlined in 10.5 to keep dirt, lint, and other foreign matter out of the thrust bearing should also be observed in connection with the guide bearings.

Sleeve-type bearings, either solid or split, are not adjustable. Therefore, if the bearing clearances differ appreciably from those shown on the generator manufacturer's assembly drawing or instruction book, the manufacturer should be consulted. If it is necessary to scrape a bearing in the field, it should be done only by someone with considerable experience in the installation of bearings.

Segmental bearings made up of independently adjustable segments should be set to the clearance shown on the assembly drawing or in accordance with the generator manufacturer's instructions.

The elevation of a self-oiled bearing must be such that the oil groove, if any, is completely covered by the opposite member. The elevation must also be such that, when the rotor is raised to its maximum upward position by the jacks, the bottom of the journal will be below the center of the guide bearing.

After the bearing has been assembled, the remaining parts of the oil reservoir are added. Clearances between these parts and the shaft must be adequate to prevent rubbing.

10.7 Installation of Lubrication System. Every section of pipe forming a part of the lubrication system should be freed of scale, reamed at both ends, and blown out with compressed air or steam before being connected. Rapping the pipe with a rawhide or wooden mallet while blowing out will help to dislodge any foreign matter which may have entered during construction. Pipe compound or a suitable oil-resistant varnish should be used on all threaded joints.

To clean the pipes, oil should be circulated through them for several hours. The oil leaving the pipes should bypass the reservoir and should be filtered to remove dirt. The reservoir itself should be filled with oil and drained, several times if necessary, to remove all traces of dirt. Finally, it should be filled with clean filtered oil.

It is recommended that the lubricating oil used be in accordance with the generator manufacturer's specifications. Oils from different producers should not be mixed without the approval of the producers.

10.8 Checking Air Gap. The variations in the air gaps should be in accordance with the tolerances specified by the generator manufacturer. If the average air gap varies appreciably from that shown on the assembly drawing, the manufacturer should be consulted. In measuring the air gap, care should be taken to measure from iron to iron at the tangential center of the pole face. A tapered air-gap gauge or a long feeler gauge may be used. If the end ring of the amortisseur winding projects above the top of the pole, a small block attached to a rod can be held against the top of the pole and an air-gap gauge placed between the block and the stator bore.

10.9 Check of Insulation Against Shaft Currents. Bearings or thrust collars, and other parts, such as instrument elements, Kaplan features, conduit, piping, etc., that make contact, directly or indirectly, with the shaft above the rotor are usually insulated from the supporting structure to eliminate the possibility of shaft currents. This insulation should be checked with a 500 V insulation resistance meter and, if the resistance is less than 200 000 Ω, the insulation should be inspected and the necessary corrections made. In the case of a thrust bearing, the insulation should be checked with the weight of the rotor on the bearing.

If double insulation is provided (two layers of insulation with a metallic compound between the layers), its resistance can be checked with the machine completely assembled. However, each parallel path must be checked individually. Often the insulation is shunted by some temporary connection such as a tool, scrap material, or dirt. A complete visual inspection should be made to eliminate this possibility.

Where single insulation is used, all connections between the rotor and the frame at the lower end of the machine must be removed to test the bearing insulation, or each joint must be isolated and tested individually.

10.10 Closing of Generator-Turbine Coupling. The closing of the coupling between the generator and the turbine shafts should be done under the supervision of the representative of the manufacturer who furnished the coupling bolts. If the two shafts were assembled for a shop check of the runout in the plant of the turbine manufacturer or the generator manufacturer, the same manufacturer usually provides the coupling bolts.

If the two shafts were assembled in a factory, they should be assembled at the installation in the same relative angular position as indicated by the factory-placed matchmarks. If the two shafts were not assembled in a factory but the high points on the faces of the two couplings have been determined (usually marked with the letter "H" on the outer cylindrical surface of the flange), the coupling should be assembled so that these points will be 180 degrees apart.

If the hydraulic turbine is of the adjustable-blade propeller (Kaplan) type, the arrangement may be such that, before the coupling is closed, the generator rotor (or the shaft and the attached thrust-bearing runner) is raised sufficiently to make connections to the oil pipes that supply oil to the blade servomotor. The generator rotating assembly is then lowered so that the weight is transferred back on to the thrust bearing.

Before drawing the couplings together, their mating surfaces must be in alignment, parallel, clean, and free from burrs. The coupling must be drawn up evenly to prevent distortion.

After the couplings have been drawn together, the bolt holes must be reamed or finish-bored (unless this has already been done in a factory assembly) to fit the permanent bolts. The fit of the bolts should be in accordance with ANSI/IEEE Std 810-1987 [6], unless otherwise specified by the generator manufacturer. The bolts must be tightened evenly in accordance with the manufacturer's instructions.

10.11 Shaft-Plumb and Straightness Check. This is a plumb-wire check of the straightness and plumbness of the combined generator and turbine shafts. The use of four plumb lines spaced 90 degrees apart around the shaft is recommended. The readings should be taken from the same points on each shaft that were used during the factory runout check. The shaft assembly shall be considered to be straight when no runout check point (correlated for diameter variations) deviates more than 0.003 in from a straight line joining the top and bottom points. The shaft assembly shall be considered to be plumb when the top and bottom points do not deviate from plumb by more than 1/4 mil/ft of shaft length.

10.12 Equalizing the Load on Adjustable-Shoe-Type Bearings. Adjustable-shoe-type bearings must be properly adjusted in order that the thrust load will be equally divided among all of the bearing shoes. There are various types of bearing designs which afford a means of reading the shoe loading directly. In some bearing designs, a strain gauge is permanently located in each jackscrew and, by connecting the strain gauges to a suitable instrument, a direct reading can be obtained of the thrust load carried by each shoe. From such readings, adjustments are readily made to equalize the loading on all shoes. In other bearing designs, the deflection of a built-in member is measured at each shoe to determine loading.

For bearing designs without built-in measuring devices, the "slugged arc" method may be used to equalize the load. There are several variations of this method, each giving equally good results.

The generator manufacturer's instruction book should describe the bearing design and the method to be used.

10.13 Check of Shaft Runout. An installation check of the runout of the combined generator and turbine shafts should be required, especially where combined alignment has not been performed at the factory. Three different methods of making this check are described in 15.1.1 and 15.1.2. As indicated therein, the methods applicable depend upon the type of thrust bearing furnished with the generator.

If the rotation check by method 1 is used, it shall be performed during the erection of the generator to avoid subsequent disassembly of the machine.

10.14 Assembly of Rotating Exciters (If Provided), Collector Rings, and Brush Rigging. The main exciter armature, if used, is often designed with a flanged shaft having a rabbetted fit which bolts to the end of the generator shaft. The pilot exciter shaft, if used, may be attached to the main exciter shaft through one or more bolted joints. This means that great care must be taken in the assembly of these armatures. Any foreign material between the flange faces or uneven tightening of the coupling bolts will cause excessive commutator runout.

Generator guide bearings may have substantial diametrical clearance and, under some conditions, the shaft may float in the bearings. Therefore, commutator runout at operating speed can be expected. Commutator runout checks should be made with a dial indicator rather than by visual observations, and should be within the generator manufacturer's tolerances.

The collector rings for the dc field current should be carefully assembled in accordance with the generator manufacturer's instructions. For the reasons mentioned, collector ring runout at operating speed can be expected. Collector ring eccentricity should be checked with a dial indicator.

Collector ring surfaces can often be kept in good condition by periodically reversing the polarity of the brushes. When collector rings and exciter leads are brought out to a circuit breaker, cables should be long enough to permit such reversal.

To ensure that satisfactory contact between the brushes and collector rings is obtained, bedding of brushes is recommended. Bedding should be performed when installing new brushes or following the switching of brushes to different brush holders.

Use medium-fine sandpaper (not coarser than 650 grains/in^2). Secure the abrasive paper to the collector ring by means of adhesive tape. With all brushes in the holders, set brushes against the abrasive paper with normal operating brush pressure. Turn the rotor by hand in the normal direction of rotation of the machine (do not press on the brush holders by hand). Should it not be possible to turn the rotor, pull the abrasive paper back and forth underneath the brushes, taking care to avoid rounding of the brush edges. When the brushes have been bedded in, carefully remove any remainder of adhesive tape from the collector rings and clean the entire brushgear by thorough vacuuming with a suitable brush attachment.

The brushes should be staggered across the collector rings to minimize grooving but should not extend beyond the edges of the rings to prevent formation of brush slivers. The brushholder springs should be adjusted in accordance with the generator manufacturer's instructions.

10.15 Installation of Instruments and Relays. Various instruments and relays, or their sensing elements, are often mounted on the generator and must be installed during its erection. This applies to such devices as oil level indicators, bearing temperature relays, indicating and recording thermometers for bearing and air temperatures, waterflow indicators, differential control temperature relay, and overspeed device. This equipment should be checked before installation. Its associated wiring and piping should be carefully installed, making sure that it does not short-circuit the bearing insulation, that is, a conducting path from any point on the shaft above the rotor to the stator frame. Suitable insulation should be provided at the proper points.

11. Mechanical Run

11.1 General. Do not apply voltage to any winding until the condition of the insulation has been checked as described in Section 13. The purchaser's written initial operation procedure should include instructions concerning all auxiliary devices and systems.

11.2 Preparation for Initial Start. Preparation of the generator for the initial start should include the following checks:

(1) During the last few days before the initial start and after all welding has been completed, make a final inspection of the thrust and guide bearings and prepare them for the initial start in accordance with the generator manufacturer's instructions.

(2) Make sure that all lubricating oil systems have an adequate supply of oil and all pumps and their control systems have been tested.

(3) Make sure that cooling water valves have been checked for the proper open or close position. Similarly, any pumps and automatic controls should be tested.

(4) Examine the interior of the stator, the air gap, exciters, collector rings, top of the rotor, and the space between poles for loose objects such as bolts, nuts, tools, etc.

(5) Make sure that all moving parts have sufficient clearance from the nearest stationary parts.

(6) Check the electrical clearance around all parts that are to be energized.

(7) Check the tightness of all foundation bolts and hold-down bolts.

(8) Clean the commutators and collector rings and check the seating of brushes.

(9) See that all protective devices are operating properly.

(10) Turn on the bearing and air cooling water (just before starting up).

11.3 Initial Start. It is customary for a representative of the purchaser to coordinate the initial start with direct supervision by the governor manufacturer's representative. The time of the start and the general procedure to be followed should be detailed by the purchaser in consultation with the representatives of the turbine, governor, excitation system, and generator manufacturers. The purchaser's personnel should operate the unit with such guidance as is necessary from the equipment manufacturers' field representatives.

The turbine should be shut down as often as is required at the request of any of the manufacturers' field representatives and opportunity should be afforded for making such inspections and adjustments as the manufacturers' representatives deem necessary.

The initial starting procedure should be agreed upon with the turbine and generator manufacturer. The following is a typical procedure:

(1) With the high-pressure lift pump running, release the generator brakes and crack the wicket gates sufficiently to allow the unit to creep. Check for any rubbing or abnormal noises.
(2) Accelerate the unit to a speed of one-third to one-half of rated speed but not less than 50 rpm so that the bearing oil film will be established quickly.
(3) Hold this speed constant and note the bearing temperatures at intervals of 1 min until they become constant. Any rapid or continued rise of the bearing temperature should be investigated.
(4) After the bearing temperature becomes constant and the unit is operating smoothly, the speed should gradually be increased to rated speed.
(5) If vibration becomes excessive at any time while the unit is being brought up to rated speed, the unit should be shut down and balanced as described in Section 12.

During no-load operation, various checks and adjustments of the turbine and governor are normally made.

11.4 Check of Shaft Runout. When applicable, checking the runout of the face of the thrust-bearing runner with respect to the shaft, as described in method 2 (15.1.1.2) may be done at this time. However, it may be necessary to balance the rotating parts of the machine before this check can be made. See Section 12.

12. Balancing

The rotating parts of the generator should be in dynamic balance. This may require the addition of balance weights to the rotor. Their size and location are, in some cases, determined entirely by trial and error; however, it is usually desirable to take measurements that will define the horizontal motion of the shaft under various conditions and, from this data, calculate the size and location of the balance weights required.

The minimum data required to make the calculations is the motion of the shaft (magnitude of the horizontal movement and the location of the "high spot") at one axial location with (1) the rotor in its original condition and (2) a trial balance weight added to the rotor. However, if dynamic unbalance is present, requiring the addition of balance weights in two planes, it may be necessary to determine the motion of the shaft at two or more axial locations with (1) the rotor in its original condition, (2) a trial weight added in one balance plane, and (3) a trial weight added in the second balance plane.

The use of special balancing equipment, designed to establish the precise motion of the shaft, results in an accurate determination of the size and location of the required balance weights. This is particularly true for higher speed units. Alternatively, the horizontal movement of the shaft can be measured with a dial indicator and the approximate location of the "high spot," which is established by applying a thin coat of whitewash to the surface and then gradually bringing in the point of a pencil or scribe until it just makes contact with the white-washed area once each revolution of the shaft.

Various methods have been published for calculating, from the data taken as described in the foregoing paragraphs, the size and location of the balance weights required.

Balance weights should be attached to the rotor in the manner prescribed by the generator manufacturer.

If, at a later time, it becomes necessary to remove a balance weight, it should be replaced in exactly the same position. Before disassembling a pole on a high-speed machine, its axial position should be accurately marked so it can be replaced in the same position. Should it become necessary to replace a field coil or a complete pole, the balance must be rechecked.

The turbine runner should also be in dynamic balance to ensure that the turbine-generator unit balance and shaft runout are acceptable. Occasionally the overall balance and shaft runout of the unit will not respond to balancing only the generator rotor. In this situation balancing should be done on the turbine runner. The results may be checked by driving the unit with the generator as a synchronous motor and the turbine unwatered with a minimum seal water flowing.

Since the nature of hydraulic turbines is such that shaft runout or vibration may result from hydraulic forces within the turbine, unwatered operation will also serve to separate mechanical unbalance from hydraulic disturbances.

If mechanical construction permits, further separation of the turbine and generator unbalance can be achieved by running the generator as a motor with the turbine uncoupled. Some machines run in this mode may be unstable. The manufacturer should be consulted before operating in this condition.

Should undue vibration develop during operation of the generator, before adding or shifting balance weights, check the possibility of the vibration being caused by misalignment, settling of the foundation, uneven air gap, rubbing of rotating parts, loose parts, bent shaft, short-circuited field coil, or unbalanced stator currents. Then, if necessary, add or shift the balance weights.

13. Insulation Testing and Drying Out

13.1 Measurement of Winding Insulation Resistance. The insulation resistance of the armature and field windings of the generator and exciter(s) serves as an indication of whether or not the machine is in condition for operation and dielectric testing.

Insulation resistance measurements of the windings should be made in accordance with IEEE Std 43-1974 [7].

All insulation resistance test results should be referred to the generator manufacturer for analysis and approval. From these data, the manufacturer can determine whether "drying out" of the windings is required before dielectric testing and operation.

13.2 Drying Out of Windings. If drying out of the windings is recommended by the generator manufacturer, the following procedures are suggested:

(1) The temperature of the winding should generally not be allowed to exceed 90 °C when measured by a resistance temperature detector or 75 °C when measured by a thermometer. The rate of heating should be such that this temperature is attained in not less than 6 h and preferably, in not less than 12 h. The winding should be brought up to temperature slowly by steps to avoid gassing of entrapped moisture and possible rupture of insulation.

(2) The armature winding should preferably be dried out by the short-circuit method. When this method is used, the machine is operated at rated speed with all phases of the armature winding short-circuited. Enough field current is applied to give an armature current (usually between 60% and 100% of rated armature current), which will produce the rate of temperature rise specified in item 1. This heating should be continued until the insulation resistance readings, corrected for any temperature differences, approach constancy. A slight amount of ventilation must be provided to exhaust the moisture-laden air.

(3) The armature winding can also be dried out by passing direct current through it with the machine stationary. A high-current, low-voltage source of dc power, such as a welding generator, is required. Where possible, the phases of the winding should all be connected in series or in parallel, so that all phases will carry the same current. Where the phase currents are unbalanced, the maximum current in any phase should be limited to that which will give the heating rate specified in item 1. Since the machine is stationary,

this current is usually between 25% and 50% of rated current. A slight amount of ventilation must be provided to exhaust the moisture-laden air.

(4) Even though the short-circuit method is used to dry out the armature winding, the resulting current in the field winding is not generally sufficient for adequate drying out of the field. One method for drying out the field is to operate the machine under load for several days. Alternatively, the field can be dried out by applying direct current to the field with the rotor stationary, but with the current limited so that the temperature given in item 1 will not be exceeded. This current should not be passed through the brushes; instead, the current should be applied to the machine field at the connection to the collector rings.

(5) An alternative method of drying out armature windings is by means of electric space heaters. They should be located in air spaces under the machine or at the back of the stator core and be distributed around the periphery of the machine to allow for an even distribution of heat. If the rotor is not in place, the ends of the machine may be closed with end bells or with large tarpaulins to reduce the heat loss. A slight amount of ventilation must be provided to exhaust the moisture-laden air. Precautions should be taken to prevent fire when this type of heat is applied.

(6) Further details of drying out windings are given in the IEEE Std 43-1974 [7].

13.3 High-Potential Tests. The procedure to be followed in making the high-potential test should be in accordance with IEEE Std 115-1983 [5]. The test voltages, frequency, and wave shapes should be in accordance with ANSI C50.10-1977 [2].

Where the assembly of a winding is completed at the destination, precluding the possibility of final high-potential tests at the factory, it is recommended that high-potential tests be made on the armature and field winding immediately after final assembly and before the machine is put into service. In some cases, it may be desirable to give the stator a final high-potential test before installing the rotor. The winding should be in good condition and the tests not applied when the insulation resistance is low because of dirt or moisture. (For additional details, see 13.1.)

When a test is made after installation on a new machine which has previously passed its high-potential test at the factory and whose windings have not since been disturbed, the test voltage should be reduced in accordance with ANSI C50.10-1977 [2].

The test voltage for rotating exciters should be in accordance with ANSI C50.5-1955 [1], and the test procedure should be in accordance with ANSI/IEEE Std 113-1985 [4].

Due to the high voltages used, dielectric tests should be conducted only by experienced personnel, and adequate safety precautions should be taken to avoid injury to personnel and damage to property. Following an alternating-voltage, high-potential test, the tested winding must be discharged to ground before it is touched by personnel. Following a direct-voltage, high-potential test, the tested winding must be grounded and thoroughly discharged. The insulation rating of the winding and the test level of voltage applied determine the period of time required to dissipate the charge and, in many cases, the ground must be maintained for several hours to dissipate the charge to avoid personnel hazard.

14. Initial Operation

14.1 No-Load Operation with Excitation. After the unit has been balanced and has had a dry-out run, it should be operated at rated speed and its voltage built up slowly by applying excitation. The terminal voltage and field current should be recorded and compared with the generator manufacturer's calculated no-load saturation curve. At rated voltage, the voltage balance should be checked and an operational check of shaft runout should be performed (see 15.1).

14.2 Connection to Power System. Before connecting the generator to the power system, the phase sequence of the generator and the connections to the synchroscope should be checked and, if they are correct, the generator leads can be connected permanently.

With the generator running at rated speed and with excitation applied, the magnitude, frequency, and phase angle of the generated voltage can be matched to that of the bus, and the generator breaker can be closed. Load should then be applied in small increments, and the temperature rises should be observed. When full load has been reached, it should be maintained for several hours and a careful check made of the temperature rise of windings and bearings, balance, collector ring and exciter brush operation, oil and water flow, ventilation, etc. Some adjustments may now be necessary to ensure continued successful operation.

14.3 Load Rejection Tests. Load rejection tests for governor and excitation system settings should be performed in the sequence of increasing loads up to full or maximum load. The unit speed and voltage rises should be carefully monitored with high response recording instruments. The maximum transient speed and voltage limits established by the generator manufacturer must be observed and maintained and the governor and excitation system adjusted.

14.4 Operation Check of Shaft Runout. An operation check of the shaft runout should be made after load rejection and while the generator is operating under full load (see 15.1).

15. Field Tests

15.1 Vertical Hydraulic-Turbine Generator Shaft Runout Tolerances, Installation Check. The runout of the combined turbine and generator shafts after installation should be checked by one of the following methods.

15.1.1 Rotational Check

15.1.1.1 Method 1. After aligning and plumbing the coupled generator and turbine shafts, the accuracy of the generator shaft thrust surface should be checked by the procedure outlined below. This method should be used for checking shafts equipped with adjustable-shoe-type thrust bearings. It may be used for checking shafts equipped with self-equalizing-type bearings if recommended by the generator manufacturer.

Mechanically rotate the unit, with the turbine guide bearing removed, and any generator bearings other than the one immediately adjacent to the thrust bearing backed off so as not to restrain the position of the shaft.

The remaining generator guide bearing prevents excessive side slip during rotation; however, unless this bearing is at approximately the same elevation as the thrust bearing, it also should be backed off or removed before the readings are taken.

Measure runout by plumb line or dial indicator readings at 90 degree intervals at both the thrust-bearing level and the turbine-guide-bearing level.

After making corrections for such side slip as has occurred in the thrust bearing, the shaft sideways deflection on the plumb lines or dial indicators should not be greater than 0.002 x L/D in, where

L = the distance in inches from thrust surface to point of measurement
D = the thrust bearing outside diameter in inches

15.1.1.2 Method 2. After initial operation of the combined unit, the accuracy of the generator shaft thrust surface should be checked by the procedure outlined below. This method should be used for checking shafts equipped with spring-type thrust bearings. It may also be used for checking shafts equipped with self-equalizing-type bearings if recommended by the generator manufacturer.

Dial indicators should be placed on two of the thrust-bearing segments in such a manner as to indicate the vertical movement of these segments. The unit should then be run and readings of the dial indicators recorded at approximately one-quarter of normal speed when the unit is decelerating. These readings will give an indication of the runout of the face of the thrust-bearing runner plate with respect to the shaft axis. This runout should be not greater than 0.002 in.

15.1.2 Operation Check. If the runout obtained by methods 1 and 2 (15.1.1) exceeds the allowable values, the runout at the guide bearings of the combined shaft should be checked with the unit running at normal speed and rated load with indicators mounted on the bearing supports. The runout of the unit (exclusive of skate[5]) should not exceed 80% of the diametrical clearance in the guide bearings and the temperature of the guide bearing should not exceed 85 °C.

In addition to machining inaccuracies of the thrust collar and thrust-bearing runner, there may be other causes of shaft runout, such as electrical or mechanical unbalance of the generator rotor, improper connection at the generator coupling, or hydraulic or dynamic unbalance of the turbine runner.

15.2 Electrical Tests. The larger generators (above 5000 kVA) usually receive only winding resistance measurements and dielectric tests at the factory, and any additional testing shall be done after installation at the site. Certain additional tests are desirable to provide information that will allow a more accurate prediction to be made of generator performance under various operating conditions.

As a minimum, these tests should include:

(1) Winding resistance measurements
(2) Short-circuit saturation curve
(3) Open-circuit saturation curve
(4) Field current at rated kVA, power factor, and voltage

Test procedure should be in accordance with ANSI/IEEE Std 115-1983 [5].

It is recommended that a representative of the generator manufacturer be present when the foregoing tests are made.

[5]Skate is the lateral random movement of a shaft superimposed on the periodic runout. This movement may be up to the full clearance of the bearing and is generally not considered significant in an analysis of shaft motion.

THIS PAGE WAS
BLANK IN THE ORIGINAL

THIS PAGE WAS
BLANK IN THE ORIGINAL

IEEE Power Engineering Training Programs

The IEEE sponsors training programs on the Color Books and other power engineering standards throughout the year.
Our training programs include:

- Protection of Co-Generation Plants Paralleled with Utility Transmission Systems
- Health Care Facilities Power Systems
- Planning, Design, Protection, Maintenance, and Operation of Industrial and Commercial Power Systems
- Electric Power Supply Systems for Nuclear Power Generating Stations
- Large Storage Batteries — Nickel-Cadmium and Lead

Special team discounts are available. IEEE-sponsored training programs may also be brought to your plant. For details, write to the IEEE Manager of Standards Training Programs, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331 USA. Or call us Toll Free at 1-800-678-IEEE and ask for Standards Training Programs.

IEEE Training Programs on the NESC

The new 1990 NESC was published by the IEEE ... and if you're a utility engineer, manager, or consultant, you'll need to know what the new Code covers. We offer two intensive training programs to help you:

- A thoroughly updated 3-day training program that covers the development and application of the Code.
- A new 4-day training program that covers the same material as our 3-day program ... plus a special section on work rules.

Special team discounts are available. IEEE-sponsored training programs may also be brought to your plant. For details, write to the IEEE Manager of Standards Training Programs, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331 USA. Or call us Toll Free at 1-800-678-IEEE and ask for Standards Training Programs.