Design, Construction, and Commissioning of the Nos.1 and 2 Units of the Ratchaburi Thermal Power Plant for the EGAT of Thailand as a Full Turn-key EPC Contract

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Power plants in Thailand, which has recently recovered from an economic crisis, are not only required to operate stably at their base loads but also to respond flexibly to shifts in the balance of demand and supply for power. In order to meet this requirement, two supercritical sliding pressure operation once-through boilers were adopted for the first time in Southeast Asia. The units are highly efficient and environmentally friendly and have excellent frequent start-and-stop and broad load change capabilities. They began commercial operation in the year 2000. In constructing the Ratchaburi Power Plant, Mitsubishi Heavy Industries, Ltd. (MHI) undertook the design, procurement, installation, and commissioning of most of the machinery and equipment in the power plant, such as the boilers, turbines, generators, cooling towers, flue gas desulfurization systems (FGD), and the foundations and buildings that house the equipment delivered by MHI. This report introduces the main features of the various types of machinery and equipment delivered by MHI together with a brief description of the field erection work.

1. Introduction

The Nos. 1 and 2 units of the Ratchaburi Power Plant including two supercritical sliding pressure operation once-through boilers began commercial operation in the year 2000.

MHI was assigned a broad scope in the construction the Ratchaburi Power Plant ranging from the design, procurement, construction, and performance testing, through commissioning of major machinery and plant equipment for the power plant, together with the construction of the foundations and buildings that house the equipment supplied by MHI. The wide-ranging work of this project served to demonstrate the integrated capability of the Mitsubishi group. This report introduces the features of the machinery and equipment delivered by MHI as well as a brief description of the contents of the field construction work that was undertaken to erect and install the equipment.

2. Outline of project

The Ratchaburi Power Plant is located about 100 km west of Bangkok, the capital of Thailand, in a rural area of the country. For the electric supply system in Thailand, the power plant is important as a major source of electric power that replaces the outdated old thermal power plants in this area.

MHI was awarded the order in an international bid for this power plant planned by the Electric Generating Authority of Thailand (hereinafter referred to as EGAT). The contract was agreed to as a so-called full turnkey project, and came into effect on November 6, 1996. Commissioning of the No. 1 unit began on June 15, 2000 and on October 28, 2000 for the No. 2 unit.

A most notable aspect of this project is the fact that each unit consists of the first supercritical sliding pressure operation once-through boiler in Southeast Asia. Other special features include the combination of a two-double low-pressure turbine/water-cooled generator and large capacity multiple pressure type condenser to improve plant efficiency, and the adoption of a burner system that is capable of both exclusive firing and mixed firing of oil and natural gas. This project is also characterized by low NOx and low SOx operation through the application of low NOx burner and high performance desulfurization system. The power plant is also capable of meeting frequent start-and-stop and quick load change requirements.

The major specifications of the power plant are listed in **Table 1**. The overall layout of the power plant and equipment delivered by MHI are shown in **Fig. 1**. A photograph of the power plant is shown at the top of this page.

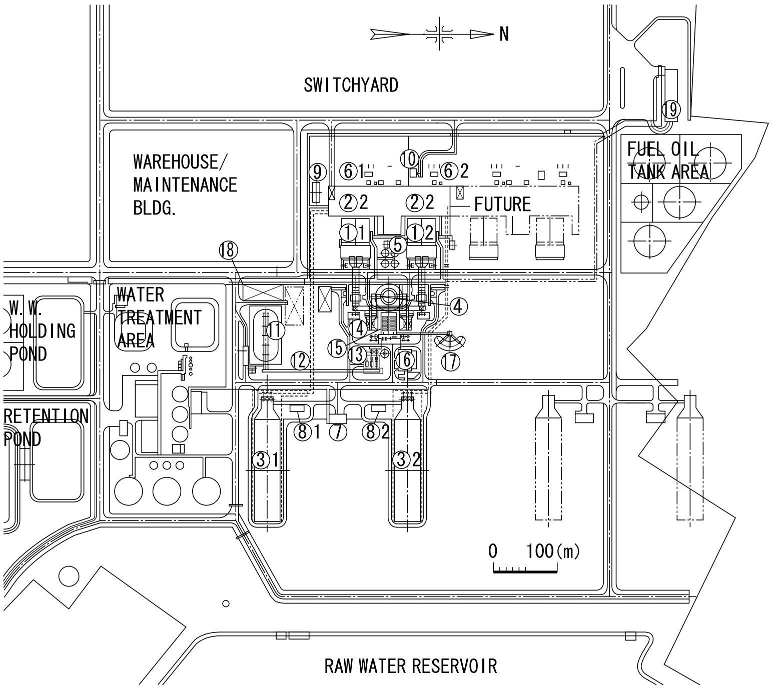
3. Boilers

3.1 Supercritical sliding pressure operation once-through boiler

The boilers are the thirtieth and thirty-first supercritical sliding pressure operation once-through boilers (fourteenth and fifteenth as oil- and gas-fired

Table 1 Major specifications of plant

Equipment		Specification
Plant	Output	735 MW at generator terminal
	Steam condition	24.22 MPaX538/566°C (at turbine inlet)
	Fuel	Oil & gas (exclusive firing / mixed firing)
	Cooling system	Mechanical draft wet cooling tower
	Condenser vacuum	700/685 mmHgvac.
	Feed water heater	8 stages
	Feed water treatment	CWT
Boiler	Type	Supercritical sliding pressure operation once-through boiler
Turbine	Type	3000 rpm tandem compound quadruple exhaust condensing type reheat and regenerating turbine, LP (low pressure) end blade length: 35.4 inches
Generator	Type	Totally enclosed, stator water cooled, rotor hydrogen cooled, complete with stationary armature and cylindrical rotor, directly coupled to the steam turbine
	Capacity	990 MVA
	Exciter	Thyristor excitation system
Flue gas Desulfurization	Type	Wet lime/lime stone gypsum process



No.	主要供給設備
1	BOILER
2	TURBINE & GENERATOR
3	COOLING TOWER & CWP
4	BOILER STACK
5	DEMI./COND. WATER STORAGE TANKS
6	TRANSFORMERS
7	CHROLINATION EQUIPMENT
8	ELECTRICAL BLDG. FOR COOLING TOWER
9	AUXLIARY BOILER
10	EMERGENCY GENERATOR
11	LIMESTONE STORAGE AREA
12	LIMESTONE CONVEYOR
13	LIMESTONE PREP. BLDG.
14	SLURRY RECYCLE BLDG.
15	FGD BYPRODUCT PROCESS
16	FGD CONTROL/ELECTRICAL BLDG.
17	SLUDGE STOCKOUT
18	FUEL GAS REDUCING STATION
19	FUEL OIL PUMP HOUSE

Fig. 1 Layout of power station and equipment delivered by MHI

boilers) to be delivered by MHI. Hence, they were designed and manufactured based on the extensive experience of MHI. The boilers have the same configuration as the Nos. 1 through 4 boilers of the 550 MW power plant built at Qurayyah in Saudi Arabia that have been in operation with an excellent performance record since 1989. Heavy oil, containing 3% sulfur, and natural gas were adopted as the design fuel. Full load operation is also possible with the exclusive firing of either fuel. **Fig. 2** shows a schematic side view of the boiler. The heat transferring system consists of a pendant type high-temperature superheater / high temperature reheater, horizontal type low-temperature reheater, and an economizer, which are provided in the order of the gas flow. In order to cope with differences in the respective heat absorption properties of gas and oil in the furnace, the temperature of the steam is adjusted by changing the amount of gas recirculation (GR) that is done. A boiler circulation pump (BCP) system has been provided in accordance with the requirements of the customer for heat recovery at the time of start-up and for reduced load operation.

3.2 Low-NOx burner

A round type oil/gas dual firing, low-NOx burner for circular firing, originally developed by MHI as one of the features of the boiler, has been adopted to satisfy demands for strict environmental protection as well as high efficiency. The burner has demonstrated significantly lower NOx emission levels than the

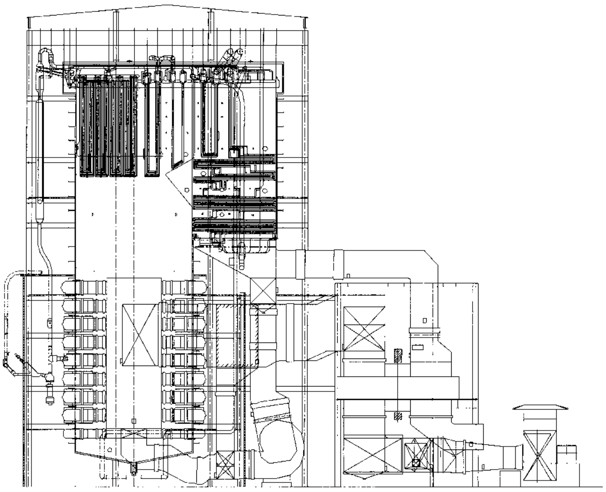


Fig. 2 Schematic side view of boiler

Fig. 3 Burning states

amount guaranteed. **Fig. 3** shows the respective states of oil and gas firing. As can be seen in the figure, the light off is stable in both cases. Low NOx emissions are obtained by the fuel-rich/fuel-lean combined flame system based on the principle of the PM (Pollution Minimum) burner developed by MHI, a principle about which MHI has accumulated extensive experience. Thus, NOx emission levels as low as 80 to 140 ppm (4% O_2) have been achieved during the firing of oil containing 0.45% N, and 20 to 40 ppm (5% O_2) while firing natural gas.

3.3 Boiler performance

Performance tests were carried out for exclusive oil firing, exclusive gas firing, and oil and gas mixed firing. In the range from 25% load through full load, excellent performance levels higher than the design values were obtained in the firing of each fuel. Stable operation was also demonstrated in the exclusive firing of each fuel when a 15% load was specified as the minimum load.

4. Steam turbine

4.1 Large-capacity tandem compound turbine

Fig. 4 shows a cross sectional schematic view of the assembled steam turbine. The major specifications of the steam turbine are listed in Table 1. Each turbine is a tandem compound type system consisting of one high-pressure turbine, one intermediate-pressure (IP) turbine, and two low-pressure turbines. The high-pressure turbine consists of a double-flow design with four main steam inlets. Each flow consists of one control stage and eleven reaction stages. The intermediate- pressure turbine consists of a double-flow design with four reheated steam inlets. Each flow consists of nine reaction stages. The low-pressure turbines also use a double-flow design, and each flow consists of seven reaction stages, including a 35.4 inch ISB LP (low-pressure) end blade. Each steam turbine has a capacity of 735 MW in rated output (841 MW maximum possible output).

4.2 Design characteristics

(1) Shaft line design to meet requirements for large output, tandem type turbines for thermal power plants

A thorough examination was made of the shaft line design taking into consideration a maximum output of 841 MW at a frequency of 50 Hz. As a result, the diameter of the bearing between the turbine and generator becomes 535 mm, which is the maximum diameter for a 3 000 rpm speed machine.

(2) Adoption of advanced fully three-dimensional design blade

In order to improve performance, advanced fully three- dimensional design blades have been adopted for the reaction stages in high-, intermediate-, and low-pressure turbines. The fully three-dimensional flow design is applied to all reaction blades, including the LP end blade.

4.3 Performance

Performance tests confirmed that each steam turbine achieved higher levels of efficiency that exceeded design values (guaranteed values) not only in 100% ECR (Economical Continuous Rating) and turbine-

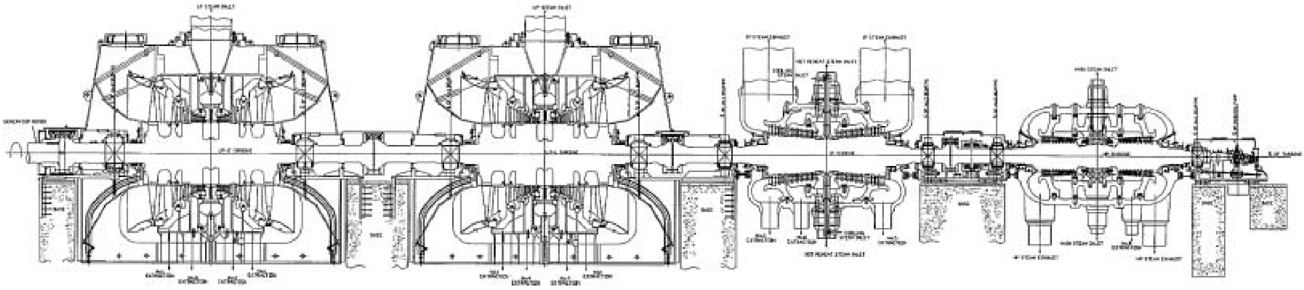


Fig. 4 Cross sectional view of 735 MW steam turbine used in the Nos. 1 & 2 units of the Ratchaburi

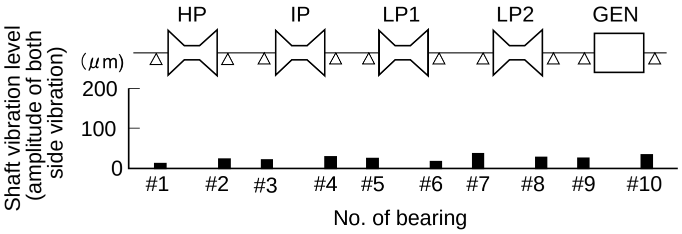


Fig. 5 Measured shaft vibration of turbine generator for the Ratchaburi No. 1 unit

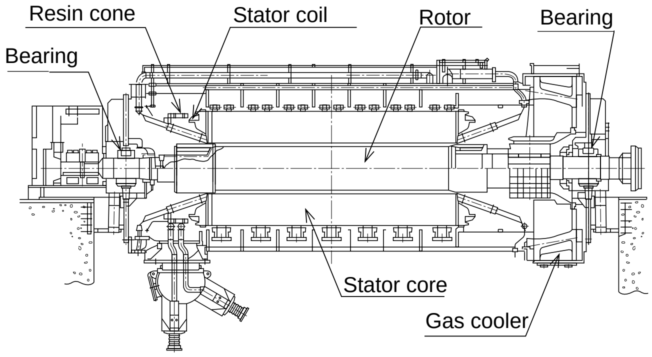


Fig. 6 Construction of generator

MCR (Maximum Continuous Rating), but also in the specified full load range.

4.4 Shaft vibration

Fig. 5 shows that shaft vibration measured at each bearing during rated speed operation is as small as 35 μ or less. This demonstrates that very stable operation is obtained.

5. Generator

The results of studies aimed at the realization of a 1 000 MW class tandem generator that were conducted continuously since 1980s have been applied to the design of the generators. **Fig 6** shows the structure of a generator. As generator capacity increases, the diameter of the rotor will invariably be increased and the stator end supports will be strengthened. Accordingly, special material was developed for the rotor that is capable of withstanding high centrifugal force. Verification tests of the system were conducted using a mock-up. Shop tests and actual load tests on site verified that the vibration in the rotor shaft and stator coil ends as well as the temperatures in the coil were all within design parameters.

6. Plant equipment

6.1 Multi-stage pressure condenser

A multi-stage pressure condensing system is employed which consists of two condensers. These condensers have different internal vacuum levels from each other and are respectively installed under the casing of each low-pressure steam turbine. A once-through water-cooling system is used in which cooling water flows continuously through both condensers.

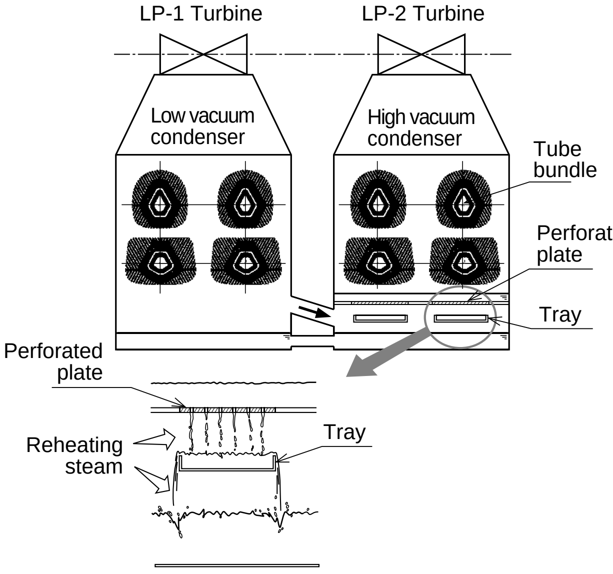


Fig. 7 Construction of multi-stage pressure type condenser

Thus, this water-cooling system is superior to single stage condensers in the following points.

(1) The turbine cycle efficiency is improved because the extent of the average vacuum in the condensers is increased.

(2) The flow rate of the condenser cooling water is reduced because it flows once through both condensers consecutively in series. As a result, the number of cells in the cooling tower can be reduced, thereby also serving to reduce construction costs.

(3) The condensate from the high vacuum condenser tube bundles is reheated by the exhaust steam from the low vacuum condenser tube bundles (condensate preheating system). In addition, the reheated condensate is mixed with the condensate from the low vacuum condenser tube bundles and sent to the boiler system. Therefore, the amount of steam extracted from the low-pressure feed water heater can be reduced, which means that an increase in output can be expected. As can be seen in **Fig. 7**, reheating can be performed by having the condensate free-fall from the high vacuum condenser tube bundles into the steam from the low vacuum condenser. The fallen condensate then generates turbulence on the surface of the condenser hot well. The turbulence accelerates heat exchanging to reheat the fallen condensate.

Performance tests confirmed that the vacuum levels in the condensers and the reheating efficiency of the condensate both equaled or surpassed the guaranteed values.

6.2 Circulating water pump

Each set of Nos. 1 and 2 circulating water pumps consists of three 50% capacity pull out type pumps (largest class in the world). In order to ensure smooth water flow from the large pool provided under the cooling tower, model tests were carried out to optimize the design of the intake pit.

6.3 Condensate pump

Each set of condensate pump consists of two 100% capacity pumps. As a single condensate pump for thermal power plants, the condensate pump is characterized by being amongst the largest capacity class of pumps in the world. It is a vertical type pump equipped with a large capacity fluid coupling in order to reduce auxiliary power consumption during partial load operation. Since these condensate pumps about seven meters in height from the installation floor and are variable in speed, they are designed based on vibration analysis that is carried out in order to reduce vibration and increase reliability.

7. Operating performance (load-following capability)

The customer requested that the units be capable of accommodating a wide range of load variations. Consequently, the equipment and controls were designed not only to meet this requirement but also to allow the application of precise adjustments during operation. As a result, the units are fully capable of accommodating the targeted load variations. This excellent operating performance is comparable to that of power plants used for utilities in Japan.

8. Water quality control (by CWT)

The Ratchaburi Power Plant is equipped with a combined water treatment (CWT) facility. The CWT facility is superior to conventional AVT (Ammonia Volatile Treatment) facilities because of the excellent environmental protection performance that is achieved through a reduction in the amount of chemicals used, the amount waste water that is re-generated from the condensate demineralizer, as well as positive economic effects that result from reduced furnace pressure loss and the frequency of boiler acid-cleaning required. Accordingly, this CWT facility is expected to be a model case for overseas plants.

9. Flue gas desulfurization (FGD) system

This FGD system is not equipped with any electrostatic precipitator (ESP). Thus, in order to achieve a high dust removal efficiency (85%), a double-contact-flow scrubber (DCFS), which is operated by a high velocity (10 m/s) gas flow, is employed as the first absorber. As an one-line desulfurizing capacity plant, the 2 224 000 Nm^3/h gas treating capacity of this system is of a comparable scale to the FGDs used in 1 000 MW class power plants in Japan, such as the Haramachi No. 1 FGD of the Tohoku Electric Power Co., Inc. and the Misumi No. 1 FGD of the Chugoku Electric Power Co., Inc. Desulfurizing performance as high as 116 mg SO_2/Nm^3 by the No. 1 unit and 112 mg SO_2/Nm^3 by the No. 2 unit have been obtained at the outlet of the stack, when burning heavy oil containing 3% sulfur. Both are less than half of the 240 mg SO_x/Nm^3 guaranteed value at 3% O_2 dry at the outlet of the stack. **Fig. 8** shows an outside view of one of the flue gas desulfurization systems.

Fig. 8 Absorber and auxiliary equipment of Ratchaburi Thermal Power Plant No.1 unit

Excellent maintainability of the system is achieved by use of a compact layout in which the gas/gas heater (GGH) is installed on the absorber, and the gypsum dewatering system and the limestone slurry preparation system are arranged close to the absorber.

10. Outline of construction work

The construction of the plant proceeded smoothly from the start of the piling work through the column lifting of the turbine building structures on December 15, 1997. In July 1997, however, the Thai economy fell into disorder due in large part to transference to a floating exchanging rate system that was accompanied by a crisis in the value of the Thai baht.

Unprecedented events such as the transference of the EGAT to private management and the decision to sell the Ratchaburi Thermal Power Plant to a third party occurred during this difficult period. Nevertheless, both the Nos. 1 and 2 units could begin commercial operation without delaying the schedule for selling the power plant.

10.1 Features of construction work of Ratchaburi Thermal Power Plant

In Thailand, construction work usually depends on human wave tactics based mainly on laborers from the east north area. Accordingly, massive manpower (1 850 000 man-days) was also needed for construction of the Nos. 1 and 2 units. In spite of this condition, the construction work could be completed without any serious accident.

The site was a swamp zone where the ground was so soft during the rainy season of 1998 that it was difficult to walk because one's feet sank in the mud up to the knees at certain places at both the construction site and the material marshal yard, and the machine equipment erection work for the No. 1 unit was peak. Under such conditions, it was useless to pave the ground with temporary curing plates and even crawler cranes were held up in the mud for a long time. Therefore, it took a lot of time to transport heavy material and to assemble cranes and transport equipment, as fights with the rain and mud continued for a long time.

10.1.1 Civil work

Given the large scale of the civil work involved, several different contractors were chosen during the selection process of the local Thai contractors. The building and foundation work was divided among two contractors, as was the piling work, and the stack construction work was undertaken by a specialized contractor. MHI coordinated all work, including co-ordination of the erection work.

10.1.2 Boiler erection work

Both of the large and sophisticated supercritical sliding pressure operation once-through boilers could be assembled to a superb degree of precision, thanks to the cooperation of the construction contractors and the supervisors of MHI. No difficulties due to poor welding work have yet been caused since completion of construction.

10.1.3 Turbine erection work

In erecting the turbines, 1500-ton cranes were used because the turbines and generators were amongst the largest in the world in terms of single capacity. Moreover, each generator stator in particular was as heavy as 400 tons, and other heavy equipment such as the deaerators, heaters, and transformers were all large and heavy items, as well.

11. Conclusion

MHI completed this project on the basis of its broad experience gained at Qurayyah in Saudi Arabia, Lal Pir, in Pakistan, Masinloc in the Philippines, and at Zhuhai in China. Recent customer requirements have become increasingly complicated as most of overseas power plant projects are shifted to IPPs (Independent Power Producers). Accordingly, MHI intends to draw on these experiences in order to meet these various future requirements, with superlative organization that is well accommodated to deal with such requirements.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