Commissioning of 87,000-kW Kaplan Turbine and Generator for Otori Power Station

Asami Sato
Keiichi Goto

OVERVIEW: The surrounding environment needs to be considered in the planning, design and construction of hydroelectric power stations, from the perspective of environmental conservation. Unit No. 2 of the Otori Power Station, which was installed by J-POWER (Electric Power Development Co., Ltd.) began operating in June 2003. The power station is located on the existing Otori Dam, which is in far upstream on the Agano River. The dam is used as an upper reservoir, and an additional 87,000-kW Kaplan turbine-generator was installed next to the existing 95,000-kW Kaplan turbine-generator. The Otori Power Station is located in the Echigo Sanzan Tadami Quasi-National Park, which is surrounded by a rich natural environment. As the construction area is close to an area that is a breeding ground for rare raptorial birds, construction was carried out to mitigate its impact on the environment as follows: (1) Locating the main structures underground to minimize changes to the above-ground environment; (2) Stopping above-ground construction work during the nesting period for local predatory birds; (3) Effectively utilizing waste products emitted from the construction work. The attention paid to this project indicates new directions in the construction of future hydroelectric power stations.

INTRODUCTION

ENVIRONMENTAL conservation has recently become a topic of interest throughout the world, and hydroelectric-power generation attracted more attention as a result. Hydroelectric-power generation offers excellent performance when assessed in terms of carbon dioxide emissions because it is natural energy to create electricity. Power stations using reservoirs are able to respond promptly to changes in demand for power during the day and at night, and are used effectively as a peak power source.

At the same time, the construction of hydroelectric-

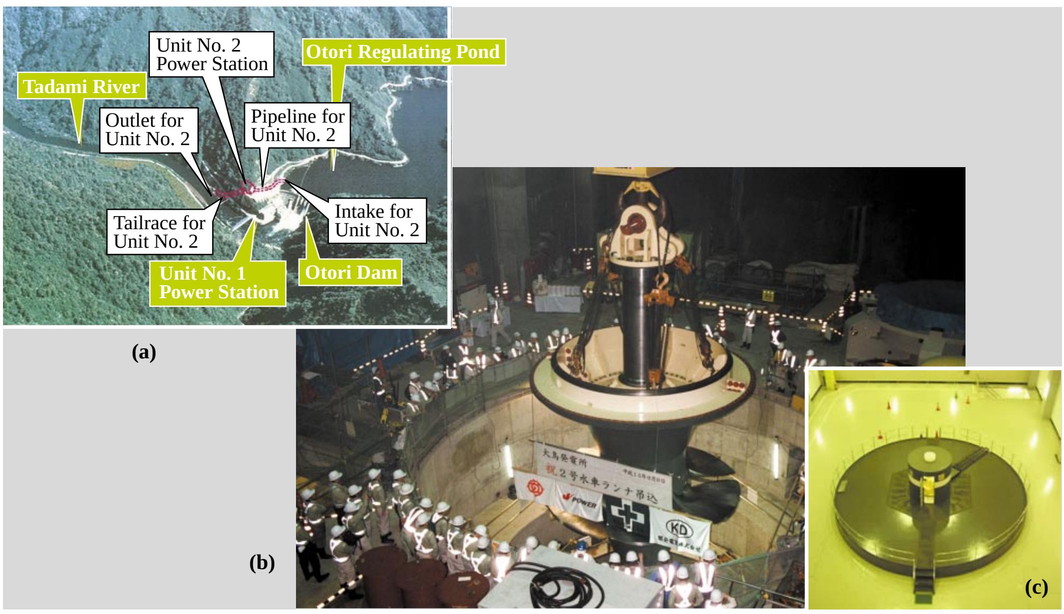

Fig. 1—Bird's Eye View of Underground Power Station (a), Kaplan Turbine Runner Being Installed (b), and Overall View of Generator (c).

power stations requires enormous building work, and poses significant challenges to mitigating the environmental impact.

Many environmental factors had to be considered during the construction and planning of Unit No. 2 of the Otori Power Station, because it is located in the Echigo Sanzan Tadami Quasi-National Park, and is surrounded by a rich natural environment. The construction area was also very close to an area that is a breeding ground for rare raptorial birds. For this reason, the existing dam and tailrace were utilized and much of the main structure was installed underground to minimize changes to the above-ground environment. As a result, we achieved increased power output and reduced the impact on the environment.

The following explains the main features of Unit No. 2 of the Otori Power Station owned by J-POWER (see Fig. 1).

OUTLINE OF OTORI POWER STATION

Unit No. 2 of the Otori Power Station is equipped with a large Kaplan hydro-turbine, whose output is only surpassed by the existing Unit No. 1 whose output is the largest in Japan. Through a process of international bidding, Hitachi, Ltd. won the tender to supply the hydro turbine-generator being a major manufacturer. As a result, Hitachi's turbine-generators were installed in both No. 1 and No. 2 units. After Unit No. 2 was constructed, the power output increased from 95,000 kW to a total of 182,000 kW. Fig. 2 is a cross-section of the assembly of a turbine-generator, and Table. 1 lists the specifications for Units No. 1 and No. 2.

Construction on Unit No. 2 began in 1999 followed by a field-operation test in February 2003, concluding with formal operations in June 2003.

KAPLAN TURBINE

Table 2 lists the main specifications for the Kaplan turbine for the Otori Power Station.

Runner

The Kaplan turbine can operate at its most efficient point by changing the angle of the runner vanes in line with the head and output, and is superior in terms of effective utilization of energy.

First, we developed performance by utilizing CFD (computational fluid dynamics), and drafted manufacturing plans of a model runner with 3D-CAD (computer-aided design). We then manufactured the model parts, checked the dimensions and verified

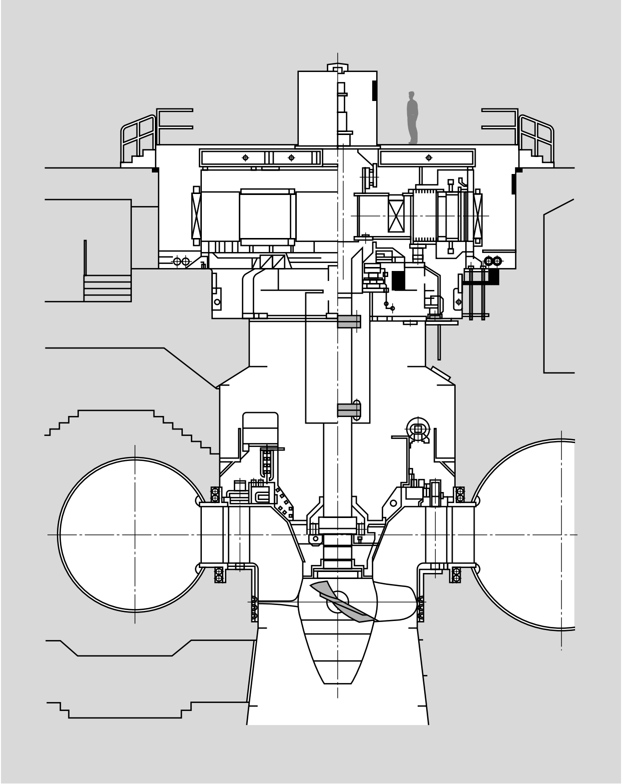

Fig. 2—Cross-section of Kaplan Turbine-Generator for Unit No. 2.
The turbine, which has a 5,100-mm diameter runner with movable blades, is a vertical axis spiral-type Kaplan turbine. The generator has an umbrella structure, without an upper guide bearing.

TABLE 1. Specifications for Otori Power Station
The main specifications for Units No. 1 and No. 2 are listed.

Specifications	Unit No. 1	Unit No. 2
Max. output	95,000 kW	87,000 kW
Max. discharge	220 m^3/s	207 m^3/s
Normal net head	50.8 m	48.1 m
Commissioned year	1964	2003

TABLE 2. Specifications of Kaplan Turbine at Otori Power Station
Hydro-turbine specifications for Units No. 1 and No. 2 are listed. No.1 has the largest output in Japan, and No. 2 the second largest.

Specifications	Unit No. 1	Unit No. 2
Type	VK-1RS	VK-1RS
Max. net head	51.0 m	48.1 m
Max. output	100,000 kW	89,500 kW
Rotation speed	125 min^{-1}	167 min^{-1}
Runner diameter	6,100 mm	5,100 mm

performance through model tests. The design, manufacture, and inspection of the prototype runner were consolidated based on the 3D-CAD data, which made quality control during each process easier, and also increased the quality of the manufactured products.

The outer diameter of the runner is 5,100 mm and it has six vanes. Fig. 3 shows the runner during the final test in shop assembly. From the perspective of environmental conservation, we adopted a hub, which kept pure water inside so that oil would not leak into the river.

Fig. 3—Final Test to Confirm Assembly of Runner for Unit No. 2 in Workshop.
The runner was assembled into a single unit and a static balance test was conducted.

Casing and Stay-ring

The casing was spiralled and large scale, with a diameter of 6,800 mm at the inlet, and a maximum outer diameter of approximately 20 m. Due to restrictions in transportation for the carry-in route to the power station, the casing was divided into several parts and welded together on site. Fig. 4 shows the process of assembly in the shop. Despite the restricted working conditions on site, we installed this large-scale casing in only three months. We adopted ultrasonic automatic-recording as a nondestructive way to test the casing weld lines.

Fig. 5 shows the process for installing the stay-ring on site. To improve turbine efficiency, the stay-vanes were located at unequal intervals. The flow guides were attached to the inlets of the main plates of the stay-ring to reduce loss in water flow.

Main Unit of Kaplan Turbine

The strength of the main unit was calculated with 3D finite element analyses. As a result, we adopted a single thick-plate structure for the head cover. Self-lubricated bearings were used in the sliding areas of the wicket gates.

Fig. 4—Shop Assembly of Casing for Unit No. 2.
Large-scale casing — the inlet diameter of 6,800 mm, with a maximum outer diameter of approximate 20 m. The casing was divided into several parts and welded together on site.

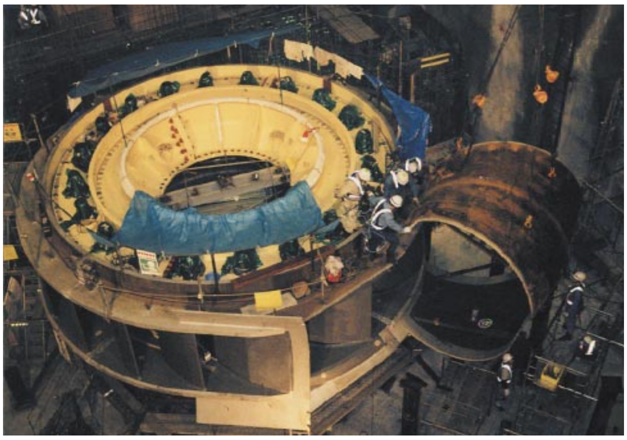

Fig. 5—Site Assembly of Stay-ring for Unit No. 2.
This shows the casing plates being attached to the stay-ring, which was assembled into a single unit on site. The stay-vanes were placed at unequal intervals.

Results of Field Tests

During commissioning, we observed water pressure pulsations inside the tailrace, which occurred after load rejection. Resonance by stationary waves inside the tailrace was considered to be the cause. To prevent rotating parts from vibrating due to water pressure pulsations, we changed the shutdown sequence.

As a result, we have had no problems with operation to date.

GENERATOR

Table 3 lists the main specifications of the generator. The rotor being hung in the power station is shown in Fig. 6. The design and manufacturing processes for the generator are described below.

TABLE 3. Specifications for Generator for Otori Power Station
The main specifications for Units No. 1 and No. 2 are listed.

Specifications	Unit No. 1	Unit No. 2
Type	$VEFK_3W$-RD	VTFKW-RD
Rated capacity	100,000 kVA	97,000 kVA
Rotation speed	125 min^{-1}	167 min^{-1}
Rated voltage	13,200 V	11,000 V
Rated current	4,380 A	5,091 A
Power factor	0.9	0.9
Number of poles	48	36
Excitation method	DC excitation → Brushless excitation	Brushless excitation

DC: direct current

Shaft Construction and Bearings

We used Hitachi's pivot spring thrust bearings as they have had a great deal of application records. We adopted a semi-umbrella construction with guide bearings in the upper rotor shaft for Unit No. 1. However, for Unit No. 2, we built a rotating silicon rectifier into the spider part of the rotor center, and shortened the length of the rotor. This umbrella construction, without upper guide bearings, allowed capacity of the upper oil tank and number of related pipes to be reduced.

We also adopted a double oil seal in the clearance between the oil dam for the thrust bearing oil reservoir and the rotating parts, and prevented oil leaks from occurring from the shaft side.

Through the use of an umbrella structure, we simplified the generator and the oil system, which made this equipment much more environmentally-friendly.

Fig. 6—Site Assembly of Rotor for Unit No. 2.
This shows the process for hanging the rotor of the generator.
The rotating silicon rectifier is contained within the rotor.

AC-exciter and Rotating Silicon Rectifier

To make Unit No. 2 maintenance-free, we adopted brushless excitation using an AC (alternating current)-exciter and a rotating silicon rectifier. Of all of Hitachi's generators with brushless excitation, the No. 2 generator has the second largest capacity surpassed only by the No.1, which has already been upgraded to this method.

Stator

Based on transportation restrictions, the stator for the generator was shipped in six parts, and delivered to the power station after the performance test had been conducted at our workshop. After that, the generator was assembled.

The stator coil using F-class pre-impregnated insulation, offered durability as well as reducing the quantity of varnish used during manufacture. The slots consisted of top-ripple springs and side-ripple springs to ensure a long life for the coil support inside the slots.

CONCLUSIONS

This report described the main features of Otori Power Station's Unit No. 2 owned by J-POWER (Electric Power Development Co., Ltd.).

Despite various restrictions related to reducing the environmental impact, the development and construction of this project was completed and Unit No. 2 successfully began operations in June 2003.

In the recent situation where global warming is posing a significant challenge, Hitachi, Ltd. intends to develop and design more efficient installations and also sustainable turbine-generators for hydroelectric power.

ACKNOWLEDGMENTS

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ABOUT THE AUTHORS

Asami Sato

Joined Hitachi, Ltd. in 1972, and now works at the Hydro Turbine Department, the Power Systems. He is currently engaged in the design of turbine equipment for hydroelectric power stations. Mr. Sato can be reached by e-mail at asami_satou@pis.hitachi.co.jp.

Keiichi Goto

Joined Hitachi, Ltd. in 2000, and now works at the Generator QA & Inspection Section, the Electric Power System & Equipment QA Department, the Power Systems. He is currently engaged in the testing and inspecting of generators and motors.
Mr. Goto can be reached by e-mail at keiichi-a_gotou@pis.hitachi.co.jp.