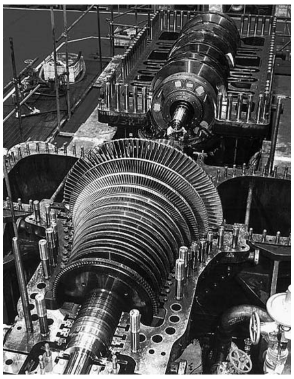

Improved Technologies of Steam Turbine for Long Term Continuous Operation

SUMIO NODA*[1] YOSHIKAZU YAMADA*[2]
SATORU ZENITANI*[2] TOMOYOSHI SASAKI*[3]

There are increased demands in recent years for improved reliability and sustainable efficiency of the mechanical drive steam turbines for long-term continuous operation of machines used in petrochemical plants for ethylene, ammonia, etc. from the standpoint of energy saving and maintenance cost reduction. This paper introduces: (1) high-reliability thrust bearings for high speed and high load condition, (2) the technology for preventing the solid particle erosion of speed-control stage nozzle caused by scales from boiler, (3) the technology for preventing the drain erosion of low-pressure stage blade caused by collision with the waterdrops contained in wet steam, and (4) the technology for improving reliability through application of fouling removal technology to the actual machine in order to improve the deterioration of efficiency during long-term operation.

1. Introduction

In recent year there are increasing demands for improved reliability and sustainable efficiency of the mechanical drive steam turbines for long-term continuous operation of machines (**Fig. 1**) used in petrochemical plants for ethylene, ammonia, etc. from the standpoint of energy saving and maintenance cost reduction. This paper introduces the technologies given below, developed and applied to actual machine for improving reliability for long-term continuous operation.

(1) Improved thrust bearing (thrust bearing)
(2) Coating technology (speed-control stage nozzle and last stage blade)
(3) Fouling removal technology (intermediate-stage nozzle and blade)

Fig. 2 shows the section of the steam turbine, with the improved technologies in the parentheses above indicating the examples of the main parts where the said technologies are applied.

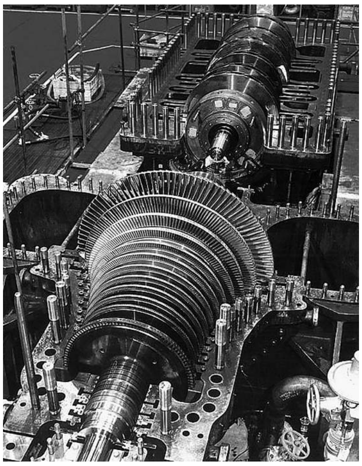

Fig. 1 MHI turbine and compressor

2. Improved Thrust Bearing

The mechanical drive steam turbine of Mitsubishi Heavy Industries, Ltd. (MHI) requires compact bearing aiming at high-speed revolution and small installation space depending on the characteristics of the driven machines such as compressor, etc. in order to improve the plant efficiency. Further, the thrust bearing, subjected to high-speed and high-load operation, had the bearing metal temperature increased, and was likely to cause deterioration of the degree of reliability allowance.

On the other hand, there is a strong demand from the end users for substantial allowance of the measured values against the specified values at operation from the standpoint of operation and maintenance, with the need for reducing the temperature of the bearing metal being particularly high.

In order to solve the aforesaid problems, the following items have been applied to the thrust bearing to ensure high reliability.

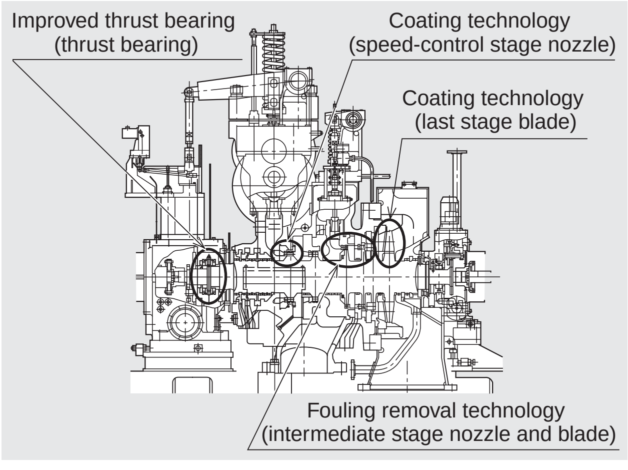

Fig. 2 Section drawing with applying of new technologies

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*1 Hiroshima Machinery Works
*2 Hiroshima Research & Development Center, Technical Headquarters
*3 MHI Turbo-Techno Co.

(1) Direct lubricating system
(2) Improved leveler
(3) Pad back metal: Chromium-copper
(4) Offset pivot

2.1 Direct lubricating type

The bearing was conventionally filled with lubricating oil in order to maintain high reliability. However, the weakness such as the problem of temperature rise in bearing metal due to high-temperature lubricating oil of the upper side pad, the increase in bearing loss due to resistance of lubricating oil by stirring at the outer periphery of thrust collar, etc. have come to the surface as the speed increases.

As a solution to this problem improvements were made in the bearing characteristics by adopting direct lubricating system, aiming at non-flood.

Fig. 3 shows the diagrams of flood type and direct lubricating type.

Fig. 4 shows the temperature rise in thrust pad of conventional type and direct lubricating type caused by changes in turbine output and rotational speed. In Fig. 4, the effect of reduction of temperature rise in thrust pad by direct lubrication can be confirmed through all zones of load, indicating substantial reduction in high-load zone especially.

2.2 Improved leveler

The leveling capability is an important characteristic of thrust bearing. It recovers the relative inclination between thrust collar and bearing, during turbine operation. The top/bottom levelers, installed to the bottom of the pad, change their positions against the nonuniform load between pads, according to the dynamic balance conditions. As a result, the up-down movement of the pad absorbs the relative inclination.

The contact surfaces of top/bottom levelers were conventionally surface contact with comparatively large frictional resistance. In order to reduce the frictional resistance the contact surface in the improved leveler has been changed to line contact to improve the leveling capability. (**Fig. 5**)

In the case of the steam turbine for synthesis gas, the thrust bearing is installed to the inner side to provide higher speed, and the thrust bearing with smaller difference between inner and outer diameters (with number of pads increased) is adopted to increase the shaft diameter. The effect of improved leveler is conspicuous in the bearing with a larger number of pads that gets largely affected by the frictional force.

Fig. 6 shows the leveling characteristics of conventional and improved levelers, with the thrust collar inclination angle and pad load ratio compared and summed up. The result clearly showed that the improved leveler had a more moderate reduction of pad load ratio than the conventional leveler against the increase in the

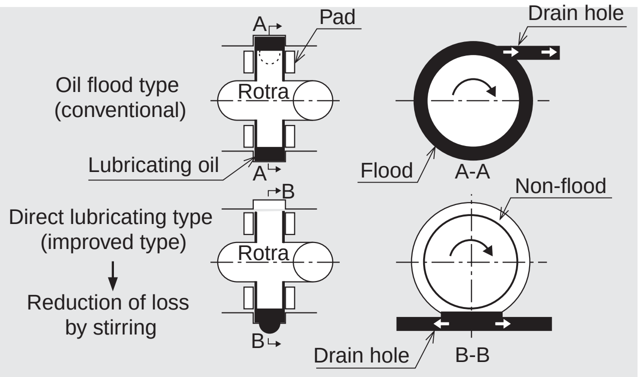


Fig. 3 Lubricating types compared

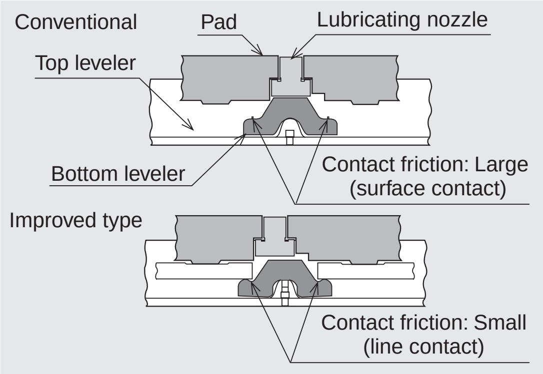


Fig. 5 Comparison of levelers

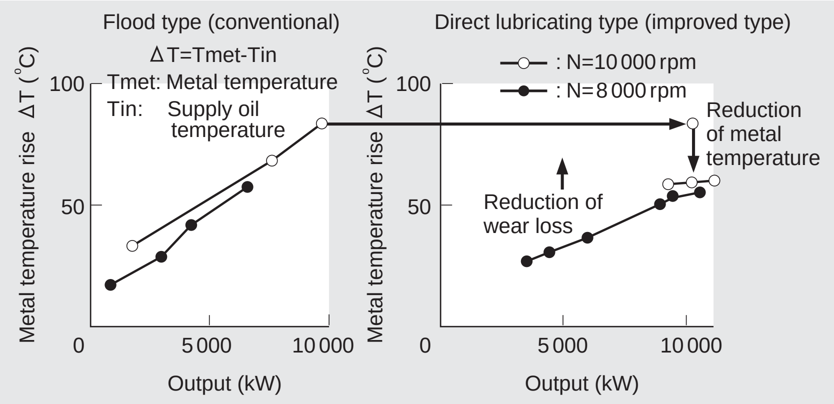


Fig. 4 Comparison of bearing metal temperatures

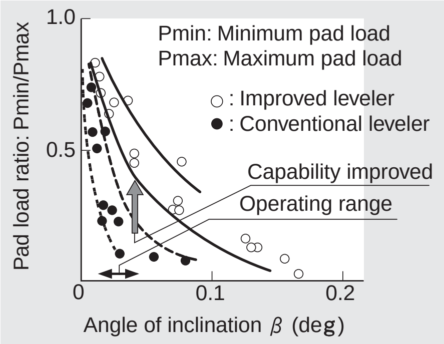


Fig. 6 Leveling capability compared

angle of inclination, ensuring drastic improvement in the leveling capability.

2.3 Pad back metal: Chromium-copper

Conventionally steel is adopted as the back metal of bearing pad. However, the improvement of the thermal conductivity of bearing pad can be considered as a means to reduce the bearing temperature.

The adoption of chromium-copper with high thermal conductivity is expected to reduce the temperature by 10 to 15°C as compared with the steel bearing (**Fig. 7**).

2.4 Offset pivot

The bearing temperature can be reduced by improving the load capacity of the bearing. The offset pivot making positive use of the wedge effect of oil film can be a good means to this regard.

The effect is shown in **Fig. 8**

3. Coating Technology

The following two can be considered as the main aged deteriorations of steam turbine during long-term continuous operation.

(1) Solid particle erosion of speed-control stage nozzle caused by scales from the boiler (iron oxide, silica, etc.)

(2) Drain erosion of low-pressure stage blade caused by collision with waterdrops under high-speed revolution in wet steam including waterdrops

Accordingly, prevention of the aforesaid erosions is vital to achievement of long-term continuous operation, and is extremely important for preventing deterioration of the turbine. **Fig. 9** shows an example of erosion preventing technology adopted by MHI.

Here, stellite cladding by plasma transfer arc welding is introduced as an example of drain erosion preventing technology for the last stage blade, and boronize treatment as an example of particle erosion preventing technology for speed-control stage nozzle.

The stellite cladding by plasma arc welding will be called hereafter as PTA stellite cladding.

3.1 PTA stellite cladding

In this method the stellite powder is supplied into the plasma arc generated between plasma welding torch and base metal (blade) to be melted and welded, and optimization of welding conditions together with robotic welding ensures steady high-quality clad-layer with less melting of the base metal (i.e. with low dilution rate) even at the thin and easy-to-melt edge section of the blade end. Further, this method has less welding deformation and does not need weld distortion removing, etc.

Fig. 10 shows the appearance of the blade applying PTA stellite cladding compared with the appearance of the blade applying the conventional stellite plate sticking by silver alloy brazing. Unlike the stellite plate sticking by silver alloy brazing, the PTA stellite cladding provides smooth, continuous and integral shape almost undistinguishable from the blade base metal.

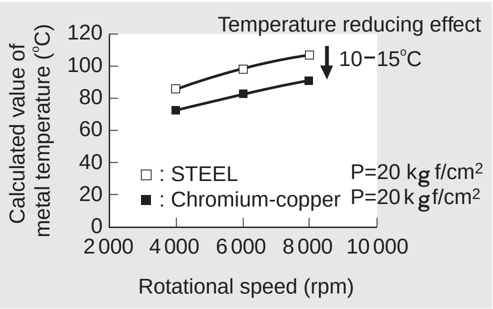


Fig. 7 Back metal material compared

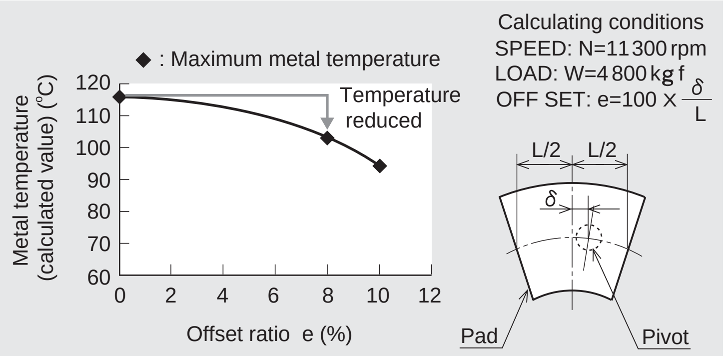


Fig. 8 Offset ratio compared

Item	Solid particle erosion	Drain erosion
Temperature condition	High	Low
Coating technology	▪ Boronizing ▪ Plasma spraying	▪ Plasma spraying ▪ Stellite plate sticking by silver alloy brazing ▪ PTA stellite cladding
Applied section	Nozzle	Blade

Fig. 9 Erosion prevention


PTA stellite cladding

Silver brazing (conventional technique)

After welding

Completed product

Completed product

Fig. 10 Stellite appearance compared

Fig. 11 shows the erosion resistance of PTA measured from the cavitation and erosion tests conducted according to ASTM G32-77 (environment: ion-exchange water, temperature: room temperature, test frequency: 18.3 kHz, test-piece end amplitude: 25 μm) and compared with silver brazing, indicating that the PTA has the erosion resistance equivalent to that of silver brazing.

Fig. 12 shows the fatigue strength of PTA evaluated by using Ono-type rotating bending fatigue test (environment: atmosphere, temperature: room temperature, frequency: 60 Hz) and compared with silver brazing, indicating that PTA has excellent fatigue strength characteristics while silver brazing has the fatigue strength reduced approximately to half of the base metal.

In view of the aforesaid points, the protected area (stellite section) in conventional method was limited to the blade tip. In the case of PTA, however, since the fatigue strength equivalent to that of the base metal can be obtained, the welding is possible up to the central portion of the blade. Thus, with the protected area expanded, application of PTA is expected to get expanded to strict erosive environment. Further, the stellite plate had problems such as difficulty in molding and necessity of manual work, whereas in the case of PTA, the welding is carried out mechanically, bringing about considerable improvement in quality and yield.

3.2 Boronizing

The boronize treatment applied to the actual machine as a technology to prevent particle erosion on speed-control stage nozzle caused by scales from the boiler, is a surface hardening technology and has the treating methods and characteristics as given below.

(1) Treating methods

- Formation of high-hardness boron alloy layer (Fe2B)
- Penetrated diffusion treatment

(2) Characteristics

- Ensures boron alloy layer of hardness Hv 1200 – 1800
- High hardness at high temperature and excellent hardwearing properties at high temperature
- High break away resistance because of penetration into the base metal
- Thin layer (approximately 80 μm) of boron alloy

Fig. 13 shows the mechanism of nozzle wear damage.

The scale is generated and grows into the inner surface of the boiler tube due to steam oxidation; the enlarged scale then gets break away because of the weakening of its adherence to the base metal of the tube at the time of start/stop of the plant before finding its way into the turbine.

Since the flow direction while passing through the nozzle profile gets sharply changed, the scale with larger specific gravity fails to catch up with the steam flow because of the effect of inertia and gets collided with the nozzle profile, causing wear damage. This is what we call solid particle erosion. Particularly the speed-control stage nozzles installed at the inlet of the turbine have larger damage.

Fig. 14 shows the test results of resistance to solid

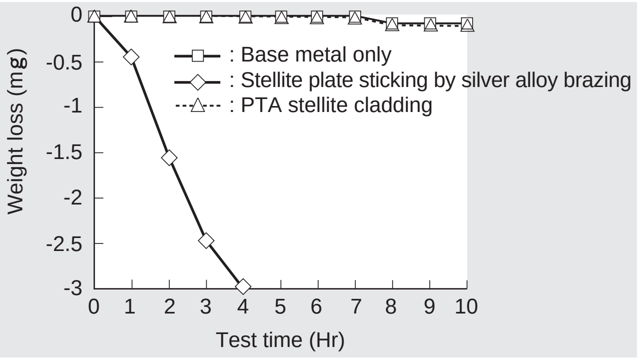


Fig. 11 Erosion resistance

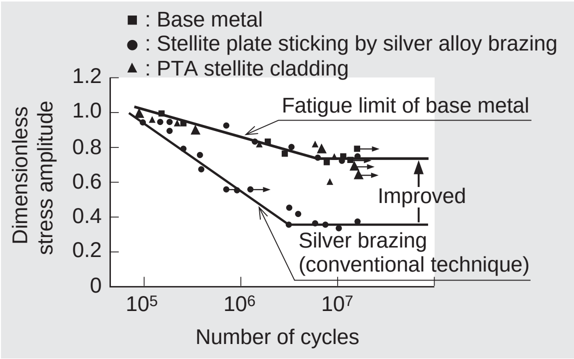


Fig. 12 Fatigue strength

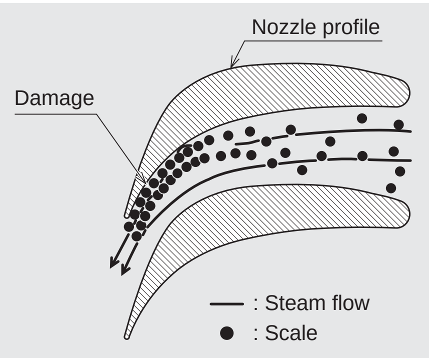


Fig. 13 Mechanism of nozzle wear damage

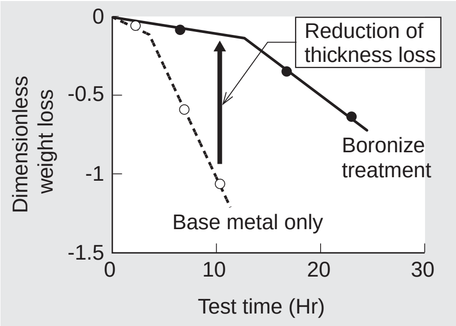


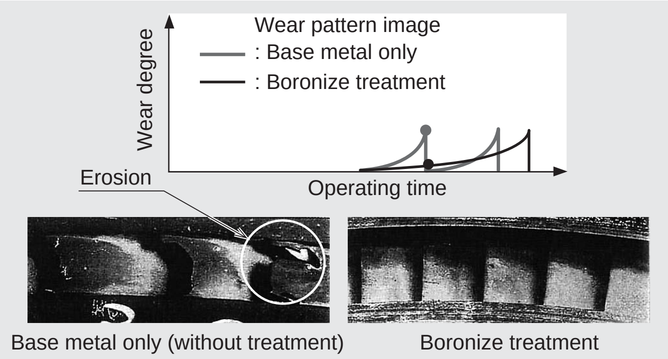
Fig. 14 Solid particle erosion test compared

particle erosion with or without boronize treatment, indicating that the wear loss of the nozzle subjected to boronizing is extremely less than that of the nozzle without boronize treatment. For example, the wear loss of the nozzle subjected to boronizing after a 10-hour test is approximately one-tenth of the nozzle without boronize treatment.

Fig. 15 shows the appearance of the actual speed-control stage nozzle subjected to boronizing compared with the appearance of the nozzle without boronize treatment. The damage is clearly visible at the outlet end of the nozzle without boronize treatment, which is not seen in the nozzle with boronize treatment, indicating the effectiveness of surface hardening treatment.

4. Fouling Removal Technology

Steam turbines subjected to long-term continuous operation have the dust (dirt) accumulated in the blade and nozzle, causing fouling problems such as deterioration of performance and efficiency, etc. Patent has already been applied for an online washing method as a solution, where water is fed into the valve chamber of the extraction control valve during normal operation to reduce the steam temperature and to increase the wetness of steam without having to reduce the plant load or to stop the turbine. The method has already been confirmed applicable to actual machine through tests using machines equivalent to the actual ones, with the effect on actual machine being under confirmation.



Base metal only (without treatment)
Boronize treatment

Fig. 15 Appearance of speed-control stage nozzle compared

5. Conclusion

With the recent trend of energy-saving and reduction of maintenance cost, the sustainable efficiency of the machines for long-term continuous operation through improved reliability and achievement of fouling removal technology is an important problem for the future.

MHI is making all efforts to develop technologies to respond to such needs and to apply them to actual machines.

In order to react and respond positively to the needs of end users regarding long-term continuous operation, it is indispensable to carry out research and development of high-reliability technologies. MHI is determined to cooperate with other related research institutes for timely application of such technologies to actual machines.


Sumio Noda


Yoshikazu Yamada


Satoru Zenitani


Tomoyoshi Sasaki