Effective Utilization of Hydraulic Energy through Improved Turbine Runner Characteristics

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OVERVIEW: Hitachi aims to enhance small to medium-sized hydropower plants built more than 50 years ago by using the latest design techniques to upgrade key turbine components and improve their characteristics so that they can utilize hydraulic energy more effectively. Considering factors such as the size of the power plant and the level of investment required for improvement, Hitachi is using flow analysis to undertake shape design and characteristics evaluation without resorting to the model testing. This work on the improvement of turbine runner characteristics is currently being conducted for existing turbines with output in the 10- to 30-MW class and involves adopting runners with forward-lean blades to satisfy the key requirements of the modern era, which include improving efficiency and reducing CO_2 emissions.

INTRODUCTION

FOR reasons relating to environmental protection, work is being done to enhance the utilization of hydraulic energy by using the latest technology to upgrade key components in existing hydropower plants instead of constructing new power plants. In the case of hydropower plants built more than 50 years ago, this involves not only efficiency improvement but also improving characteristics to suit modern operational requirements.

This article describes improvements for small to medium-sized hydropower plants that are upgraded by applying the latest design techniques to the turbine runners.

USE OF CFD FOR RUNNER PROFILE DEVELOPMENT

Traditionally, model testing has been an essential part of turbine performance development for the flow path components of a turbine in order to achieve sufficient accuracy in assessing efficiency and cavitation characteristics. In fact, minimum values for the test head and runner size of the model turbine are specified in Japanese and international standards[(1), (2)]. However, this means that model testing accounts for a relatively large proportion of project costs in the case of power plants where the turbine output is low. In particular, if a project involves upgrading the runner only at a small to medium-sized hydropower plant like those discussed in this article, the cost of model testing and the development time become key factors in deciding whether the project is to proceed.

Meanwhile, dramatic advances in both software and hardware mean that CFD (computational fluid dynamics) analysis of the flow can be used to evaluate turbine performance development[(3), (4)]. Specifically, if model test data is available for reference, CFD is now able to evaluate a new shape to roughly the same level as is possible using model testing (see Fig. 1). As a result, the term "CFD runner" has been coined to refer to runners developed using CFD with no model test.

The main flow path components in a turbine are the casing, stay vanes, guide vanes, runner, and draft tube. For a new plant, turbine performance development would be performed for all of these components, but for a characteristics improvement project the development work is only undertaken for those components that are to be upgraded. Model testing requires that test models be produced for all components that form the test loop, not just those being upgraded. This means that using model testing as part of the development may incur

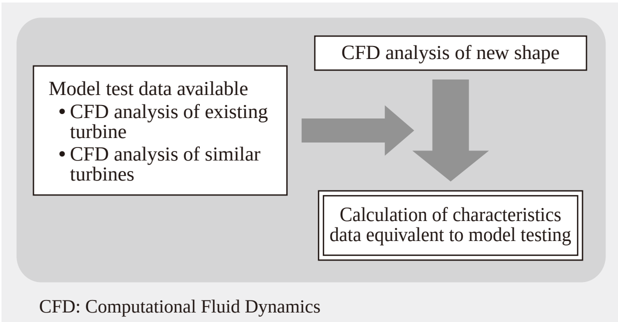


Fig. 1—Use of CFD to Calculate Characteristics Data.
Runner shapes can be developed without resorting to model testing by using CFD-based flow analysis.

costs that are not directly related to the upgrade. In the case of CFD analysis, however, provided the boundary conditions are specified appropriately, it is possible to conduct an analysis for only those components being upgraded. This is one of the advantages of CFD.

FLB RUNNERS

The main part of a characteristics improvement project is the upgrading of the runner to achieve better turbine efficiency and cavitation characteristics. As the power plants in which these projects are carried out were built 50 or more years ago and use design shapes current at the time of construction, in most cases they differ somewhat from what are now considered optimum design dimensions. Also, whereas the nature of the electricity system in those days meant that maximum output was an important criterion, nowadays the ability to operate efficiently and reliably at partial load is also required.

The shape design used to satisfy these criteria is the FLB runner (runner with forward-lean blades). FLB runners have a shape in which, at the blade inlet, the band end of the blade is further forward (in the direction of rotation) than the crown end. A feature of this shape is that it achieves a good flow of water over the blades by minimizing the bias in the flow toward the band end caused by the centrifugal force associated with runner rotation. In Japan, this design is chosen to improve the efficiency when running at partial load and minimize cavitation erosion to the blade surface in particular.

Naturally, FLB runners are used for new plants as well as for upgrade projects.

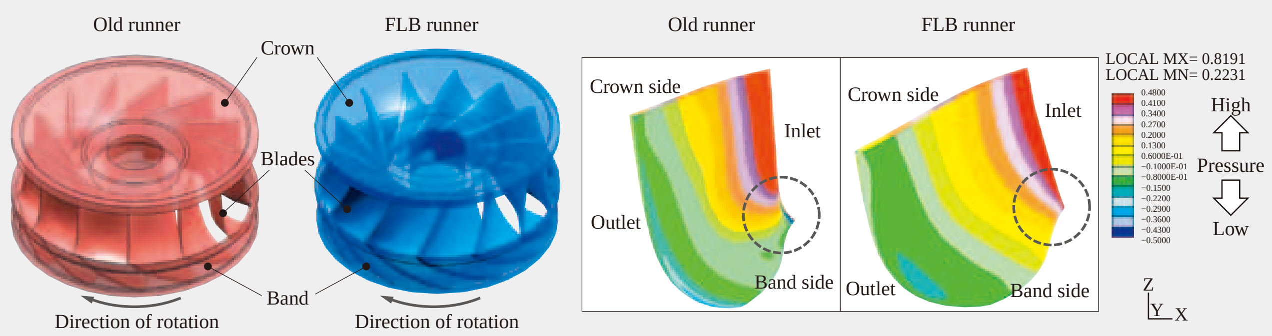
CHARACTERISTICS IMPROVEMENT FOR FLB RUNNERS

The following sections describe examples of characteristics improvement projects for small to medium-sized hydropower plants that have enhanced the utilization of hydraulic energy by using FLB runners developed using CFD analysis.

Nishi-yoshino No. 2 Power Plant

The Nishi-yoshino No. 2 Power Plant of Electric Power Development Co., Ltd. (J-POWER), which commenced operation in 1955, has a Francis turbine with an output of 14 MW and head of 77.4 m. Although this turbine has an overhaul period of around 15 years, it has suffered from cavitation erosion to the runner blades that required repairs every three to four years. The issues were the cost of repairing this erosion and the overflow power while the plant was shut for repairs.

First, a CFD analysis was performed for the existing runner to identify the local pressure drops at the blade surface associated with the occurrence of cavitation. Next, an FLB runner was selected for the new runner shape and CFD was used to survey the shape definition parameters and find a shape that would not be subject to cavitation under normal operating conditions. Fig. 2 shows the improvement in cavitation performance of the FLB runner. The pressure distribution graphs in the figure show how the low pressure regions that occurred on the band-side inlet to the suction surface on the old runner have been eliminated.



(a) Runner shape (b) Distribution of pressure on blade suction surface calculated using CFD

FLB: forward-lean blade

Fig. 2—Use of FLB Runner to Improve Cavitation Performance.
A feature of the runner shape (a) for an FLB runner is that the band end on the inlet side of the blade (circumferential tip) is further forward relative to the direction of rotation than the crown end (the blades have a forward sweep). Also, the distribution of pressure on the blade suction surface calculated using CFD (b) shows that a localized region of low pressure is present at the blade inlet near the band end on the old runner (indicated by the dotted line). Cavitation occurs in this low-pressure region. On the FLB runner, this region is not present and therefore cavitation does not occur.

The new runner commenced operation in February 2008 and underwent its first inspection in September of the same year to confirm that no erosion was occurring. This can be seen as proof that the FLB runner with a shape developed using CFD succeeded in improving the cavitation characteristics.

Towa Power Plant

The Towa Power Plant of Electric Power Development Co., Ltd., which commenced operation in 1954, has two Francis turbines with an output of 16.5 MW and maximum head of 93 m. With a minimum head (before the upgrade) of 72 m, the comparatively large variation in head is a feature of the plant. As operational demands meant the upper dam was to operate with a lower water level than in the past, it was desirable that the upgraded plant be able to operate with an even lower minimum head. This meant that, when assessing the characteristics for a particular head, the efficiency needed to be improved over the entire range of flow rates compared to the old runner. There was also a need to improve the cavitation performance of the runner blades.

To satisfy these requirements, CFD was used to develop an FLB runner for this power plant. Fig. 3 shows the efficiency characteristics calculated using CFD for the case of maximum head. The efficiency of the new FLB runner is 1.5 to 2% better than the old runner over the entire range. One of the turbines commenced operation using an FLB runner in December 2010.

Ichiarakawa Power Plant

Ichiarakawa Power Plant of The Kansai Electric Power Co., Inc., which commenced operation in 1944, has two Francis turbines with an output of 26.35 MW and a head of 69 m. A review of its recent operational performance concluded that efficient two-unit operation could be achieved by reducing the maximum design flow by 7% from that of the existing plant. Also, because the plant design is so old (it commenced operation in 1944), its characteristics

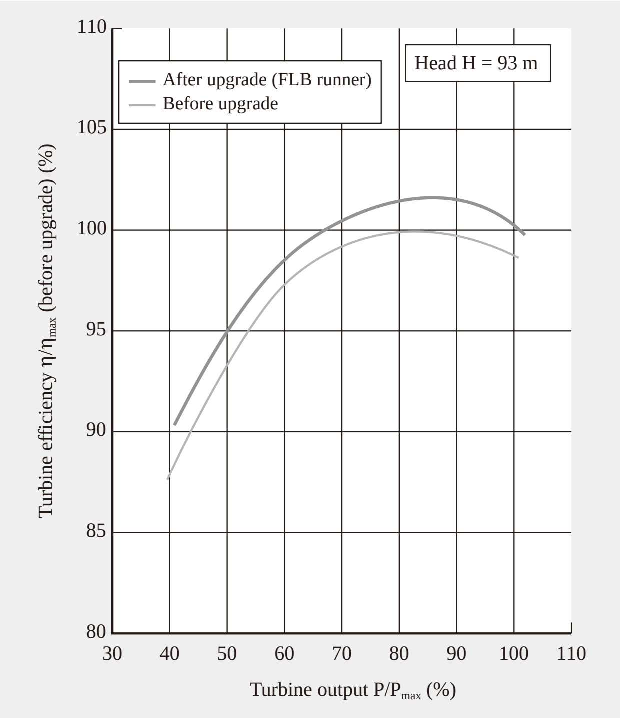


Fig. 3—Verification of Characteristics Improvements Using CFD.
Adopting FLB runners (thick line) improved efficiency by 1.5 to 2% over the entire operating range compared to before the upgrade (thin line).

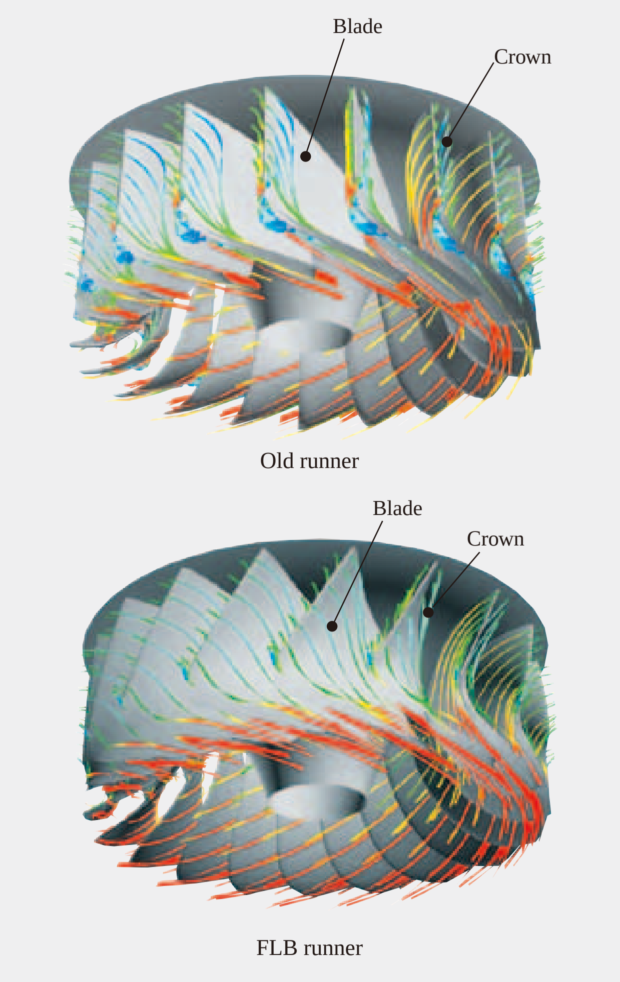


Fig. 4—Patterns of Flow through Runners Calculated Using CFD.
The figure shows the patterns of flow through the runners (with the band removed). On the old runner, the flow becomes detached in the inlet region and is biased toward the band end. In the FLB runner, in contrast, the flow in the inlet region is smooth and extends to the crown end without being biased toward the band end.

could be improved by replacing other components, not just the runner. However, to minimize the cost and time required for the overhaul, it was decided that the characteristics improvement project should involve an FLB runner only. Compared to the old runner, this new runner would improve the flow at the blade inlet region and achieve smooth flow through the runner (see Fig. 4). One of the turbines commenced operation using an FLB runner in April 2011.

Based on calculations by The Kansai Electric Power Co., Inc.[5], total annual power production will increase by 14 GWh (4.7%) once the upgrade is complete for both turbines. This corresponds to an annual reduction in CO_2 (carbon dioxide) emissions of 3,710 t.

Oike No. 2 Power Plant

The Oike No. 2 Power Plant of Tohoku Electric Power Co., Inc., which commenced operation in 1956, has a Francis turbine with an output of 11.13 MW and a head of 135.68 m. As more than 50 years had passed since the plant commenced operation, a full upgrade of the turbine (excluding the draft tube) was undertaken. Oike No. 2 is a run-of-the-river hydropower plant and an FLB runner (see Fig. 5) was adopted to achieve turbine characteristics that would maximize annual production of electric power. Other flow path components were also optimized using CFD. The result was a 3% increase in maximum turbine output despite the head remaining largely unchanged from before the upgrade.

The plant restarted in December 2010. For environmental reasons, the turbine has water-lubricated bearings that do not use lubricating oil.

Fig. 5—FLB Runner.
The photograph shows the FLB runner prior to delivery from the factory. It has an outlet diameter of about 1 m and 15 blades.

CONCLUSIONS

This article has described characteristics improvement for small to medium-sized hydropower plants which are upgraded by applying the latest design techniques to the turbine runners.

Installing FLB runners developed using CFD in small to medium-sized hydropower plants that commenced operation 50 or more years ago to improve their characteristics results in better utilization of the hydraulic energy. Hitachi intends to continue its involvement in characteristics improvement projects for existing power plants for reasons that include contributing to the global environment.

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