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BULB TURBINE AND GENERATOR FOR AKAO POWER STATION OF THE KANSAI ELECTRIC POWER CO., INC.

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I. FOREWORD

The unit machine capacity of the bulb turbine, spotlighted as the turbine which permits the most economical use of ultra-low head water power, had to be increased substantially up to about that of vertical shaft machines to improve its economy still further.

Since the vertical shaft machine is uniformly supported from the surrounding concrete, high rigidity and the prevention of deformation are easy to achieve, even with large machines. However, since the loss given to the flow around the outside of the generator and the generator in the flow must be supported at a bulb turbine, the larger machine, the more difficult it is to secure ample rigidity and prevent deformation.

We solved this problem by vastly improving structural analysis techniques, centered around the finite element method, based on our record of delivery of numerous bulb turbines, and have developed a large capacity bulb turbine generator, together with a high specific speed runner.

One of the largest bulb turbine and generator in the world now being installed in the field for the Akao power station of the Kansai Electric Power Co., Inc. is the result of this research and development. The record of bulb turbines in the world is shown in *Fig. 1*.

The large capacity bulb turbine and generator incorporating numerous special features is outlined here.

II. OUTLINE OF POWER STATION

The power station is situated at the upper flow of the Shogawa in Toyama prefecture as shown in *Fig. 2*. The water from the new Akao dam (effective dam quantity 600,000 m^3) flows to the Ohara dam.

The power station employs a remote control operating system, and is normally unmanned, but is desired to patrol about once every ten days. The load of the power station is used as a peak load. Since a large machine is installed in a mountainous snowy region, while having a low head,

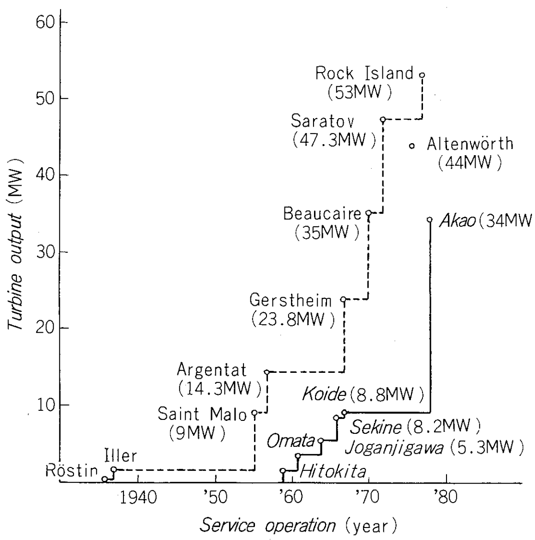


Fig. 1 Record of bulb turbines in the world

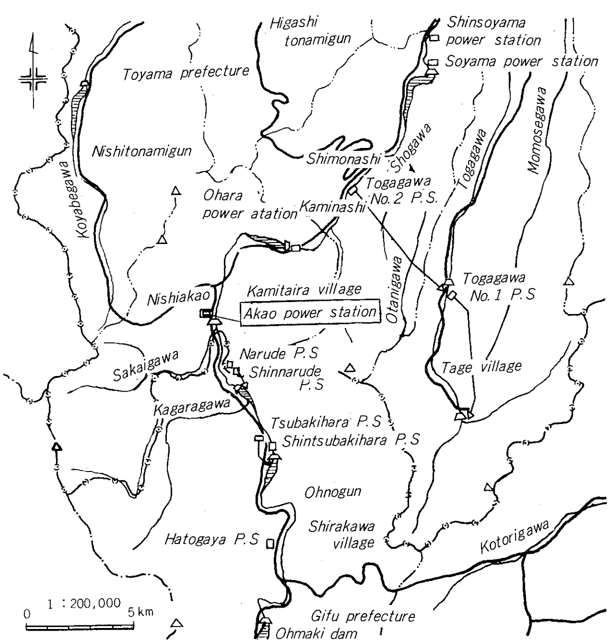


Fig. 2 Location of Akao power station

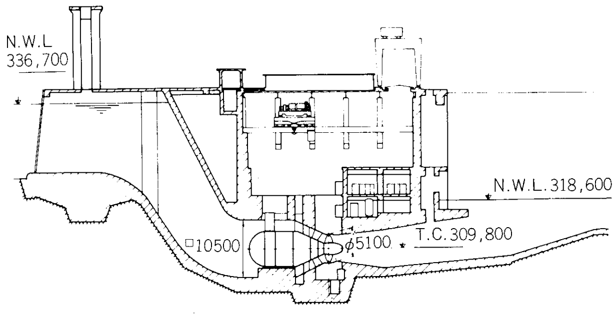


Fig. 3 Section of power station

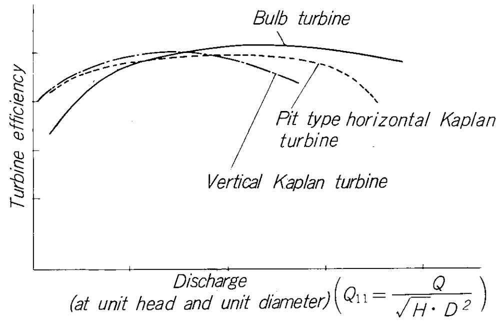


Fig. 4 Comparison of efficiency of turbine

special considerations had to be paid to transportation and storage.

To minimize construction costs by minimizing excavation, the building width was made 10.5 m, the same as the flow width, and the building structure was made long in the flow direction so that the top of the draft tube could be utilized as an auxiliary machinery room and assembly room. The sectional view of the building is shown in *Fig. 3*. A plan which reduces the erection process was adopted. The erection period after the beginning of operation of the crane is forecast to be about 10 months. A 30 t/3 t outdoor equipment carrying in use gantry crane and 110 t/25 t overhead traveling crane are installed.

III. TURBINE AND GENERATOR SPECIFICATIONS

1. Hydraulic Turbine

Type	:	Horizontal shaft, bulb turbine with movable guide vane and adjustable runner blade
Rated output	:	34,000 kW
Net head	:	17.4 m
Discharge	:	220 m^3/s
Rated speed	:	128.6 rpm
Specific speed	:	660 (m-kW)
Runner outside diameter	:	5,100 mm
Turbine inlet section	:	10,500 x 10, 500 mm
Maximum gross head	:	35 m
Maximum speed rise	:	60%

2. Generator

Type	:	Horizontal shaft 3-phase synchronous generator
Rated output	:	36,000 kVA
Rated voltage	:	6,600V
Rated frequency	:	60 Hz
Rated power factor	:	0.9 (lagging)
Rated speed	:	128.6 rpm
Outside diameter of stator frame	:	6,300 mm

IV. HYDRAULIC CHARACTERISTICS

Since the flow of a bulb turbine is straight, its efficiency is maintained over a wide discharge range. A comparison of the efficiency of various Kaplan types of turbines is given in *Fig. 4*. Model tests were conducted with a 1/15 scale model.

Since the discharge height at the top and bottom of the large diameter runner is substantially different, the prototype turbine center was selected by considering the distribution of cavitation coefficient for the each part of the runner.

In addition, the distribution of water pressure in the flow was measured, and foundation data were obtained by computing the various loads produced at the bulb and the dynamic load at each place of the concrete foundation. The center of the draft tube is generally perfectly horizontal up to the outlet end, but because of excavation limitations, it was designed so that the center line rises slightly within the range at which efficiency is not impaired.

Since a small turbine outside diameter was selected, because of the flow conditions, the fly wheel effect of the rotor became somewhat low. Consequently, a high speed rise rate of 60% was adopted.

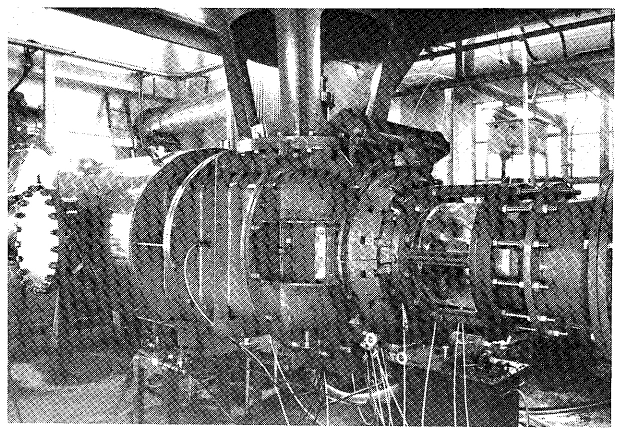
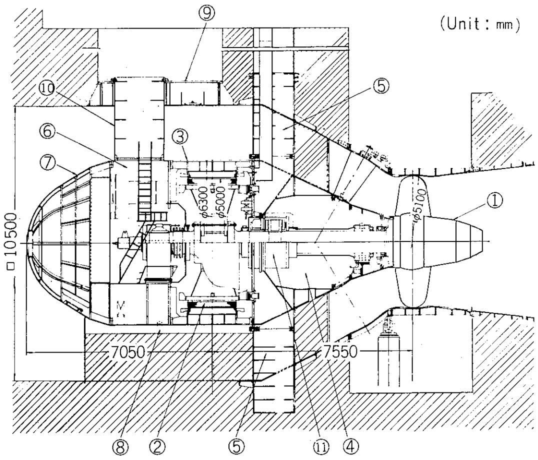


Fig. 5 Model test for bulb turbine

V. FEATURES AND CONSTRUCTION OF TURBINE AND GENERATOR

Harmonizing the turbine and generator is especially important with a bulb turbine, and they must be handled



① Runner
② Rotor
③ Stator
④ Turbine inner casing
⑤ Stay vane
⑥ Bearing casing
⑦ Bulb nose
⑧ Support for bearing housing
⑨ Hatch
⑩ Access shaft
⑪ Thrust bearing

Fig. 6 Section of turbine and generator

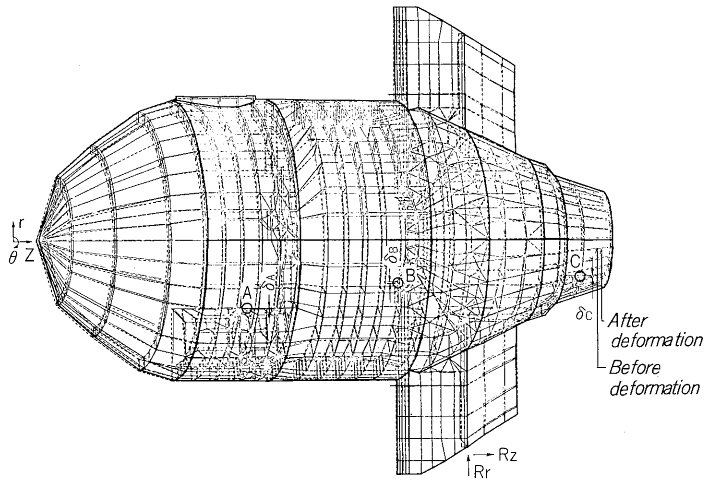


Fig. 8 Example of stress and deformation analysis by FEM

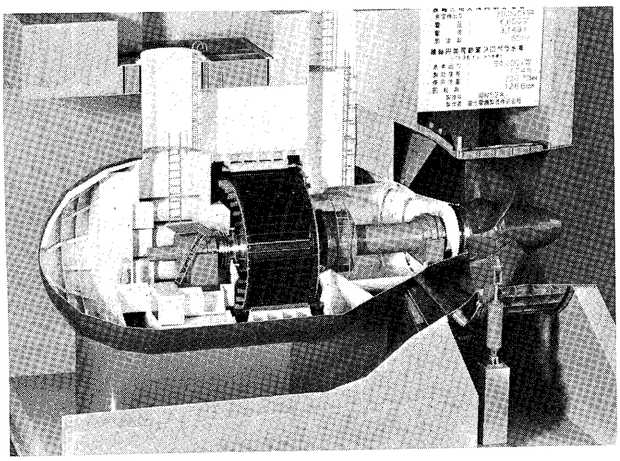


Fig. 7 Sectional view of model of turbine and generator

as a single machine. The features of the construction of these machines are described below.

A sectional view of the turbine and generator is given in *Fig. 6*, and a sectional view of the model of the turbine and generator is given in *Fig. 7*.

1. How to Support the Bulb

Extremely large static and dynamic loads, as well as hydraulic thrust and short circuit torque, are worked to the bulb. The greater part of these loads is transmitted to the building foundation through the stay vane protruding perpendicularly from the inner casing.

The bearing housing supports that are located bottom of the housing support the whole of generator weight, and is rigid in the vertical direction of the bulb and flexible in the flow and circumferential directions. Moreover, a bulb throw stop is provided horizontally at both sides of the bearing housing to follow deformation of the foundation wall.

The bulb itself is a large, thin outside pressure vessel, and since the bearing weight is received locally, securing ample rigidity, together with the bulb support construction, was an important consideration. These were analyzed by the finite element method, and the fact that the stress and deformation were within the allowable values under all operating conditions was confirmed.

An example of this analysis is shown in *Fig. 8*.

2. Selection of Number of Bearings and Arrangement

Generally, two bearings (three bearings for large machines) are selected, considering allocation of the bearing load, cost, and maintenance. However, since the air gap of the generator is comparatively small, ample attention must be given to distortion of the shaft when selecting the number of bearings. Three bearings are used in this machine, based on various studies.

Moreover, since the thrust bearing supports an extremely large load, because it is a horizontal machine, special attention must be given to deformation of the bearing support and the bearing load must be equalized. The thrust bearing of this machine is supported by a large, rigid inner casing to rationally transmit the load to the foundation.

The bearings are lubricated by a forced lubrication system, using the lubricating pump with an upper lubricating oil tank. And since each guide bearing receives a high load, an oil injection unit is provided for protection of the bearings at starting and stopping.

3. Generator Ventilation and Cooling System

Since the outside diameter of the stator of a bulb turbine generator is restricted to obtain the most convenient ratio between the inlet section and runner diameter, it must be about 30% smaller than the standard design of a general turbine generator. Therefore, the ratio of the core length to pole pitch becomes large, and special consideration must be given to ventilation and cooling. This machine is ventilated

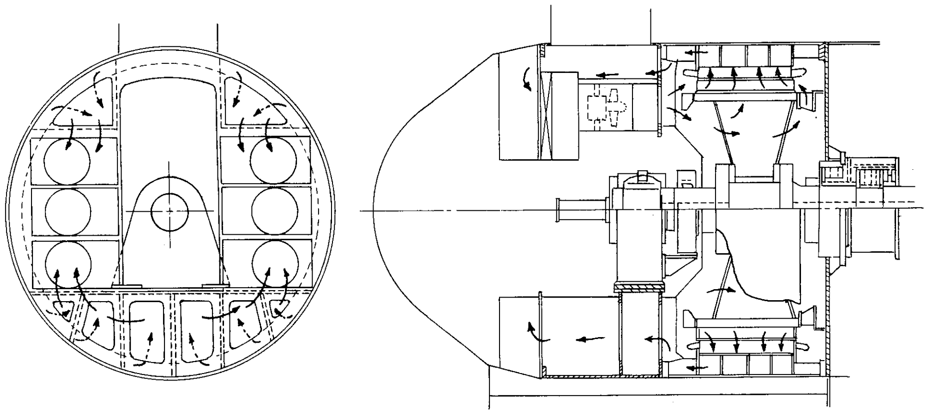


Fig. 9 Air route for cooling of generator

and cooled by the totally enclosed forced air cooling system shown in *Fig. 9*. An air cooler is installed immediately in front of each fan. Part of the air blown in by the fan enters directly from between the poles at the upflow side and part enters the stator from between the poles at the downflow side through the rotor spider. These two flows converge at the stator frame and are returned to the upflow side through an air duct. To improve cooling of the middle portion of the core, consideration has been given to the interpole air guide and yoke ventilation, and its effectiveness was confirmed at both the model tests and prototype shop test respectively.

An auxiliary self-fan is provided at both ends of the rotor to improve cooling of the stator coil end. The ventilation route is a completely independent closed circuit consisting of the generator stator and air cooler, separate fan, and air duct. Since the bearings, slip rings, etc. are installed outside this circuit, the entry of oil, brush powder and other contaminates into the machine is completely prevented, and their maintenance and inspection during machine operation are simple.

4. Waterproof of Generator

Subject for the waterproof are an important subject with bulb turbine generators. The joints in the axial direction of each casing, which are separated because of transportation restrictions, are tightly bolted together with flanges and then seal welded to secure ample watertightness. Furthermore, an O-ring is inserted at the flange surfaces between the stator and inner casing or stator and bearing housing, and other parts which must be disassembled in the future. The entry of water is prevented, and the back-up groove is also provided at the inside of the O-ring to permit inspection if water leakage should occur. Moreover, this groove is sealed with a special packing for watertightness back-up.

Since the outside surface of the stator contacts the water directly, dew condensation inside the machine is also an important consideration. In this machine, the humidity is maintained at a suitable value by installing a dehumidifier inside the machine. In addition, water detecting units are installed at several points at the bottom of the stator to detect water leakage and abnormal dew condensation.

5. Other Points of Turbine and Generator Constructions

Numerous anchors are welded to the outside of the steel sheet welded outer casing and draft tube liner, which are welded together at the site and then embedded in concrete. The hydraulic thrust, short circuit torque, runner thrust and other loads produced at the valve are transmitted to the stay vane through the inner casing that transmits these loads to the foundation concrete. Therefore, numerous shear connectors are welded to the outside of the stay vane so that slipping does not occur at the embedded part of the vane.

The stay vane is the hollow style fabricate construction, and the height is up to the floor. Its dimensions are selected so inspection, wiring, piping and lifting out of the parts are possible. Maintenance is simplified by using all oilless bearings at the bearings of the sixteen conically arranged guide vane bearings with their operating mechanism. Since the inner guide vane bearing is displaced in the downstream direction when the thrust load works to the stay vane in this connection guide vane bearings are adopted the scissure preventing construction.

The guide vanes are operated by two oil pressure driven servomotors, and an emergency pressure tank is installed as a stand-by in addition to the main pressure tank pressure. The regulating ring is supported by a special bearing capable of simultaneously supporting both the radial direction and axial direction loads. A weak link is used at the guide vane link. This link prevents interference of each guide vane even after an abnormality is detected. The runner vane consists of the large five blade, 5.1m diameter runner, and is installed so that it overhangs at the downstream side of the valve.

The runner servomotor is installed inside the runner hub, and is operated by the hydraulic pressure sent through the center of the shaft from an oil head installed to the end of the upstream side shaft of the generator. Otherwise, the construction of the runner is the same as that of our large Kaplan turbines, and have several special features. Since the runner overhangs at the downstream side of the bulb, and the turbine bearing is an especially high load stress bearing, it has a spherical construction capable of responding to tilting of the shaft. The shaft seal is the low friction carbon packing with sliding plate having so many experiences in the vertical machines, and can be approached for maintenance even while the machine is operating.

The generator rotor consists of poles, rotor center and generator shaft, and is supported by two bearings. The poles employ a bolted construction. The rotor center is constructed by connecting the spider section, which supports the poles, and the inner boss with a spider, and is separated into two sections for the shipping limitation. A welded intermediate shaft is installed between the generator shaft turbine shaft, and the two shafts are connected by long coupling bolts to release the repeated bending moment, because it is a horizontal machine.

The large temperature difference between the core and stator frame of the generator stator, compared to that of common machines, is considered, and long-term reliability is secured by eliminating joining by laminating the core as a perfect ring at the site.

The upstream side bearing is a spherical shell type capable of following tilting of the shaft, and employs a special construction which permits installation of the intermediate bearing by matching it to the tilt of the shaft because of the relationship with the thrust bearing. The thrust bearing is installed at the turbine shaft side, and is separated into two parts from the standpoint of assembly. Since the thrust bearing receives a record horizontal shaft load of 320 tons, it was specially analyzed, considering pad fastening method, displacement of the support section, etc. Furthermore, an actual load (320 tons) running test was conducted carried out using the actual bearing, and its performances were confirmed successfully.

A brake has ample capacity against leakage torque and installed at the downstream side of the rotor. The generator main bus, piping, etc. are led through the stay vane. Shop assembly of the generator is shown in *Fig. 10*.

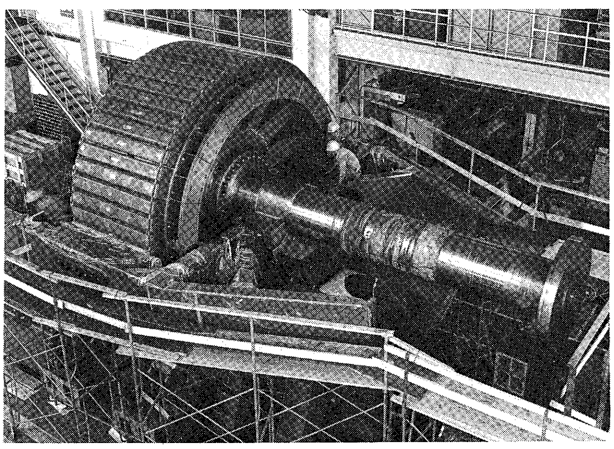


Fig. 10 Shop assembly of generator

6. Dismantle and Reassembly

Both the turbine and generator can be independently carried in and out of their respective access pits. A large generator hatch is provided at the top of the generator for the dismantling purpose. To be carried out independent removal of the runners without dismantle the turbine and generator main parts is a common feature to the bulb turbine.

VI. FIELD INSTALLATION AND ASSEMBLY

Since many of the equipments of this power station, which, while large, was built under severe transport limitations, are separated into a number of parts, special consideration had to be given to their installation and assembly.

The draft tube is simultaneously embedded with first stage concrete placing, then the casing and hatch installed with embedded pipe in concrete after station overhead crane operation. The casing is an extreamly-large 14 m high. 11 m width field welded construction. Moreover, it contains several machined parts which rom the installation reference of the generator. But since its rigidity is low, various techniques and measures were employed to secure the correct dimensions after its installation.

Since the building area is small, because of the special features of the bulb turbine, transportation and assembly procedure and location of assembly bay were carried out in accordance with the deep considerations.

Large parts were assembled to units at the assembly bay and then turned over and lifted in. Numerous special tools were used in this field work for safety and efficiency.

Field installation of turbine casing is shown in *Fig. 11*.

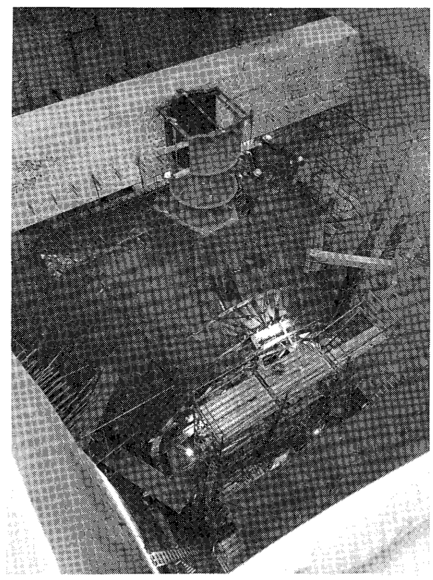


Fig. 11 Field installation of turbine casing

VII. CONCLUSION

Commercial operation of the Akao Power Station outlined here is scheduled to start in November 1978. Completion of this station is expected to be a large driving force behind the development of low head large capacity power stations in the future.