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# A runner modernization in a Deriaz turbine hydropower station

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**Abstract.** This paper introduces our experience of a Deriaz turbine modernization project. N hydropower station in Japan, with the 50MW Deriaz turbine (turbine mode only), had been operated for approximately 50 years. Not only for the purpose of the maintenance but also for the energy production increase, the turbine modernization was planned along with the scheduled overhaul. The modernization scope of the hydraulic parts was discussed and the blade only option was selected. In the new blade development, the existing mechanical limits were the restriction and the lack of recent experiences in Deriaz turbine development was a challenge. For the challenge, a development procedure special for the project was introduced, using state of the art CFD technology and the model test. As the result, within the existing mechanical limits, 3% gain in performance at the full load has been achieved and the performance was successfully confirmed in the model test and the prototype site test.

## 1. Introduction

Recently there are a number of modernization projects of hydropower plants in Japan. Large-scope renovations, called “scrap & build” projects, are planned for hydropower plants, 40-50 years or older, to exploit the potential of the water energy and to maintain the functionalities using the existing civil structures, for example, the dam, the penstock and the tailrace. Within the limited project budget, there are also a number of modernization projects limiting the scope of the replacements. In the case, the main hydraulic component of runners is often selected as the scope. Having the recent advanced design technology as the backdrop, the modernized runners and the other hydraulic parts, for example, guide vanes have the sufficient improvement in performance for the investment, even before reaching its lifetime. Therefore, they are often replaced along with the overhaul for the maintenance and also for the purpose of the increase of the output, the turbine efficiency and the annual energy production.

In this paper, a modernization project with the runner blades replacement in a Deriaz turbine is presented. Generally, Deriaz turbines, diagonal double-adjustable turbines, are suitable for the higher head range from 50 to 100 meters than typical Kaplan turbines and are adopted for the power plants that requires high efficiency over a wide flow range. In Japan, the first Deriaz turbine was installed in 1961, and then 50MW class power plants with Deriaz turbines were built from 1965 to 1970. N Deriaz hydropower station, being presented in this paper, was also built in 1968 in Japan. Table 1 shows the main specification of the station and Figure 1 shows the simplified cross section.

In the regular inspection, it was found that the turbine suffered from the cavitation damages. Also it turned out that welding repairs were risky for the material degradation of the runner blades. The owner of the power plant decided to replace the blades at the next scheduled overhaul. To make the most of



the chance, the owner made a choice of the replacement with the modernized blades to improve the turbine performance.

To offer the best proposal, the scope and the goal of the project were discussed.

The scope of the project was decided as follows.

- Runner blades replacement only. Reuse of the hub, the wicket gates, and the embedded hydraulic parts from the cost-effectiveness point of view. No change in servomotors for the runner blades and guide vanes was planned.
- The generator or the axial thrust bearing are not the scope.

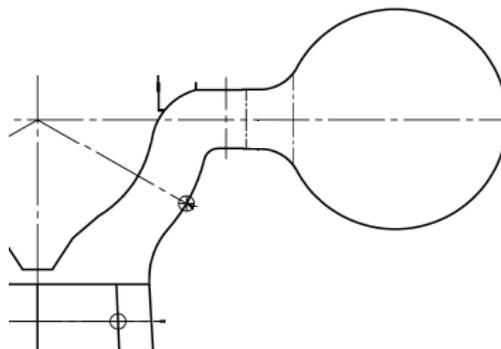
The conditions of the blade development and the goal of the project are summarized as follows.

- The new blades need to reach the maximum discharge within the existing servomotor strokes.
- The blade torque shall be under the capacity of the existing servomotor
- The runaway shall be under the limit of the existing generator
- The axial thrust shall be under the limit of the existing thrust bearing
- Improvement of the turbine performance characteristics
- Improvement of the cavitation characteristics

In fact, in addition to above, at the time when the project started, we did not have the recent experience of Deriaz turbine development, which was a challenge for the project.

**Table 1.** Specification of the existing N hydropower station.

Rotational speed ( $\text{min}^{-1}$ )	257		
Net head (m)	99	97	92.5
Turbine output (MW)	50	50	46.4



**Figure 1.** Cross section of N Deriaz turbine.

## 2. Development of the new runner

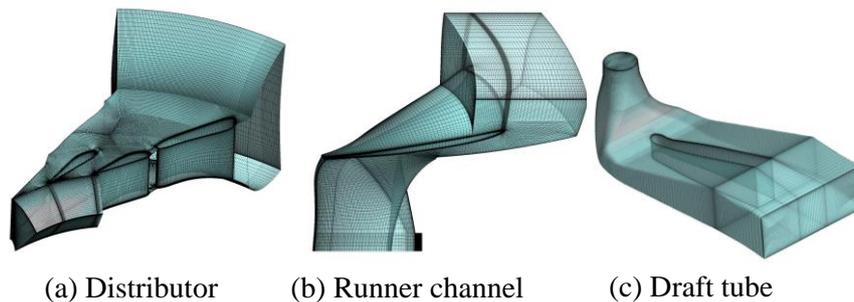
### 2.1. Typical performance development process in CFD design

Conventionally hydraulic developments of runners have been carried out by the iteration in the physical model test stand. Having a benefit of the recent progress in CFD (Computational Fluid Dynamics) technology, instead of physical model test stands, we have got to be able to make the better predictions in CFD simulation. Thus CFD analysis has become a major tool for recent runner designs

from 2000s. For the runner design purpose, RANS (Reynolds-Averaged Navier-Stokes) is widely used for the turbulence model because the computational load is low and it gives quick designs. Table 2 shows the CFD method applied in the blade development and Figure 2 shows the CFD meshes.

**Table 2.** A detail of CFD method.

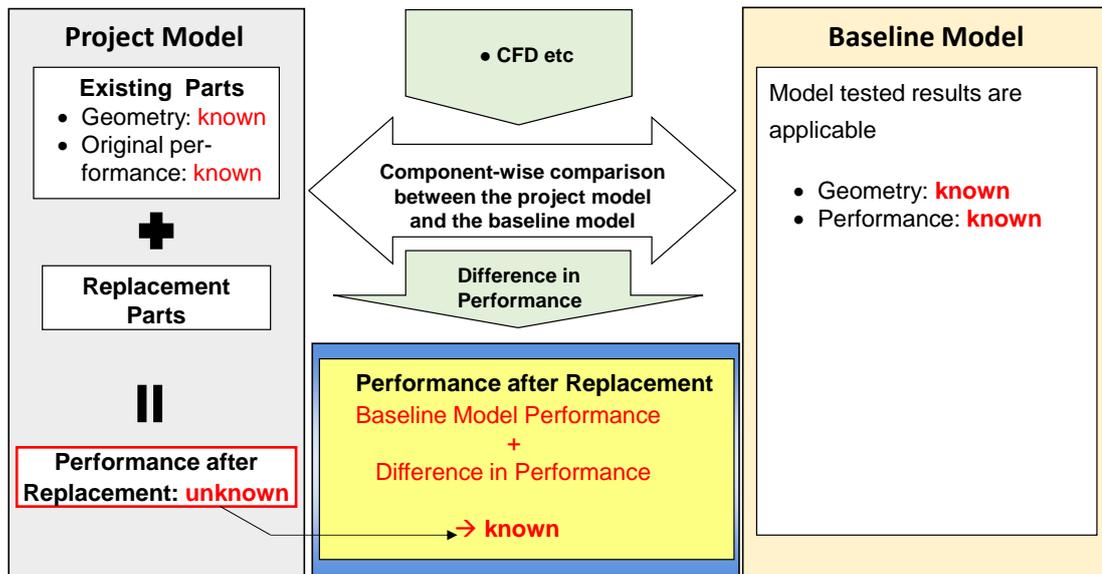
Software	CFX (ANSYS Inc.)
Equation	RANS (for the design iterations)
Turbulence model	SST model
Grid	Total number of nodes: 3 million Including Stay Vane (1pitch), Guide Vane (2 gates), Runner (1 pitch) and Draft tube



**Figure 2.** CFD mesh used in the N Deriaz turbine runner blade development.

Nevertheless, the stand-alone CFD accuracy of the performance prediction is limited. To maintain the accuracy with the simulation model, the CFD application needs special cares. The process of performance prediction is shown below (See also Figure 3). The methodology is generally applied in the CFD design iteration. The iteration ends when the targeted performance is achieved.

- (1) A baseline model close to the project specification and the geometry is selected out. The baseline model was previously tested in the laboratory and had complete sets of turbine characteristics.
- (2) CFD simulations for both turbines of the baseline model and the project turbine with new components are performed and component to component loss comparisons are made between them. Then the loss difference is obtained for each components.
- (3) The total loss difference is added to the baseline model performance. Then the expected performance for the turbine with the new components was obtained.



**Figure 3.** Prediction of the performance in the CFD design.

For most of modernization projects of Francis and Kaplan turbines, the performance predictions are possible by the methodology shown above based on fairly amount of the experiences for these types of machines and the accuracy of the performance prediction is ensured enough. However, for Deriaz type of turbines, it was the first time in a decade or so to develop the new blade and there was no modern baseline model suitable for the N turbine specification when the project was awarded to us because of the small Deriaz turbine market in the world for a dozen of years thus the lack of the recent experience. Therefore we had to take a different process in the performance development.

### 2.2. Special performance development process applied for N Deriaz turbine project

The high-quality blade design in CFD must be supported by the physical model test experience. Especially, it is important for the better estimation of the on-cam condition and flow velocity distribution downstream of the runner. We took the following special process in the development of N Deriaz turbine blade performance. To cover the lack of recent experiences, we made two steps with the physical model tests.

#### Step 1: CFD-alone design iteration as a preliminary process

- (1) To start the new blade design iteration with the existing blade profile, the performance and the other properties of the internal flow for the existing turbine was checked by the CFD simulation.
- (2) The preliminary designs of the new blades were compared to the existing blade in the CFD simulation throughout the iterations. The blade profile was optimized in the CFD simulation.

#### Step 2: Adjust the design based on the preliminary model test results to refine the blade

- (1) The CFD-optimized blade as a preliminary design was fully evaluated in the model test stand and data collections were made for the future adjustment of the discrepancies in the flow features between the CFD results and the model results.
- (2) The final blade profile was designed based on the preliminary blade design experience. The performance of the final blade design was confirmed again in the model test (Section 3).

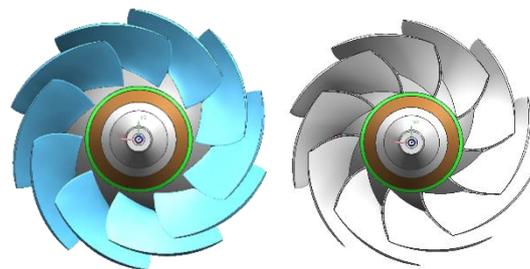
### 2.3. Overview of the final blade obtained in the design iteration

Figure 4 shows the existing and the new blade. The cavitation characteristics was improved by correction of the blade profile to equally distribute the blade load from the inlet to the discharge.

Figure 5 shows the CFD comparisons of the local Thoma number at the maximum discharge on the blade tip near the discharge edge, where  $L$  is the length from the inlet along with the blade tip. The Thoma number distribution of the old blade has a quick rise around the discharge, exceeding the plant Thoma number. On the other hand, the new blade has a great improvement in the cavitation feature on the blade.

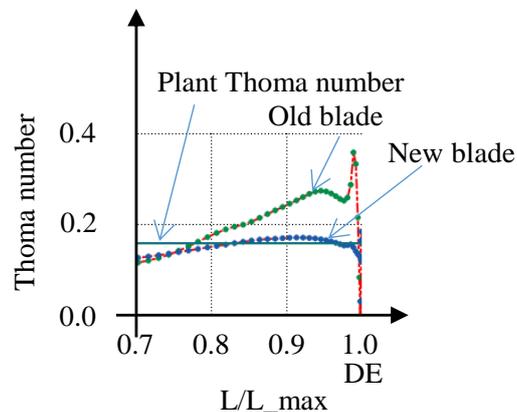
Figure 6 shows the internal flows in the new blade. The flow was well aligned to the blade and the secondary flow was controlled. The reduction of the loss in the runner was also confirmed by CFD loss analysis.

Figure 7 shows the internal flow of the draft tube. The streamlines were smooth and the flow was equally distributed in the draft tube enough to minimize the loss.

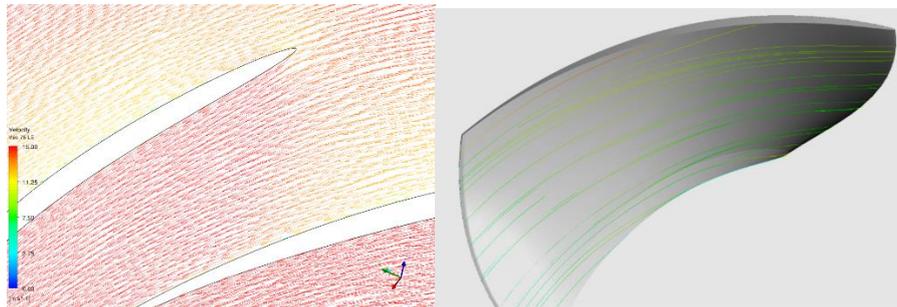


(a) Old runner blades (b) New runner blades

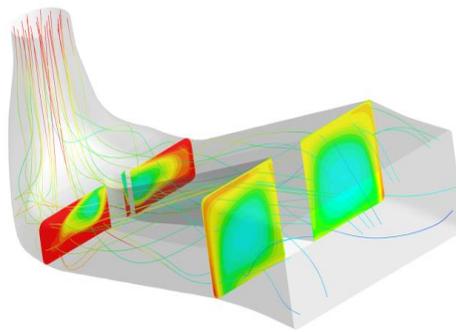
**Figure 4.** Comparison of the blades.



**Figure 5.** Comparison of the achieved local Thoma number along the suction side of the blades at the tip around the discharge edge between the old blade and the new blade.



(a) Flow vectors at mid-span (b) Limiting streamlines on the blade  
**Figure 6.** Internal flow of the blade.



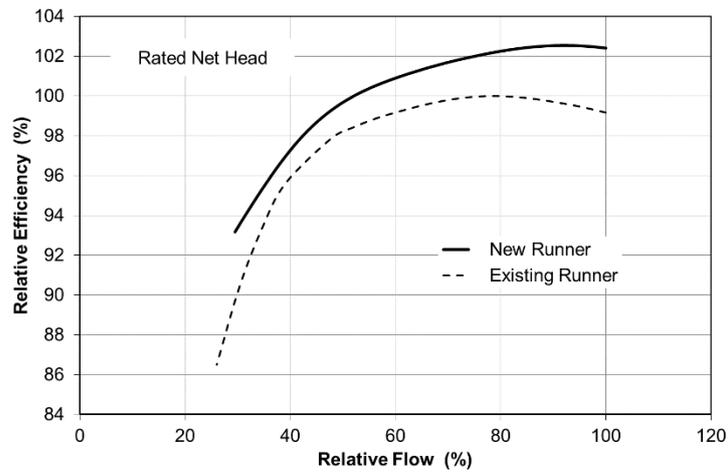
**Figure 7.** Internal flow of the draft tube (streamlines and cross section velocity distribution).

### 3. Verification of the turbine performance

#### 3.1. Model test results

The model test was executed to verify the turbine performance with the final design of the blade and to check if the mechanical limits were satisfied. Main results are summarized as follows.

- Gains in turbine efficiency reached 3% compared to the old blade at a rated operating point. Figure 8 shows relative turbine efficiency.
- Other properties of the blade was shown in the Table 3
- For Deriaz turbines, the blade tip clearance is sensitive to the runner setting elevation compared to other types of turbines. Depending on the runner setting elevation, the loss at the gap flow changes to a large extent. The impact of the runner setting elevation on the efficiency was also investigated in the model test to determine the allowable gap to meet the performance guarantee.



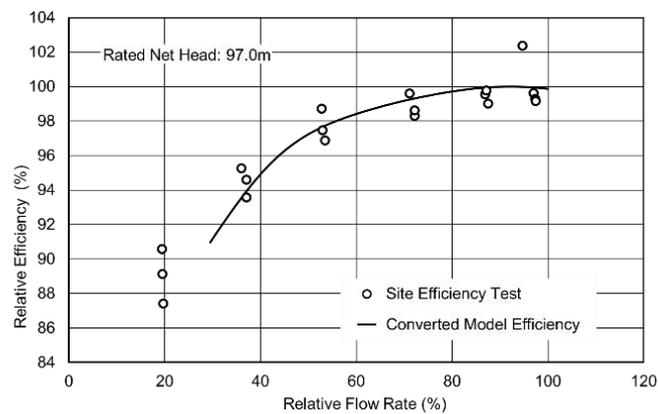
**Figure 8.** Model turbine efficiency.

**Table 3.** The summary of the achievements in the blade development confirmed in the model test.

Design condition	Achievement
Gate opening	Achieved the max discharge within the limit
Blade opening	Achieved the max discharge within the limit
Blade torque	Less than the limit
Axial Thrust	60% to the limit
Runaway	70% to the limit
Cavitation	Better in the simulation and accepted in the model test
Performance	+3% increase at the max discharge
Gap sensitivity to the performance	Achieved the max output within the possible gap increase

### 3.2. Site efficiency test results

The prototype turbine efficiency was measured at site. The Gibson method and the acoustic method were applied for the measurement of the discharge. Figure 9 shows the efficiency test results by the Gibson method. In the plot, the transposed model efficiency to the prototype is also shown for the comparisons. It was confirmed that the prototype efficiency fit well with the performance. As a result, turbine output increased from 48MW to 49.5MW and annual energy generation increase reached to 6.6 GWh.



**Figure 9.** Field turbine efficiency test results.

## 4. Conclusion

The runner blade modernization project of N Deriaz hydropower station was introduced in this paper. The blade only replacement scope was selected along with the overhaul for the turbine maintenance reason and the performance improvement. In the blade development, the existing mechanical limits were the restriction and the lack of recent experiences in Deriaz turbine development was a challenge. To overcome the challenge, a development procedure special for the project was introduced, using state of the art CFD technology and the model test. As the result, within the existing mechanical limits, 3% gain in performance has been achieved and the performance was confirmed in the model test and the prototype machine at site.