Performance Improvement of Pump-turbine for Large Capacity Pumped Storage Power Plant in USA

—300-MW Pump-turbine for the New York Power Authority's Blenheim-Gilboa Pumped Storage Power Project—

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OVERVIEW: Concern about the global environment and the need to make effective use of energy resources are driving plans to utilize the latest technology to upgrade the key components used in existing hydroelectric power plants with the aim of improving operating efficiency and increasing output. One example of this is a project in the USA to upgrade large 300-MW class pump-turbines and generator-motors originally installed in the 1970s. To improve the characteristics of a pump-turbine, the turbine profile is designed by using the latest flow simulation techniques to obtain a detailed understanding of the flow dynamics. The results of this work allow the pump-turbine equipment to be upgraded to meet the needs of current operation.

INTRODUCTION

A series of large-scale pumped storage power plants incorporating multiple 300-MW class pump-turbines were constructed in the USA during the 1970s as part of a move toward greater use of nuclear power plants and diversification of the power supply structure[1]. Because of the potential for using hydraulic design based on CFD (computational fluid dynamics) to improve characteristics, and with the aging of the equipment used in these power plants which have now been in service for more than 30 years, equipment upgrade projects to replace key components in these pump-turbines are starting to be undertaken. Based on the operational requirements of modern power plants, the improvements sought by these projects include longer maintenance periods, greater pumping capacity so that pumping times can be shortened, and stable operation over a wider range of turbine output levels than intended when the plants were originally constructed. Naturally, there is also a need to perform the upgrade work quickly and efficiently, with consideration for the environment, and in ways that keep costs down.

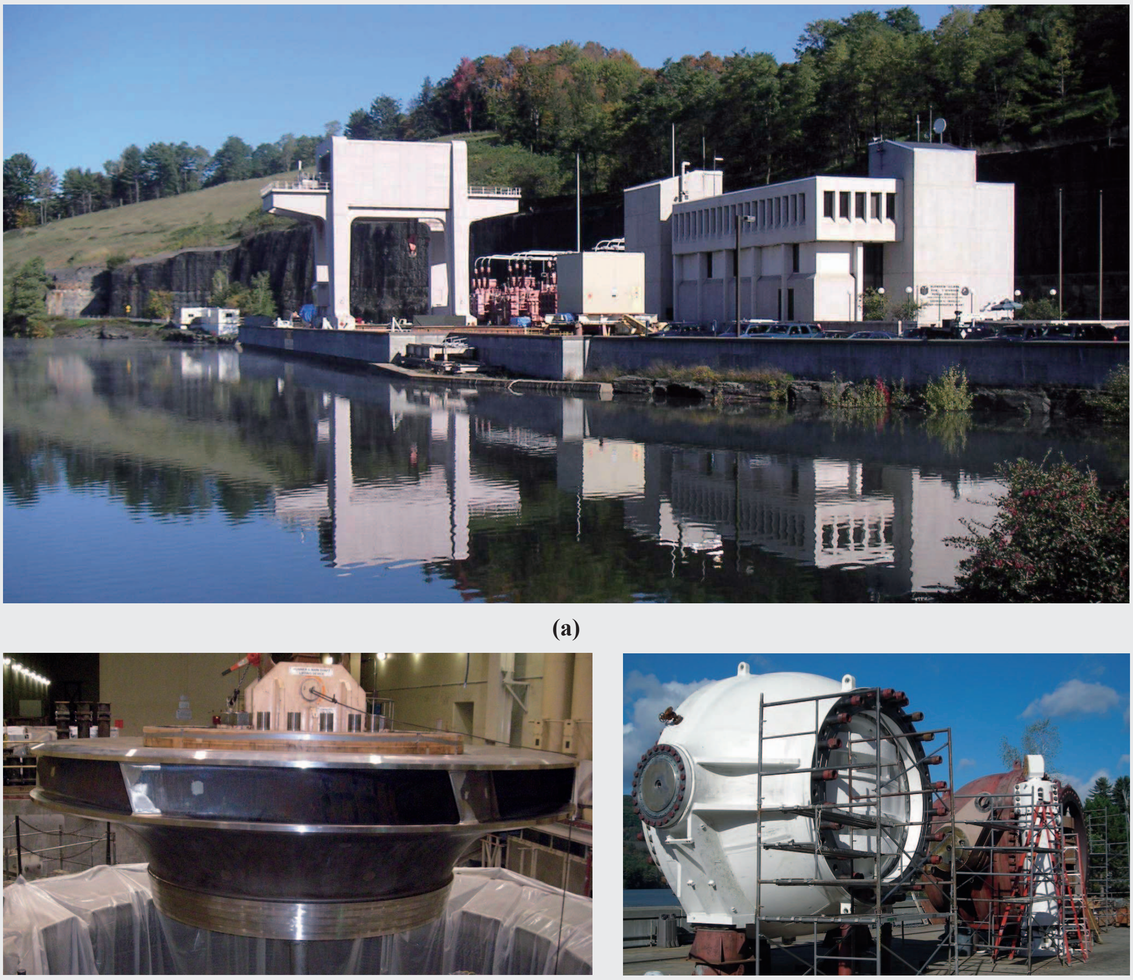
Hitachi supplied four pumped storage power plants to the USA and for one of them, the Blenheim-Gilboa power plant supplied to the New York Power Authority, Hitachi's bid for the LEM (life extension and modernization) project[2] that includes upgrading the runners was selected in a competitive tender against other suppliers. As of March 2009, the upgrade work is complete for two of the four units, with work underway on the third unit and equipment fabrication in progress for the fourth (see Fig. 1).

This article describes the hydraulic design undertaken at the customer's request to improve the characteristics of the New York Power Authority's Blenheim-Gilboa power plant, and the equipment fabrication and site work carried out for the two units that have already been completed.

PROJECT OVERVIEW

The Blenheim-Gilboa power plant started operation in 1973. It is located in the Schoharie Valley on the upper Hudson River, approximately 160-km north of New York City. Hitachi supplied key equipment used in the power plant including pump-turbines and generator-motors. This pumped storage power plant has four 300-MW pump-turbine units. Table 1 lists the power plant specifications including the improvements made during the upgrade and Table 2 gives an overview of the project. The background to the upgrade work is as follows.

When operating in generating mode, pumped storage power plants are required to vary their output



(a)

(b) (c)

Fig. 1—Blenheim-Gilboa Pumped Storage Power Project, Upgraded Runner, and Inlet Valve Before and After Refurbishing.
The lower reservoir of the partially underground pumped storage power plant (a) is formed by a dam across the Schoharie Valley on the upper Hudson River. A pump-turbine runner being lowered into place (b) and an inlet valve after refurbishing (foreground) and an inlet valve that has been removed but not yet refurbished (rear) (c) are shown. The pump-turbine runner provides for stable operation over a wide range of operating conditions.

to match changing electricity demand. However, it is easy for the operating state of the system to become unstable when operating away from the design point due to unsteady phenomena such as vibrations caused by flow separation or vortex generation. For this reason, the plant upgrade needed to include a pump-turbine capable of stable operation over a wide range of conditions.

Whereas pumped storage power plants in Japan typically operate as generators during the day time and as pumps during the night, the Blenheim-Gilboa power plant often generates electricity during week days and operates in pumping mode on weekends. Accordingly, to shorten the period of time during which the plant must purchase electricity for pumping, the plant requires a pump-turbine capable of pumping a large discharge per unit of time.

The upgrade also needed to improve the efficiency of the pump-turbines to make effective use of energy resources.

In addition to the characteristics improvement discussed above, key items of equipment used in the power plant were replaced or refurbished to extend the life of the equipment after the upgrade. The approach adopted to improve the efficiency of the upgrade and shorten the time required for the work was to use newly manufactured parts for the four runners and the upper cover and bottom ring on the first pump-turbine unit only, and then to refurbish the parts removed from each unit for use on the next unit. The existing parts on the final pump-turbine are to be scrapped.

TABLE 1. Pump-turbine Specifications and Characteristics Improvement
The operating range in generating mode has been extended from 57 MW to more than150 MW. Pumping discharge has also been increased by approximately 18%.

		Before upgrade	After upgrade
Generation	Maximum turbine output	300 MW	
	Maximum head	342 m	
	Operating range (generator output)	203 – 260 MW	140 – 290 MW
Pumping	Maximum total pump head	359 m	
	Maximum pump discharge	74.9 m^3/s	88.2 m^3/s

TABLE 2. Overview of Upgrade Project
The table below lists the work to be performed in the project including upgrade work and manufacturing of new parts.

Equipment to be upgraded	Four pump-turbine units
Testing	Model testing, on-site testing
Upgrade work	Disassembly of existing equipment
	Runner upgrade
	Refurbishment in factory, refurbishment on site
	Reassembly
New components to be manufactured (for one unit)	Inlet valve
	Upper cover and bottom ring

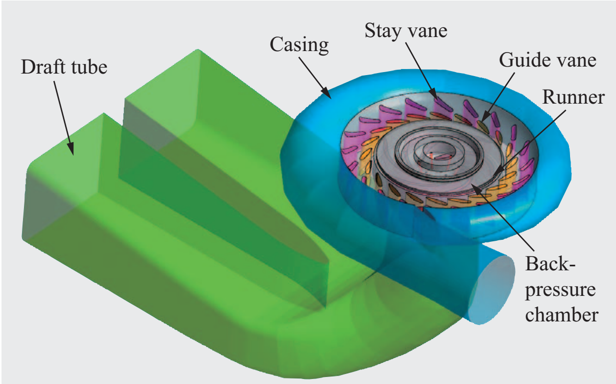


Fig. 2—Analysis Domain of Overall Model.
Including all hydraulic components of the turbine in the analysis shows up any interference between components and allows the analysis to be performed with a high level of accuracy.

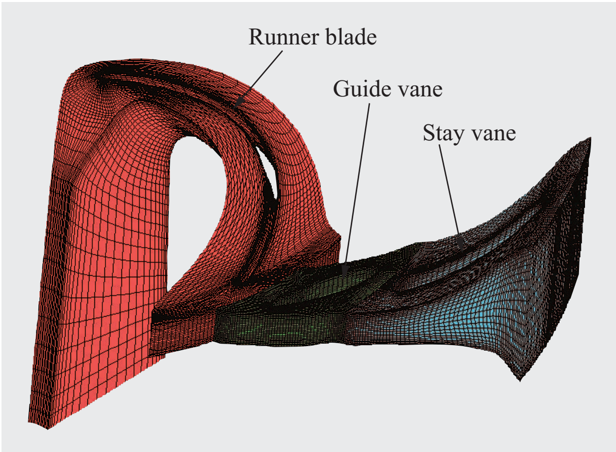


Fig. 3—Analysis Grid for Single Flow Path Model Analysis.
The flow around each component can be simulated in detail.

PROFILE DEVELOPMENT FOR CHARACTERISTICS IMPROVEMENT

Computational Flow Simulation

Profile development was undertaken for those hydraulic components in the pump-turbine that are able to be upgraded or modified. CFD-based flow simulation was used during the design process to verify the effectiveness of these profiles(3). Based on the profiles to be analyzed and the time that would be required, the analysis was divided into an analysis of the overall model shown in Fig. 2 and an analysis of single flow path shown in Fig. 3. In addition to its use in improving efficiency, the overall model analysis is also valuable for simulating any problems caused by interference between the various hydraulic components. The model was also used to test the design for vibration caused by the whirling of vortices in the draft tube downstream of the runner. The single flow path model analysis was useful for tuning the characteristics of each component.

Improved Profile

Although one way of improving characteristics is to increase the number of runner blades, a requirement of the customer was to improve the characteristics by changing the profile only and keeping the number of blades the same as before (seven). Also, optimization of the profile took account of the intended production method from the profile design stage in which it was assumed that rolled steel would be used instead of castings for the runner blades because of its better internal quality and lower cost.

CFD was also used to optimize the profile of the stay vanes and guide vanes, and optimization of their profile is an important part of improving the efficiency characteristics. Fig. 4 shows the flow patterns during turbine operation for the existing and improved profiles. Whereas the existing profile exhibits separation of the flow from the stay vanes and low-velocity regions around the guide vanes, both of which are associated with a lowering of efficiency, the results show a clear improvement on the improved profile. On the actual plant, characteristics improvement was achieved by replacing the guide vanes with new vanes and modifying the existing stay vanes on site.

The profiles of the seals, which consist of

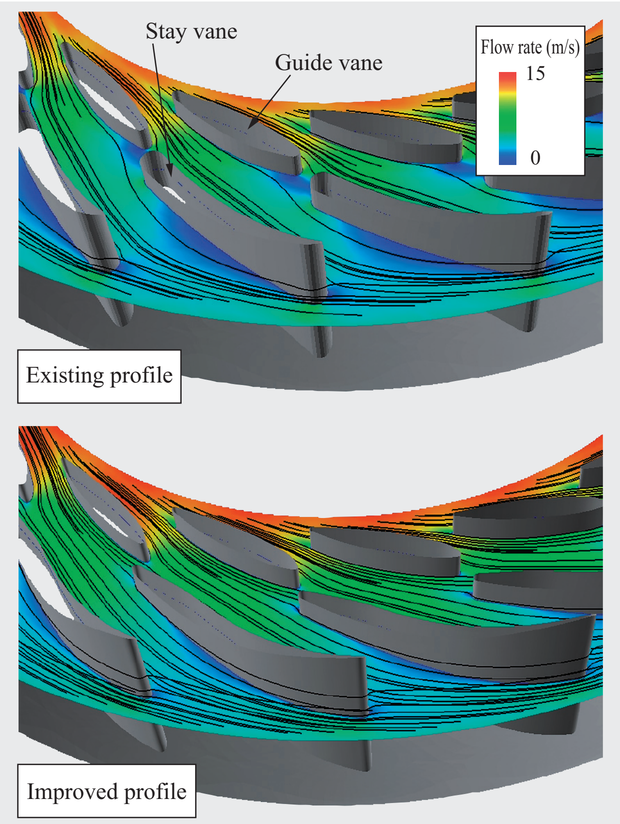


Fig. 4—Improvement in Characteristics Achieved by Modifications to Stay Vane and Guide Vane.
Low-velocity regions at the entry to the stay vanes and the leading edges of the guide vanes (shown in dark-blue in the figure) are present for the existing profile and cause the flow to separate from the profile. In contrast, the improved profile achieves a smooth flow that does not separate.

the rotating runner and the fixed liner, were also modified in conjunction with the runner upgrade to help improve efficiency further.

Model Test

After CFD had been used to determine the optimum profile, a 1/12.13 scale model of the actual pump-turbine was produced and the model test performed in accordance with the IEC60193:1999 standard to verify the hydraulic characteristics. Testing was performed for the existing profiles as well as for the absolute values of the upgraded profiles to quantify the extent of improvement and confirm the effectiveness of the upgrade.

COMPARISON OF CHARACTERISTICS BEFORE AND AFTER UPGRADE

Turbine Operating Range

A vibration caused by a vortex immediately below the runner occurs in the existing pump-turbine runners when operating near the maximum output or partial output region and this restricts the electricity generation output to the range between 203 and 260 MW in practice. By designing improvements to the runner profile, however, it is possible to control the flow that causes this vortex. Model test was used to measure the pressure fluctuations that are related to this operating restriction and this confirmed that the vibrations that occur in the existing plant have been reduced (see Fig. 5). Testing on the actual plant also confirmed that, with a full range in net head, the plant could operate with a generator output of anywhere between 140 MW and maximum output. That is, the operating range has been expanded from 57 MW per unit to more than 150 MW (more than 600 MW in total for the four units) which makes the plant suitable for use as a variable power source able to adjust to the changing load on the power system.

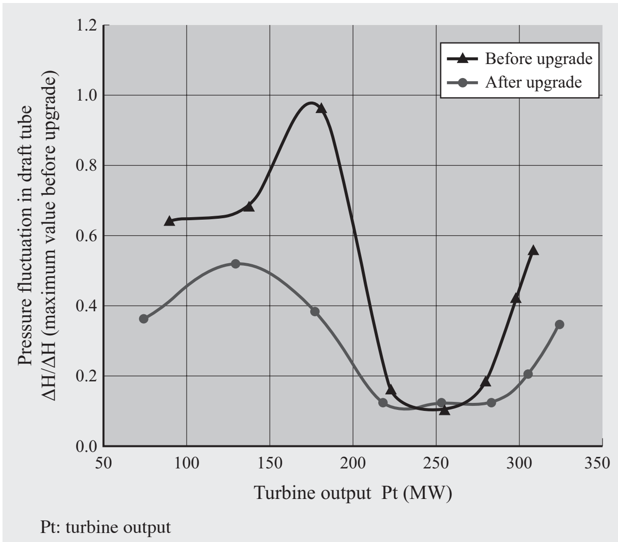


Fig. 5—Pressure Fluctuation in Draft Tube During Turbine Operation.
Pressure fluctuation testing carried out on a model pump-turbine confirmed that the upgrade would expand the stable operating range.

Pumping Discharge

Fig. 6 shows how the design improvements to the runner profile increased the pumping capacity over the entire operating range while also improving other flow performance parameters. In particular, the maximum pumping discharge has been increased by about 18% from 74.9 m^3/s to 88.2 m^3/s. This allows the plant to operate efficiently for short periods of time.

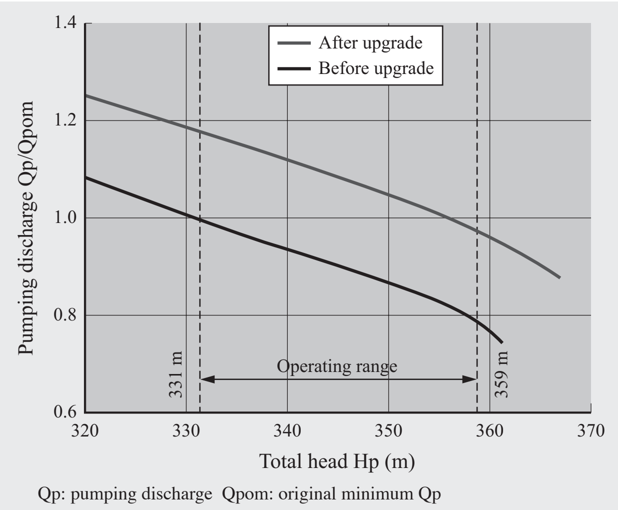


Fig. 6—Increase in Pumping Discharge When Operating as a Pump.
The pumping discharge has been increased by 18 to 20% over the entire operating range.

MANUFACTURE OF NEW COMPONENTS AND ON-SITE REFURBISHMENT

Prototype Runners

The prototype runners were fabricated by welding plate steel blades to a cast steel crown and band. 13Cr5Ni stainless steel was used to ensure good weldability. The runners have seven blades each and an outer diameter of approximately 6 m. Fig. 1 (b) shows an upgraded runner being installed.

Equipment Upgrades

In general, equipment that did not require profile improvements such as the runners were removed and refurbished on site or at the factory. This refurbishment included repair of any corrosion or other damage. Although this was cheaper than replacement with new components, it required the power plant to be shut down for a longer time. Because the Blenheim-Gilboa power plant has a one-to-four pipe configuration (whereby a single pipe from the upper reservoir splits into four pipes just upstream of the pump-turbines), the other three pump-turbine units are also unable to operate during the time when the inlet valve for one of the units is being removed. To shorten this shutdown time, the plan involved manufacturing a new inlet valve for the first unit and then replacing each inlet valve in turn using the refurbished inlet valve removed from the previous unit. The diameter of the inlet valves is 2.8 m. The same progressive refurbishment and replacement method was also used for the upper covers and bottom rings.

The project is scheduled to proceed at a rate of one unit per year so that work can start in the fall and end in spring to avoid the peak in power demand that occurs during summer. The upgrade of all four units is scheduled to be completed in May 2010.

CONCLUSIONS

This article has described the hydraulic design undertaken at the customer's request to improve the characteristics of the New York Power Authority's Blenheim-Gilboa power plant, and the equipment fabrication and site work carried out for the two units that have already been completed.

After 30 to 40 years of operation, this large pumped storage power plant has now re-emerged as a facility that utilizes the latest technology to obtain the high efficiency needed to meet modern-day requirements and place less of a burden on the environment. Hitachi intends to continue to supply highly efficient hydroelectric power plant equipment, including modernization projects for existing facilities.

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