Efficiency Improvement by Hydro Turbine Analysis

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Abstract

In recent years, to create a sustainable society, efforts to realize a carbon-neutral and decarbonized society are required. We are proceeding with technological development to improve the efficiency of hydro turbines.

One of the technologies required for development is fluid analysis of hydro turbines using numerical fluid calculations, and the accuracy of this analysis has been significantly improved using analysis tools. With the aim of improving product competitiveness, we began efforts in fiscal 2018 to acquire technology that allows us to design highly efficient hydro turbines and improve their efficiency. To accelerate the acquisition of technology and advance analysis technology, we are conducting joint research program with Professor Miyagawa of WASEDA UNIVERSITY and EAML Engineering CO., LTD. – a hydropower systems manufacturer. To improve the efficiency of Francis turbines, we are currently conducting research to improve the conventional design flow, perform step-by-step analytical design, and evaluate turbine performance.

1 Preface

Against a background of environmental issues, there is a need for higher efficiency hydro turbines. Among these, Francis turbines have a wide range of applications and are available in large numbers in the market, so there is an extremely high demand for high efficiency. **Fig. 1** shows the flow path configuration of a Francis turbine. The shape of the flow path, which is one of the important factors that determines water performance, is comprised of the casing, stay vanes, guide vanes, runner vanes, and draft, and has a wide variety of design elements. The design largely depends on the knowledge and experience of the design engineer, and producing optimal design is not easy. To achieve the optimal design of the flow path, we conducted a fluid analysis design of a hydro turbine using Computational Fluid Dynamics (CFD), which has been attracting attention in recent years, and verified the validity of the performance using a model hydro turbine. We are conducting a joint research program with WASEDA UNIVERSITY and EAML Engineering CO., LTD. – a Meiden Group company. This paper introduces flow path optimization technology, which is the result of this joint research, and examples of its application.

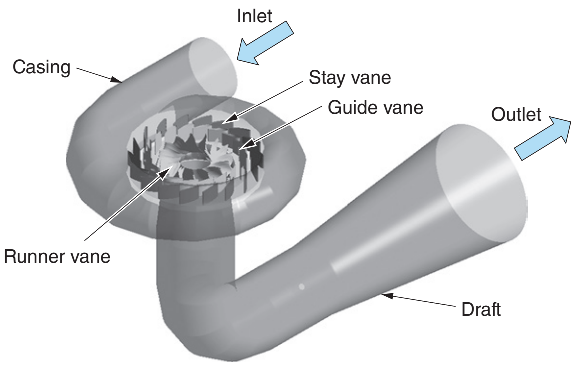
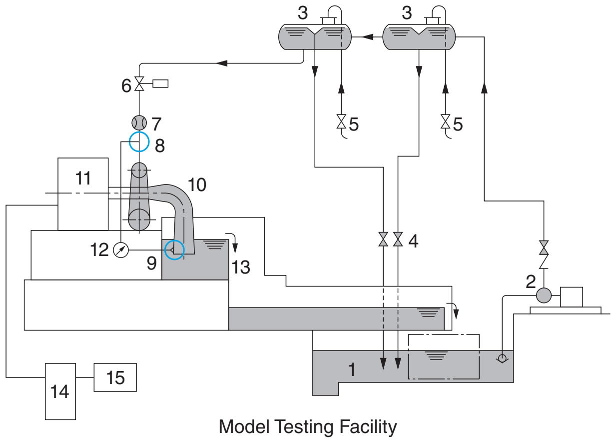


Fig. 1 Flow Path Configuration of Francis Turbine

A flow path configuration of the Francis turbine is shown from its casing to the draft.

2 Conventional Hydro Turbine Design

With conventional design, it was difficult to predict the water flow in the hydro turbine flow path because only a one-dimensional study was possible. For this reason, hydro turbine manufacturers repeatedly conducted experiments on model hydro turbines based on "JIS B 8103 – Methods for model tests of hydraulic turbine and reversible pump-



1. Water tank
2. Feed pump
3. Upper water tank
4. Overflow regulation valve
5. Air intake valve
6. Inlet valve
7. Electromagnetic flow meter
8. Inlet pressure monitoring position
9. Outlet pressure monitoring position
10. Model hydro turbine
11. Dynamometer
12. Differential pressure sensor
13. Overflow weir
14. Dynamometer control panel
15. Telemetry system

Fig. 2 **System Diagram of Model-Based Test Facility**

A system diagram of the model-based test facility possessed by EAML Engineering CO., LTD. is shown.

Fig. 3 **Panoramic View of Model-Based Test Facility**

A panoramic view of the model-based test facility owned by EAML Engineering, CO., LTD. is shown.

turbine", and adopted a method that reflects the results in their designs. However, model-based testing requires large-scale equipment, so it is time-consuming and costly.

This is also the case with EAML Engineering CO., LTD., a joint research company in this study. This company owns model-based testing equipment and designs hydro turbines based on a database created from the test results. Fig. 2 shows a system diagram of the model-based test facility at EAML Engineering CO., LTD. Fig. 3 shows a panoramic view, and Fig. 4 shows an external appearance of the model hydro turbine.

Even today, when designing a hydro turbine

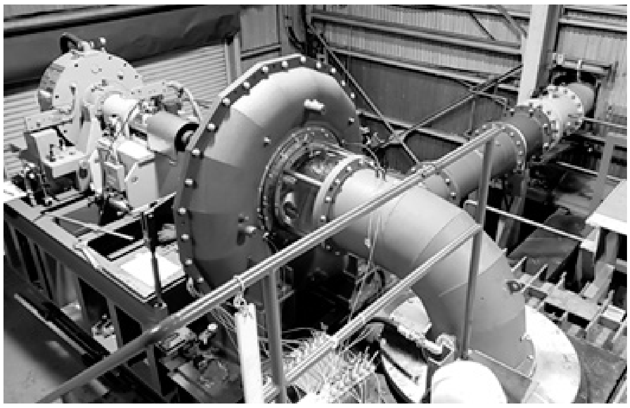


Fig. 4 **External Appearance of Model Hydro Turbine**

An external view of the model hydro turbine owned by EAML Engineering CO., LTD. is shown.

with strict specifications, it is necessary to conduct model-based tests, which is a major issue in terms of time and cost.

3 Hydro Turbine Design by CFD

Hydro turbines have a long history and is generally recognized that their performance has reached saturation. Computer-based technology, however, has advanced significantly in recent years, making it possible to optimize the channel shape in a short period of time, thereby improving performance. To improve the accuracy of analysis design, it is essential to conduct validation by model-based tests in parallel to acquire analysis technology. The accumulation of this validation can be said to be the know-how of hydro turbine manufacturers.

Our company and EAML Engineering CO., LTD. began efforts to acquire analysis technology using CFD, but initially the lack of resources and analysis experience was an issue. We began joint research program with WASEDA UNIVERSITY, Tokyo, Japan to accelerate and advance development.

Fig. 5 shows the technical development procedure for hydro turbines. As an approach to improving the efficiency of Francis turbines, we conducted an analysis design using CFD in three steps.

(1) Step 1: Analyze the conventional design model of EAML Engineering CO., LTD. to understand the current situation and clarify the problems

(2) Step 2: Proceed with technology development in order, starting with the runner and implement improved design for the runner only

(3) Step 3: Improved overall design from casing to draft

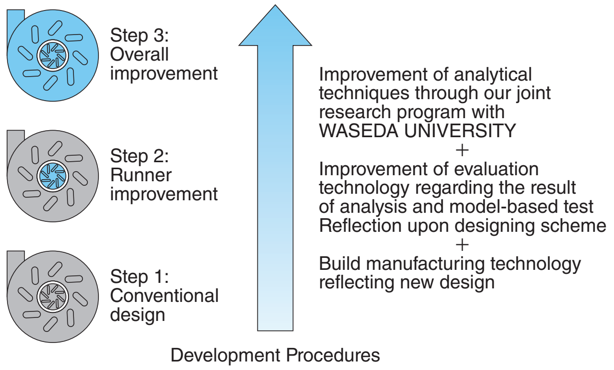


Fig. 5 **Technical Development Procedures for Hydro Turbines**

Technical development procedures are shown from Step 1 to Step 3 for the improvement of hydro turbine performance.

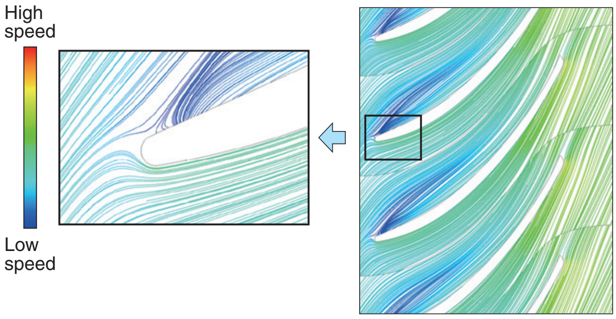


Fig. 6 **Blade Inlet Streamlines of Conventional Model**

Runner vane inlet flowlines of a conventional design model are shown. It is verified that streamlines are exfoliated due to mismatching between inlet flow and blade inlet angle.

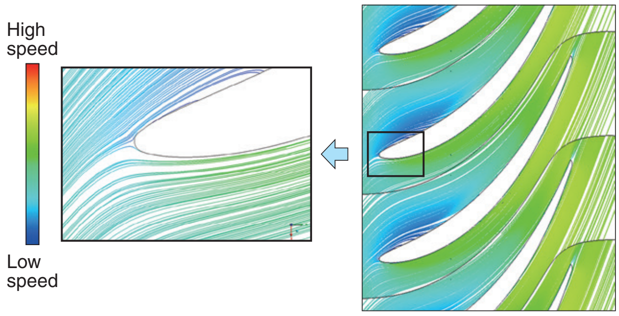


Fig. 7 **Blade Inlet Streamlines of Improved Model**

Runner blade inlet streamlines of the improved design model are shown. It is confirmed that a favorable balance is maintained between inlet streamlines and blade angle, and that smooth streamlines are secured due to improvements.

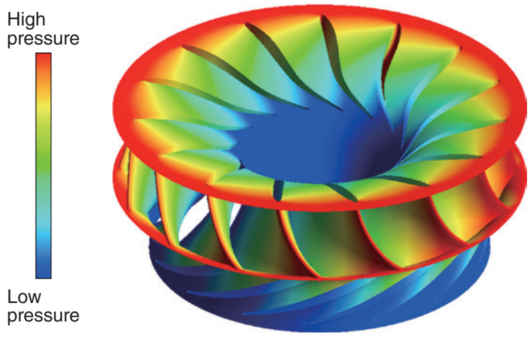


Fig. 8 **Runner Wall Pressure Distribution of Improved Model**

A runner wall pressure distribution of the improved model is shown. No local pressure drop can be observed.

The development goal is to improve performance by three points over the conventional design model, and it is currently developing the technology to target power plants with a hydro turbine output of 10,000 kW or less.

4 CFD Application Example

Following the technology development procedure in **Section 3**, we analyzed the conventional design in Step 1. **Fig. 6** shows the blade inlet streamlines of the conventional model. In the conventional design, analysis results show that vortices are generated at the blade inlet, causing turbulence in the flow, and reducing the flow velocity in the subsequent stage.

In contrast, **Fig. 7** shows the results of an improved runner design carried out in Step 2. From the analysis results, we were able to suppress the flow turbulence as in Step 1 by aligning the runner inlet with the inflow angle, and we were able to design the runner outlet while checking the angle that would not disturb the direction of the water flow. **Fig. 8** shows the runner wall pressure distribution of the improved model. The pressure is uniformly high on the inlet side of the runner and low on the outlet side, confirming that water energy can be sufficiently converted into rotational force.

Fig. 9 shows a comparison of hydro turbine efficiency based on analysis of the conventional model and the improved model. We confirmed that efficiency can be greatly improved just by improving the runner. **Fig. 10** shows a comparison of the hydro turbine efficiency between the analysis of the improved model and the experiment. It was confirmed that the efficiency values and performance curves of the analysis and model test matched, and that there were no problems with the analysis accuracy.

We are presently moving to Step 3, removing dimensional constraints on stationary parts other than the runner, and improving the entire flow path.

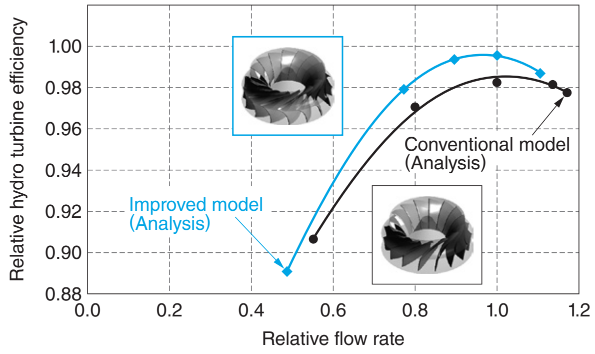


Fig. 9 **Comparison of Hydro Turbine Efficiencies Based on Analysis of Conventional Model and Improved Model**

Comparison of hydro turbine efficiencies was carried out based on the result of analysis for a conventional model (Step 1) and the improved model (Step 2). In all flow rate domains, the improved model was found to be superior to the conventional.

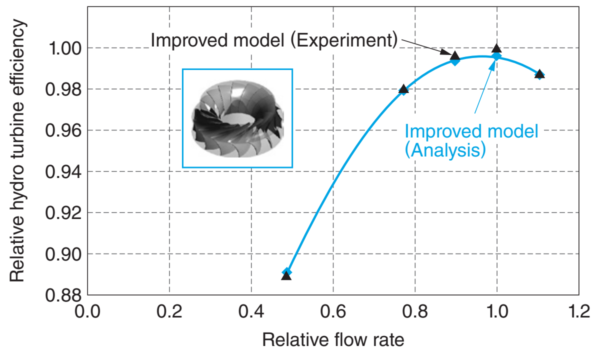


Fig. 10 **Comparison of Hydro Turbine Efficiency between Analysis of Improved Model and Experiment**

Comparison of hydro turbine efficiencies was carried out based on the result of analysis and model test for the improved model (Step 2).

Cavitation is an important element of hydro turbine characteristics as well as efficiency. This is a phenomenon in which air bubbles form when the pressure drops in flowing water, and when the pressure recovers, the air bubbles collapse and cause damage to the blades. Cavitation is also affected by the installation height of the hydro turbine. Improving cavitation performance will, therefore, also lead to a reduction in the civil engineering costs associated with excavating the floor of the power plant. This cavitation can also be predicted by CFD two-phase flow analysis of water and steam, so we are proceeding with verification in conjunction with efficiency studies.

5 Postscript

We introduced the efforts of our company and EAML Engineering CO., LTD. to improve the efficiency of hydro turbines. We will continue to absorb cutting-edge analysis and design technology through joint research programs and contribute to society by promoting the use of renewable energy resources.

Lastly, we would like to express our deepest gratitude to Professor Miyagawa of WASEDA UNIVERSITY, who gave us precious advice and guidance over the years during our development of technology for optimizing the shape of hydro turbines.