Completion of Turbine Replacement with 54-inch Blade Low Pressure Turbine at KRSKO Nuclear Power Plant with Very Short Outage Period

HIROMU SAGIMORI*1
HIROHARU OOYAMA*2
TATSUYA FURUKAWA*2
HIROSHI OTAGURO*1

KRSKO Nuclear Power Plant (700 MW class) in the Republic of Slovenia replaced its low-pressure turbine rotor with a monoblock type low-pressure turbine from Mitsubishi Heavy Industries, Ltd. (MHI) as a measure against stress corrosion cracking in April 2006. The replacement work was completed in a very short period, 27 days, and the plant is now operating steadily with a satisfactory performance improvement. MHI longest blades, 54 inches, were fitted to this turbine for the first time in a plant. The turbine is made of low-strength material against stress corrosion cracking owing to eliminating the keyway structure and has lower stress due to its monoblock rotor. This paper reports the design, operation, and replacement work of the low-pressure turbine with 54-inch blades.

1. Introduction

KRSKO, the only nuclear power plant in Slovenia, started commercial operation in 1983 in the days of the former Yugoslavia. It supplies power not only to Slovenia but also to Croatia and other neighboring nations (**Fig. 1**).

Originally, a steam turbine from Westinghouse of the United States was used. This was replaced with a 54-inch blade low-pressure turbine monoblock rotor from MHI in April 2006 as a measure against stress corrosion cracking of the low-pressure turbine rotor and to enhance the power output.

2. Outline of Replacement Work

2.1 Outline of KRSKO

The plant specifications of KRSKO are shown in **Table 1**. The original low-pressure turbine was a Westinghouse shrunk-on 44-inch rotor.

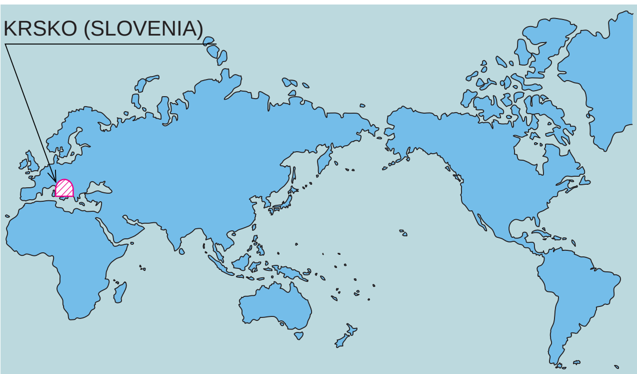

Fig. 1 Location of KRSKO, Slovenia

Table 1 Plant specifications of KRSKO

Item	Specifications
Reactor Type	Pressurized Water Reactor
Number of Steam Generators	2 pcs
Steam Generator Thermal Output (MWth)	2 000
Cycle Frequency (Hz)	50
Turbine Type (before replacement) (after replacement)	TC4F-44 TC4F-54
Rated Output (MW)	727
Turbine Inlet Steam Pressure (MPa)	6.2
Turbine Rotating Speed (rpm)	1 500
Generator Capacity (MVA)	813

2.2 Scope of replacement of low-pressure turbine

The scope of replaced components is shown in the colored area in **Fig. 2**. In addition to the low-pressure turbine rotor exposed to stress corrosion cracking, the inner casing, journal bearing, thrust bearing, jack shaft, gland, oil retaining ring and other parts were also replaced. These replaced components contributed to a short outage period, the capability of the longer 54-inch blade application and reliability enhancement.

3. Design of New Low-Pressure Turbine

The existing mechanical design of KRSKO was not available, so the following measures were taken to install the high-efficiency and high-reliability low-pressure turbine in a short outage period.

*1 Takasago Machinery Works
*2 Power Systems Headquarters

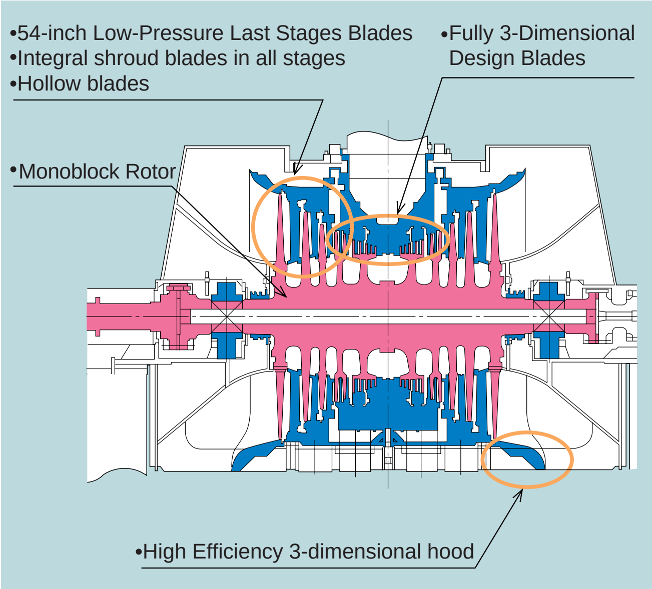

Fig. 2 Scope of Low-Pressure Turbine Replacement (colored area)

Fig. 4 Mounting of Torsional Vibration Measuring Pickups

3.1 Dealing with existing turbine

(1) Three-dimensional measurement of existing turbine

During the overhaul inspection of the turbine, the interface sections with the existing machine were measured three-dimensionally. The data was then fed back to the structural design of the new turbine. This meant that the machining work in the field could be reduced and interference was prevented. Consequently, replacement work was conducted smoothly. Examples of the measurement results are shown in **Fig. 3**.

(2) Torsional vibration measurement of existing turbine in the field

The natural torsional frequency of the existing machine was measured because the generator was out of scope and it had unknown torsional vibration characteristics. Using the three-dimensional measurement results, a bracket for the pick-ups was designed which could be installed on a narrow pedestal. The pick-ups were installed onto the bracket to measure the natural torsional frequency (**Fig. 4**). The results coincided closely with the predicted values, and a torsional natural frequency near 100 Hz, which is particularly important for design, was less than 0.1 Hz different from the predicted value. As a result, the validity of the analytical model of torsional vibration including the generator was verified, and high torsional vibration reliability was realized.

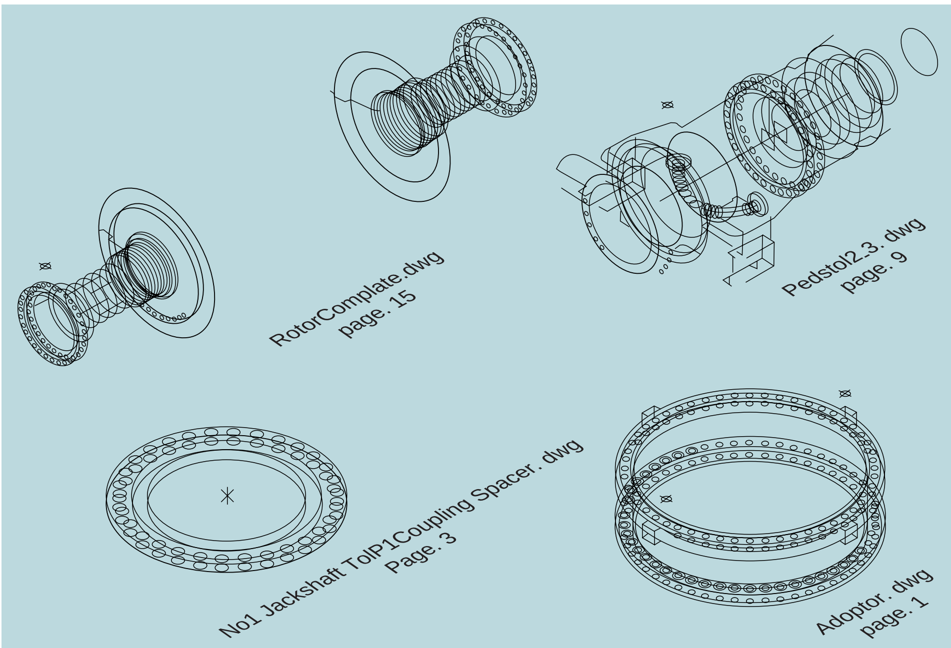

Fig. 3 Examples of 3-Dimensional Measurement

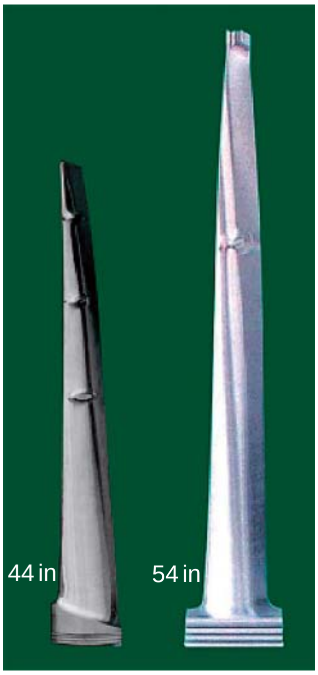

Fig. 5 44-inch Blade and 54-inch Blade


Fig. 6 New Low-Pressure Turbine Rotor

Fig. 7 Delivery of Low-Pressure Turbine Rotor to High-Speed Balancing Facility

3.2 Higher efficiency technology

The following latest high-efficiency techniques were applied to the new low-pressure turbine, and high performance was realized.

- 54-inch integral shroud blades application
- Hollow blade application
- Flow optimization by three-dimensional computational fluid dynamics in all blades
- High-efficiency three-dimensional hood
- Optimization of inlet chamber shape to blades
- Optimization of seal portion shape

(1) Application of 54-inch last blades

The low-pressure last blades were changed from the existing 44-inch group blades to 54-inch integral shroud blades, MHI's longest blades, by extending the blade length by ten inches in order to decrease the exhaust loss (**Figs. 5** and **6**). In the development and verification stages of the 54-inch blades(1), rotating tests with full-scale blades and comprehensive verification tests with a scale model of L-3 to L-0 stages using actual steam were conducted. The reliability of the last-stage blades was confirmed through these tests. Additionally before the rotors were shipped, the natural frequencies of the rotating blades were measured under actual rotating conditions in a high-speed balancing facility and the separation from resonance was confirmed. The natural torsional frequencies were also measured in the high-speed balancing facility, and soundness against blade-shaft coupled torsional vibration was confirmed. **Figure 7** shows a delivery scene to the testing facility.

In the stationary blades of the last three low-pressure stages, hollow blades of the drill hole type were applied, and higher efficiency and lower erosion were realized by drainage removal.

(2) Integral shroud blades with fully three-dimensional design

The new low-pressure turbine consists of ten reaction blade stages including the 54-inch last-stage blades. High performance technology using integral shroud blades in all reaction blades is based on a highly reliable design confirmed in previous replacement work(2). Analysis by three-dimensional computational fluid dynamics was applied to all blades, and the flow path was optimized.

3.3 Measures against stress corrosion cracking

(1) Use of low-strength material

Stress corrosion cracking of steam turbine rotors is connected to the rotor material strength(3). Material of low yield strength is used in the new low-pressure turbine rotor, and resistance to stress corrosion cracking is improved.

(2) Use of monoblock rotor

Susceptibility to stress corrosion cracking is connected to the loaded stress. The monoblock rotor does not require the keyway structure that is needed by the shrunk-on rotor, so stress concentration in the keyway can also be eliminated, and resistance to stress corrosion cracking is improved.

Fig. 8 Scene of Replacement Work

Furthermore, the shaft and discs of the monoblock rotor are integrated and the sectional area of the disc is consequently increased. Therefore the average stress can be decreased and resistance to stress corrosion cracking can be improved.

3.4 Other technologies for higher reliability and performance

The new low-pressure turbine is further enhanced in reliability and performance by employing other techniques, such as large blade attachment structure, larger bearing size, high-efficiency three-dimensional hood, optimization of the inlet chamber shape to blades, and optimization of the seal section shape.

4. Replacement Work

This operation was a big project for Slovenia's only nuclear power plant, and attracted wide attention among the population and mass media. The scheduled work period was only 28 days, about half the period of conventional replacement work, 60 days, of low-pressure turbines in Japan, so there was little margin for error.

The field work period was shortened by preparatory steps in design, such as replacing the inner casings, jack shafts, glands, and oil retaining rings, fitting hydraulic coupling bolts and hydraulic wrench for inner casing bolts and preparing spare parts for work. The field work period was also shortened by a strict schedule plan, the employment of skilled field workers, cooperative negotiations with the customer, and a three-shift working system. As a result, the replacement work was completed in 27 days, one day earlier than planned. A replacement work scene is shown in **Fig. 8**.




Hiromu Sagimori   Hiroharu Ooyama   Tatsuya Furukawa   Hiroshi Otaguro

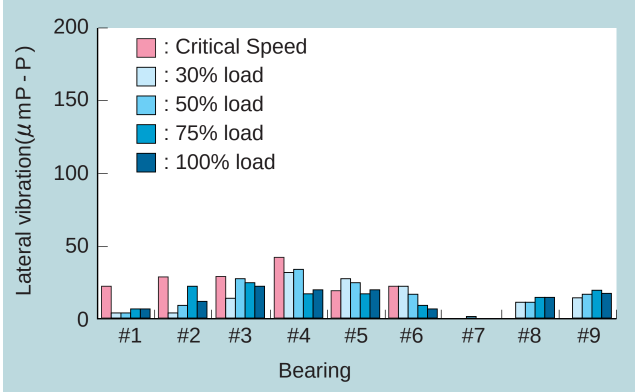

Fig. 9 Lateral Vibration Record upon startup

5. Operation of New Turbine

After completion of the replacement work in April 2006, operation was successfully started after one session of high-pressure turbine balancing in May, and immediately reached rated thermal power operation. **Figure 9** shows the lateral vibration results in the commissioning stage. It is acceptably small at about 50 μmp-p at critical speed during startup, and 25 μmp-p or less at 100% load with no unusual vibration changes during load increase, and very favorable vibration characteristics were confirmed. The electrical output at the generator end after replacement was higher than the design output. The electrical output increased by about 4.5% in high vacuum operation comparing with the design output before replacement, and the actual performance reached the expected performance. As a result of the operation, the utility of the present high-efficiency technology has been verified.

6. Conclusions

The low-pressure turbine of the KRSKO Nuclear Power Plant was replaced with a 54-inch blade turbine with a monoblock rotor. The work period was extremely short, 27 days, less than half that of conventional replacement work of low-pressure turbines in Japan. Favorable lateral vibration characteristics and a turbine performance higher than expected were confirmed, and satisfactory operational records were obtained.

MHI will continue to develop new technologies which contribute to society, and will concentrate its further efforts on building a firm and stable future.

References

(1) Watanabe et al., Development of High Efficiency and Reliability Low Pressure End Blade, Mitsubishi Juko Giho Vol.38 No.2 (2001) p.92
(2) Watanabe et al., Application to Nuclear Turbines of High-Efficiency and Reliable 3D-Designed Integral Shrouded Blades, Mitsubishi Heavy Industries Technical Review Vol.36 No.1 (1999) p.11
(3) Itoh et al., Strength Dependence of Intergranular Stress Corrosion Cracking Susceptibility on 3.5% NiCrMoV Steel at 403K, Material Science Research International Vol.10 No.1 (2004) p.33