

Application of World's Longest 50/60-Inch Titanium Blades for Large Fossil Power Plants



TAKESHI KUDO*1

YUTAKA YAMASHITA*2

KOJI OATA*3

HIDEO YODA*2

As a role of energy equipment manufacturers in dealing with environmental problems, in addition to energy resource issues and CO₂ emissions control, there is increasing demand to reduce the environmental impact of products considering their lifecycle, namely cost reduction of power plant construction and operational cost. Mitsubishi Hitachi Power Systems, Ltd. (MHPS) has developed 50-inch and 60-inch titanium alloy blades, the world's largest blade length for full-speed (3,000 rpm and 3,600 rpm) steam turbines using the latest design and verification technologies. The construction of large coal-fired power plants applying these turbine blades has been completed in Poland and Korea. The commercial operation of these plants has commenced and they continue to operate stably. This paper describes the contents of the development design and verification test of the long blade and the outline of the applied power plant, and introduces some of the technology of MHPS's power plants.

1. Introduction

The low pressure final stage of a steam turbine is one of the most important elements that determine the performance, reliability and overall configuration of the turbine because of its high output load. Longer blades for the last stage can contribute to a reduction of building size due to a decrease in the number of turbine cabins, as well as a reduction in terms of construction cost including equipment manufacturing expenses, in addition to improved efficiency by lowering exhaust loss and increasing single turbine capacity. MHPS developed the world's largest class of 50-inch and 60-inch titanium last stage blades (50/60 LSB)⁽¹⁾. These blades meet recent demand for CO₂ emissions reduction and expectations for higher efficiency in large-capacity coal-fired power plants of over 1000 MW. In this paper, various verification examples carried out in the development of the blades are introduced, and examples of application in actual machines are described.

2. Basic design

Table 1 lists the specifications of the developed blades. As the material of the developed blade, Ti-6 Al-4 V, which has been used for long steam turbine blades for more than 30 years, was adopted. The blade structure is an integral shroud structure in which adjacent blades are connected in contact with each other at the tip and middle of the blade by means of torsion return by centrifugal force. The straight axial entry type, which offers abundant application examples and high reliability, is applied to the blade root which fixes the blade to the rotor. The 50/60 LSB has an identical design reflecting the difference in rotational speed.

*1 Manager, Steam Turbine Engineering Department, Steam Turbine Technology & Production Integration Division, Mitsubishi Hitachi Power Systems, Ltd.

*2 Chief Staff Manager, Steam Turbine Engineering Department, Steam Turbine Technology & Production Integration Division, Mitsubishi Hitachi Power Systems, Ltd.

*3 Steam Turbine Engineering Department, Steam Turbine Technology & Production Integration Division, Mitsubishi Hitachi Power Systems, Ltd.

Table 1 50/60-inch LSB basic specifications

	50-inch	60-inch
Turbine speed (rpm)	3,600	3,000
Blade height (mm)	1,250	1,500
Annulus Area (m ²)	11.5	16.5
Blade material	Ti -6 Al -4 V alloy	
Blade root form	Straight axial entry	

(1) Performance

The tip peripheral velocity of the newly-developed blade exceeds 780 (m/s), so it is necessary to design a turbine blade profile with reduced supersonic flow loss. On the other hand, since the peripheral velocity of the blade root is relatively low, it is necessary to reduce the loss as much as possible in the flow field with strong three-dimensional characteristics affected by the difference in the peripheral velocity in the blade height direction and the rotating flow accompanied by rotation. For these performance issues, meridional flow line curvature control was implemented by means of a proprietary three-dimensional stage turbulence analysis method to verify the calculation accuracy, and designs of the stationary blade profile, peripheral wall shape in meridional and rotor blade profile were created ⁽¹⁾.

Figure 1 shows an example of the calculation of the Mach number distribution between stationary blades and rotating blades. The loss is reduced by optimizing the relative Mach number of the stationary blade outflow and rotating blade inflow.

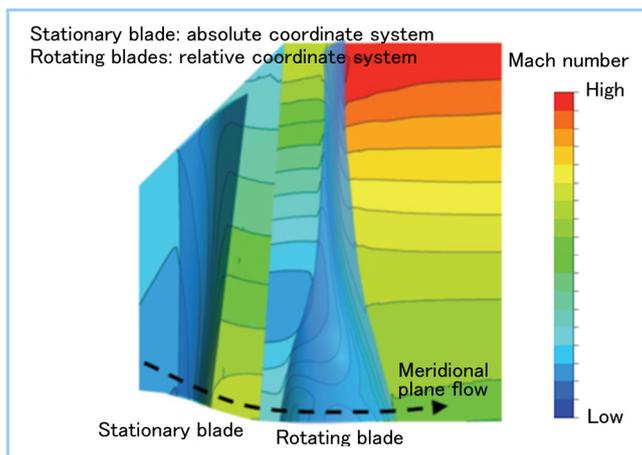


Figure 1 Three-dimensional flow analysis results (Mach number distribution on meridional plane)

(2) Strength

Titanium alloy is used as the blade material to reduce centrifugal load. Therefore, a long blade with the world's largest annulus area was realized, while the conventional material (3.5. Ni-Cr-V Steel) was used for the rotor. Titanium alloys are not only lightweight, but are also superior to steel in terms of corrosion fatigue and stress corrosion cracking, which are problems of turbine blades used in wet areas such as low-pressure final stage blades.

To increase the rigidity and vibration damping of one assembly blade structure, a contact connection structure was adopted for this airfoil. Since the contact force acts on the contact area during turbine rotation, it is important to have sufficient resistance against fretting fatigue and wear of the contact surface. A test method that can simulate the dynamic characteristics of the contact area was devised ⁽²⁾, and the optimum design of the contact area shape was made to ensure sufficient strength and avoid excessive wear. **Figure 2** illustrates the static stress distribution during blade rotation. The strength integrity was confirmed without exceeding the design-allowable stress at all positions of the blade.

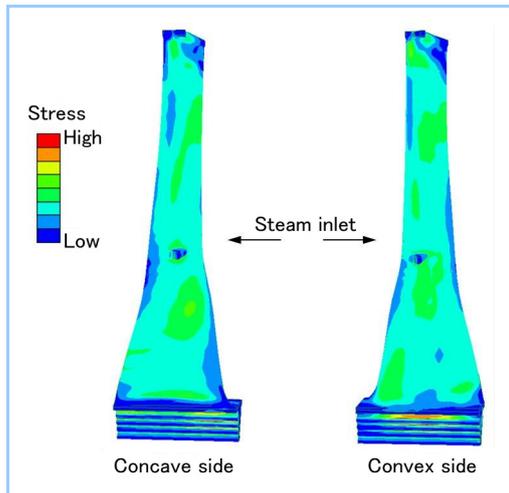


Figure 2 Static stress distribution

(3) Vibration

This blade structure has a structure in which the entire circumference forms one ring, and forms a vibration mode similar to that of a disk as shown in **Figure 3**. These vibration modes resonate at an integer multiple of the rotational speed, but it is essential to avoid resonance in a low-order vibration mode in which the vibration stress is particularly large. It is also necessary to suppress the occurrence of rotational asynchronous vibration, such as flutter or random vibration, which is influenced by the state of steam flow. These vibration responses are predicted and analyzed in advance using vibration analysis⁽³⁾ reflecting the contact state of the blades, and then verified by verification tests.

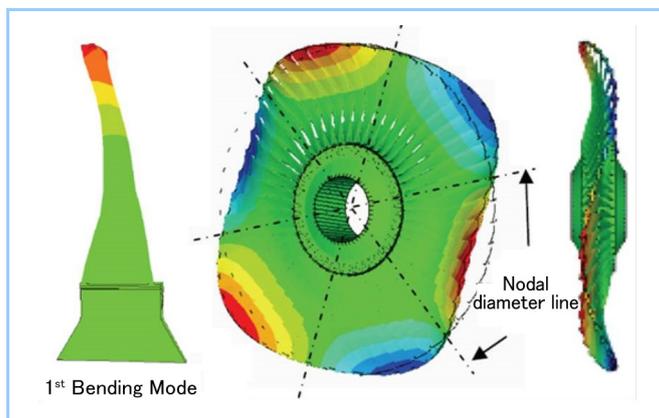


Figure 3 Vibration mode diagram (Example of 3 nodal diameters)

3. Verification test

(1) Actual load performance test

Figure 4 depicts the appearance of the test turbine installed in the test facility, and **Figure 5** presents the layout of the test turbine. This test facility is equipped with a boiler, a condenser, a cooling tower, etc., and can simulate the operating conditions of an actual machine over a wide range. **Figure 6** shows the test turbine for the demonstration. The turbine has four stages including the low-pressure last stage blades. For the 50/60 LSB, conditions for which various operating conditions were simulated were set, and reliability verification through vibration stress measurement of moving blades and performance verification through the measurement of internal pressure and temperature were conducted. **Figure 7** gives an example of the turbine performance characteristics. This figure presents the results of measuring the turbine efficiency characteristics with respect to the steam flow rate at the final stage outlet by changing the steam flow rate and the degree of exhaust vacuum. It was confirmed that the turbine performance was in good agreement with the prediction in the applicable flow velocity range.

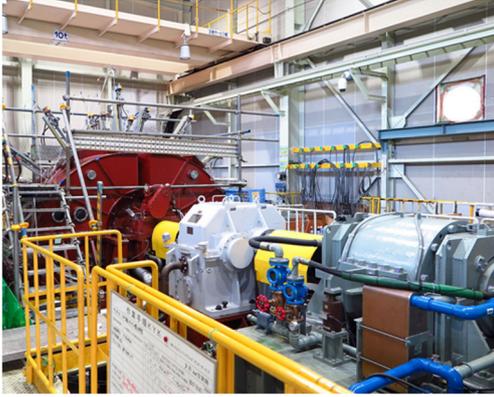


Figure 4 Steam turbine in the test facility



Figure 6 Test turbine

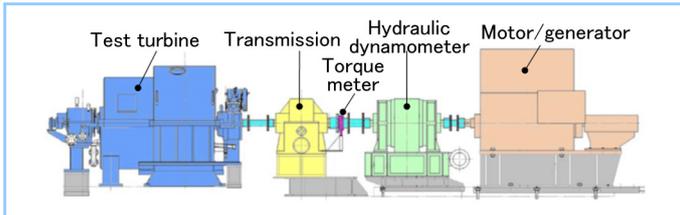


Figure 5 Layout of test turbine facility

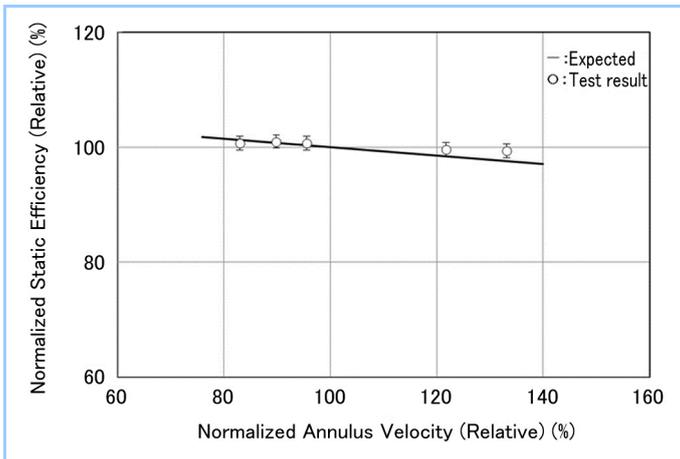


Figure 7 Test results of turbine performance

(2) Verification of reliability of rotating blades

It was verified that rotational asynchronous vibration such as random vibration and flutter, which are influenced by steam flow during operation, does not pose a problem in terms of reliability in actual machines. A telemeter was installed on the actual rotor, and measurements were carried out using a measuring device mounted on the rotating blade for the purpose of avoiding resonance during operation and confirming the asynchronous vibration level. **Figure 8** is an example of the measurement results of the asynchronous vibration stress of a blade during operation. It was confirmed that the asynchronous vibration was sufficiently lower than the design-allowable stress (100% of the graph's vertical axis) in the operational range from the plant partial output to the rated output.

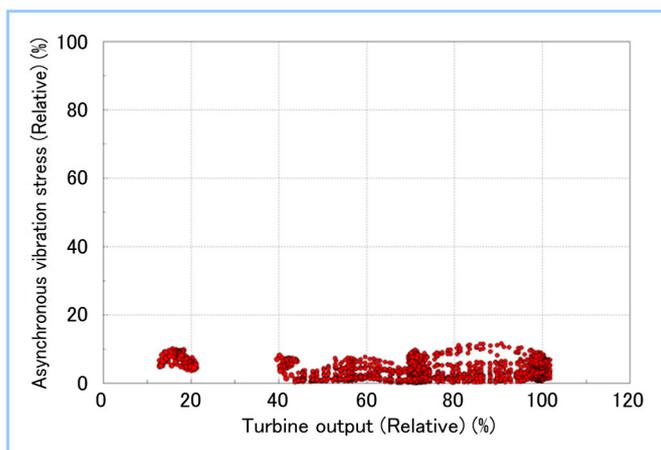


Figure 8 Asynchronous vibration stress

4. Examples of application in actual machines

The 3000 rpm 60-inch titanium blades have been put into practical use in the steam turbine of a 1075 MW coal-fired plant for the ENEA Wytwarzanie S.A. Kozenice power plant No. 11 unit in Poland. **Figure 9** depicts the appearance of the steam turbine and **Figure 10** illustrates its structure. The plant is a joint order with a consortium partner, Polimex-Mostostal S.A., and MHPS supplied the boiler, the generator, the environmental equipment and the steam turbine. The contract was signed in September 2012, and commercial operation started in December 2017 after trial operation. The turbine type is a tandem compound TC4F type with single-shaft series structure, and the steam condition is ultra-supercritical pressure in which the main steam pressure is 25 MPa, the main steam temperature is 600°C and the reheat steam temperature 620°C. The plant efficiency met the planned value, and the resulting CO₂ emissions could be reduced by 25% compared with many subcritical coal-fired power plants in Poland. In addition, the Environmental Regulations for Air Pollutants, Industrial Emissions Directive (IED) requirements, which will come into effect in 2021, have been significantly exceeded. Furthermore, 60-inch titanium blades will be applied to a 660 MW supercritical coal-fired power plant in Greece.



Figure 9 Poland Kozenice power plant No. 11 unit

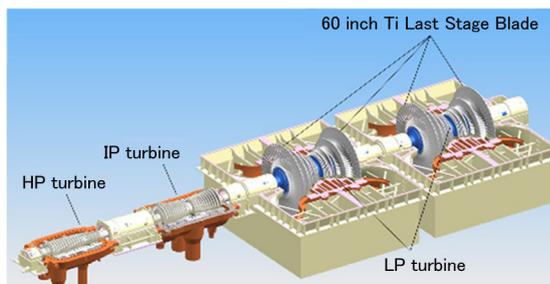


Figure 10 Structure of 1075 MW steam turbine with 60 inch Last Stage Blade

On the other hand, 3600 rpm 50-inch titanium blades were adopted in a 1050 MW supercritical coal-fired power plant for Tai'an No. 9 unit and No. 10 unit of Korea Western Power Co., Ltd., and commercial operations of the No. 9 unit in October 2016 and No. 10 unit in June 2017 commenced after construction and trial operation. These plants have the largest capacity among thermal power plants in South Korea and play a role in the stable supply of electricity to the Korean capital.

These plants are operating satisfactorily, contributing to the stable supply of electricity and CO₂ emissions reduction in Poland and South Korea.

5. Conclusion

Developed using the latest design technology and validation methods, the 50/60 LSB has been applied to high-capacity coal-fired power plants in Poland and South Korea and is contributing to the stable supply of electricity globally. Although the construction of coal-fired

power generation plants is decreasing from the perspective of CO₂ emissions, it is difficult to stably supply electricity using only renewable energy to meet the electricity demand resulting from economic development on a global scale. For this reason, technological development of CCUS (Carbon dioxide capture, utilization and storage) that captures CO₂ and actively uses it has seen progress in recent years. Along with these new technologies that make effective use of CO₂, this blade is expected to be utilized in the future as a technology for high-capacity and high-efficiency coal-fired power plants to play a role in energy mix optimization.

References

- (1) Shigeki Senoo, et al, "Development of Titanium 3600rpm-50inch and 3000rpm-60inch Last Stage Blades for Steam Turbines", *Proceedings of IGTC 2011*, IGTC2011-0249, (2011), pp. 1-8.
- (2) Kunio Asai, et al, "Experimental Validation of Fretting Fatigue Strength and Fretting Wear Rate at Contact Surface of Turbine-Blade-Shroud Cover", *Proceedings of ASME Turbo Expo 2012*, 0GT2012-68576, (2012), pp.1-8.
- (3) Yutaka Yamashita, et al, "Vibration characteristics of a continuous cover blade structure with friction contact surfaces of a steam turbine", *10th International Conference on Vibrations in Rotating Machinery*, (2012), pp.323-332.