G-E THRUST BEARINGS

GENERAL ELECTRIC

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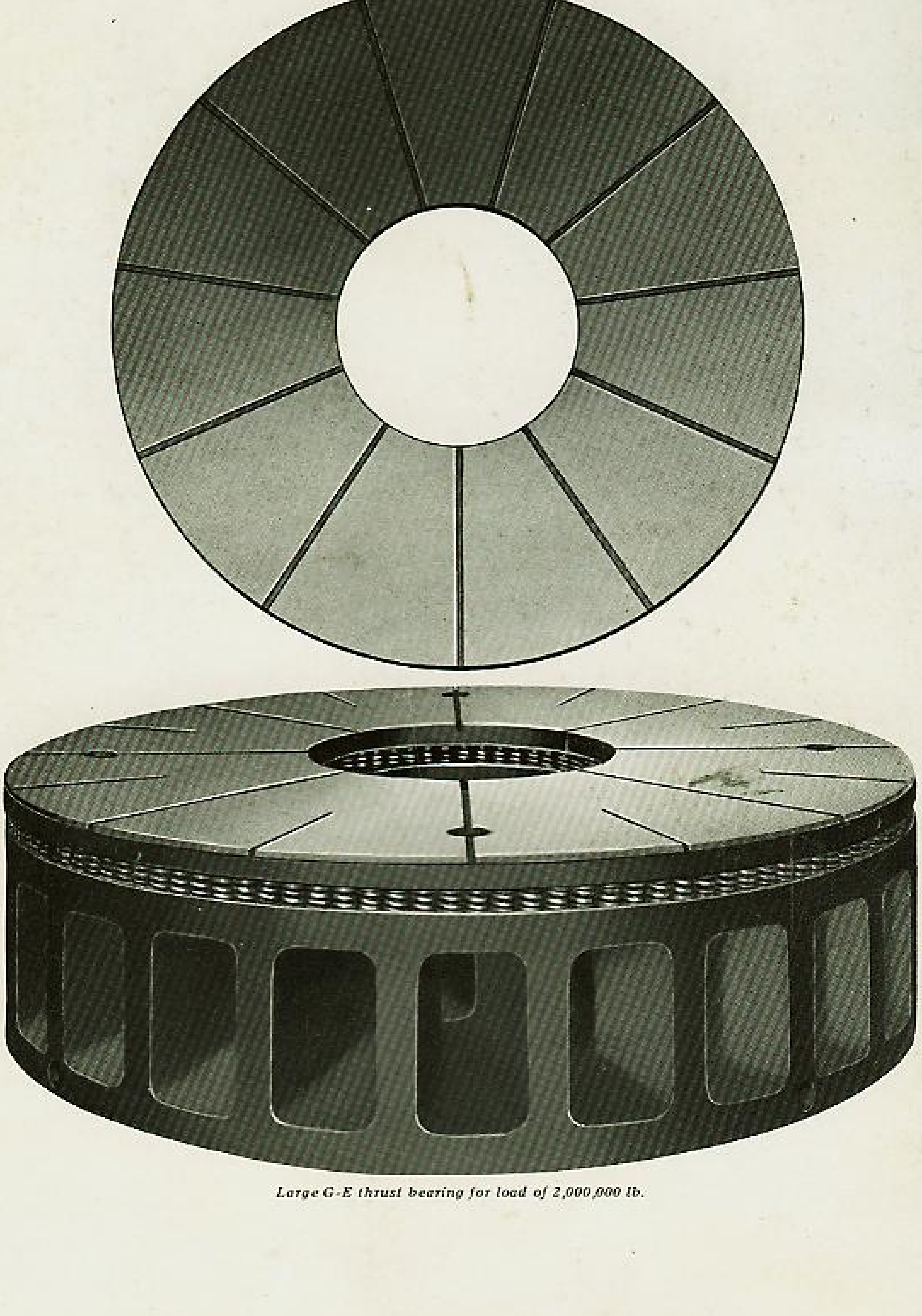
SCHENECTADY, N.Y.

GEA-2251



Large G-E thrust bearing for load of 2,000,000 lb.

FOREWORD

GENERAL ELECTRIC thrust bearings are the simplest and most reliable on the market today. They are readily applicable throughout the entire range in size and speed of vertical machines. They are inherently accessible, require no adjustment during assembly, or scraping to fit the surfaces under load, and are automatically self-aligning to equalize the pressure distribution over the whole surface.

This bulletin, which describes the General Electric thrust bearing, includes an explanation of the function that each part exercises in operation. The more important operating characteristics are discussed and a description of various forms of application for different types of machine constructions is included, together with a list of many of the important hydroelectric units equipped with these bearings.

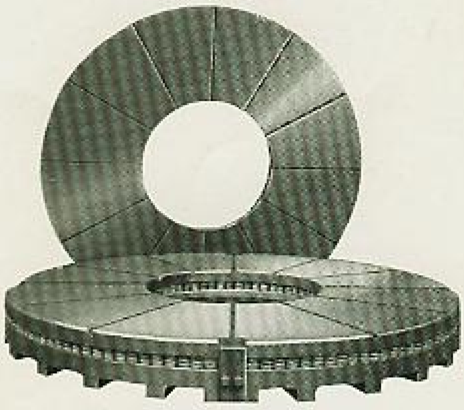
G-E THRUST BEARINGS

THE General Electric thrust bearing consists of a grooved, rotating, steel plate, rigidly fastened to the shaft by means of a thrust block, and a grooved, stationary, babbitted plate. The latter has some flexibility and is supported by a large number of precompressed springs. During operation, a film of oil is maintained between the rotating and stationary plates. This film is thick enough to prevent metallic contact of the surfaces, and results in operation with a low coefficient of friction. It is not sensitive to changes of speed or loading, nor is it so delicate that a small amount of sludge or small particles will disrupt it. When rotation is started, the film forms by the time half of the distance between the grooves is traversed, because both the stationary and the rotating grooves are chamfered to direct the oil between the surfaces. The stationary plate and its spring support are so proportioned that, as the oil film begins to form, the flexibility of the structure insures its assuming a position which will produce the most effective shape of film.

The heat generated in the bearing is carried away by the oil. The grooves in the stationary plate provide one source of cool oil for lubrication, and the grooves in the runner provide another. In addition, the runner grooves, acting as centrifugal pumps, create a profuse flow of oil to remove the heat from the bearing surface. The operation of the General Electric thrust bearing depends upon the combined effects of the grooved rotating and stationary plates and of the flexible support. The paragraphs following describe their functions and present a clear picture of their performance.

RUNNER GROOVES

A thrust bearing, consisting of a solidly supported, plain, stationary plate and a rotating



Typical large thrust bearing, showing grooves in runner and stationary plate

plate, having radial oil gooves with ample chamfers at the leading edge of the sectors, will support a load. This fact was demonstrated analytically about thirty years ago, and many such bearings are in operation today. In such bearings, the oil grooves provide an entrance for cool oil to separate the two rubbing surfaces. A pressure is built up by the chamfer to form a film capable of supporting limited amounts of load, with perhaps high frictional loss. The shorter the length of the segments, the more effective is the establishing and maintenance of the film. Also, within limits, the greater the entering chamfer, the better the running performance, although too extreme values may be detrimental, both at starting and while running. Besides forming an entrance for fresh oil to the following film, the grooves act as scavengers to take away part of the hot oil from the preceding film. As a result of centrifugal force, the oil in the center of the radial grooves has a relatively high radial velocity. This tends to scrub the hot oil off the stationary plate and force it out into the oil reservoir. Just in front of the chamfer, the oil piles up as a result of the tangential velocity head and, although it also has a radial velocity, the resultant action is to provide a constant source of fresh oil for the film. The scavenging effect of the oil grooves has been observed on glass models to be between 15 and 25 per cent of the oil in the film.

STATIONARY GROOVES

With the exception of the pumping by centrifugal force, a bearing consisting of a grooved stationary plate and a plain runner acts in the same way as one with a grooved runner and a plain stationary plate. There is simply less oil flow, with less renewal of oil; consequently, such a bearing is suitable only for lower operating limits or factors of safety.

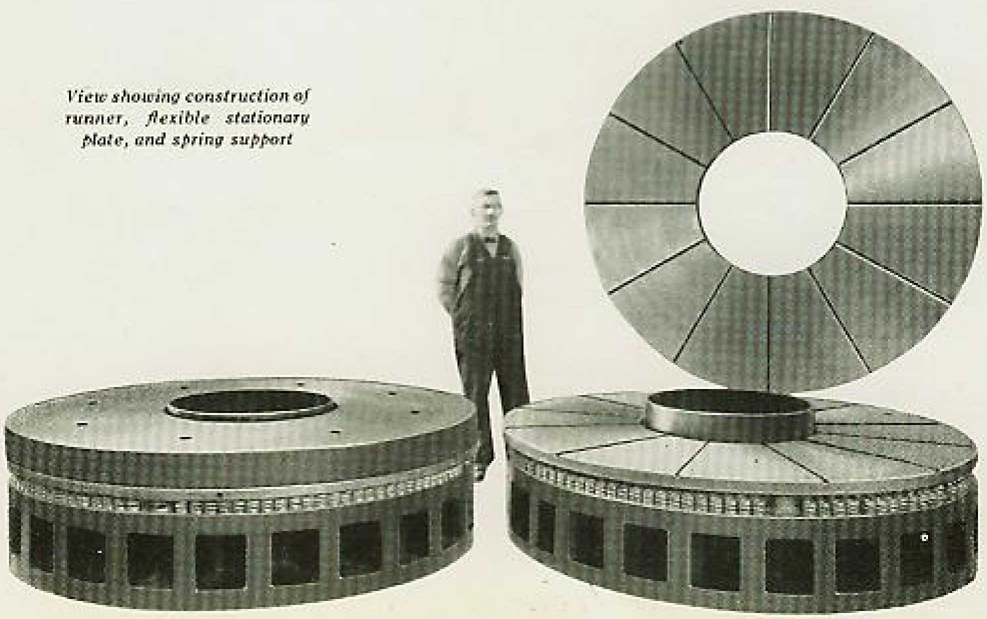
There is, however, a very important protective function of the stationary grooves. If the oil is dirty or sludgy, or the bearing starts to wipe, the runner will carry the foreign bodies until a stationary groove is reached. They will then be deposited, unless they are too large, and the bearing will be protected, to quite an extent, from failure. It is evident that the closer these grooves are placed, without impairing other operating characteristics, the greater the protection this will afford.

The stationary plate has a radial saw cut through it to avoid any possibility of dishing of the plate by temperature effects which would distort the otherwise uniform loading of the bearing. In some cases, the stationary plate and the rotating plate are cut into two or more sectors to facilitate handling.

FLEXIBLE SUPPORT

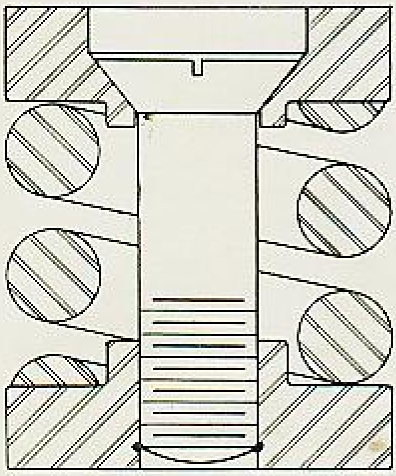
The function of the flexible plate and spring support is to permit the formation of an alternately converging and diverging oil film. By this means, the performance becomes far superior to that obtained with a solid support and may be superior to that of pivoted segment bearings. In bearings of the two last-named types, the oil film must be

View showing construction of runner, flexible stationary plate, and spring support



simply converging, since the segments must have sufficient rigidity for the effective point support. In the General Electric bearing, the plate can and does assume the most efficient form which the oil-film conditions, side leakage effects, and changes in viscosity through the film tend to produce.

When G-E thrust bearings were first developed, the springs were free, with only the compression resulting from the effective loading. As an improvement in their design to counteract the secondary effects associated with some hydraulic conditions of waterwheels, each individual spring is now precompressed according to its proportion of the total load for which the bearing is designed. Theoretically, a precompressed spring will not deflect until the loading attains that of the precompression. However, measurements show that, where the precompression is obtained by means of a screw in a tapped washer, as illustrated at the right, the desirable characteristic of small amplitudes of motion with small variations in loading is obtained. This gives the assembly sufficient flexibility so that the principal force which resists deformation of the plate, even under adverse conditions of nonuniform or light loading, is the stiffness of the plate itself, resulting in a regular deformation as determined by the film requirements. If, for any reason, the line-up of the unit becomes imperfect, the flexible support will automatically and continually deflect to equalize effectively the pressure distribution over the entire bearing.



Individual spring, showing method of precompression

OPERATING CHARACTERISTICS

LOSSES

In electric machines, bearing losses are relatively unimportant, as far as machine efficiencies are concerned, because of their small magnitude in comparison with other losses. Consequently, the main purpose of having accurate data on losses is associated primarily with methods of cooling or otherwise dissipating bearing losses without excessive temperature rises.

The technical press is replete with articles discussing careful measurements and methods of observation to determine the losses accurately. These articles are significant in their lack of uniformity in results, simply because so many widely variable factors, such as temperature, viscosity, temperature effects of oil, finishes, and loading conditions, all enter into the determination, to say nothing of the difficulties of segregating thrust bearing from guide bearing, or other even more important, losses.

Field tests on completed units give fair accuracy when cooling coils are utilized for removing bearing losses, and the flow and temperature rise of water can be very accurately determined, although losses of heat by direct radiation and conduction are quite uncertain quantities. Where a guide bearing has the oil bath common with the thrust bearing, no satisfactory method of segregation is available. Numerous laboratory tests have been made to determine, as accurately as possible, losses on various types of thrust bearings. Only minor differences are discernible, and they are of less significance than variations accompanying ranges in loading temperatures, and viscosity during operation.

General Electric thrust bearings are designed for loadings of approximately 400 lb per sq in. With this loading, the film thickness is as large, and the coefficient of friction as small, as can be obtained with a factor of safety which will provide for usual operating contingencies.

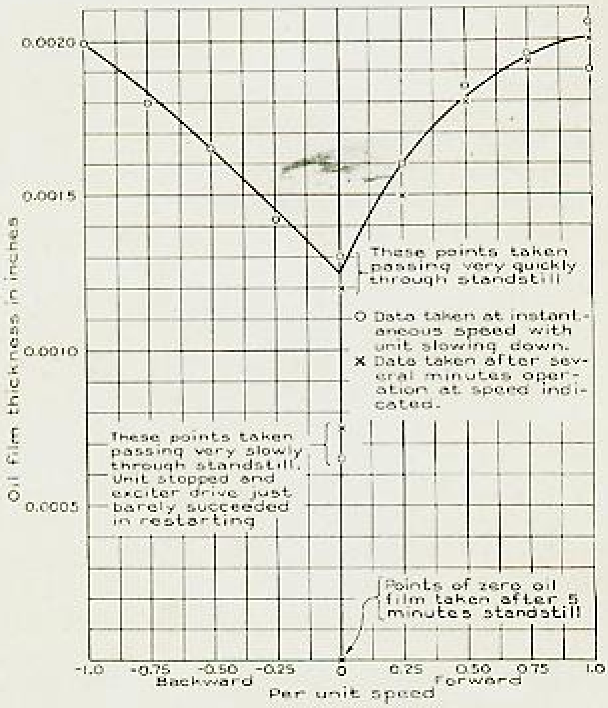
WEAR AND NOISE AT STARTING

Such progress has been made in thrust-bearing design and manufacture that a thrust bearing is one of the parts of a machine which requires the least attention during normal operation. There is practically no wear, with the possible exception of that which may occur at the instant of starting and before the oil film is formed. The wear under these conditions is small, for one reason, because of the inherent characteristic oil has of depositing a greasy residue on the surfaces, which residue has sufficient stability to persist until a complete film is formed. This is evidenced by the low coefficient of static friction of 0.08 to 0.10 occasionally observed. Another reason for small wear lies in the use of a babbitt with minimum dry-wear rate and minimum tendency to crumble or fail under pounding. Incidentally, this babbitt also has a very low chemical action on oil, a property desirable since excessive saponification produces early failure of a lubricant.

Many operating companies have noticed, in their vertical units, after a shut-down period of any extent, that there is a distinctly audible noise at the instant of starting. This noise has been variously described as a grunt, twang, or groan. It does not appear to be peculiar to thrust bearings of any particular manufacture. Because of the apparent erratic characteristic of the noise, it has sometimes been erroneously attributed to frictional distress. Observations on a number of machines show that, even if the noise energy produced were only one per cent of the total energy involved, this energy would be very small in comparison with any energy required at bearing failure. By using a sound-level meter, it has been found that the major part of the sound generally emanates from some part of the structure which resonates freely, as, for example, a cover over the top of the oil housing. The starting of relative motion between surfaces initially at rest is an alternate change from static to greasy friction and then back to static, similar to the passage of a finger, at the proper angle, over a dull surface. When sufficient velocity is attained between the points of metallic contact, the static friction is eliminated. Hence, it may be seen that the starting of a waterwheel-driven unit consists of a series of forward jumps and stops until an oil film is formed or for a minimum distance corresponding to one-half the distance between bearing grooves. During the period of this jerky motion, resonating parts are set into vibration, producing the noise.

OIL-FILM THICKNESS AND STABILITY

The oil film in a thrust bearing is of an alternately diverging and converging shape, the minimum value being of the order of thousandths of an inch, depending upon such factors as load, speed, and oil viscosity. The curve below shows the variation of minimum film thickness with regard to speed for a particular machine. It is not strictly a function of speed, but also involves time in a rather complicated manner, so that, at zero speed, the oil film requires time to become established, or when it is once established, time is required for it to vanish. It, therefore, has an essentially stable characteristic—not readily destructible by effects of short duration. Because of the "residual" oil film at zero speed, once even a very large machine is started rotating, it can be maintained in motion by hand by one or two men.



Curve showing variation of oil-film thickness with change of speed

Two men can often restart a large machine and keep it rotating by hand after it has been stopped for an instant.

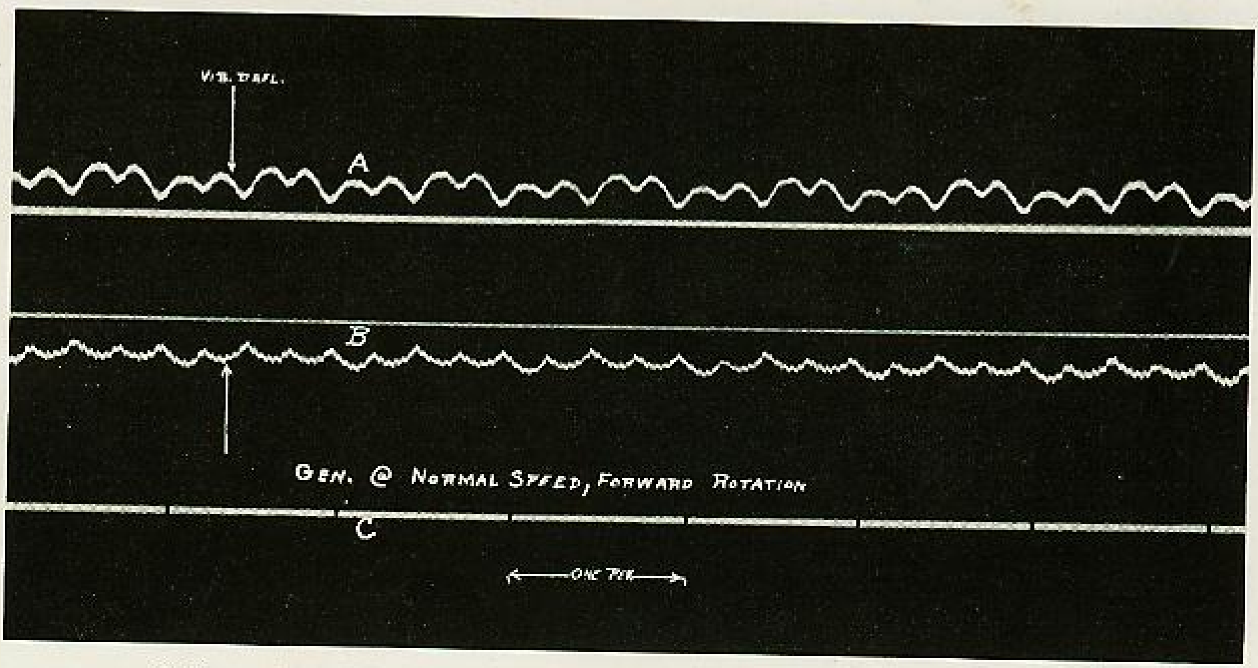
An excellent illustration of oil-film stability at low speeds was afforded by a series of accidents which required a General Electric bearing, of 92-in. outside diameter with a normal speed of 88 rpm, to carry the weight of the rotating parts (about 1,400,000 lb) for more than two hours at 2 or 3 rpm. Subsequent to this inadvertent operation, the bearing surfaces were examined carefully and no distress whatsoever was discernible.

MOTION OF FLEXIBLY SUPPORTED PLATE DURING OPERATION

The action of the stationary plate under all conditions of starting and operation has been mathematically analyzed, and thorough studies by means of an oscillograph have completely confirmed the results. The oil film is thickest at the entering edge, causing a slight depression of the plate, which takes the form of waves or ripples, each following a rotating oil groove. These waves are continuous, even over the plate at the radial saw cut, although of somewhat different magnitude. The oscillogram below shows the motion of the flexible plate during operation at normal speed. (Note: The small high-frequency ripples shown are unfiltered harmonics of the testing circuit, and are present in the record with the machine standing still.) The springs for this test were precompressed to the equivalent of 4.5 times the test load. The motion is essentially the same with free or slightly precompressed springs.

Of the many thrust bearings on the market, the General Electric bearing is the only one which automatically relieves the high local pressure which might occur as a result of inaccuracies of workmanship. Also, it adjusts itself for misalignment conditions which might occur in installations. The thrust block in the bearing for which tests are shown was 0.0015 in. higher on one side than on the other. This introduced an irregularity in the deflection characteristics during rotation, the plate assuming a position inclined slightly to the horizontal as seen on the oscillogram, In spite of the eccentricity, the waves are essentially equal in area from one position to the other, showing complete, automatic equalization of local pressures.

Oscillograms taken during starting show that the oil film is built up by the time a rotor groove has moved the distance of half a segment.



Oscillogram showing deflection of stationary plate   A—Opposite radial saw cut   B—At radial saw cut

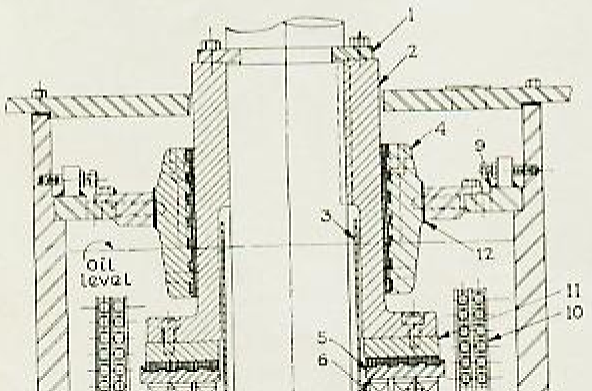
TYPES OF CONSTRUCTION

BEARING ARRANGEMENT

1. With the conventional bearing arrangement, in use for many years on vertical machines, the thrust bearing is located at the top of the machine with upper and lower guide, or steady, bearings. This provides maximum bearing accessibility since the continuous bearing plates can be lifted out after removing exciters or other equipment mounted above the bearing.

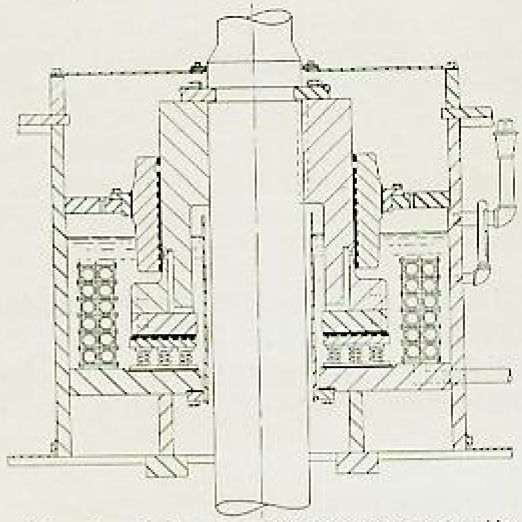
In the smaller sizes the upper guide bearing is of the "combined" type acting on the collar of the thrust bearing. This results in a self-oiling guide bearing which pumps its own oil. The illustrations on this page show this type of construction. In the illustration below, the oil supply to the guide bearings is through suitable grooves in the babbitt. The two illustrations at the right show an arrangement wherein the intake is through passages in the thrust collar. These lead to spiral grooves in the journal surface. This construction gives very positive action at low shaft speeds. With either arrangement, the lower guide bearing is separately oiled, usually by means of a geared pump.

In larger sizes, where radial-arm upper brackets are required in order to support the very heavy loads encountered, it is preferable to employ a



1. Split Retaining Ring
2. Thrust Collar
3. Oil-well Tube
4. Guide Bearing
5. Stationary Babbitted Ring
6. Springs
7. Clamps for Springs
8. Dowel Pin
9. Guide Bearing Support
10. Cooling Coils
11. Rotating Ring
12. Insulation

Sectional view of combined upper guide and thrust bearing

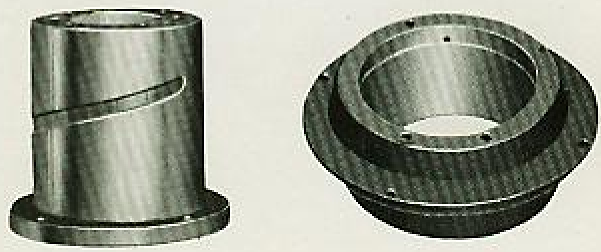


View of combined guide and thrust bearing with guide bearing lubricated through passages in thrust collar

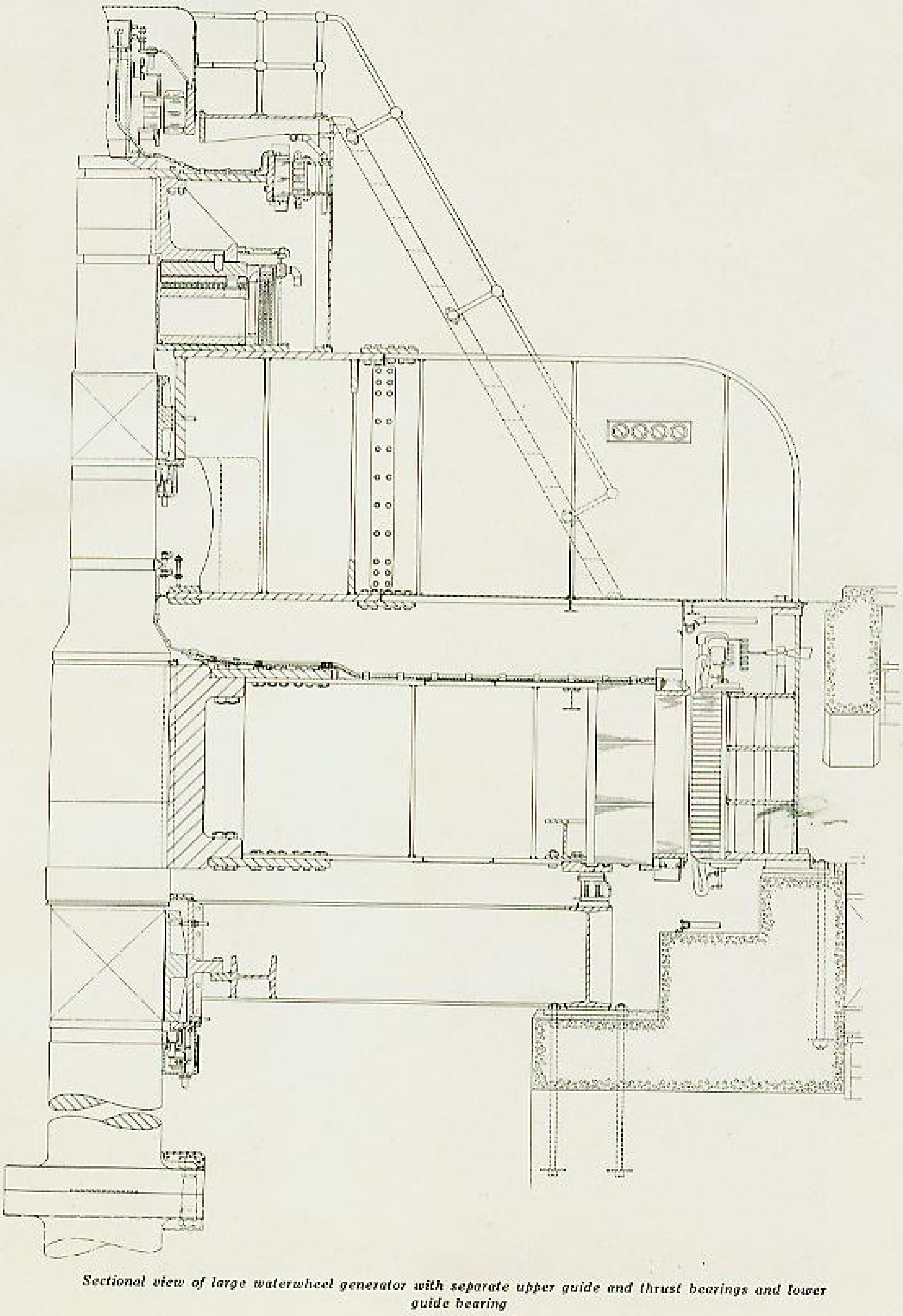
separate upper guide bearing, located at the center of the radial arms, while the thrust bearing is located in a shallow housing above the bracket. The illustration on page 9 shows a sectional view of such a machine. The generator has a unit oiling system. Oil is supplied to both guide bearings by a pump geared to the generator shaft.

The guide bearings are furnished in two or more sections when necessary for assembly. The combined bearings may be removed by raising them out of their seats, removing the joint bolts, and withdrawing the segments horizontally. After removal of the oil pans, the separate guides can be lowered, split, and carried out horizontally without disturbing other parts of the unit.

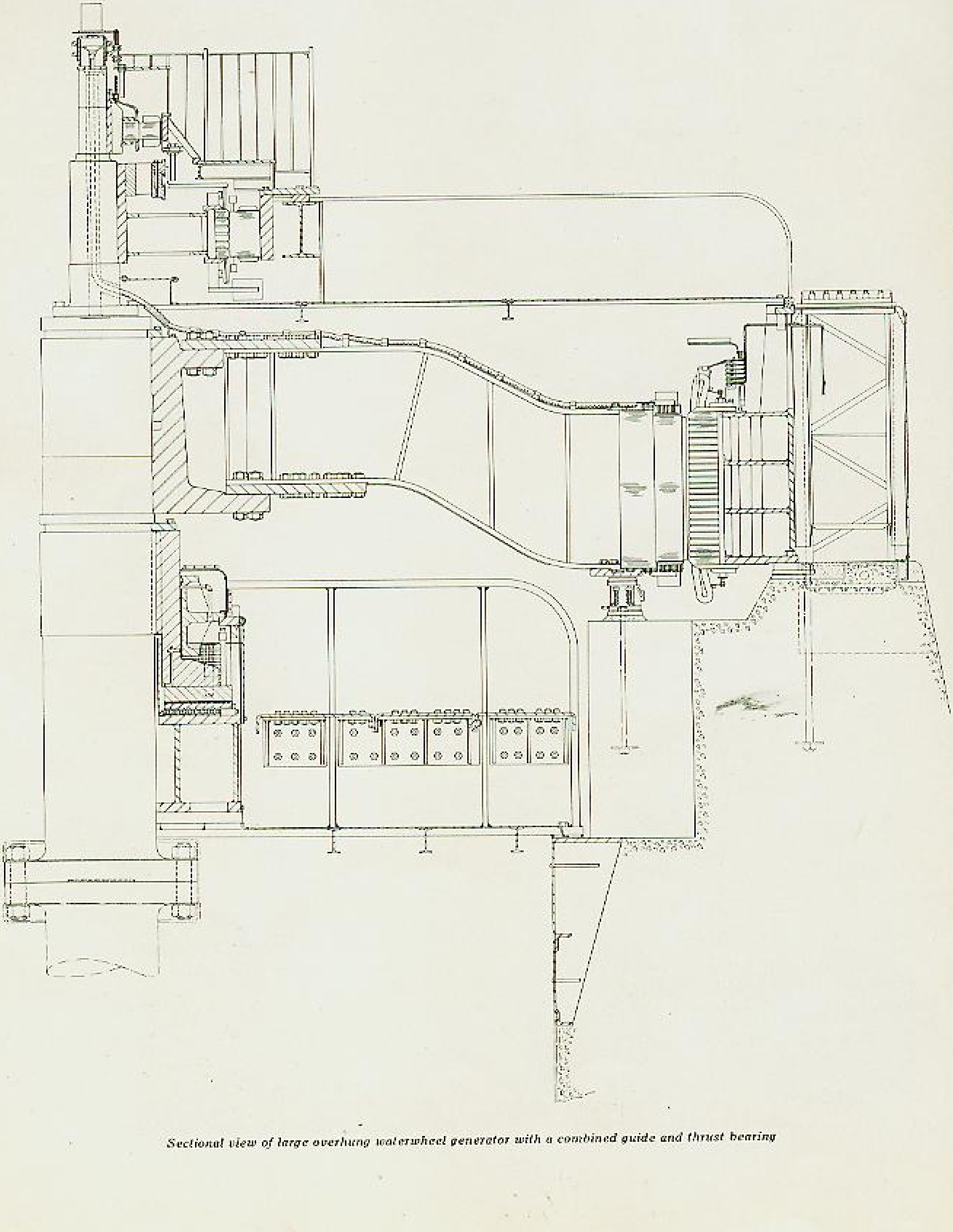
2. In recent years, a number of machines of the overhung type have been built, chiefly to per-



Thrust collar and guide bearing, showing oil grooves



Sectional view of large waterwheel generator with separate upper guide and thrust bearings and lower guide bearing



Sectional view of large overhung waterwheel generator with a combined guide and thrust bearing mit a saving in station headroom. In these machines, the thrust bearing and a guide bearing are placed immediately below the rotor, and the upper guide bearing is omitted. Alignment, therefore, depends upon both generator guide and waterwheel guide bearings.

Some characteristics of this type of construction are as follows:

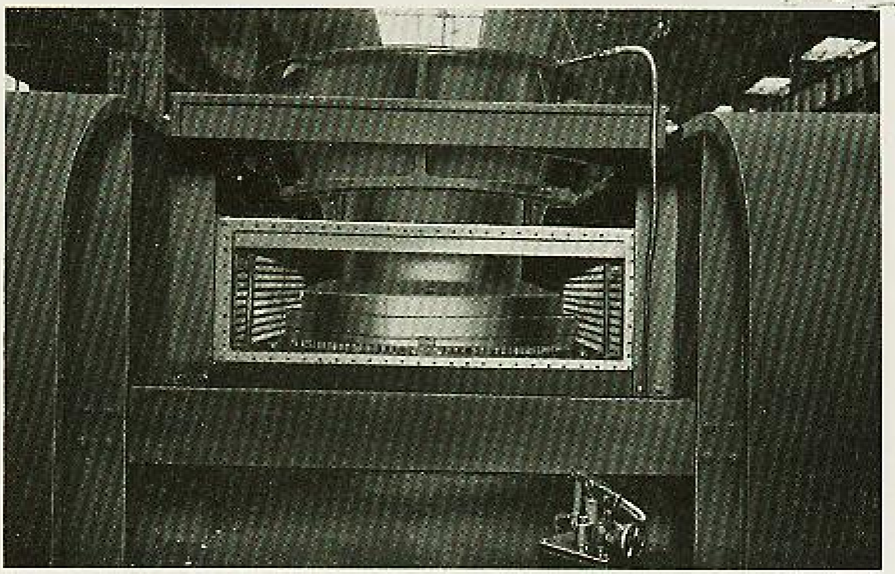
a. It is limited to moderate or low speeds.
b. Station headroom may be lower if generator lift is limiting feature.
c. The generator price is slightly lower.
d. Stator and rotor are more accessible.
e. Location of the thrust bearing below the rotor involves special problems in providing for accessibility of the thrust bearing, particularly in small machines. In the larger sizes, the bearings can usually be made accessible without disturbing the major parts.
f. The oiling system is somewhat simplified.
g. Generators of this type cannot be tested in the field with the waterwheel disconnected.
h. The generator inherently has less mechanical stability during transient electric or hydraulic disturbances.

Where an appreciable saving in station cost can be made by the reduction in headroom, and where the speed is suitable, this construction is justifiable. Other advantages are, in general, of a minor nature.

Either a combined guide and thrust bearing, or separate guide and thrust bearings, can be used, depending on size and other characteristics. The illustrations on this and the page opposite show a 47,000-kva unit employing a combined guide and thrust bearing. The housing is integral with the bracket. The thrust-bearing plates are in halves and can be taken out sidewise through the covered openings. The guide bearing is raised out of its seat by hydraulic jacks, the halves are unbolted, and moved out on carriages running on the top of the main girders.

3. More recently, in order to obtain greater mechanical stability than can be had with the overhung construction, a third type of machine has been devised. This consists of a bearing arrangement similar to the overhung, except that an upper guide bearing is employed. The saving in headroom over the conventional machine with a thrust bearing above and two guide bearings is almost as great as can be realized with the overhung unit; yet it has the inherent mechanical stability of the conventional machine and can be tested independently of the waterwheel.

This type of machine is finding increasing acceptance, particularly in important stations where continuity of operation is paramount.

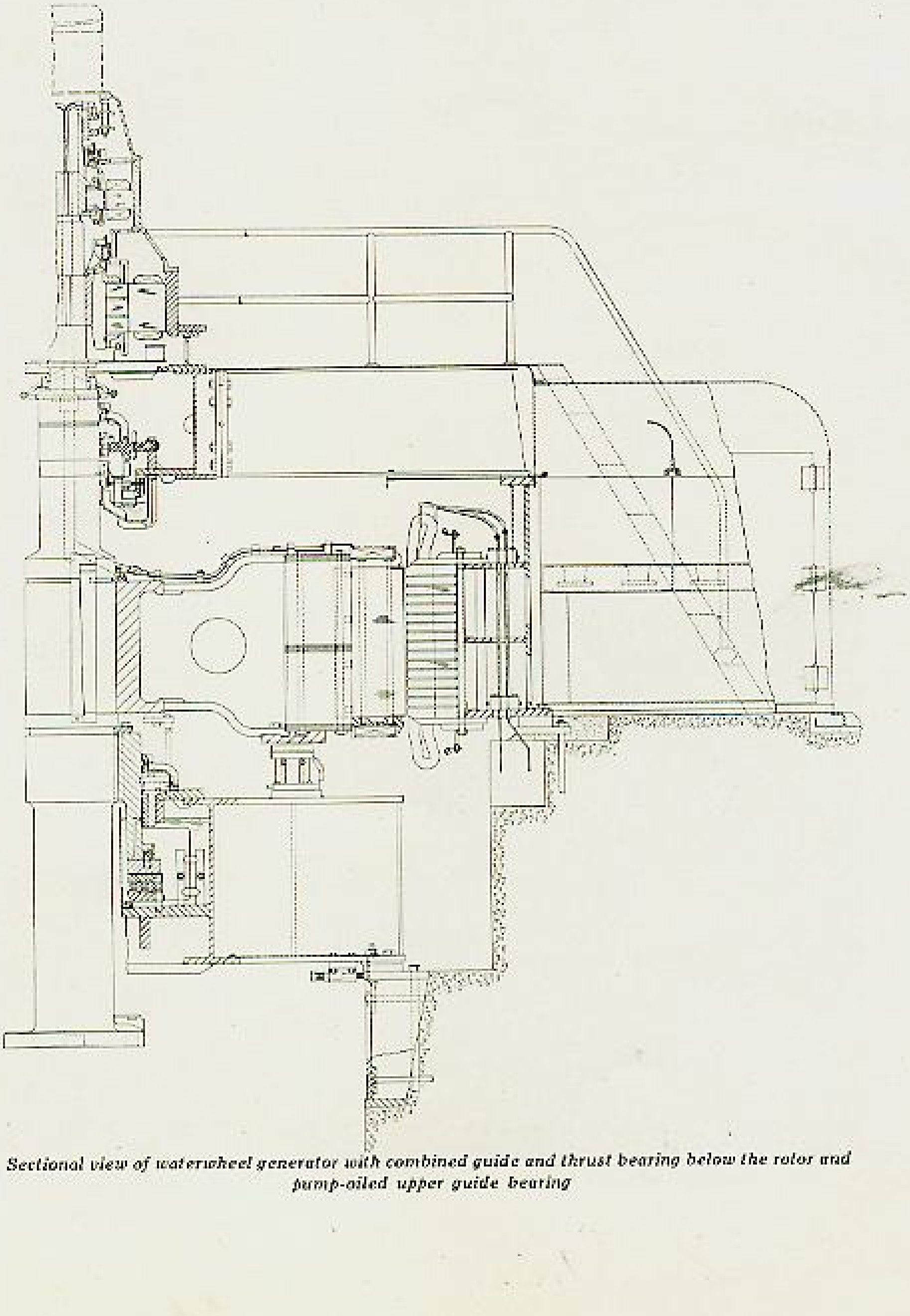


Combined guide and thrust bearing for large overhung waterwheel generator

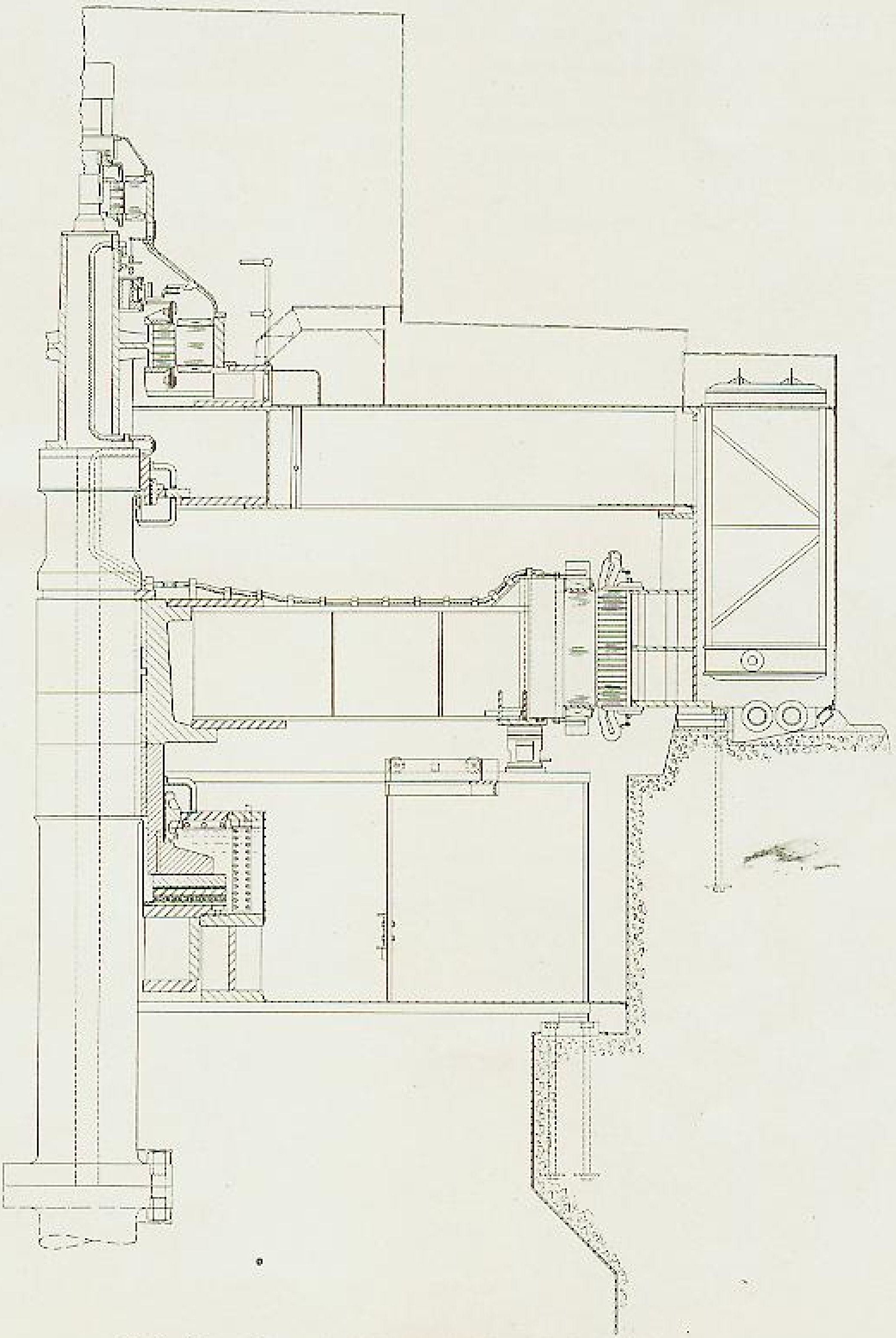
It is realized that this type has no advantages over the conventional arrangement unless the reduced headroom can be converted into a saving in station cost or unless an outdoor or semioutdoor installation is contemplated. In the latter case, there are some advantages in having the thrust bearing located beneath the rotor so that bearing disassembly can be carried out without disturbing the outdoor housing.

This construction is shown below, where the lower guide bearing is combined with the thrust bearing and operates in the same oil bath. The upper guide bearing has its own self-contained oiling system, which employs a geared oil pump.

The illustration on page 13 shows the same bearing arrangement, except that the upper guide bearing is made self-oiled without the use of a pump, by means of a sleeve on the shaft. The use of a separate base or support for the thrust bearing permits the coupling to pass through the bracket, and allows the thrust collar to be assembled permanently on the shaft in the factory.



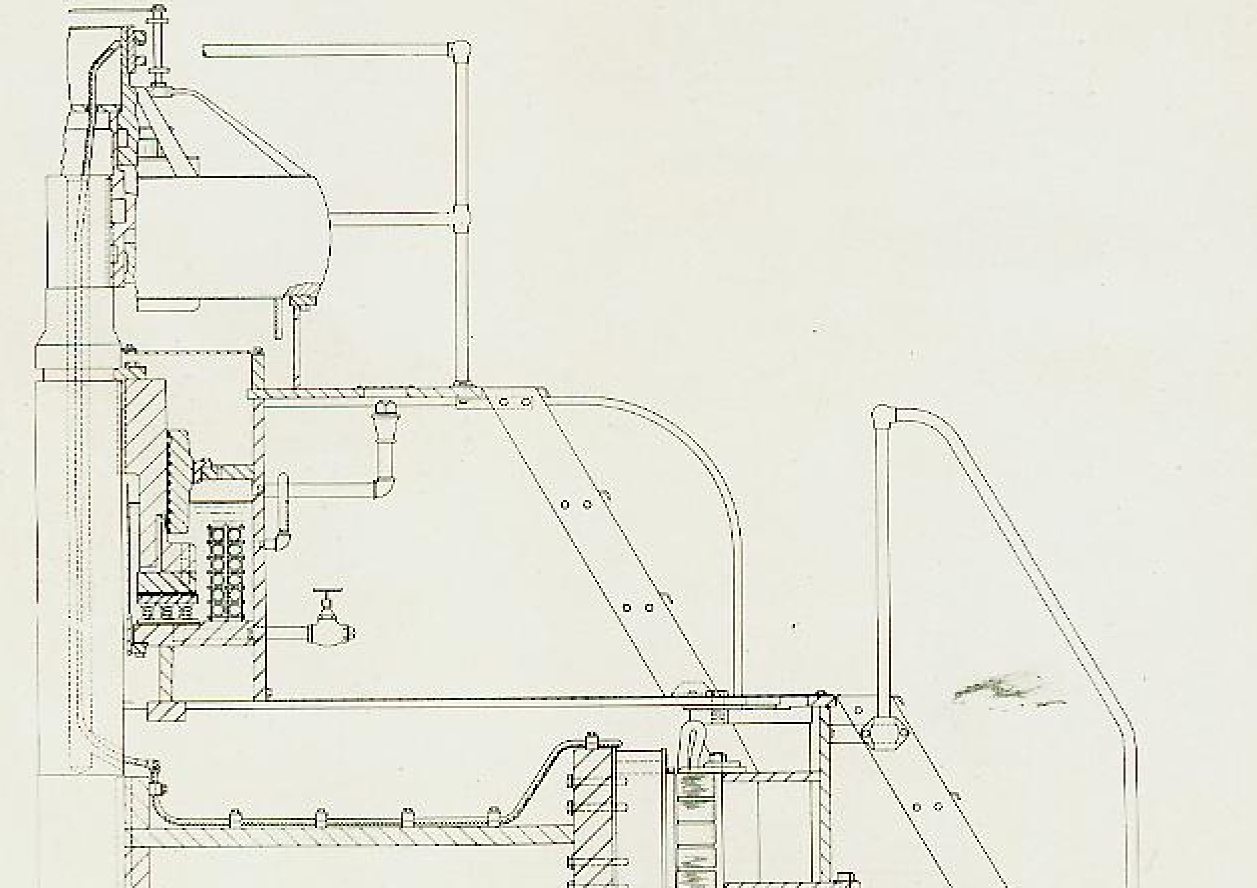
Sectional view of waterwheel generator with combined guide and thrust bearing below the rotor and pump-oiled upper guide bearing



Sectional view of large waterwheel generator with combined guide and thrust bearing below the rotor and self-oiling upper guide bearing

OILING SYSTEMS

Earlier practice employed station oiling systems in which all oil was circulated through a station filter and back to the bearings. In stations where the number of units was large, the piping required was quite complicated, and a unit oiling system was developed as an improvement. This provided a small filter for each machine, and the oil was circulated through the filter and back to the bearings, usually by means of gear-driven pumps. It has been found that continuous filtering of oil is unnecessary, and the oiling system is now further simplified by operating thrust bearings, and guide bearings of the combined type where used, in a self-contained oil bath. In general,



Sectional view of small waterwheel-driven generator with combined upper guide and thrust bearing and self-oiling lower guide bearing separate guide bearings employ a geared pump which pumps oil past a sight-flow indicator and to the top of the bearing.

In some cases, separate guide bearings have been made self-oiling without the use of a geared pump by means of a sleeve on the shaft. This results in an arrangement similar to that of the combined guide bearing which pumps its own oil. The illustration on page 14 shows a machine with a combined upper guide and thrust bearing and a self-oiling lower guide bearing.

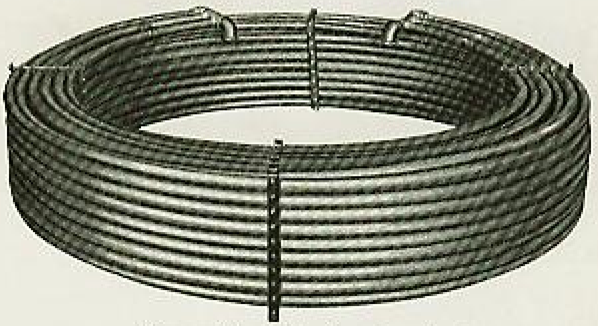
Because of the heavy loads carried on the thrust bearings of vertical generators, it is very essential that only high-grade lubricating oil be used. Oil should be purchased directly from oil manufacturers of recognized standing who will assume the responsibility for the selection of the best oil for the service.

Experience has shown that, in general, the viscosity of the oil at a temperature of 100 F as determined by the Saybolt viscosimeter, should not be less than 200 seconds, or much more than 300 seconds.

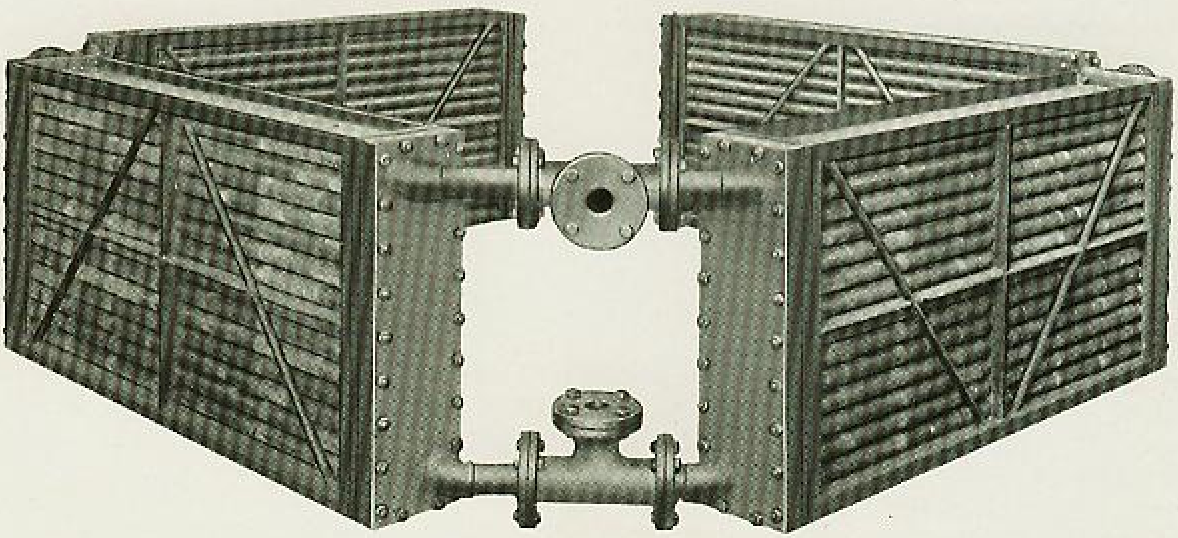
BEARING COOLING

Small thrust bearings may be run air-cooled, but the larger ones require other means for removing heat from the oil and housing. The simplest and most common way to keep the oil cool is by the circulation of water through coolers in the oil bath. The standard coolers are designed to maintain the required oil-bath temperature when supplied with water at a temperature of 25 C and at the rate specified by their manufacturer for each case. Trouble with the bearing surfaces is generally accompanied by a quick rise in oil temperature over that encountered under normal operating conditions.

In some installations, water pressure is not available for the bearing housing without special pumps. In these cases, the oil is cooled by pumping it through an external cooler. The pumps are driven directly from the generator shaft or by separate motors, and the coolers are of either the air or water type, depending upon local conditions. Motor-driven pumps are ordinarily furnished in duplicate, and the two units usually have different power supplies.



Water-cooling coil for thrust-bearing oil



Fin-type coolers for thrust-bearing oil

INSTALLATION OF GENERAL ELECTRIC THRUST BEARINGS

The simplicity of the bearing—which consists of only three principal parts: a stationary plate, a rotating plate, and a set of springs—together with the inherently uniform loading obtained with the spring support, makes the General Electric thrust bearing the simplest and quickest to install or disassemble.

FACTORY FINISH AND PROTECTION DURING SHIPMENT

The bearing surface of the rotating plate is carefully ground and polished at the factory to obtain a true and smooth surface. The stationary babbitted plate is machined to a uniform thickness. Because of the flexibility of this plate and its spring support, the General Electric thrust bearing can be put in service without fitting or scraping.

All steel or iron bearing surfaces are shipped from the factory with a protective coating to prevent rust. The rotating plate is packed in a special manner to prevent the protective coating from rubbing off and the polished bearing surface from being scratched.

ASSEMBLY OF THE BEARING

The protective coating on the bearing surface is easily dissolved by benzol, gasoline, or kerosene and removed with the use of clean rags (*not cotton waste*) and wood scrapers.

Before assembly, all parts of the bearing and the bearing housing should be inspected to insure absolute freedom from dirt, lint, or other foreign matter. Next, the bracket should be lined up and leveled. If a bearing base ring is used, this should then be brought into position and lined up by dowel pins. Next, the springs should be assembled on the base or floor of the housing. The babbitted stationary plate should then be placed on the springs and dowels which line up and hold the plate to prevent turning. Before assembling the rotating plate, the rubbing surfaces of both plates should be inspected to be sure that they are free from scratches. Then, the stationary plate should be covered with grease or preferably with a thick mixture of heavy lubricating oil and fine flake graphite. When the runner plate is lowered, it may easily be rotated to line up with the vertical dowels in the thrust collar.

On the overhung type of generator where the thrust bearing is located below the rotor, the stationary and rotating plates are made in halves to make possible their assembly and disassembly without disturbing the rotor. The bearing parts are assembled in the order described above, but, instead of being lowered over the top of the shaft, the half plates should be carried horizontally into the bearing housing through large openings provided for this purpose. This is the arrangement shown in the illustration on page 11. Where the bearing parts are very heavy, special carriages are provided for assistance in removing or reassembling the bearing.

Where the thrust bearing is located above the rotor, insulating material is used either under the base ring or between the thrust collar and rotating plate, to prevent flow through the bearing of circulating currents from the shaft. After the bearing is assembled and partially loaded, this insulation should be given a high-potential test of 500 volts. When the thrust bearing is below the rotor, it need not have any insulation against these circulating currents.

As soon as the bearing parts and cooling coils are assembled, the housing should be filled with clean lubricating oil. This protects the metallic parts from rust during the period required to finish the assembly of the generator; the bearing is then ready for service whenever the generator is ready to start.

INITIAL STARTING

If there are cooling coils in the thrust-bearing housing, turn on the water before starting. Start the bearing slowly and run at one-third speed for half an hour and, at first, note the oil temperatures at one-minute intervals. Any injury of the rubbing surfaces will be indicated by a rapid rise of the oil temperatures in the housing.

If the bearing operates well at one-third speed, the speed may be gradually increased to normal.