Practical Application of High-performance Francis-turbine Runner Fitted with Splitter Blades at Ontake and Shinkurobegawa No. 3 Power Stations of THE KANSAI ELECTRIC POWER CO., INC.

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OVERVIEW: As a first in Japan, two splitter-blade-fitted runners were installed in the Francis turbines at the Ontake Power Station of THE KANSAI ELECTRIC POWER CO., INC., and commercial operation of the first runner unit started in April 2003 and that of the second unit in May 2004. This application is a so-called "scrap and build" project that aims to convert hydraulic turbines that started operations in 1945 into the latest hydraulic turbines with hydraulic-power characteristics that meet the power demands of the present day. Furthermore, the same type of splitter-blade-fitted runner was also installed in the No. 2 Unit of Shinkurobegawa No. 3 Power Station of THE KANSAI ELECTRIC POWER CO., INC., and this unit started commercial operation in January 2005. These runners were substituted for conventional runner in line with meticulous testing. The splitter-blade-fitted runner is a practical application achieved through joint research, utilizing the latest fluid-analysis technology, model testing, strength analysis, etc., between Hitachi and THE KANSAI ELECTRIC POWER CO., INC. Introducing a short "splitter" blade between the blades of a conventional turbine runner has the effect of rectifying the flow, thereby improving the efficiency, under partial loading in particular, and reducing equipment vibration induced by pressure pulsation. The splitter-blade-fitted runner contributes to reducing carbon-dioxide emissions by improving utilization ratio of water resources and suppressing increases in firing at thermal power stations.

INTRODUCTION

HYDROELECTRIC power—which produces "clean" energy from the viewpoint that it does not emit global-warming-accelerating carbon dioxide—plays a crucial

Fig. 1—Water-turbine Runner with Splitter Blades for Ontake No. 3 Power Station of THE KANSAI ELECTRIC POWER CO., INC.
The runner has 13 main blades and 13 splitter blades. Viewed from the inlet side (i.e. horizontally), the number of blades looks like 26, but viewed from the outlet side (i.e. from the bottom), it appears to be 13. The photo shows the runner viewed from the bottom; the outlet of the main blades and the splitter blades (shorter than the main blades) between the main blades can be seen.

role in regards to environmental conservation. At the same time, owing to the various civil-engineering works that accompany the construction of hydro-electric power plants, their influence on the natural environment is undeniable. Under these circumstances, in recent years, attention is being focused on attaining new energy increases by means of modifying existing hydroelectric power plants. In Japan, however, there are a fair number of the hydroelectric power plants that have poor efficiency under partial-load operation according to the relationship between water volume and load adjustment of the electric power system.

Against this background, Hitachi—in a joint research project with THE KANSAI ELECTRIC POWER CO., INC.—has developed a Francis-turbine-type runner with splitter blades for improving efficiency under partial-load operation (see Fig. 1). In regards to recent upgrading of equipment at hydropower plants, this Francis-turbine-type runner was installed for the first time in Japan at two power plants, namely, Ontake Power Station (two runner units) and Shinkurobegawa No. 3 Power Station (one unit).

In the rest of this paper, the characteristics of the developed Francis-turbine-type runner with splitter blades are described, and some results regarding actual on-site application of the runner are presented.

FEATURES OF WATER-TURBINE RUNNER WITH SPLITTER BLADES

Structural Characteristics

Fig. 2 shows a 3D schematic image of the splitter-blade-fitted Francis-turbine runner with the shroud ring removed. With uniform blade inlet diameters, the main blades and the splitter blades (which are shorter) are arranged alternatively. As a result of this blade configuration, the runner has the following main characteristics:

(1) There are fewer blades on the runner-outlet side, so the blades can be lengthened toward the downstream side (i.e. the internal-diameter side). By doing so, the whirl flow at the outlets of the runner is lessened, resulting in:

(a) Improved variable discharge characteristics and improved turbine efficiency under both partial-load operation and maximum-power-output operation.

(b) Whirl flow in the draft tube under both partial-load operation and maximum-power-output operation is lessened; draft vibration, head-cover vibration, and low-frequency vibration are suppressed.

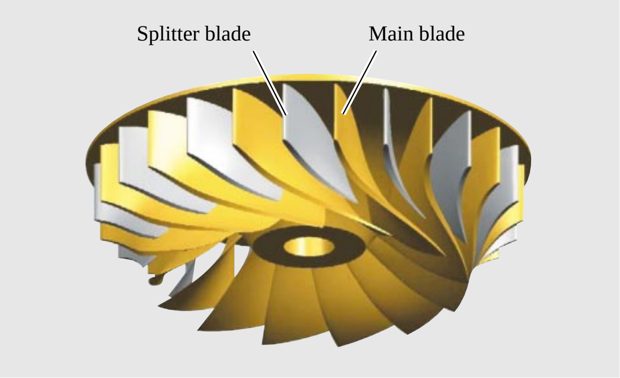

Fig. 2—Schematic Diagram of Water-turbine Runner with Splitter Blades.
Length of the splitter blade is varied from the turbine specification.

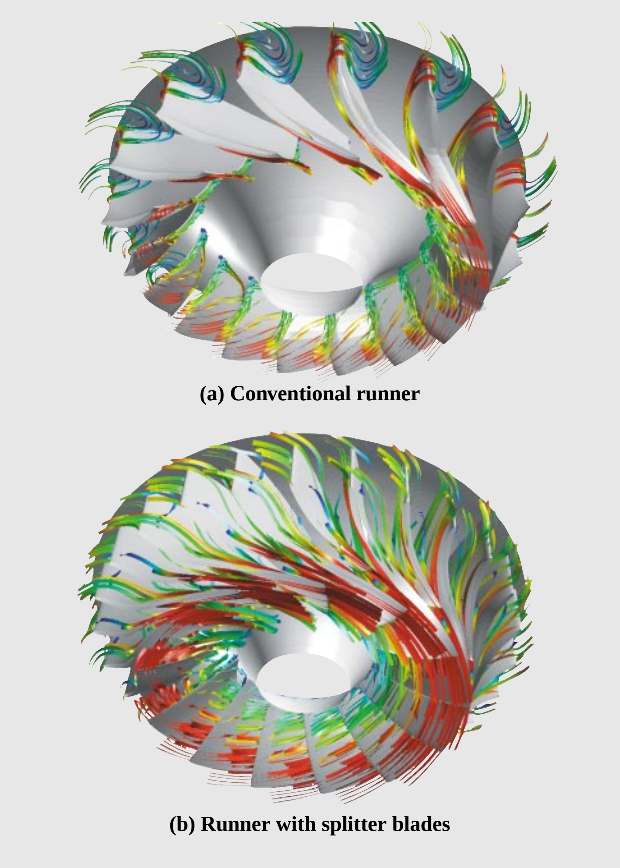

Fig. 3—Flow Pattern in Runner.
Bands show lines of flow, and as the color gets richer, the flow speed increases.

(2) Increased blades on the runner-inlet side means that:

(a) Blade load on the runner-outlet side is eased, so the cavitation characteristics on the outlet side are improved.

(b) Load per blade is reduced, so cavitation at the

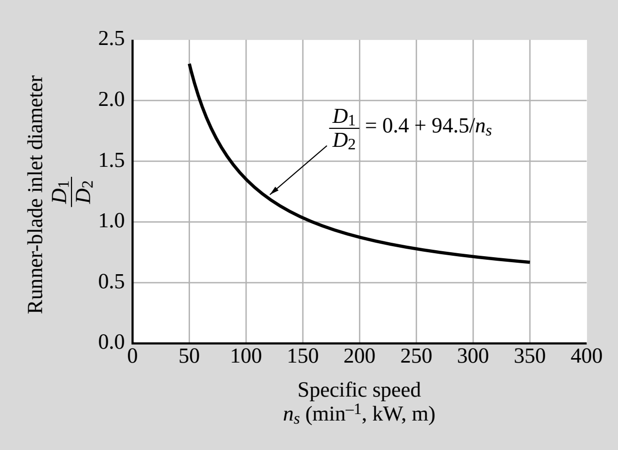

Fig. 4—Relationship between Inlet Diameter and Outlet Diameter of Runner of Francis Turbine.
Specific speed of 150 or less is the optimum operation range for a splitter-blade-fitted runner.

TABLE 1. Specifications of Francis Turbines Applied in Actual Units of Target Power Stations
The table lists the specifications for Ontake Power Station and Shinkurobegawa No. 3 Power Station of THE KANSAI ELECTRIC POWER CO., INC.

Power station	Ontake	Shinkurobegawa No. 3
Type	VF-1RS	VF-1RS
Maximum head	229 m	290 m
Maximum output	23,800 kW	60,000 kW
Revolution speed	600/500 min^{-1}	450 min^{-1}
Runner diameter	1,575.2 mm	2,256 mm
Turbine specific speed	104 min^{-1}, kW, m	92 min^{-1}, kW, m

inlet becomes more difficult to generate.
(c) Flow at the inlets becomes difficult to detach, so variable head characteristics are improved.

Flow Pattern

Fig. 3 shows the flow pattern in the runner determined by turbulent flow analysis for partial-load operation. In the case of the conventional runner, the flow at the tips of the blade inlets separates into a curled state, and close to the blade outlets, the flow is skewed toward the shroud side. In the case of the splitter-blade-fitted Francis-turbine runner, it is clear from the figure that the splitting of the flow at the tips of the blade inlets is suppressed. Furthermore, in the interior of the runner, there is no skew of the flow in the direction of the crown shroud, and the out flow through the blade outlets maintains that state. Transformation in the complexion of the flow in this manner brings about an improvement in turbine efficiency.

Specific-speed Application

According to the approximation for past data[(1)], the relationship between the ratio of runner outlet diameter of a normal Francis turbine (D_2) and runner-blade inlet diameter (D_1) and specific speed (ns) is plotted in Fig. 4. In the case of the splitter-blade-fitted runner, since the splitter blades are mounted on the blade-inlet side, the result is more improved characteristics with longer blades and a tapered flow path in the runner. Given this fact, $D_1/D_2>1$ is ideal. Accordingly, a specific speed of 150 or less is the optimum operation range for a splitter-blade-fitted runner.

APPLICATION TO ACTUAL MACHINES

Power-plant Specification

Table 1 lists the specifications for the Francis turbines of Ontake Power Station and Shinkurobegawa No. 3 Power Station of THE KANSAI ELECTRIC POWER CO., INC.

Fluid Design

As for the fluid design of the runner, the first time one had been applied at the Ontake Power Station, performance design was carried out by CFD (computational fluid dynamics), and the design was validated by model testing. As for the splitter-blade-fitted runner installed at the Shinkurobegawa No. 3 Power Station, since the effectiveness of design by CFD was confirmed from the results for the Ontake Power Station, fluid design by CFD only was performed (i.e. modeling was not needed). According to the results of these design procedures, in the case of both power stations, the number of blades in the runner is 13 main blades and 13 splitter blades.

Manufacture of Runner

The splitter-blade-fitted runner has a welded structure composed of three main parts: crown, shroud, and blades. Since the runner is a welded structure, before welding, the crown, shroud, and blades each are exclusively finished by NC (numerical-control) machining. In the welding procedure, the amount of welding deformation is estimated in advance, and the crown, shroud, and blades are assembled temporarily according to the estimated deformation.

On-site Testing

At the Shinkurobegawa No. 3 Power Station, model testing could be omitted, so on-site efficiency testing was carried out, and CFD (computational fluid dynamics)-determined characteristics of the splitter-blade-fitted runner were compared with measured characteristics of an existing runner (measured before the runner was replaced). These CFD and measurement results are shown in Fig. 5. According to this figure, the measured efficiency characteristic of the splitter-blade-fitted runner, compared with the measured efficiency of the existing runner at the power plant, shows an improvement of 7% at maximum efficiency and 11% at partial loading of 40%. Similarly, in the case of the splitter-blade-fitted runner, CFD-estimated efficiency is in accordance with the measured efficiency.

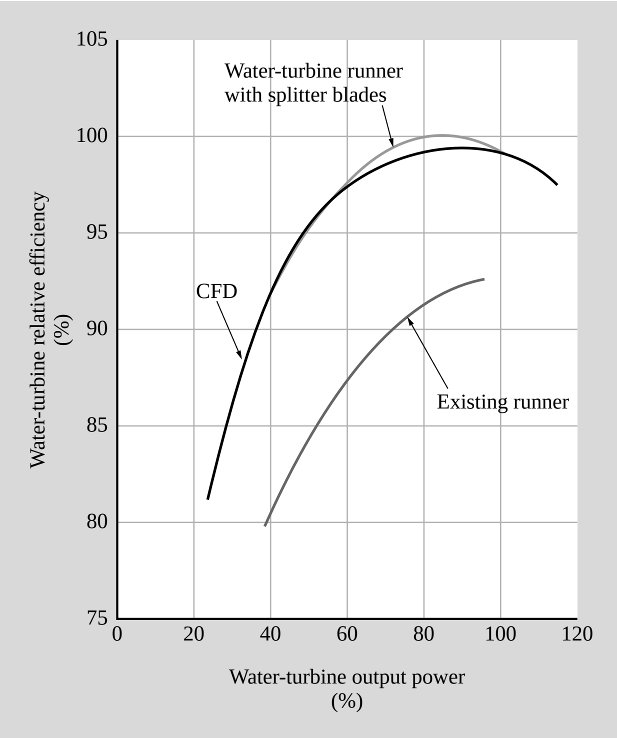

Fig. 5—On-site Efficiency Test Results for Shinkurobegawa No. 3.
The graph plots an estimation of the output-power ratio of the water-turbine runner with splitter blades against an efficiency ratio.

Fig. 6 compares vibration measurement results for each part in the turbine (i.e. main guide bearing case and draft pipe) in the cases of the existing runner and the splitter-blade-fitted runner. According to the graph, since the vibration level of the splitter-blade-fitted runner is significantly lower in the case of both parts, it can be concluded that the operation condition of the turbine equipment is improved.

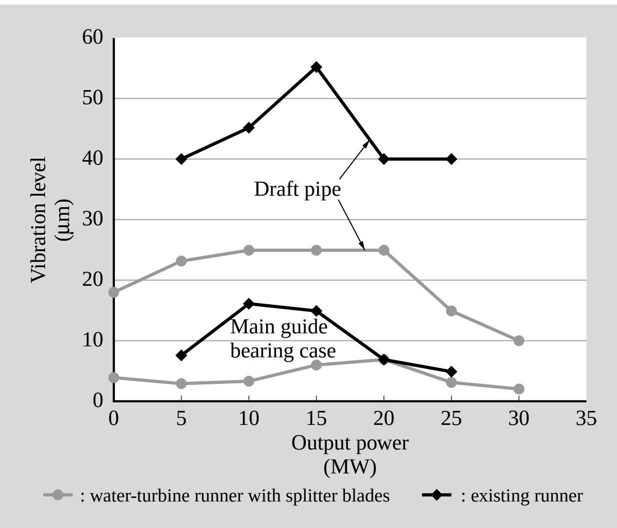

Fig. 6—Measurement Results on Vibration between Turbine Metal Case and Draft Pipe.
It shows the vibration characteristics under partial loading (when the vibration level is high).

CONCLUSIONS

This paper described the characteristics of a splitter-blade-fitted runner and presented the results of its practical application at Ontake Power Station and Shinkurobegawa No. 3 Power Station of THE KANSAI ELECTRIC POWER CO., INC. In the case of at the Ontake Power Station, annual generated power output as a result of improved efficiency is estimated to increase by 5 million kWh, and the consequent CO_2 reduction is forecast to be 3,200 t per year. Moreover, although wear-out of parts by silt erosion is severe at the two power plants described here, the splitter-blade-fitted runner applies a rectifying influence on the flow, so the degree of collision of silt passing through the runner with the runner blades is lowered, and the amount of wear-out is expected to be less. Although on analysis level, compared with the amount of wear at the blade outlets of a conventional runner, that of the splitter-blade-fitted runner can be decreased by 90%[(2)]. By applying the splitter-blade-fitted runner, the lifetime of the runner can be extended.

Amid calls for measures to reduce global warming, Hitachi will continue its efforts to develop and design turbines that satisfy environmental-conservation concerns while further improving efficiency.

ACKNOWLEDGMENTS

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Ontake Power Station and Shinkurobegawa No. 3 Power Station, the authors sincerely thank all those concerned at THE KANSAI ELECTRIC POWER CO., INC. for their valuable guidance and advice.

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