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Introduction

The development of the hydroelectric power industry in the United States has been intimately bound up with the invention and development of the Kingsbury Thrust Bearing.

In the early nineteen hundreds, growth in the physical size of hydraulically driven generators was in danger of coming to a standstill because of the difficulties experienced with the types of thrust bearings available at the time.

It was just during this period that Albert Kingsbury, having by experimental investigation established the validity of the principle on which his invention was based, was seeking opportunity to demonstrate his bearing in commercial application.

This opportunity arose in 1912 in the form of an order for the replacement of a troublesome thrust bearing in a 10,000 kva unit in the Holtwood Station of the Pennsylvania Water and Power Company on the Susquhanna River. The replacement was accomplished with outstanding success and was quickly followed by similar replacements in the other units of the station.

It is no exaggeration to say that this installation marked a turning point in the progress of the waterpower industry. Relieved of concern regarding the ability of the thrust bearing to carry greater rotating loads, the manufacturers of water turbines and generators soon moved to take advantage of this new freedom. The ratings and size of hydraulically driven generators has grown steadily these past 70 years.

Dr. Kingsbury proceeded to set up an organization to design his bearings, and imbued his staff with his own concepts of thorough engineering and meticulous workmanship, thereby establishing a standard quality which has been unsurpassed through the years.

Kingsbury, Inc. has manufactured numerous vertical bearings for new hydraulically driven generator applications, as the partial list of bearing applications included in this brochure reveals. However, as in the case of Dr. Kingsbury's initial successful bearing application, we have continued to solve bearing problems in poorly operated generating units. The enclosed installation list shows units Kingsbury has successfully retrofitted with redesigned bearings to reduce down time and vibration problems. Our 70 years of design and troubleshooting experience places us in a unique position to diagnose and eliminate bearing problems.

Rocky Reach Dam—Pub. Utility Dist. #1 Chelan County, Washington State.

The Kingsbury Principle

Experience has shown that a rotating plate (such as the runner of a vertically disposed thrust bearing) and a stationary bearing surface, if held in rigid parallelism, are difficult to lubricate. But Albert Kingsbury found that if the bearing surface was supported on a pivot so as to be capable of tilting slightly with reference to the runner, then the oil film between the surfaces at once became self-renewing and lubrication was automatic so long as lubricant was supplied.

The property of the lubricant which causes the formation of the wedge-shaped oil film between the bearing surfaces is, of course, the adhesion of the oil to the surface of the rotating runner. By dividing the bearing surface into a number of segments each supported on a pivot, there is immediately created a device that automatically permits introduction of a separating film of oil between the bearing surfaces, entirely eliminating metallic contact.

The discovery was the basis for the development of the Kingsbury pivoted-shoe thrust bearing. The validity of the principle was both demonstrated by experience and supported by the theoretical determinations of Osborne Reynolds and others. The pivoted shoe is simpler than, and superior to, any other device designed to achieve the same result. Many thousands of installations in every field of application where long life and dependability are paramount considerations have established the pivoted-shoe thrust bearing as the accepted standard.

A rotating runner and stationary pivoted segments or "shoes" are the vital elements of the Kingsbury Thrust Bearing. As they run in a bath of oil, not under pressure, the oil clings tenaciously to the runner surface, and is drawn between the runner and shoes, forming separating films of remarkable load-carrying capacity. This is possible only because the shoes are pivoted and free to tilt microscopically, thus permitting the formation of wedge-shaped films with the thick end on the entering side. (A running journal naturally takes a position which allows a tapered film to form. The diagrams on the facing page show how the journal bearing forms an oil wedge and how the same result is reached with pivoted shoes in Kingsbury Thrust Bearings.) The oil films are continuously renewed, due merely to the rotation of the oil-flooded runner, and the working surfaces never touch each other as long as the shaft turns. Consequently the loads carried may be far in excess of those possible with any bearing that lacks the pivoted segment feature; and the friction is far less.

Since the loads are so concentrated and speeds are often high, the oil becomes heated by its own "shearing" friction. To remove the heat, the oil is cooled either by radiation or by water cooling, within the oil bath or by an outside cooler and circulating pump. Kingsbury Bearings might be described as being built around circulating oil films, on which the load is "floated" by the motion of the runner and the viscosity of the oil.

The loads carried per square inch of shoe area depend on shoe size, oil viscosity and speed. The number of shoes selected for the bearing design depends on the load and the shaft diameter.

This illustration shows established oil film in a running journal bearing.

journal
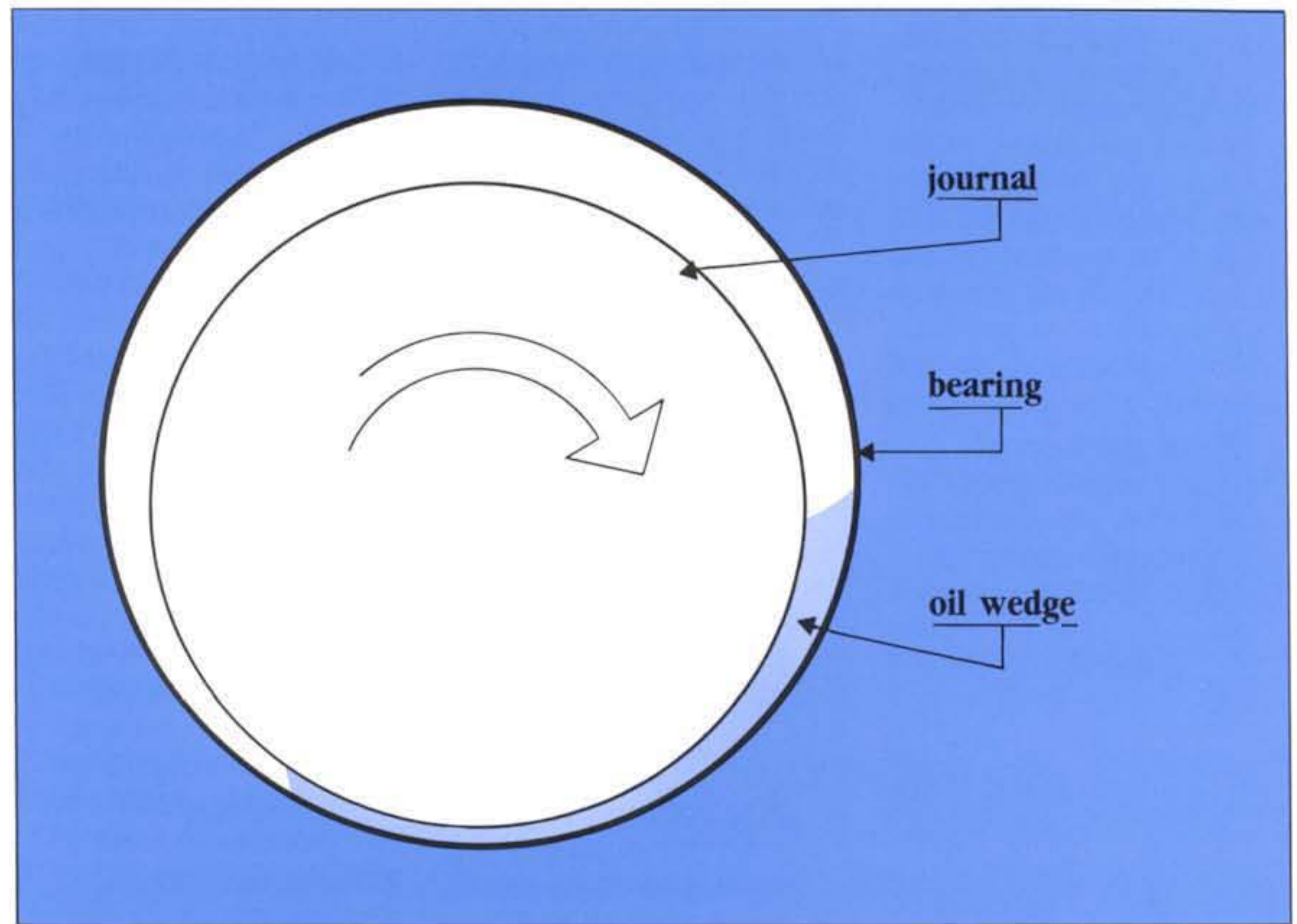
bearing

oil wedge

This illustration shows a Kingsbury Thrust Bearing automatically establishing an oil wedge.

runner

pivoting thrust shoe

oil wedge
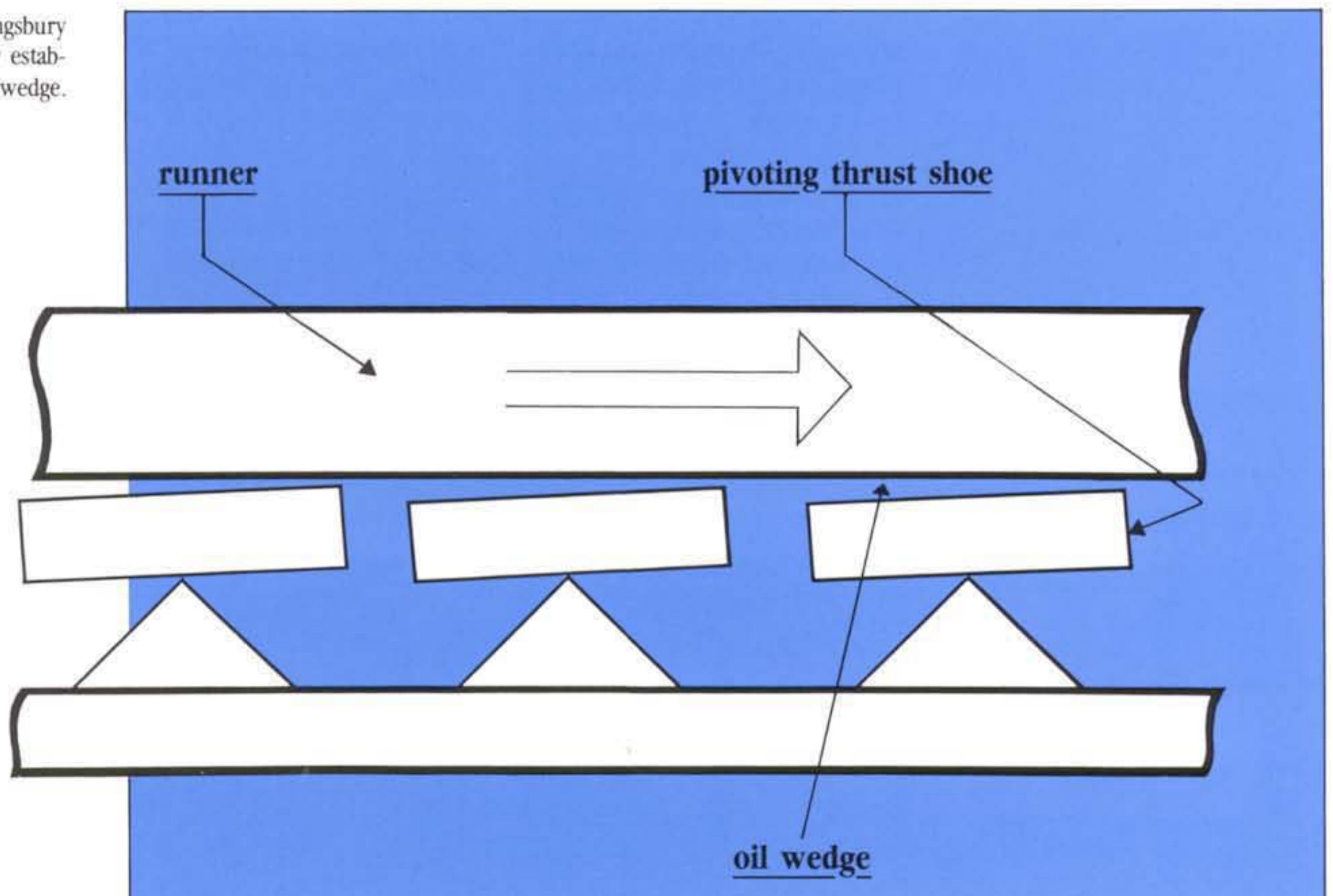
Adjustable Type Bearings

The provision of a separate adjusting screw under each thrust bearing shoe affords a simple means of equalizing the shoe loads, aligning the unit and raising or lowering the rotating parts for fine adjustment of turbine clearance.

The principal elements of the bearing are the rotating runner and the stationary pivoted shoes. The pivot for each shoe is formed by, or carried on, the head of a jackscrew. Hence the shoes are free to tilt slightly in any direction, permitting the formation and maintenance of wedge-shaped oil films separating the bearing surfaces.

The runner receives the load through a thrust block of massive proportions either secured on the shaft or intergral with it. The runner itself is usually solid in the small to moderate sizes and split in the large units for better accessibility. When split, the edges of the joint are slightly rounded and the halves are securely bolted together and finished as a unit.

When adjusting the bearing for load the elasticity of jackscrews, pivots, supports and other parts involved makes it possible to equalize the jackscrew loadings.

An adjusting wrench is used to determine the angular movement of the jackscrew from its fully loaded to its unloaded position. Acting as a micrometer the jackscrew enables this angle to be measured with extreme accuracy and if the parts involved are uniformly elastic the loads carried by the shoes may be equalized with great precision.

To obtain proper alignment of the unit measurements are taken to determine the amount and direction of the required shaft movement. Then a simple calculation will determine the proportionate amount of raising or lowering required for each jackscrew in order to bring the shaft into a plumb position.

When the shoe loads are equalized and the shaft properly plumbed the jackscrews are immobilized by means of lock wrenches or locking caps.

Besides the virtue of simplicity, the individual support of the shoes provides ease of examination of the bearing. One shoe at a time can be lowered by backing off its adjusting screw and the shoe removed for examination of its condition, and also for access to a portion of the runner surface for the same purpose. After such examination the shoe is returned to its operating position by wrenching the jackscrew to the position it occupied before.

Because the shoe and runner surfaces are so nearly perfectly fitted, the shoes tend to cling to the runner when their jackscrews are backed off or the runner is raised. If no means were provided for preventing this, there would be danger of damage if a shoe let go. This is alleviated by providing a "stripper pin" at each shoe location to engage the edge of the shoe and break the adhesion between the shoe and runner surfaces.

In smaller sizes of bearings the shoes, jackscrews and associated parts are usually mounted in a "base ring," but in large units they are generally set directly in a foundation provided by the purchaser.

The adjustable type is particularly popular for the umbrealla type generator where the jackscrews add to generator rotor stability.
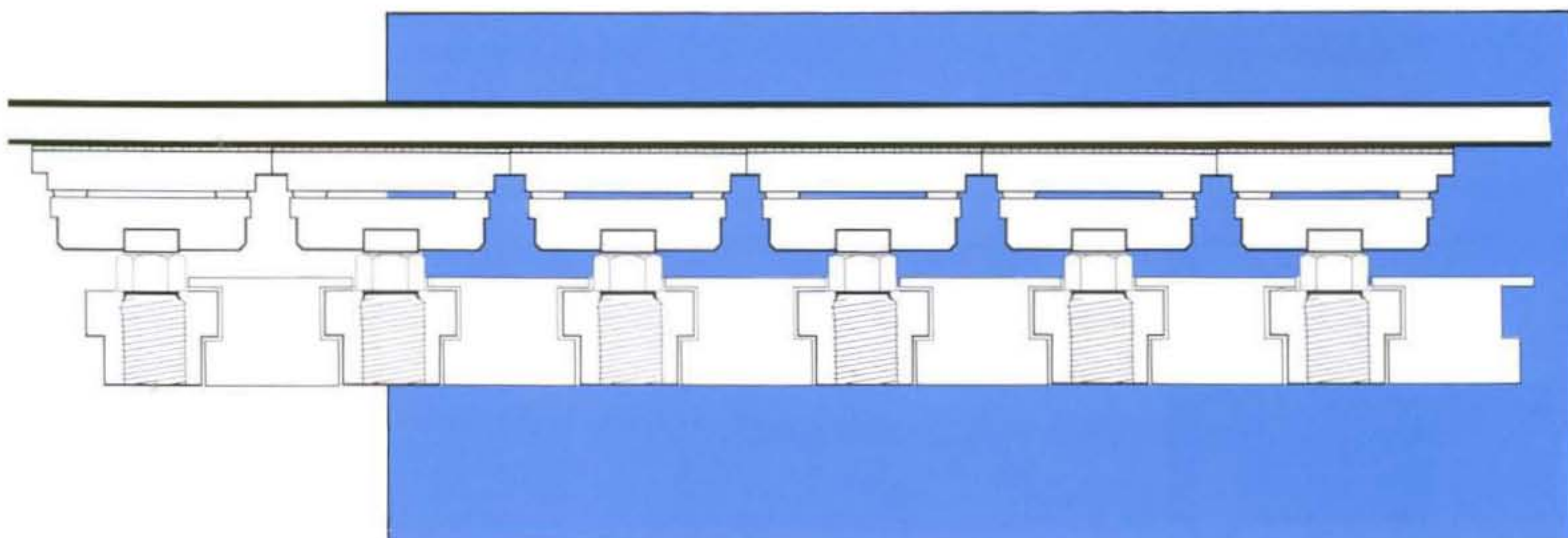
Equalizing Type Bearings

The characteristic feature of this type of bearing is the system of interacting levers on which the thrust shoes are supported. These levers, called "leveling plates," comprise two groups—the "lower" leveling plates which rest in the base ring, each on a radial rib or blunt knife-edge on which it can rock slightly, and the "upper" leveling plates, each of which is supported on the wings of two lower leveling plates. Each upper leveling plate supports one thrust shoe and it is obvious from the illustration below that the leveling plate system is not in equilibrium unless the forces acting on the shoes are equal.

In the developed section schematically shown below, the operation of the leveling plate assembly may readily be visualized. Supposing the runner to have been removed, if one shoe is depressed the adjacent shoes on either side will rise up because the lower leveling plates on each side of the depressed shoe have been tilted so that their other ends press upward, thus tending to lift the shoes they support. Of course when the runner is in place no actual motion will occur unless there is misalignment, in which case the whole leveling plate and shoe assembly will adjust itself to suit the condition.

As a result of this interaction the bearing is not only automatically equalizing, as to shoe loads, but is also self-aligning within reasonable limits. Thus proper operation is insured in spite of misalignment, inaccuracies in foundation or minor variations in thickness of the shoes.

In large bearings friction between the mating surfaces of the upper and lower leveling plates is minimized by interposing hardened steel rollers between them and thus substituting rolling motion for rubbing, although it must be understood that the relative movements, if any, of these parts are very small.

The thrust shoes are restrained radially by shoe retainers bolted to the base ring and shoe "strippers" are provided in the larger units to part the shoes from the runner face when the rotor is jacked up for examination of the surfaces.

Bearings of the equalizing type involve a somewhat larger number of parts and in consequence may be somewhat more expensive than the adjustable type, particularly in the larger sizes. Never the less the self-equalizing and self-aligning features are attractive for many conditions of service.

The equalizing type is particularly suitable when the thrust bearing is located above the generator rotor. Since no adjustment of shoe loading is required it is particularly easy to install.
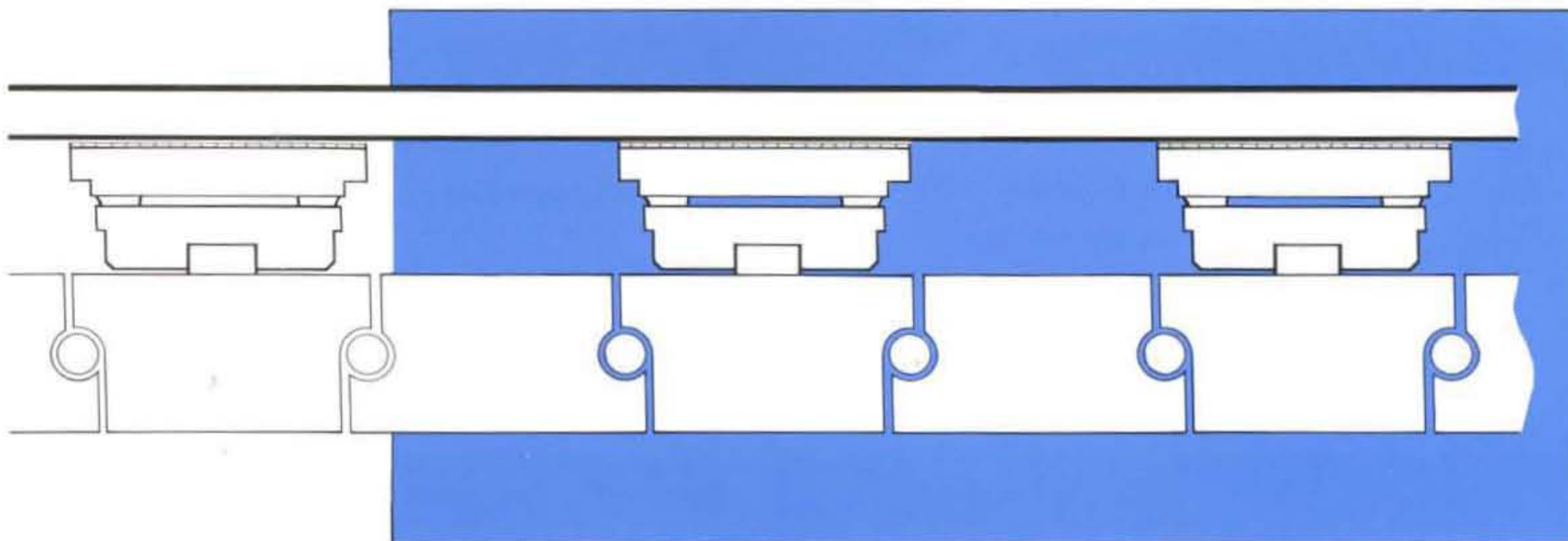
Design Features

Thrust Runner

The thrust runner is manufactured from a steel forging to assure that there are no internal voids, gas holes or cracks that may develop in steel plates. It is also annealed to relieve any stresses that have built up in the forging process. The forging is then machined, taking fine cuts to assure that the machining process does not build in internal stresses. After machining, the thrust face is lapped to obtain very fine finishes of 8 to 16 RMS. Lapping of the thrust runner face is very important for long life of this style thrust bearing. Runners which are manufactured in halves and bolted together are keyed the entire radial length of the runner and hand-fitted to assure that after manufacture, when the thrust runner is disassembled and reassembled, perfect alignment is maintained. The joint bolts are preloaded by means of a torque wrench to assure that the runner joint will not separate during operation.

Thrust Bearing Shoes

It is generally recognized that the best operating conditions are achieved when the thrust bearing shoe is approximately square—that is, its mean length is equal to its radial width. All hydroelectric thrust shoes have been designed to have a length-to-width ratio falling between 0.8 to 1.1, thus achieving this optimum condition. During operation, a normal thrust shoe would tend to become convex around its point of support due to the load that the shoe is carrying and the temperature difference from the operating face to the back of the shoe. To overcome this tendency, we have designed our thrust shoes and support system to insure uniformly flat shoe surfaces throughout the range of operating loads and temperatures.

Without exception, we use a high tin base babbitt, ASTM B-23 Grade #2. Lead is held to a minimum since lead and tin can form a low melting point. Further, the fatigue resistance of high tin base babbitt is above that of lead base babbitt. The babbitt surface is finished by means of hand-scraping. Experiments have shown that scraping of the babbitt will help improve load capacity, particularly at startup and shutdown when film thicknesses are at a minimum. It also greatly reduces starting torque when it is required to start the generator without the use of a hydrostatic lift system.

Babbitt bonding of the thrust shoes is based on our many years of experience in this area. Babbitt is statically poured onto the thrust shoe to achieve a metallurgical bond. We have very stringent bond requirements, which assures a 90 to 95% bond over the surface of the shoe. Each shoe is checked ultrasonically for bond and is not passed until it reaches these requirements.

Shoe Supports and Load Cells

The shoe supports and the load cells are designed to carry four times the normal load before crushing. This assures that bearing failure will not occur even if the loads exceed the design requirements.

Thrust Load Equalization

A. Adjustable Jackscrew Design

Adjustable jackscrews provide a stiff and rigid bearing support, well suited for stabilizing vibrations so common in pump/generator rotors.

Jackscrews and their bushings are lapped together by hand to obtain a precise fit, this increases their load carrying capacity and assures easy turning for field adjustments.

B. Equalizing Leveling Plate Design

Forged steel upper leveling plates are fitted with hardened inserts at the point of contact with the shoe support to preserve surface geometry.

Forged steel lower leveling plates support the upper leveling plates through hardened and ground pins. The lower leveling plates are supported by the bearing housing on hardened inserts.

Pin contact surfaces on the upper and lower leveling plates are honed to provide near perfect equalization.

Once the load is equalized the leveling plates can be locked so that bearing rigidity and stiffness approaches that of the adjustable jackscrew design.

Bearings for Hydroelectric Applications

Kingsbury vertical thrust bearings combine simplicity with the utmost reliability. They are available in styles to suit every kind of hydroelectric installation.

There are two basic designs, each capable of wide variation to suit special conditions. These are the **Adjustable** and the **Equalizing** types.

In the **Adjustable** type each shoe is separately supported on a jackscrew by means of which it can be raised or lowered. This is to obtain proper alignment, correct generator and turbine clearances, and equal division of load among the several shoes.

In the **Equalizing** type the shoes are mounted on a series of interlocking levers, or "leveling plates," the interaction of which automatically produces equal loading and correct alignment.

These two types of bearings provide the means for transmitting the thrust of the rotating elements to the stationary parts in any type of vertically disposed power apparatus, of any required size and operating conditions.

The adjustable type has for years been popular for bearings of large size and heavy load. Its simplicity and ease of assembly recommend it highly. The majority of

high capacity installations are of this type.

The equalizing type has long been a favorite for units of moderate size and relatively high speed. Large installations of this type have been designed and installed, notably at Hoover Dam and in the Andre Blondel development on the Rhone River in France. Its self-aligning and automatic load-equalizing features are important considerations in its favor.

85 ½ inch Equalizing Kingsbury Bearing installed at Hoover Dam.

High Pressure Lift Systems

High pressure lift systems are now a mandatory requirement of practically all recent hydro bearing specifications. The system is generally cycled to operate prior to start-up, and again during run-down, to reduce break away torque, and to minimize wear on the bearing components. Their purpose is to introduce a thin film of oil between the thrust shoes and the bearing runner.

Kingsbury has pioneered in the development of the shoe modifications needed for this feature, and can also provide devices, manifolds, pump consoles and other hardware for a complete installation.

These systems may readily be retro-fitted to existing bearing installations. Kingsbury engineers will determine the correct thrust shoe modifications, and specify the proper ancillary equipment. This is based on data supplied, including the bearing's physical details, load, speed, lubricant specification and operating bath temperature. Kingsbury service engineers will arrange the machining of the shoe modifications, etc., and supervise the installation of the entire system.

Installations of hydro generators fitted with Kingsbury lift systems are identified in the Partial List section of this brochure.
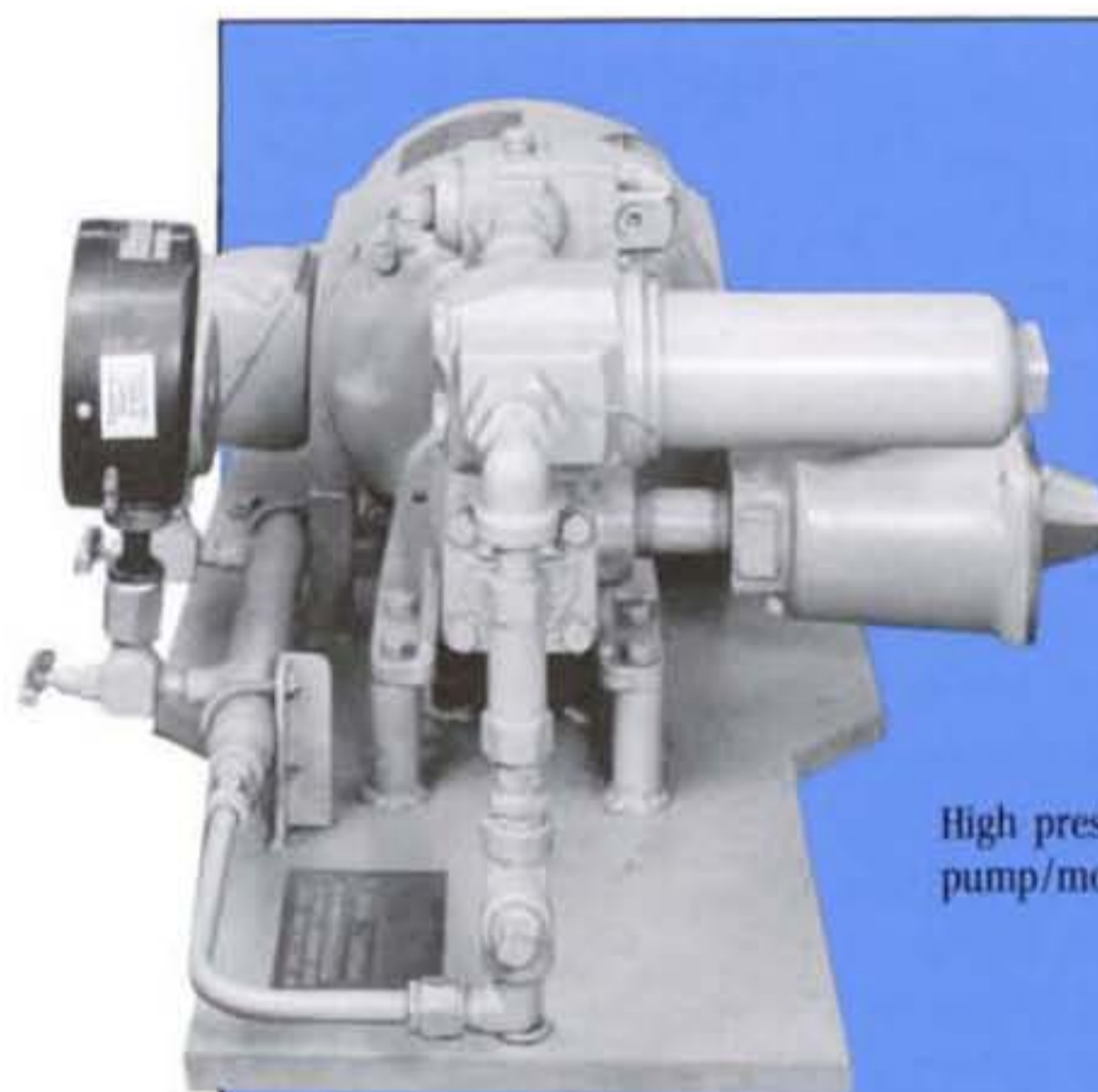
High pressure lift pump/motor consol.

Thrust shoe machined for high pressure lift. Note the hand scrapping of the bearing face.

Load Measurement and Instruments

Bonded strain gage type load cells, can be provided for most vertical fluid-film thrust bearings.

Load cells are mounted under the shoe supports, and are a convenient and accurate system of checking load distribution on thrust shoes. They also permit the monitoring of hydraulic loads under various flow and head condition of the turbine runner.

Readout instruments are available for operation at various voltages, and are selected to be compatible with inhouse systems. The instruments are calibrated to indicate percentage of full load, or direct thrust-pounds, on analog meter, digital display or strip chart recorder.
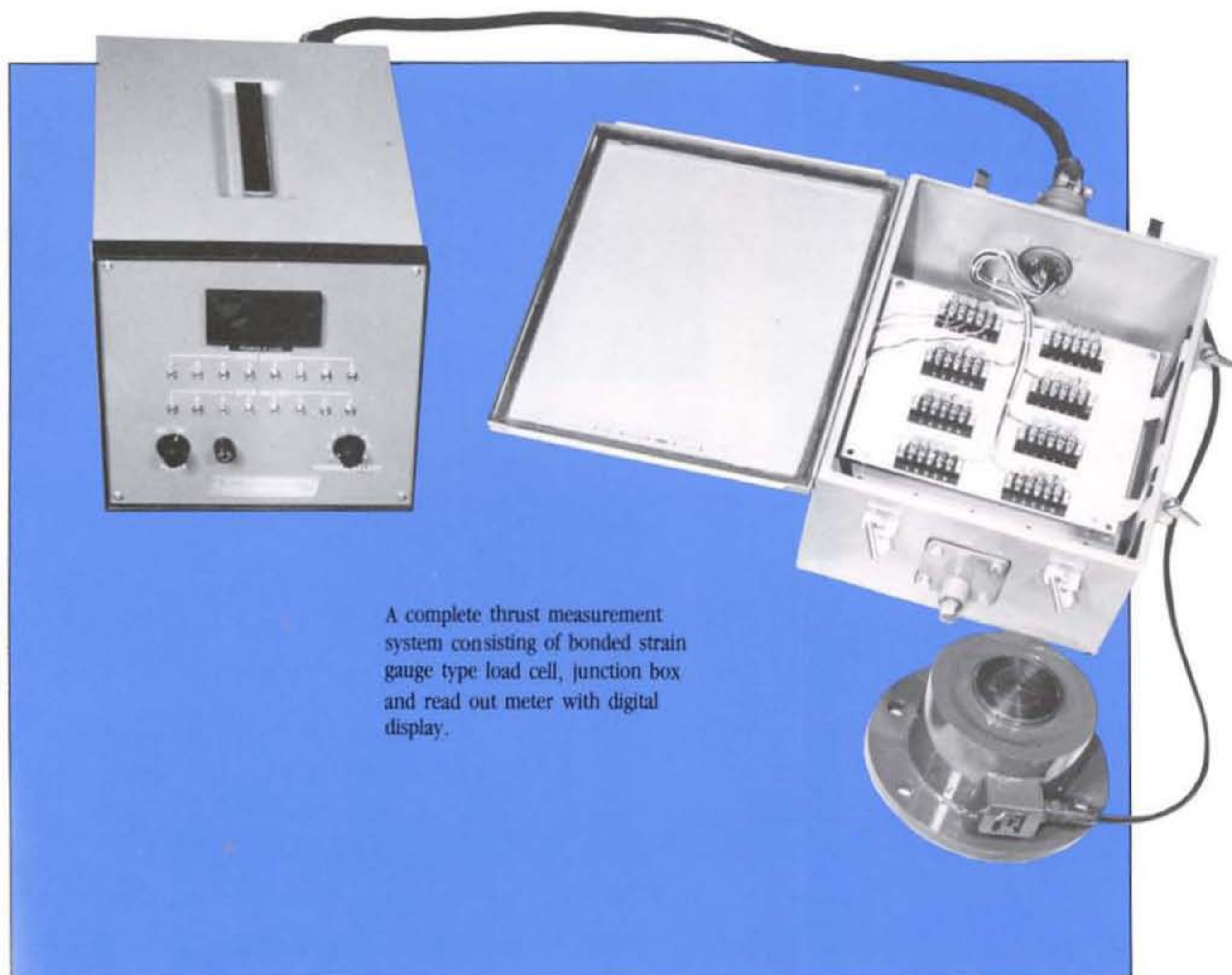
A complete thrust measurement system consisting of bonded strain gauge type load cell, junction box and read out meter with digital display.

Field Service and Bearing Repair

Kingsbury provides a world-wide field service for all types of fluid-film thrust and journal bearings.

Our experienced field service engineers are available to provide a diagnostic service on hydro-electric bearing problems. They are also qualified to supervise the removal of bearings and components, to undertake repairs or replacements of parts, and to oversee the proper re-assembly of the bearings.

The field service engineers are supported by Kingsbury design engineering, the R&D laboratory, and extensive computer facilities at the Philadelphia plant.

When bearings are shipped to the factory for evaluation, they are completely disassembled, cleaned and examined by the service group. A repair recommendation is quickly prepared and the customer notified. Upon confirmation by the customer, the repair work orders are generated and renewal procedure is carried out promptly, by specially trained personnel.

In the case of breakdown repairs, procedures are accelerated, and the work is carried out by technicians, dedicated to such repair work, including machining, babbitting, hand finishing and installation of instrumentation, as necessary to complete the whole procedure in the shortest possible time frame.

Re-installing a 60 year old Kingsbury Thrust Bearing that has been cleaned and inspected.
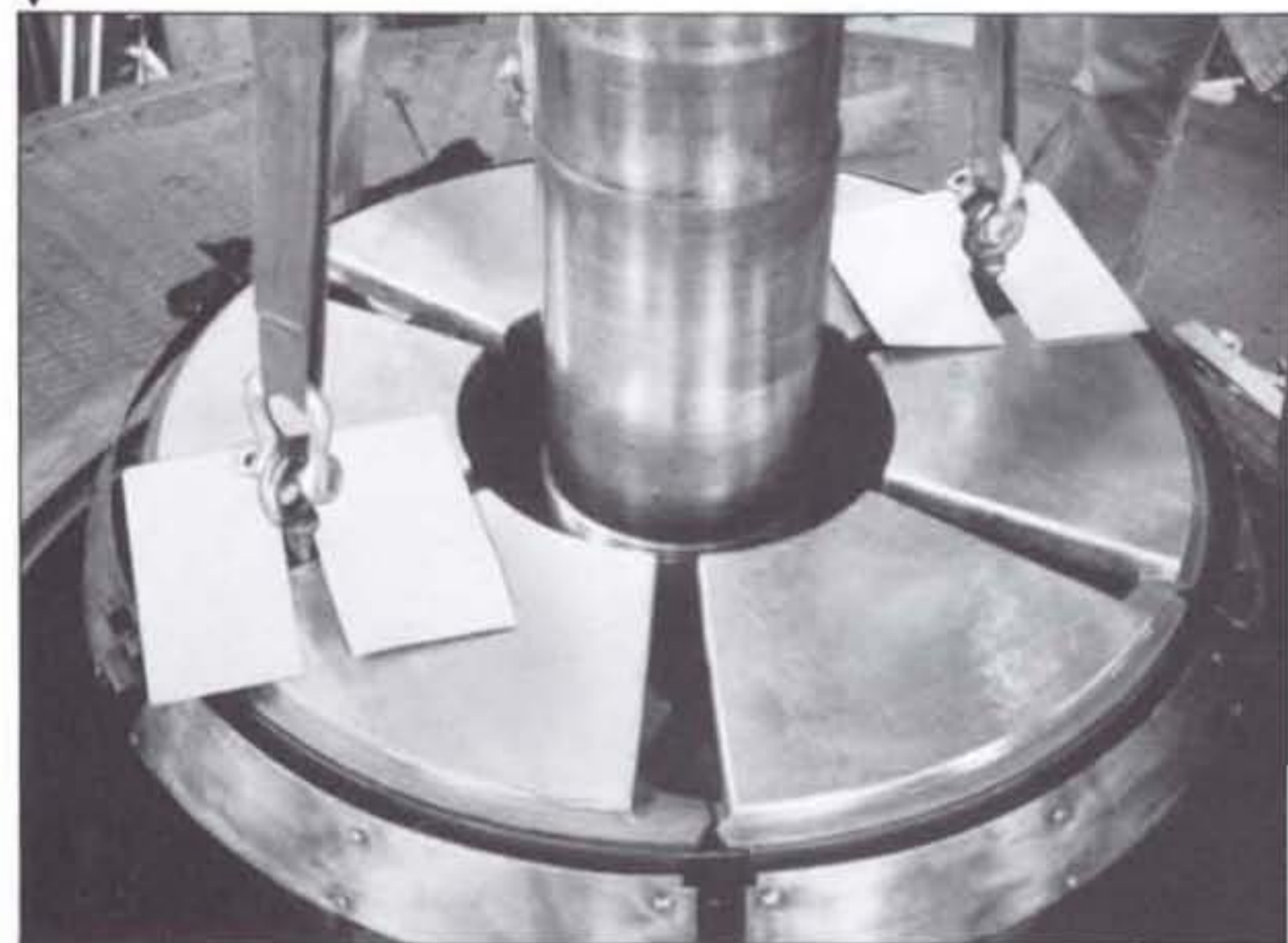
Adjusting a 70 year old Kingsbury Thrust Bearing to assure each shoe is supporting its share of the thrust load.

Assembling a Thrust Runner to its Thrust Block and Shaft.

Adjusting a Kingsbury Type Thrust Bearing to equalize the thrust load on all shoes.

Pump Storage Application

Kingsbury thrust bearings provide the bearing support characteristics needed for successful pump storage service.

The Kingsbury adjustable type bearing permits precise and ready positioning of the turbine runner in its scroll case, to ensure optimum performance and lowest vibration amplitude, when operating in the pump mode.

Careful application engineering, and attention to design criteria, control unavoidable vibration levels through a balanced selection of thick oil films, and the required support structure stiffness to effectively attenuate and dampen the destructive dynamic forces.

Kingsbury has often been retained as a consultant on problem applications that have resulted in frequent, and costly, bearing outages. When the analysis has determined an inadequate bearing design, Kingsbury has successfully redesigned and manufactured replacement components, or entire bearings.

Kingsbury bearings installed in pump storage applications are identified in the chart below.

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
Virginia Electric Power Co.	Bath County Project	108.5	2,998,000	556	257	Adj.	6	—	1981
Appalachian Power Co.	Smith Mountain	102	2,500,000	504	90	Adj.	1	47,500	1977
Tennessee Valley Authority	Raccoon Mt.	93	2,314,800	592	300	Adj.	4	—	1971
Argentina	Rio Grande #1	84	1,680,000	557	250	Adj.	4	—	1978
State of California	Thermalito Oroville Div.	72	1,213,000	471	138.5	Adj.	1	—	1966
South Carolina Electric & Gas Co.	Fairfield	65	855,000	477	150	Adj.	8	—	1973
U.S. Army Corps of Engineers	DeGray Project	61	749,000	452	150	Adj.	2	—	1968
State of California Water Facility	Thermalito Power Plant	59	650,000	422	112.5	Adj.	3	30,600	1966

Partial List of Installations

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
Public Utility District #1 Chelan County	Rocky Beach	116.5	4,309,000	624	85.7	Adj.	4	—	1973
Virginia Electric Power Co.	Bath County Project	108.5	2,998,000	556	257	Adj.	6	—	1985
Public Utility District #1	Wells Dam	107	3,550,000	583	85.7	Adj.	7	81,500	1964
Douglas County, Washington	Wells Dam	107	3,550,000	583	85.7	Adj.	3	81,500	1965
Compagnie Nationale du Rhone, France	Andre Blondel	105	3,080,000	610	107	Eq.	1	59,000	1952
Compagnie Nationale du Rhone, France	Andre Blondel	105	3,080,000	588	107	Eq.	2	59,000	Future
Appalachian Power Co.	Smith Mountain	102	2,500,000	504	90	Adj.	1	47,500	1977
Tennessee Valley Authority	Kentucky	94	2,200,000	550	78.3	Adj.	5	35,000	1944-46
Tennessee Valley Authority	Chickamauga	93	2,075,000	464	75	Adj.	4	30,000	1940-51
Tennessee Valley Authority	Fort Loudoun	93	1,800,000	402	105.8	Adj.	4	35,555	1943-47
Tennessee Valley Authority	Wheeler	93	1,825,000	480	85.7	Adj.	6	36,000	1940-49
Connecticut Light & Power Co.	Shepaug	93	2,100,000	469	138.5	Adj.	1	43,750	1954
Alabama Power Co.	Bankhead	93	2,080,000	465	90	Adj.	1	—	1961
Alabama Power Co.	Logan Martin Dam	93	1,842,000	412	102.8	Adj.	2	47,500	1961
Alabama Power Co.	Logan Martin Dam	93	1,842,000	412	102.8	Adj.	1	47,500	1962
Tennessee Valley Authority	Raccoon Mt.	93	2,314,800	592	300	Adj.	4	—	1971
Tennessee Valley Authority	Cherokee	89	950,000	381	94.7	Adj.	2	33,333	1942
Tennessee Valley Authority	Douglas	89	950,000	381	94.7	Adj.	2	33,333	1943
Tennessee Valley Authority	Douglas	89	970,000	389	90	Adj.	1	28,800	1948
Tennessee Valley Authority	Guntersville	87	2,000,000	515	69.2	Adj.	3	27,000	1939
U.S. Bureau of Reclamation	Hoover Dam	85.5	1,800,000	444	180	Eq.	2	82,500	1938
U.S. Bureau of Reclamation	Hoover Dam	85.5	1,834,000	451	180	Eq.	2	82,500	1952
U.S. Bureau of Reclamation	Hoover Dam	85.5	2,008,000	494	180	Eq.	2	83,500	1970
Alabama Power Co.	Mitchell Dam	85	1,895,000	547	85.7	Adj.	8	—	1980
Appalachian Power Co.	Smith Mountain	84	1,397,000	462	105.9	Adj.	2	69,500	1960
U.S. Army Corps of Engineers	Carters Dam	84	1,548,000	512	163.6	Adj.	2	—	1967
Argentina	Rio Grande #1	84	1,680,000	557	250	Adj.	4	—	1978
Tennessee Valley Authority	Hiwassee	84	1,365,000	452	106	Adj.	1	70,000	1955
Safe Harbor Water Power Corp.	Safe Harbor	82	1,560,000	440	109	Adj.	2	36,000	1931[1]
Safe Harbor Water Power Corp.	Safe Harbor	82	1,750,000	493	107	Adj.	3	36,000	1931-33
U.S. Army Corps of Engineers	W.F. George	82	1,750,000	514	112.5	Adj.	4	36,111	1969
Phila. Electric Co. Philadelphia, PA	Conowingo	80	1,450,000	402	81.8	Adj.	3	40,000	1928[1]
U.S. Bureau of Reclamation	Hoover Dam	78	1,550,000	481	180	Adj.	1	100,000	1961
U.S. Bureau of Reclamation	Hoover Dam Unit N8	78	1,550,000	481	180	Adj.	1	100,000	1961
Portland General Electric Co.	Round Butte	76	1,300,000	499	180	Adj.	3	91,500	1962
Pacific Gas and Electric Co.	Belden	73	1,406,000	524	225	Adj.	1	—	1967
Espirito Santo Centrals Electrical SA, Brazil	Mascarenhas Project	73	1,503,000	561	105.9	Adj.	2	—	1971
Manitoba Hydro Electric Board	Seven Sisters	73	1,450,000	499	138.5	Adj.	3	32,500	1930-31[2]
P.U.D. #1 Chelan County, Wash.	Rock Island	73	1,265,000	455	100	Adj.	6	25,000	1952
Pacific Power & Light Co. Portland, Oregon	Merwin	73	1,100,000	436	120	Adj.	1	56,250	1931
City of Seattle	Diablo	72	1,080,000	364	171.5	Adj.	2	66,700	1931[1]

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
Merced Irrigation District, Merced, CA	New Exchequer	72	1,110,000	502	180	Adj.	1	—	1965
State of California	Thermalito Oroville Division	72	1,213,000	471	138.5	Adj.	1	—	1966
U.S. Army Corps of Engineers	J. Percy Priest	72	1,239,000	482	128.6	Adj.	1	—	1966
Republic of Turkey	Gokcekaya	72	1,030,000	466	187.5	Adj.	3	—	1968
Central Nebraska Public Power and Irr. District	Kingsley	72	1,259,000	485	180	Adj.	1	—	1983
U.S. Army Corp. of Engineers	Greers Ferry	69	972,000	477	120	Adj.	2	—	1961
Hydro Electric Power Commission of Ontario	Chats Falls	69	1,095,000	422	125	Adj.	2	23,500	1931[2]
Niagara Falls Power Co.	Cliff 3-C	69	1,250,000	482	107	Adj.	3	62,000	1923
Hydro Electric Power Commission of Ontario	Queenston	69	960,000	388	187.5	Adj.	7	45,000	1921-30[2]
U.S. Army Corps of Engineers	Fort Peck	69	742,000	342	128.5	Adj.	2	38,900	1941-51
U.S. Army Corps of Engineers	Bull Shoals	69	860,000	396	128.5	Adj.	4	42,100	1952
Tennessee Valley Authority	Wilson	69	882,000	406	100	Adj.	10	28,000	1942-49
Alcoa Power Co., Ltd. Quebec, Canada	Chute-a-Caron	69	1,175,000	453	120	Adj.	4	50,000	1930[2]
New England Power Co.	Wilder	69	1,023,000	471	112.5	Adj.	2	18,000	1950
P.U.D. #1, Pend Oreille County, Wash.	Box Canyon	69	1,040,000	437	100	Adj.	4	16,667	1955
British Columbia Elec. Co. Ltd., Vancouver, B.C.	Ruskin	69	720,000	278	120	Adj.	1	44,000	1930[2]
South Carolina Elec. & Gas Co.	Saluda	66	875,000	420	138.5	Adj.	4	40,625	1930[1]
New England Power Co. Fifteen Mile Falls	Lower Dev.	66	834,000	401	138.5	Adj.	4	39,000	1931[1]
Gatineau Power Co. Quebec, Canada	Bryson	65	966,000	420	120	Adj.	2	25,000	1924-28[2]
Manitoba Hydro Elec. Board	Great Falls	65	800,000	348	138.5	Adj.	2	21,000	1922[2]
Shawinigan Water & Power Co. Montreal, Que., Canada	La Gabelle	65	1,050,000	458	120	Adj.	4	33,000	1924[2]
Shawinigan Water & Power Co. Montreal, Que., Canada	Rapide Blanc	65	694,000	417	109	Adj.	5	36,000	1931[2]
Arkansas Power & Light Co. Little Rock, Ark.	Carpenter	65	688,500	414	94.7	Adj.	2	31,111	1930
Idaho Power Co. Boise, Idaho	Lower Salmon	65	983,000	443	120	Eq.	4	17,500	1948
U.S. Army Corps of Engineers	Fort Peck	65	800,000	446	128.5	Adj.	2	42,105	1960
U.S. Army Corps of Engineers	Bull Shoals	65	755,000	422	128.5	Adj.	2	43,368	1961
U.S. Army Corps of Engineers	Bull Shoals	65	755,000	422	128.6	Adj.	2	—	1961
U.S. Army Corps of Engineers	Broken Bow	65	800,000	461	128.6	Adj.	2	—	1965
South Carolina Electric & Gas Co.	Fairfield	65	855,000	477	150	Adj.	8	—	1973
Aluminum Co. of America	Calderwood	64	703,000	303	150	Adj.	3	45,000	1930-38[1]
Alabama Power Co.	Thurlow Dam	64	725,000	313	100	Adj.	2	29,000	1928[1]
Alabama Power Co.	Jordan Dam	64	755,000	326	100	Adj.	4	29,000	1928[1]
Montana Power Co. Great Falls, Mont.	Morony	64	606,000	263	81.8	Adj.	2	25,000	1929[1]
Carolina Power & Light Co. Raleigh, North Car.	Tillery	61	640,000	355	75	Adj.	1	24,000	1927
Carolina Power & Light Co. Raleigh, North Car.	Tillery	61	700,000	389	90	Adj.	2	29,000	1927
Quebec Hydro-Electric Commission	Cedars	61	550,000	328	55.6	Adj.	10	7,500	1914-16
Tennessee Valley Authority	Wilson	61	806,500	398	100	Adj.	4	32,500	1925
Imperial Irrigation District California	Pilot Knob	61	826,000	446	128.5	Adj.	2	20,000	1956
Appalachian Power Co.	Smith Mountain	61	804,350	439	138.5	Adj.	2	—	1961
U.S. Army Corps of Engineers	DeGray Project	61	749,000	452	150	Adj.	2	—	1968
Salt River Project	Mormon Flat	61	718,000	435	138.5	Adj.	1	—	1969

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
State of California Water Facility	Thermolito Power Plant	59	650,000	422	112.5	Adj.	3	30,600	1966
Aluminum Co. of America	Chilhowee	57	825,000	540	128.5	Sph.	3	19,608	1957
U.S. Bureau of Reclamation	Hoover	57	680,000	456	237	Adj.	1	40,000	1934
U.S. Bureau of Reclamation	Palisades	57	570,000	351	163.5	Eq.	4	30,000	1956
U.S. Army Corps of Engineers	Fort Gibson	57	520,000	350	100	Adj.	4	12,500	1953
U.S. Army Corps of Engineers	Whitney	57	475,000	319	128.5	Adj.	2	16,667	1953
Gatineau Power Co. Quebec, Canada	Farmers Falls	57	750,000	424	90	Adj.	3	21,000	1926-28[2]
Gatineau Power Co. Quebec, Canada	Chelsea Falls	57	748,000	423	100	Adj.	2	36,000	1926-28[2]
Niagara Mohawk Power Co. Syracuse, N.Y.	South Colton	57	585,000	393	120	Adj.	1	21,500	1954
Niagara Mohawk Power Co. Syracuse, N.Y.	Blake Falls	57	585,000	393	112.5	Adj.	1	16,000	1956
Saguenay Power Co. Montreal, Canada	Isle Maligne	57	750,000	424	112.5	Adj.	8	30,000	1925-28[2]
So. California Edison Co. Los Angeles, Cal.	Big Creek #4	57	650,000	400	257	Eq.	1	42,000	1950
New Kanawha Power Co. West Virginia	Hawks Nest	56	560,000	389	150	Adj.	4	30,000	1932[1]
Penna. Power & Light Co.	Holtwood	56	543,000	324	94.7	Adj.	2	15,000	1924[1]
Tennessee Valley Authority	Wilson	56	575,000	344	100	Adj.	4	25,000	1925[1]
Tennessee Valley Authority	Blue Ridge	56	570,000	396	163.5	Adj.	1	25,000	1931[1]
Union Electric Co. St. Louis, Mo.	Keokuk	56	593,000	378	62	Adj.	15	9,000	1913-48
Western Carolina Power Co. Charlotte, N.C.	Claremont	56	470,000	277	120	Adj.	2	22,500	1928[1]
Central Maine Power Co.	Brunswick	54	605,000	452	90	Adj.	1	—	1980
Brazilian Hydro-Electric Co., Ltd.	Parahyba	53	580,000	379	125	Adj.	1	25,000	1928
Brazilian Hydro-Electric Co., Ltd.	Parahyba	53	613,000	400	125	Adj.	2	25,000	1923
Gatineau Power Co. Quebec, Canada	Grand Falls	53	647,000	423	164	Adj.	7	23,000	1928[2]
Gatineau Power Co. Quebec, Canada	Paugan Falls	53	650,000	424	125	Adj.	7	28,500	1928[2]
Imperial Irrigation District California	Drop #4	53	555,000	395	150	Eq.	1	12,000	1938
Oakdale & S. San Joaquin Irrigation District, Cal.	Tri-Dam Donnells	53	600,000	468	240	Adj.	1	67,500	1956
Kajaani O.Y. Pohjolen O.Y., Finland	Katerma	53	548,000	390	136	Adj.	1	8,000	1949
Shawinigan Water & Power Co. Montreal, Que., Canada	Grand Mere	53	576,450	377	112.5	Adj.	1	25,000	1930[2]
Nantahala Power & Light Co., Franklin, N.C.	Nantahala	51	575,000	472	450	Sph.	1	54,000	1941
Aluminum Co. of America	Cheoah	51	550,000	452	164	Sph.	1	37,500	1949
Aluminum Co. of America	Tuckertown	51	615,000	504	138.5	Sph.	3	15,555	1962
U.S. Bureau of Reclamation	Blue Mesa	50	665,000	500	200	Eq.	2	—	1964
City of Tacoma Washington	Nisqually	49	540,000	408	257	Adj.	1	40,000	1943
U.S. Army Corps of Engineers	Fort Peck	49	402,000	363	164	Adj.	1	16,667	1941
U.S. Army Corps of Engineers	Tenkiller Ferry	49	396,000	357	150	Adj.	2	17,985	1953
Idaho Power Co. Hagerman, Idaho	Lower Salmon	49	475,000	396	138.5	Adj.	1	9,000	1937
Niagara Falls Power Co.	Cliff #3-B	49	500,000	379	150	Adj.	3	32,500	1919
Pacific Gas & Electric Co. San Francisco, Cal.	Pit River #1	49	475,000	360	257	Adj.	2	35,000	1921
Pacific Gas & Electric Co. San Francisco, Cal.	Pit River #3	49	450,000	341	225	Adj.	3	27,000	1925
United Paper Mills, Ltd. Finland	Valkeakoski	49	366,000	330	107	Adj.	1	5,000	1951
West Kootenay Power & Light, Co., Trial, B.C.	Bonnington Falls	49	470,000	356	100	Adj.	2	17,500	1924[2]
Churchill River Power Co. Winnipeg, Man., Canada	Island Falls	49	470,000	356	160	Adj.	3	14,000	1929[2]

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
Alabama Power Co. Birmingham, Ala.	Lock #12	48	425,000	369	100	Adj.	2	14,500	1916[1]
Aluminum Co. of America, Badin, N.C.	High Rock	48	423,000	362	90	Adj.	3	13,750	1929[1]
Carolina Power & Light Co.	Waterville	48	450,000	384	400	Adj.	3	45,000	1929-31[1]
City of Seattle Washington	Gorge	48	447,100	358	257	Adj.	2	30,000	1924[1]
Duke Power Co. Charlotte, N.C.	Rhodhiss	48	366,000	313	100	Adj.	3	10,625	1925[1]
Georgia Power Co. Atlanta, Ga.	Bartletts Ferry	48	500,000	400	150	Adj.	3	18,750	1928[1]
Penna. Power & Light Co.	Holtwood	48	405,000 470,000	346 402	94 116	Adj.	8	10,000 13,750	1912-17
Connecticut Light & Power Co., New Milford, Conn.	Rocky River	46	517,000	450	327	Adj.	1	30,000	1928
Duke Power Co.	Wateree	46	400,000	354	100	Adj.	5	14,000	1919
Duke Power Co.	Dearborn	46	415,000	367	112.5	Adj.	3	18,750	1923
Duke Power Co.	Mountain Island	46	415,000	367	112.5	Adj.	4	18,750	1924
Hydro Electric Power Commission of Ontario	Nipigon	46	400,000	354	120	Adj.	2	10,625	1921[2]
MacLaren-Quebec Power Co.	Masson	46	500,000	435	180	Adj.	3	28,000	1928[2]
MacLaren-Quebec Power Co.	High Falls	46	470,000	409	167	Adj.	4	26,200	1931[2]
Minnesota Power & Light Co., Duluth, Minn.	Fond du Lac	46	300,000	318	120	Adj.	1	15,000	1924
Stora Kopparbergs Co., Sweden	Forshuvud	46	375,000	332	83.3	Adj.	2	6,500	1921
Utah Power & Light Co. Salt Lake City, Utah	Cutler	46	335,000	355	150	Adj.	2	18,750	1925
Verkstaden Kristinehamn	Sweden	46	375,000	332	83.3	Adj.	1	—	1920
City of Tacoma Washington	Cushman #2	45	460,000	486	300	Sph.	1	30,000	1951
City & County of San Francisco, Cal.	Cherry Plant	45	475,000	470	400	Adj.	2	75,000	1959
Idaho Power Co. Bliss, Idaho	Lower Malad	45	288,000	309	200	Eq	1	15,500	1947
Loup River Public Power District, Nebraska	Columbus	45	325,000	352	150	Adj.	3	14,000	1936
Cia Agric. y de Fza. Elec. Del Rio Conchos, SA.	Rosetilla Chih. Mexico	45	324,000	354	128.5	Sph.	1	11,100	1930
Terni-Societa per l'Industria e' Electtricita	Italy	45	575,000	523	375	Adj.	1	—	1961
Sacramento Municipal Utility District	Union Valley	45	450,000	445	277	Eq.	1	35,000	1962
U.S. Bureau of Reclamation	Nimbus California	43	397,000	429	150	Eq.	2	7,500	1954
U.S. Bureau of Reclamation	Alcova Wyoming	43	379,000	410	163.5	Eq.	2	18,950	1953
City of Tacoma Washington	Cushman #2	43	480,000	476	300	Adj.	2	30,000	1929
Dairyland Power Coop. La Crosse, Wis.	Flambeau	43	320,000	346	225	Adj.	3	6,250	1950
Minnesota Power & Light Co., Duluth, Minn.	Blanchard Falls	43	275,000	379	100	Adj.	2	7,500	1924
So. California Edison Co. Los Angeles, Cal.	Big Creek #8	43	425,000	422	450	Adj.	1	35,000	1928
Tennessee Valley Authority	Great Falls Tennessee	43	340,000	338	163.5	Adj.	1	20,625	1925
Tennessee Valley Authority	Wilbur, Tennessee	43	393,000	425	180	Adj.	1	7,777	1950
Washington Water Power Co., Spokane, Wash.	Lewiston, Idaho	43	325,000	323	138.5	Adj.	2	6,250	1927
Westinghouse Elec. International Co.	Yokohama, Japan	43	383,000	380	277	Adj.	1	—	1929
Alabama Power Co. Birmingham, Ala.	Lock #12	42	324,000	389	100	Adj.	5	13,000	1914[1]
Daido Electric Power Japan	Momoyama	42	300,000	360	250	Adj.	2	15,000	1924[1]
Daido Electric Power Japan	Yomikaki	42	330,000	396	360	Adj.	3	17,000	1923[1]
Montana Power Co. Butte, Mont.	Holter	42	328,000	393	150	Adj.	4	12,000	1918
Pacific Gas & Electric Co. San Francisco, Cal.	Merced Falls	42	244,000	285	128	Adj.	1	4,000	1930[1]
Penna. Electric Co. Johnstown, Pa.	Piney Creek	42	282,000	334	133	Adj.	2	12,000	1924[1]

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
Shawinigan Water & Power Co. Montreal, Que., Canada	Grand Mere	42	330,000	396	120	Adj.	6	14,700	1914[1]
Shawinigan Water & Power Co. Montreal, Que., Canada	Grand Mere	42	405,000	474	120	Adj.	2	18,500	1921[2]
Idaho Power Co. Boise, Idaho	Twin Falls	41	191,000	272	240	Adj.	1	13,500	1935
Montana Power Co. Butte, Mont.	Ryan	41	348,000	381	200	Adj.	6	10,000	1914-16
Pacific Gas & Electric Co. San Francisco, Cal.	Balch	41	355,000	423	400	Adj.	2	54,000	1957
U.S. Bureau of Reclamation	Delta Mendota	41	250,000	325	180	Adj.	6	—	1950
So. California Edison Company	Big Creek #3 Unit #5	41	370,000	440	450	Adj.	1	—	1979
Ministry of Mines & Energy, Indonesia	Wonogiri Project	41	341,711	407	273	Adj.	2	—	1982
U.S. Bureau of Reclamation	Pole Hill	41	350,000	416	450	Eq.	1	35,000	1953
Aluminum Co. of America	Santeetlah	40	358,000	412	450	Adj.	2	25,000	1928
City of Tacoma Washington	Cushman #1	40	350,000	403	200	Adj.	2	20,000	1924
Calgary Power Co., Ltd. Alberta, Canada	Ghost	40	327,550	377	150	Adj.	2	15,500	1929[2]
Consumers Power Co. Jackson, Mich.	Hodenpyl	40	300,000	345	120	Adj.	2	9,000	1924
Holyoke Water Power Co. Holyoke, Mass.	Plant #1	40	275,000	316	128.5	Adj.	1	5,000	1931
Idaho Power Co. Boise Idaho	American Falls	40	203,000	329	120	Adj.	4	7,500	1923-27
Montana Power Co. Butte, Mont.	Black Eagle	40	310,000	357	180	Adj.	3	7,000	1927
Penna. Power & Light Co. Allentown, Pa.	Wallenpaupack	40	312,000	359	300	Adj.	2	25,000	1925
Sanitary District of Chicago	Lockport	40	340,000	391	163.5	Adj.	2	7,500	1935
International Paper Co. Newfoundland	Deer Lake	40	328,000	377	214	Adj.	2	21,000	1929
Shebaura Eng. Wks. Japan	Tenryugawa	40	318,000	366	300	Adj.	1	—	1927
Westinghouse Electric International Co.	Yokohama Japan	40	375,000	432	450	Adj.	2	—	1929
So. California Edison Co. Los Angeles, Cal.	Big Creek #1	40	400,000	460	428.5	Adj.	3	28,000	1922
Southern Canada Power Co. Montreal, Que., Canada	Hemming Falls	40	298,000	343	138.5	Adj.	2	6,000	1925[2]
Utah Power & Light Co. Alexander, Idaho	Soda Point	40	180,000	292	150	Adj.	2	8,200	1923
Aluminum Co. of America Tapoco, N.C.	Cheoah	39	290,000	350	171.5	Adj.	4	21,053	1919-25
Aluminum Co. of America Badin, N.C.	Narrows	39	295,000	356	154	Adj.	3	18,000	1917
Daido Electric Power Co., Ltd., Tokyo, Japan	Ohi	39	295,000	356	180	Adj.	4	13,750	1924
Price Brothers & Co., Ltd. Quebec, Canada	Kenogami	39	260,000	314	128.5	Adj.	1	11,000	1923[2]
Kerla State Electric Board, India	Trivandrun-1	39	280,000	382	500	Adj.	1	55,800	1978
Kerla State Electric Board, India	Pamba Project	39	280,000	382	500	Adj.	6	55,800	1963
Central Nebraska Public Power & Irrigation District	Jeffrey Canyon	37	250,000	336	180	Adj.	2	10,000	1938
Central Nebraska Public Power & Irrigation District	Johnson Canyon	37	250,000	336	180	Adj.	2	10,000	1939
Cia Force e Luz de Carioba, Brazil	Americana	37	229,000	366	200	Adj.	2	12,500	1948
Consumers Power Co. Jackson, Mich.	Junction	37	192,000	300	100	Adj.	3	6,250	1917[1]
Hydro Electric Power Commission of Ontario	Toronto Plant	37	300,000	414	250	S.A.	2	10,000	1925[2]
Idaho Power Co. Bliss, Idaho	Upper Malad	37	156,000	239	225	Eq.	1	8,400	1947
Pacific Gas & Electric Co. San Francisco, Cal.	Dutch Flat	37	299,500	438	400	Adj.	1	27,000	1942
Pacific Gas & Electric Co. San Francisco, Cal.	Melones	37	212,000	295	277	Adj.	2	13,500	1928[1]
Pacific Gas & Electric Co. San Francisco, Cal.	West Point	37	252,000	403	300	Adj.	1	16,000	1948
Rochester Gas & Elec. Corp. New York	26-A	37	260,000	380	150	Adj.	1	4,500	1952
Rumford Falls Power Co. Maine	Lower Station	37	218,000	348	180	Adj.	2	8,000	1954

Company	Station	Brg. Size (in.)	Thrust Load (pounds)	Unit Load (psi)	R.P.M.	Brg. Type	No. of Brgs.	kva (per unit)	Approx. Year of Installation
Sao Paulo Tram. Lt. & Pwr. Co., Brazil, S.A.	Rasgao	37	263,000	384	128.5	Adj.	2	11,250	1924
So. California Edison Co. Los Angeles, Cal.	Big Creek #8	37	310,000	408	428.5	Eq.	1	25,000	1932
Los Angeles Dept. of Water & Power	San Francisquito #2	37	300,400	439	514	Eq.	1	17,500	1966
National Power Corporation	Angat River Unit 3	37	242,000	444	333	Eq.	1	6,667	1979
U.S. Bureau of Reclamation	Flatiron	37	275,000	402	257	Adj.	1	8,500	1953
U.S. Army Corps of Engineers	Narrows	37	180,000	288	225	Adj.	2	9,444	1949
Idaho Power Co. Boise, Idaho	Shoshone Falls	36	230,000	371	240	Adj.	1	12,000	1921
St. Lawrence River Power Co.	Massena	36	250,000	386	110	Adj.	5	3,500	1913-14
Western Massachusetts Electric Co.	Turner Falls & Cabot	36	232,000	358	97.3	Adj.	6	7,500	1914-17
Brown Corporation Shelbourne, N.H.		35	162,000	337	120	Adj.	1	2,250	1929
New England Power Co.	Vernon	35	255,000	417	75	Adj.	1	6,000	1922
Escher Wyss Co.	Handeck	35	176,000	264	500	Adj.	2	—	1928
Henry Ford & Sons Troy, N.Y.	Green Island	35	235,000	352	80	Adj.	4	800	1921
Portland Gen. Elec. Co. Oregon	Oak Grove	35	280,000	418	514	Adj.	2	30,000	192330
Public Service Co. of New Hampshire	Garvin's Falls	35	240,000	359	138.5	Adj.	1	4,000	1924
Public Service Co. of New Hampshire	Hooksett	35	202,000	302	100	Adj.	1	2,000	1927
U.S. Bureau of Reclamation	Alcova	35	238,000	356	225	Adj.	3	12,000	1937-38
U.S. Army Corps of Engineers	Bonneville	35	234,000	350	257	Adj.	1	5,000	1936
Wisconsin Public Service Corp.	Grandfather Falls	35	236,600	354	180	Adj.	1	13,750	1938
Duke Power Co. Charlotte, N.C.	Bridgewater	34	200,000	340	171.5	Adj.	2	12,500	1917
Duke Power Co. Charlotte, N.C.	Lookout Shoals	34	210,000	357	144	Adj.	3	7,800	1914
Montana Power Co. Butte, Mont.	Thompson Falls	34	210,000	357	100	Adj.	6	6,250	1914-16
Tennessee Valley Authority	Great Falls	34	237,000	403	150	Adj.	1	14,300	1916
Tennessee Valley Authority	Hales Bar	34	210,000	357	100	Adj.	2	4,250	1916
City of Los Angeles	San Francisquito	33	247,000	418	450	Adj.	1	17,500	1933
Keewatin Power Co. Kenora, Ontario, Canada	Norman Dam	33	225,000	381	120	Adj.	5	3,300	1925[2]
Metropolitan Water District of So. Calif.	Gene & Intake	33	167,000	335	400	Eq.	4	—	1954
Metropolitan Water District of So. Calif.	Eagle Mtn. & Hayfield	33	228,000	457	450	Eq.	8	—	1956-58
Modesto & Turlock Irrigation Districts, Cal.	Don Pedro	33	232,000	393	257	Adj.	2	9,375	1927
Oakdale & S. San Joaquin Irrigation District, Cal.	Tri-Dam Beardsley	33	207,000	380	300	Adj.	1	11,000	1956
U.S. Bureau of Reclamation	Kortes	33	202,000	405	240	Eq.	3	13,333	1948
Wis.-Michigan Power Co. Appleton, Wis.	Big Quinnesec	33	182,000	365	200	Adj.	2	8,890	1949
Wis.-Michigan Power Co. Appleton, Wis.	Chalk Hill	33	201,000	369	150	Adj.	3	3,250	1951
Wis.-Michigan Power Co. Appleton, Wis.	Peavy Falls	33	190,000	381	200	Adj.	2	7,500	1942
Wisconsin River Power Co.	Castle Rock	33	200,000	367	150	Adj.	5	3,750	1950
U.S. Army Corps of Engineers	Cougar	33	240,000	440	400	Eq.	2	23,300	1961
State of Cal., Dept. of Water Resources	Pear Blossom	33	298,000	548	514	Eq.	2	—	1975