Commencement of the Commercial Operation of 600 MW Unit, "Hirono No. 5 Thermal Power Station of The Tokyo Electric Power Co., Inc."

HIROMASA MOMMA*1 JUNICHI ISHIGURO*1
TAKAYUKI SUTO*1 TOSHIHIRO MIYAWAKI*2
RYUJI IWAMOTO*3 TSUYOSHI NAKAHARA*4

Commercial operation of The Tokyo Electric Power Co., Inc. Hirono No. 5 Thermal Power Station commenced in July 2004. This plant is a 600 MW coal-fired supercritical power plant. The main line-up of the plant, which features a steam turbine and a boiler, are supplied by Mitsubishi Heavy Industries, Ltd. (MHI). MHI set up this plant with a range of such key equipment along with ancillary facilities such as control systems, a flue gas treatment system, a wastewater treatment system, and stacks. This report gives a brief overview of the advanced technologies applied to the steam turbine and boiler of this plant supplied by MHI.

1. Introduction

The Hirono No. 5 Thermal Power Station began commercial operation in July 2004. It is a 600 MW coal-fired, supercritical power plant that operates under the highest global standards for steam conditions (24.5MPa x 600/600°C).

The steam turbine has various advanced MHI technologies, including the first 600 MW class two-casing turbine, high- and intermediate-pressure combined casing developed by utilizing high temperature materials and cooling structures to cope with the ultra supercritical steam condition, 48 inch steel integral shroud blade (ISB), a new type of condenser, and a single shell deaerator cum storage tank.

The boiler adopted in this plant has MHI's advanced technologies. They are reduced emission of NOx and unburned carbon with the A-PM burner and MRS pulverizer. In addition, the vertical waterwall furnace that uses high temperature compatible materials and rifled tubes are adopted.

Further, the plant is very much streamlined through the use of such simple systems and equipment as described below:

(1) unification of air duct and flue gas duct into a single line through the adoption of a maximum capacity class fan,
(2) unification of all feed water heaters into a single line,
(3) unification of circulating water pumps into a single line, and
(4) adoption of a plant starting system that does not rely on the boiler circulating pump.

Since the plant is located in a narrow site adjacent to existing units operated using oil and gas, the overall arrangement of the plant has been improved by consulting with the Owner and is arranged in a more compact manner.

Advanced MHI technologies have also been adopted in ancillary facilities. This includes the use of a dry selective catalytic NOx removal system, a high performance flue gas treatment system based on the harmonious design of a double contact flow scrubber type flue gas desulfurization system with a low-low temperature dry electrostatic precipitator, an overall waste water treatment system, and self-supporting group stacks. In this way, MHI has drawn upon all of its competencies in establishing this plant.

2. Steam turbine

Figure 1 shows an external view of the Hirono No. 5 steam turbine.

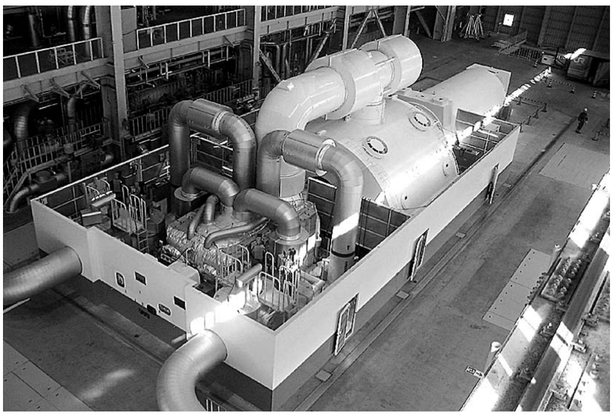


Fig. 1 View of the 600 MW Hirono No.5 steam turbine

*1 Power Systems Headquarters
*2 Takasago Research & Development Center, Technical Headquarters
*3 Takasago Machinery Works
*4 Nagasaki Shipyard & Machinery Works

Table 1 Major specifications of steam turbine

Item	Specifications
Type	Tandem compound, double exhaust, reheat condensing type
Output (rated)	600 000 kW
Steam conditions	
Main steam pressure	24.5 MPa
Main steam temperature	600 °C
Reheat steam temperature	600 °C
Rotational speed	3 000 rpm
Vacuum	− 962.6 hPa
Last stage blade length	48 inches
Number of feed water heaters	8

Table 1 shows the major specifications of the turbine.

The turbine is of a two-casing type consisting of a combined casing made up of a high-pressure turbine and an intermediate pressure turbine and a single low-pressure turbine casing. It has the world's largest capacity as two-casing structure.

Usually, in the 600 MW class turbines, two low-pressure turbine casings (quadruple exhaust flows) were required in order to secure last stage exhaust area meeting the requirements for steam flow. Since 48 inches, the longest last stage steel blades in the world for the 3000 rpm machine were adopted in this turbine, it became possible to unify the low-pressure turbine into a single casing (double exhaust flows), thereby realizing a compact design.

In addition, the high- and intermediate-pressure turbines are combined into one casing, and both main steam and reheat steam with a temperature of 600°C are led into it. MHI has developed a high performance and highly reliable frame drawing on the company's high temperature technologies cultivated by the development of the 1 000 MW-600°C class turbines(1) and the track record of the 700 MW class large capacity high- and intermediate-pressure combined turbines(2).

2.1 Design features

High temperature materials and cooling structures with good track records for 600°C steam conditions have been adopted in the high- and intermediate-pressure turbines.

Since ultra supercritical steam condition requires additional number of blade rows and the space for them due to the increase of heat drop in the turbine, performance of the blade rows and overall size of the frame were optimized in the design of the high- and intermediate-pressure combined frame in order to secure the performance and reliability of shaft dynamics.

As for the low-pressure turbine, various high performance and highly reliable technologies such as 48 inch last stage steel blades, a high performance exhaust hood, and a bearing base structure directly supported by foundation have been adopted.

2.1.1 High temperature materials

The new 12Cr forged steel is used for the high- and intermediate-pressure turbine rotor, while 12Cr cast steel is used for the inner casing, and 9Cr steel is used for the turbine inlet valves and the interconnecting piping between the valves and the casing.

2.1.2 Structure for high temperature

The longitudinal center section of the rotor as well as blade grooves at intermediate-pressure inlet section are cooled by the leaking steam from the control stage outlet to the intermediate-pressure turbine side along the rotor.

In addition, a thermal shield is installed so that the inner surface of the outer casing at the intermediate-pressure inlet section is not directly exposed to the reheat steam of 600°C, and cooling steam from the high-pressure turbine exhaust is led into a space between the thermal shield and the outer casing.

2.1.3 48 inch ISB low-pressure last stage steel blades

Until the late 1990s, the length of the steel blades for 3 000 rpm machines was limited to the 40 inch class. In 1998, ahead of the industry, MHI completed the development of a 3 000 rpm 48 inch blade, which was the largest steel blade of its type in the world, along with a 3 600 rpm 40 inch blade, which was the scaled design blade of the 3 000 rpm 48 inch blade(3).

A highly reliable ISB structure has been adopted for the blades, which were developed by latest vibration analysis technology. Three-dimensional multi-stage viscous flow analysis based on advanced computational fluid dynamics (CFD) technology was used in the aerodynamic design. Moreover, the rotating vibratory test using a full-size blade, and the verification tests for performance and vibratory strength using the model turbine on-load test facility in MHI are performed before the blades are applied to an actual machine.

Though the 48 inch blade is first applied in this unit, the 3 600 rpm 40 inch blades, which are scaled design blade, has already been used in many number of units and are in operation since 2000. Use of these blades has made it possible to obtain excellent operating results in terms of performance and reliability. **Figure 2** shows the appearances of the 48 inch ISB and the low-pressure turbine rotor.

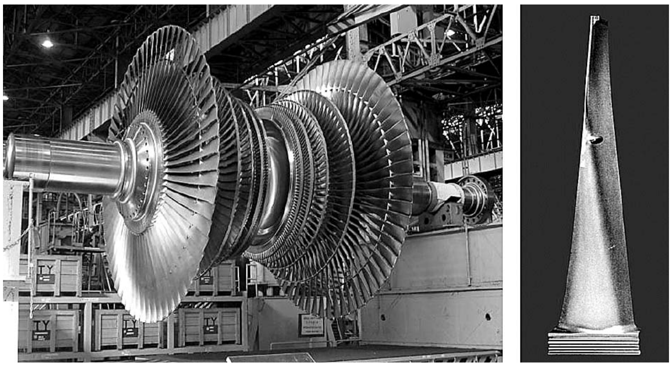


Fig. 2 48 inch steel ISB and Hirono No.5 low-pressure rotor

2.2 Operating experience and verification results

Various operational parameters were monitored, including shaft vibration, which showed sufficiently lower values than the allowable values. Namely, stable operation was achieved and the reliability of the turbine was confirmed.

2.2.1 High- and intermediate-pressure combined casing

In order to verify the reliability of the 600°C class high- and intermediate-pressure combined casing, approximately fifty thermocouples were fitted onto the outer surface of the outer casing, and the distribution of metal temperatures was measured. As a result, the temperature distribution was found to be as predicted, and the temperature gradient in the axial direction was sufficiently small. In this way, the effect of the casing cooling structure was confirmed.

2.2.2 48 inch ISB

As the 48 inch last stage blades are first applied in this unit, a final confirmation test was performed for this unit. Strain gauges were attached to the last stage rotating blades, and signals from the rotating part were transmitted to the stationary side via a telemeter system to measure the vibration stress on the blades.

As a result, the generated stress was very small in all operating ranges starting from the no-load to the rated load, and it was equivalent to stress levels measured during model turbine tests. Hence, it could be confirmed that the 48 inch blades have a sufficient reliability.

2.2.3 Performance

The high efficiency technologies applied in this unit include a fully three-dimensional design reaction blade, high efficiency 48 inch last stage blades, and an optimized geometry for low-pressure exhaust hood.

As a result of these improvements, it was verified through performance tests that the turbine efficiency surpasses the design values in all loads, as shown in **Fig. 3**, thereby providing a highly efficient unit.

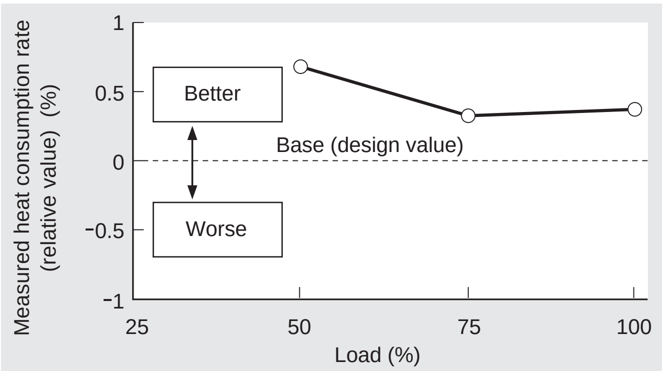


Fig. 3 Turbine performance test results

3. Boiler

3.1 Major features

The major specifications of the boiler are shown in **Table 2**, and a side view of the boiler is shown in **Fig. 4**.

Table 2 Major specifications of boiler

Boiler type	Radiant reheat type sliding pressure operation once-through vertical waterwall furnace boiler (Indoor type)	
At maximum continuous load (BMCR)	Main steam flow rate	1 770 000 kg/h
	Steam pressure at superheater outlet	25.40 MPa
	Steam temperature at superheater outlet	604°C
	Steam temperature at reheater outlet	602°C
Fuel		Coal, light oil (30% ECR capacity)
Combustion system		Circular firing with A-PM burner and A-MACT method
Pulverizing system		Unit direct pressurizing system
Type of drafting system		Balanced draft
Steam temperature control method	Main steam	Fuel/Feed water ratio, spray
	Reheat steam	Gas biasing damper for back pass
		Spray (transient)

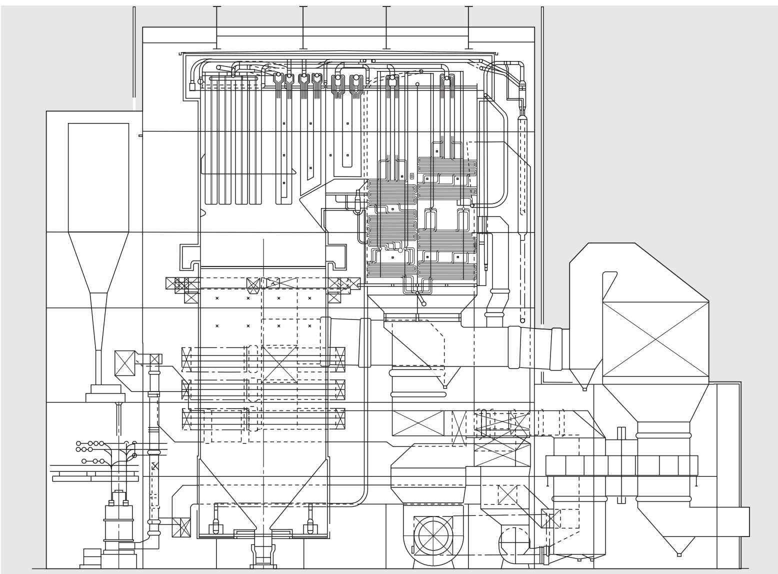


Fig. 4 Side view of boiler

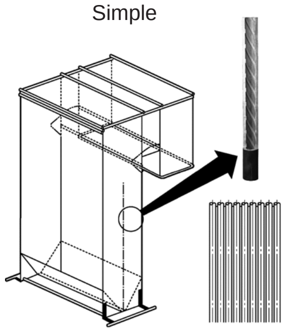
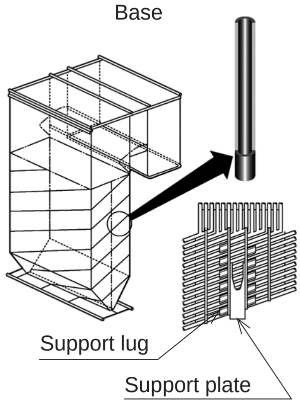
Item	Vertical waterwall furnace system	Spiral waterwall furnace system
Furnace structure	Simple 	Base 

Fig. 5 Comparison of furnace structures

A vertical waterwall furnace system using rifled tubes has more advantages than spiral waterwall furnace systems. The major advantages of this system are described below.

(1) Since the mass velocity is low in the vertical waterwall tubes, pressure loss in the furnace system is less thereby making it possible to save auxiliary power consumption.

(2) Since the boiler is formed with a simple structure in which the furnace wall tubes are placed in the vertical direction, the furnace can be supported easily and the number of attached fittings for supporting is less. Hence, the reliability, ease of installation, and maintainability of the system are increased (**Fig. 5**).

(3) In the coal-fired unit, the adhesion of ash to the waterwall tubes cannot be avoided over time, however, the natural fall of slag is facilitated and the amount of ash that adheres to the furnace waterwall is reduced.

(4) The amount of friction loss of the heated waterwall tubes is small compared with total pressure loss, and variations in flow when the amount of heat absorption of the waterwall is varied, are also small.

MHI is a world's sole manufacturer of sliding pressure operation once-through boilers that adopt the vertical waterwall furnace system, which has such a large number of advantages as mentioned above. MHI has an extensive track record of delivery of these types of boilers.

This boiler is rationally designed in which a forced draft fan, primary air fan, air preheater, and induced draft fan are integrated into a single line system without installation of a gas re-circulation fan and a boiler circulating pump for heat recovery during start-up. MHI's equipment with its exclusive technologies has also been adopted for the major boiler auxiliary equipment, such as regenerative air preheater, forced draft fan, induced draft fan, and primary air fan.

During commissioning, excellent steam temperature characteristics, load variation characteristics, and start-up time that completely met design requirements were confirmed.

3.2 Efforts to reduce NOx

In order for this boiler to satisfy strict environmental requirements, it employs a low NOx combustion system formed by combining an A-PM (Advanced-Pollution Minimum) burner, an in-furnace DeNOx system (A-MACT), a high fineness MRS (Mitsubishi Rotary Separator) pulverizer, and Selective Catalytic NOx Removal System (SCR) with MHI circular firing system.

(1) A-PM burner

Further reductions in NOx emissions have been achieved through the adoption of conc. and weak combustion, which is a basic MHI technology first applied in the original PM burners. In addition, an advanced A-PM burner realizes superior maintainability, reliability, and durability is adopted by reducing the number of wind box dampers and improving accessibility to the burner section (**Fig. 6**).

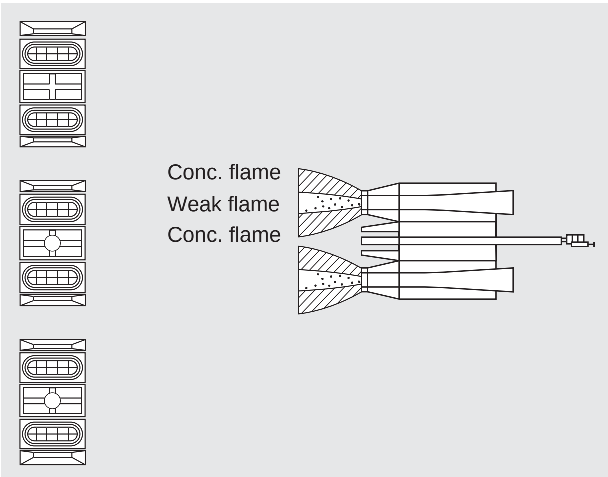


Fig. 6 A-PM burner

(2) In-furnace DeNOx system (A-MACT)

The in-furnace DeNOx system (A-MACT) has been adopted, and additional air (AA) is injected in order to complete the combustion of any unburned fuel remaining after NOx reduction, while sufficiently ensuring a NOx reduction region for in-furnace DeNOx of the upper surface of the main burner.

(3) MRS pulverizer

This unit adopts an MRS pulverizer capable of stably realizing excellent fine particle characteristics and high fine particle operation that has a significant effect on low NOx and low unburned carbon combustion.

(4) Selective Catalytic NOx Removal System (SCR)

A Selective Catalytic NOx removal system with an extensive track record has been adopted to further reduce the NOx to acceptable level in the combustion gas emitted from the furnace. As a result, excellent performance was confirmed across all loads.

3.3 Boiler performance

The efficiency of the boiler was verified by the performance tests, and the results are shown in **Fig. 7**. As a result of the adoption of a high performance A-PM burner plus A-MACT and MRS pulverizer, the actual efficiency of the boiler surpassed the design values, and it was confirmed that these devices contribute greatly to the highly efficient operation of the plant.

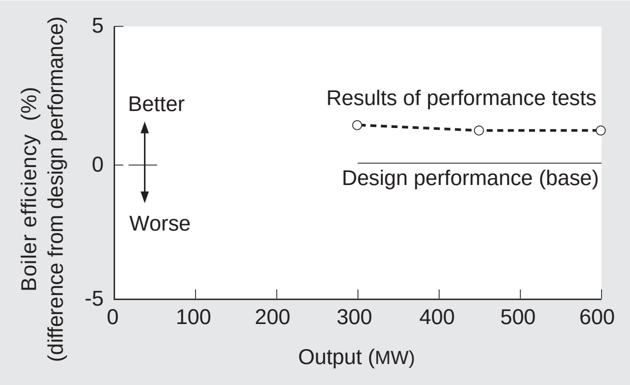


Fig. 7 Results of boiler performance tests

3.4 Reduction in construction time at site

In order to reduce the length of construction time at the site, the installation of flat-blocked steel frames and large-sized parts (main pipes, ducts) were performed in parallel. The method used to construct pressure parts consists of lifting the pressure parts together with the ceiling girder (SBS construction method: Steel Structure Boiler Simultaneous Construction).

4. Conclusion

MHI is confident that, technologies that allow improved efficiency, and high reliability through the adoption of advanced technologies, especially suited to high steam conditions, are co-exist with each other could be established with the completion of the Hirono No. 5 Thermal Power Station. Such technologies are expected to contribute greatly in the development of forthcoming plants in the future.

MHI will make every effort possible to further achieve the successful development and commercialization of the technologies demanded by society to advance the dreams of an ever better future.

Lastly, MHI wishes to express its sincere appreciation to everyone of the Tokyo Electric Power Co., Inc. who guided us on the operation and design of this plant and to all others concerned for their support and encouragement.

References

(1) Murayama et al., Design and Operating Experience of the Tachibana-wan No.2 1050 MW Steam Turbine of the Electric Power Development Co., Ltd., The Thermal And Nuclear Power Vol.54 No.566 (2003) p.40

(2) Nakamura et al., Design for Kobe Power Station No.1, Mitsubishi Juko Giho Vol.40 No.4 (2003) p.208

(3) Yamamoto et al., Development of 3000 rpm 48 Inch Low Pressure End Blade, Mitsubishi Juko Giho Vol.35 No.1 (1998) p.6

Hiromasa Momma

Junichi Ishiguro

Takayuki Suto

Toshihiro Miyawaki

Ryuji Iwamoto

Tsuyoshi Nakahara