UDC 621.224.3 + 621.313.322

LARGE BULB TURBINE AND GENERATOR (FOR NEW MARTINSVILLE HYDROELECTRIC PROJECT)

Junichiro Saito
Masanobu Yano
Akira Abe

1 FOREWORD

It has been 20 years since large bulb turbine and generator units with output of 10 MW or more and runner diameter of 4m or more were developed for use where the net head is 25m or less. Recently, however, the advantages of these large bulb turbines and generators have been restudied. Fuji Electric has continued to manufacture and deliver many large bulb turbines and generators ever since the Kansai Electric Akao Power Station (34MW, runner diameter 5.1m) commenced operation in 1978. The large bulb turbines and generators designed manufactured, and now being installed at the New Martinsville Power Plant in West Virginia, U.S.A., one of the largest in the world, is outlined here. The turbine runner diameter for these units is 7.3m and stator frame diameter 8.4m.

2 OUTLINE OF PROJECT

This project is for installation of two 19,540kW maximum generator output bulb turbines and generators using a maximum net head of 6.4m and maximum water flow of 396m^3/s at a powerhouse built beside the left abutment of the Hannibal Dam on the Ohio River, a tributary of the Mississippi River, in the U.S.A.

A map of the vicinity of the power station is shown in *Fig. 1*, the powerhouse layout is shown in *Fig. 2*, and a sectional view of the turbine and generator is shown in *Fig. 3*. This power station is built incidental to a dam constructed earlier for navigation purposes, and similar development is expected to proliferate in the future.

Fig. 1 Map of vicinity of the power station

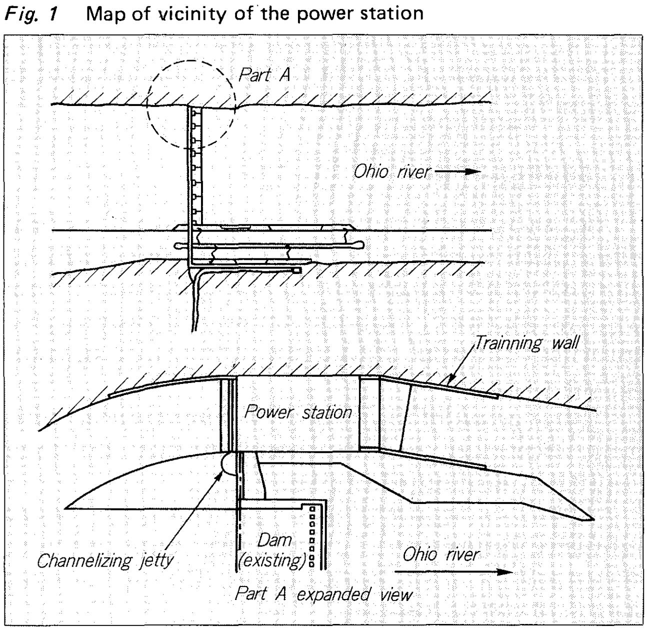


Fig. 2 Powerhouse layout

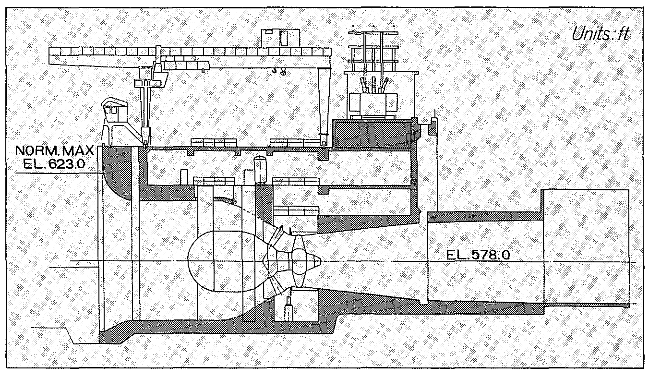
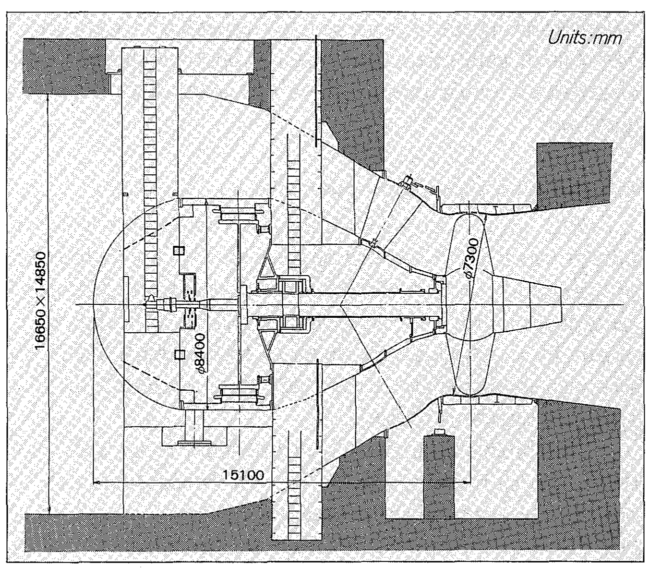


Fig. 3 Section of turbine and generator



The construction of this power station is by turnkey contract with the developer, Catalyst Energy Corporation. Its planning and implementation is not only for the design and manufacture of the equipment, but also includes much total engineering work, Fuji Electric, together with Bechtel of the U.S.A., participated in the preparation of the overall plan, which considered the power station position, building construction, main unit output and dimensions, annual power production, installation method and period, economy, etc., and optimized the power station from the feasibility stage. Especially, when selecting the main unit output and dimensions, the use of an 8.0m diameter runner, the largest in the world, was also considered, and the river flow, annual power production, shipping restrictions, etc. were studied. Athough it was not used, a plan for using a pre-fabricated powerhouse structure and assembling the turbines and generators at the factory and shipping the turbine and generator as a unit for each powerhouse was studied.

The final main unit specifications are shown below.

2.1 Specifications

2.1.1 Turbine

Type: Bulb turbine
Output: 7230/18,710/9370kW
Maximum output: 20,040kW
Net head: 6.4/5.4/3.3m
Water flow: 127.1/396.2/353.4m^3/s
Rated speed: 64rpm
Specific speed: 1074(m-kW)
Runner diameter: 7300mm
Maximum pressure: 18.3m (at turbine center)
Maximum speed rise: 60%

2.1.2 Generator

Type: Horizontal 3-phase synchronous generator
Capacity: 21,620 (max)/18,800 (rated)kVA
Rated voltage: 6.9kV
Rated frequency: 60Hz
Rated speed: 64rpm
Rated power factor: 0.9 (lagging)
Diameter of stator frame: 8400mm
Excitation system: Thyristor static excitation system

3 FEATURES

3.1 Extra large bulb turbine and generator

The runner diameter of this turbine is 7.3m. Its size is the among the largest in the world, including those currently being designed, manufactured, and installed. (See *Table 1*.) Therefore, the force received by the turbine and generator is also large and careful studies based on constructural analysis by F.E.M. (Finite Element Method), etc. and Fuji Electric's record of achievements were made in its design.

3.2 Very low head turbine

The maximum net head of this power station is a low 6.4m, and it is in a very low head and large head variation area where it operates at a net head of 3.3m for about 5% of the year. One hour operation at a net head of 2m is also demanded. To satisfy these very low head and large head variation specifications, a three blades runner was used and good efficiency and cavitation characteristics were obtained.

3.3 Unit shipment of main parts of turbine and generator

Even through it is a large turbine and generator, the runner, inner and outer guide vane ring, stator, rotor, top cover, and other main components were assembled together and shipped from Japan. The shipping dimensions were a maximum 10.8m x 10.8m x 3.5m (inner and outer guide vane ring). After the assembled main parts were shipped to New Orleans through the Panama Canel, they were loaded onto a barge. It took about five weeks for the barge to cover the 3000km up the Mississippi and Ohio rivers from New Orleans to the power station site. This is considered to have shortened the installation period at the site considerable and to have reduced the total construction cost of the power station.

4 HYDRAULIC PERFORMANCE

Taking stiffness and economy into account, the dimensions of a very low head large water flow turbine must be as small as possible and with a smaller machine, the unit

Table 1 List of large bulb turbines in the world

(Runner diameter ≧7.0m)

Power station name	River name (country name)	Number of units	Output (MW)	Net head (m)	Runner diameter (m)	Commercial operation (year)
Murray L and D	Arkansas (U.S.A.)	2	19.5	5.6	8.4	Being manufactured
Sydney A. Murray. Jr. (Vidalia)	Mississippi (U.S.A.)	8	24.0	4.5	8.2	Undecided
Racine	Ohio (U.S.A.)	2	24.6	7.0	7.7	1983
Saratov	Volga (U.S.S.R.)	2	47.3	15.0	7.5	1972
Jenpeg	Canan (Canada)	6	28.0	4.9	7.5	1976
Rock Island	Columbia (U.S.A.)	8	53.0	12.1	7.4	1977
New Martinsville	Ohio (U.S.A.)	2	19.8	6.4	7.3	Being installed
St. Mary's	Saint Mary (Canada)	3	18.0	5.7	7.1	1983

discharge [Q11 = $Q/D^2 \cdot \sqrt{H}$, where Q: Water quantity (m^3/s), H: Net head (m), D: Runner diameter (m)]. However, if the unit discharge is increased, the ratio of head loss total head is increased. Thus reducing the head loss of the entire power station becomes a major consideration.

In the case of this turbine, the unit discharge corresponding to the prototype maximum water quantity (approximately $400m^3/s$) amounts to 3.3m/s and the velocity head (kinetic energy) at the runner outlet at this time reaches approximately 100% of the net head. A straight type draft tube is used to recover this velocity head (kinetic energy) by converting it to hydraulic pressure as much as possible.

However, even when an optimized draft tube is used, much of the kinetic energy is not recovered and remains as outlet loss at the draft tube outlet. Therefore, the shape of the trailrace of the downstream draft tube was also studied and the outlet loss was minimized by installing a trainning wall at both sides of the powerhouse outlet.

The water velocity and inlet angle of the powerhouse inlet flow must be uniform, but the main flow of the river blocked by the dam flows into the powerhouse together with the powerful secondary flow. Therefore, the flow is disturbed at the intake and the trashrack head loss by eccentric flow cannot be ignored. A streamlined guide pier is provided at the intake from the Ohio River to minimize this loss and reduce the eccentric flow.

With this kind of power station, various measures are taken not only for the turbine, but also for the powerhouse intake and the shape of the trailrace to minimize the head loss.

The effectiveness of these measures was confirmed by hydraulic research the university of lowa, one of the three largest institutes for hydraulic research in the United States, using homologous models of the entire dam (scale 1/160) and the area around the powerhouse (scale 1/40).

On the other hand, a three blades runner with a smaller number of blades than in the past is used to cope with the large unit discharge. For this reason, the hydraulic load per blade is large and cavitation occurs easily.

Therefore, a design stresses the cavitation characteristics, as well as efficiency, is necessary. We succeeded in developing a runner with both superior efficiency and superior cavitation characteristics by three dimensional water flow analysis by computer analysis.

Model tests for confirming the performances of the turbine were conducted at the Fuji Electric hydraulic laboratory and confirmed that the hydraulic performance was satisfactory.

5 TURBINE CONSTRUCTION

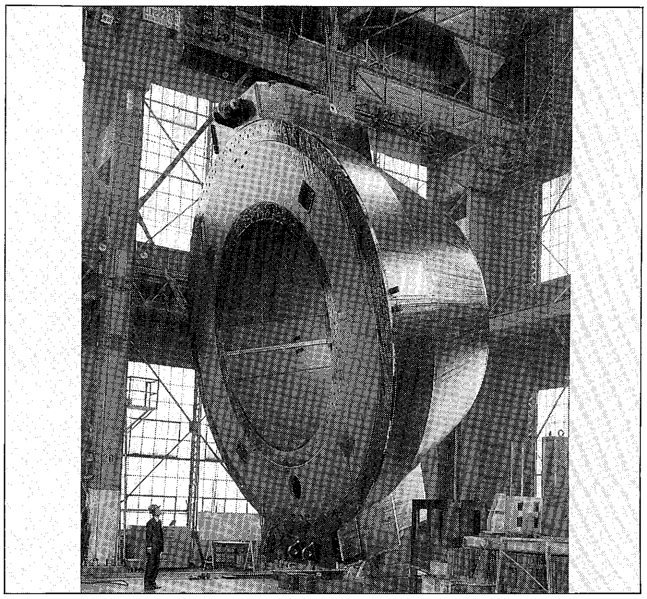
5.1 Bulb supporting structure and stiffness

There are several methods of supporting the bulb, on which the hydraulic thrust load, bearing load, rotation torque, vibration load, etc., with foundation concrete. The selected method of bulb support was based on the results of careful studies on inner guide vane ring deformation, guide vane side gap changes, effect on the runner gap, etc. under general operating conditions by a finite element method reflecting past field measurement data. The bulb is supported mainly by upper and lower stay vanes at this power station, with its large diameter turbine runner. The stay vanes have a strength and stiffness which satisfy the important points of the previously mentioned design and the necessary maintenance space and are arranged so that they have little effect on the water flow and concrete work is easy. Besides the stay vanes, auxiliary anti-vibration stays and casing are provided to increase the natural frequency of the bulb.

5.2 Main embedded parts

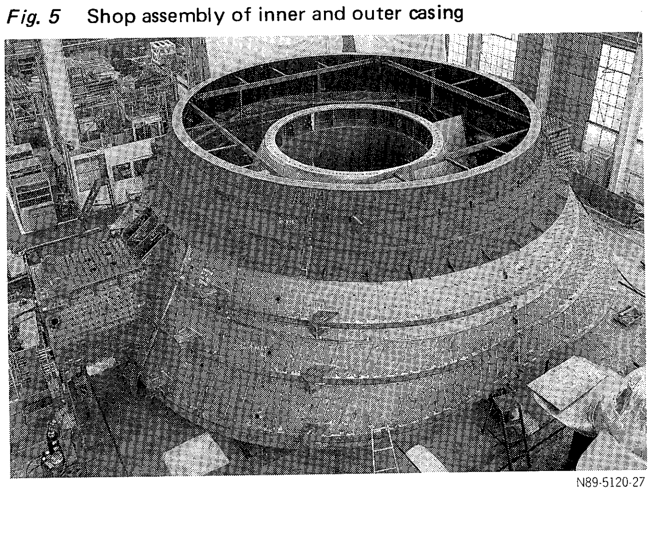
After the welded steel plate outer casing and draft tube liner are assembled and welded at the site, they are embedded in concrete. The draft tube liner is assembled

Fig. 4 Shop assembly of inner casing



N89-5120-6

Fig. 5 Shop assembly of inner and outer casing



N89-5120-27

and embedded in a parallel with placing and curing of the powerhouse concrete. The inner and outer casings are assembled and embedded after the powerhouse concrete work is completed.

The inner casing is divided into two pieces horizontally and connected by bolts. The stay vanes are butt welded in the field. The inner and outer casings downstream side flange and inner casing upstream side flange are important reference planes which govern the generator air gap, guide vane gap, runner gap, etc. The center line of the draft tube liner embedded in advance and the center line of the casing are aligned. The installation technique which secures the reference planes with low-stiffness parts is refined so that installation is performed in the minimum number of days by utilizing our considerable experience with large bulb turbines.

5.3 Guide vanes and their operating mechanism

The guide vanes are made of welded steel plate. Both end faces and the shutter face are made of stainless steel. The inner and outer shafts are supported by spherical type bearings to cope with deformation of the inner guide vane ring. The guide vanes are operated by two double acting servomotors and will be closed automatically by a counter-weight if the oil pressure fails.

Since bending link rings are used at the guide vane rings, the construction is such that the shear pin cascade phenomena by free guide vane, which occurs in the case of a shear pin, does not occur.

5.4 Runner and its operating mechanism

The 7.3m diameter runner which has three adjustable blades is installed by suspending it at the downstream side of the bulb. Since it has three blades and there is a comparative surplus of space for housing the runner operating mechanism, a new construction that is easy to assemble was used. The Kaplan device is installed at the upstream side of the generator rotor and pressurized oil is transmitted to the runner servomotor located in the runner hub through the center bore of the main shaft. The Kaplan device sealing construction uses the floating metal system already developed for horizontal machines. Since this system is stable against installation error and vibration, it is used with all Fuji Electric large bulb turbines.

5.5 Others

The guide vane, turbine shaft, and shaft sealing device are the most important parts of any bulb turbine. The proved Fuji Electric standard construction is used for these parts.

6 GENERATOR CONSTRUCTION

6.1 Ventilation and cooling

A totally enclosed forced air cooling system using an air cooler is used to ventilate and cool the generator. Part of the cooling air blown in by a motor operated blower enters the stator from the upstream side gap between the poles and part enters the stator from the downstream side gap via the rotor center. This air is guided by an air guide installed at the upstream side of the stator fame and returns to the blower via the top cover and air cooler. With this machine, efforts were made to minimize the ventilation resistance by scale model ventilation tests and the blower capacity was reduced to about 50% that of existing machines.

The slip ring is located in a closed area separated from the main parts to prevent the carbon dust of the brush room from entering the main parts. The slip ring room is cooled by radiation from the outside surface of the cover.

6.2 Stator

The outer diameter of the stator was selected as 8.4m by considering the hydraulic water flow, GD^2, $\triangle n$, $\triangle d$, etc.. When the diameter is large, deformation of the stator becomes a problem in the installation procedure. Moreover, since thermal expansion of the stator core is restrained by a stator which is cooled by the water flow during operation, stress so large that it cannot be ignored is also generated at the core. Since this high internal stress causes the core to buckle easily, the following countermeasures were taken:

Fig. 6 Finite element method analysis of runner hub

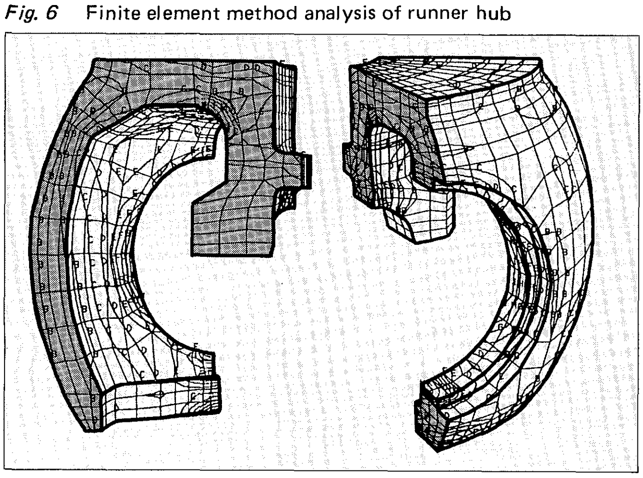
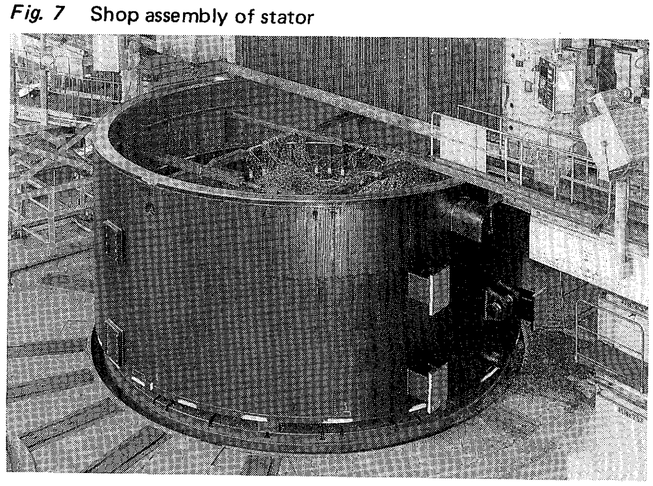
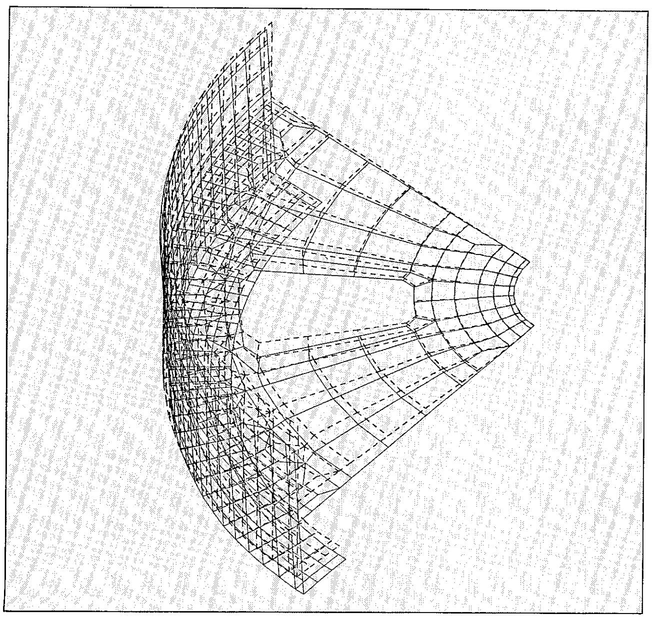


Fig. 7 Shop assembly of stator



N89-5119-4

Fig. 8 Finite elements method analysis of generator



(1) A permanent reinforcing beam was installed in the stator to improve the stiffness of the stator during installation and operation.
(2) Special consideration was given to the stator frame and the outside of the stator core to avoid restraining of the core in the radial direction by the stator frame.
(3) A stator frame matched to the bend of the stator was installed to the turbine casing at an angle to make the air gap the same in the axial direction at installation.

6.3 Rotor

The rotor consists of poles and a rotor center. The rotor center is fastened perfectly to the main shaft by numerous reamer studs. The poles are installed to the rotor center by studs. The rotor center uses the so-called figure T center construction consisting of a rim and disk.

To use a large diameter figure T center, natural frequency analysis by the finite element method and unbalance of axial deformation of the center rim at the runaway speed and stress analysis were performed and the optimum shape and dimensions were decided.

6.4 Bearing

The bearings are lubricated by a gravity type forced lubrication system using the lubrication head tank used which supplies oil all the bearings. A lubrication system that permits safe unit shutdown even when the oil supply is stopped by trouble at the lubrication pump, etc. is used. An oil lifter is provided at the guide beating of the turbine and generator to increase bearing metal safety at low speed.

Considering the shaft system critical speed, bending, bearing maintenance, shortening of the installation period, etc., the bearing arrangement uses a two bearing system which overhangs both the runner and generator rotor. A self-equalizing type thrust bearing with an ample margin not only for 300t downstream thrust load, but also for 600t reverse thrust load at load rejection is provided.

The guide bearing is installed in a guide bearing support having a special flange so that tilting of the shaft by overhanging of the rotor can be followed easily.

6.5 Others

Water leakage and moisture condensation countermeasures are important features for a bulb turbine and generator installed in water. Water leakage is prevented by providing double O-rings at all the divided flanges which contact the outside water and providing a groove between the double O-rings. This groove is provided so that water leakage can be detected and water tightness can be backed up by sealing in a special packing if water leakage should occur. A drainage pump that starts automatically when abnormal water leakage and moisture condensation occurs, is provided at the top cover and the bottom of the stator frame. A dehumidifier is also installed to prevent moisture condensation from forming inside the machine when the main unit is stopped.

7 CONCLUSION

The features and an overview of the bulb turbine and generator for the New Martinsville Power Station are described above. As previously mentioned, the development of power stations with large bulb turbine and generators is expected to increase steadily. The authors will be pleased if this article serves as reference in planning the development of these stations.