Completion of High-efficiency Coal-fired Power Plant

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OVERVIEW: Raising the efficiency of thermal power plants has become quite important in order to reduce carbon dioxide (CO_2) emissions to minimize the global warming effect. Recognizing these circumstances, Hokkaido Electric Power Co., Inc. (HEPCO)'s new 700-MW Tomatoh-Atsuma Power Station No. 4 Unit, a coal-fired power plant that adopts Japan's highest steam pressure and temperature conditions of 25 MPa-600°C/600°C, was completed in June 2002. Hitachi, Ltd. designed and built the turbine generator, the primary equipment at the power plant. The design achieved excellent efficiency with high reliability by developing a high-performance steam turbine well adapted to higher temperature and pressure steam conditions, a condenser featuring a newly developed arrangement of condenser tubes that balances the steam inflow and optimizes condensing efficiency, and other leading-edge technologies. Running and operating the power plant has also been markedly improved through centralized operation and supervision using a CRT (cathode-ray tube)-based operation system and sharing operational data on a large 100-inch screen. This enables the plant to be operated by a small number of personnel from the central control room.

INTRODUCTION

NOW that environmental issues have become such a pressing global concern, improving the efficiency of Japan's coal-fired power plants to reduce CO_2 emissions and the load on the environment has become an important objective. There is also a need to be able to consistently run and operate plants from startup to shutdown with just a few operators by promoting further automation and more advanced control equipment. At the same time, every effort must be made to achieve power plant cost-effectiveness to reduce the cost of generating power and the cost of new plant and equipment investment.

Hitachi is addressing these needs by adopting

Fig. 1—Bird's-eye View of the Completed of Tomatoh-Atsuma Power Station of Hokkaido Electric Power Co., Inc. (left), and the 700-MW Turbine Generator for the No. 4 Unit (right).
The Tomatoh-Atsuma Power Station is located between the towns of Tomatoh and Atsuma, and with the completion of Unit No. 4, has an output capacity of 1,735 MW, making it the largest power station in Hokkaido.

highly efficient leading-edge technologies to power plants. By developing and deploying advanced power generating systems based on the most economical design, Hitachi has now set a new world standard in plant efficiency for coal-fired power plants.

This article gives a detailed overview and trial performance results for an advanced turbine generator developed by Hitachi and now deployed at Hokkaido Electric Power Co., Inc. (HEPCO)'s Tomatoh-Atsuma Power Station (see Fig. 1).

OVERVIEW OF TURBINE GENERATOR EQUIPMENT

Plan Overview

The specifications for the main components of the recently delivered No. 4 unit steam turbine are shown in Table 1 in comparison with those of the No. 2 unit turbine that was built earlier by Hitachi. The key features of the No. 4 unit equipment are summarized as follows:

(1) High pressure/temperature steam conditions

The efficiency of the turbine generator was improved by adopting a main steam pressure of 25 MPa in combination with main steam and reheat steam temperatures of 600°C each. This improved the efficiency of this turbine by approximately 2.8% (relative) compared with the performance of our previous installation.

(2) System configuration

A 700-MW class standard configuration was adopted for the turbine, and various auxiliary systems and equipment were rationalized.

Overview and Features of Main Component Technologies

Steam turbine

The steam turbine was designed to achieve high reliability and efficiency by applying high pressure and steam conditions and by developing new long blades that are compatible with the low temperature of seawater that is available in the jurisdiction of the Hokkaido Electric Power Co., Inc. The key features of these component technologies are summarized as follows:

(1) New materials that withstand elevated steam conditions

In order to adopt higher temperature and pressure steam conditions, new 9%Cr forged steel that can withstand temperatures up to 600°C was used for several key components of the turbine including the main stop valve, adjustable valve, combined reheat value, and the main steam and reheat steam inlet pipes. In addition, 12%Cr steel was used for the HP-IP (high-pressure, intermediate-pressure) rotor, the HP-IP casing, the nozzle box, and the HP-IP diaphragm.

Table 2 shows a comparison between the materials used for the main components of this turbine with the components of the No. 2 unit that was deployed earlier.

(2) Long 43-inch (109-cm) blades

A 40-inch (102-cm) last stage blade was optimum in the low-pressure sections of the previous 600-MW turbine, but for the No. 4 unit 43-inch (109-cm) blades with a larger exhaust annulus area proved more efficient. Among other reasons, this is because the

TABLE 1. Comparison of Turbine Specifications.
Comparison of the main specifications between the new 700-MW unit (No. 4) and the earlier 600-MW unit (No. 2) developed by Hitachi and deployed at the Tomatoh-Atsuma Power Station is shown.

Item		No. 4 Unit	No. 2 Unit
Turbine	Output	700 MW	600 MW
	Main steam pressure	25.0 MPa	24.1 MPa
	Steam temperature	600°C/600°C	538°C/566°C
	Rotating speed	3,000 min^{-1}	3,000 min^{-1}
	Exhaust vacuum	-98 kPa	-98 kPa
Generator	Capacity	778,000 kVA	670,000 kVA
	Hydrogen press. (MPa)	0.41 MPa	0.41 MPa
	Frequency	50 Hz	50 Hz
	Terminal voltage	23,000 V	19,000 V
	Power factor	0.90	0.90
Condenser	Cooling area	31,000 m^2	33,290 m^2
	Vacuum	-98 kPa	-98 kPa
	Cooling water temperature	15°C	15°C
	Cooling water amount	96,600 m^3/h	91,700 m^3/h

TABLE 2. Key Component Materials for Unit No. 4 (700 MW).
Comparison of main component materials between the new 700-MW unit (No. 4) and the earlier 600-MW unit (No. 2) is shown.

Item		Main steam temperature 600°C (No. 4)	Main steam temperature 538°C (No. 2)
Main valve		9%Cr forged steel	Cr-Mo-V forged steel
Rotor	HP-IP rotor	New 12%Cr forged steel	Cr-Mo-V forged steel
	LP rotor	Ni-Cr-Mo-V forged steel	Ni-Cr-Mo-V forged steel
Nozzle box		12%Cr forged steel	Cr-Mo-V forged steel
Movable blade		New 12%Cr forged steel	Cr-Mo-Nb-V forged steel
Casing		12%Cr forged steel	Cr-Mo-V forged steel
Turbine inlet pipe		9%Cr forged steel	Cr-Mo-V forged steel

turbine exhaust was under higher pressure due to the low temperature of the condenser water in Hokkaido (seawater). New 43-inch last stage blades were developed for the No. 4 unit based on 40-inch blades that were previously the longest.

The blades are held together to form a single ring of blades by an integral shroud cover and tie-bosses in a configuration called a CCB (continuous cover blade), an arrangement that provides more stable vibration characteristics and better reliability. Fig. 2 shows a side-by-side comparison between the 40-inch blade and the newly developed 43-inch blade.

(3) Rotor configuration features

The turbine rotor configuration adopts an integral high-pressure and intermediate-pressure turbine for steam conditions of 600°C, and by adopting a three-casing tandem compound rotor structure for the 700-MW steam turbine for 50-Hz use, the turbine generator has been implemented more compactly. Fig. 3 shows the sectional arrangement of the new steam turbine for the No. 4 unit.

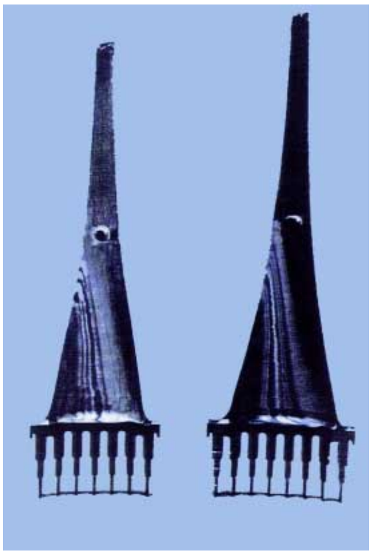

Fig. 2—Previous 40-inch (102-cm) Long Blade (left) and the New 43-inch (109-cm) Long Blade (right) for 50-Hz Use.
Adopting improved high-strength 12%Cr forged steel, the longer 43-inch blade has been developed.

Condenser

The primary factors governing the performance of the condenser are the shape of the condenser tube bundles and the arrangement of the cooling tubes. To further enhance condenser performance, Hitachi developed and verified a new condenser tube arrangement called SBDF (super-balanced downflow). Observing that the steam inflow in the condenser was analogous to suction flow of fluid-dynamic theory, we concluded that the steam inflow along the streamline of the suction flow is proportional to the condensing steam.

This new SBDF arrangement has now been applied to more than twenty thermal power plants of varying capacity as Hitachi’s new standard tube bundle arrangement, including the No. 4 unit at the Tomatoh-Atsuma Power Station.

Fig. 4 shows the concept behind the SBDF tube arrangement based on the suction flow theory.

Plant Supervision and Control Equipment

As a large-capacity coal-fired thermal power plant, the No. 4 unit has considerable auxiliary equipment to be controlled and data that must be monitored. So inevitably the supervision and control system has grown in scale. Consisting of (a) a distributed computer system providing general control, automation, and supervision over plant units, and (b) digital control equipment providing distributed control on a functional unit basis, the system is implemented very compactly

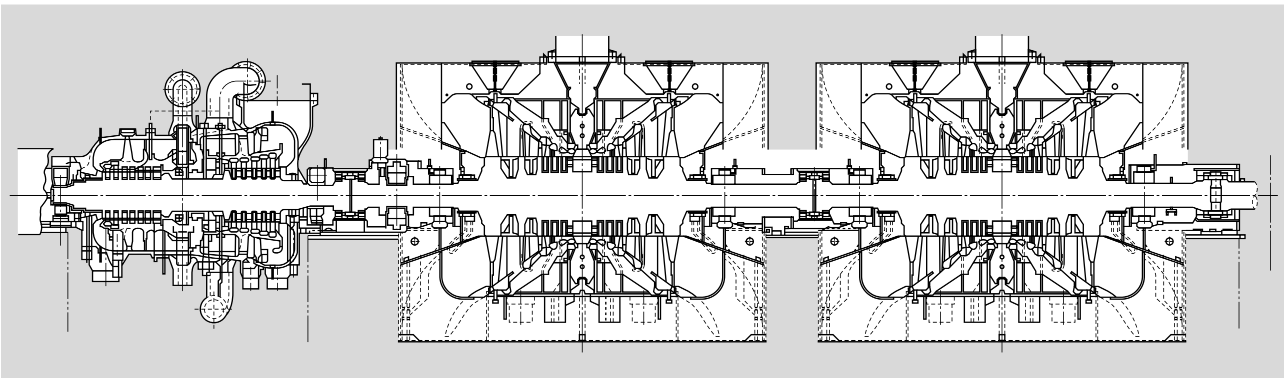

Fig. 3—Sectional Arrangement of the Steam Turbine.
The turbine features an integral high-pressure and intermediate-pressure casing, and the 43-inch blades are applied in the last stage.

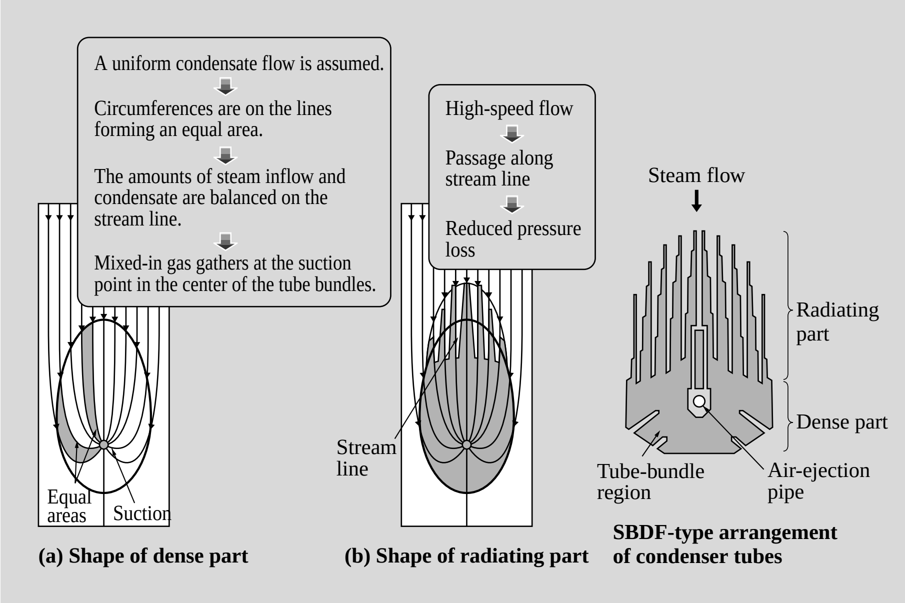

Fig. 4—Concept Behind the Tube Arrangement Based on the Suction Flow Theory.
The radiating part is linear to the flow of steam, and the circumference of the tube bundle is on the lines forming nearly an equal area.

yet provides excellent monitoring and control capabilities. The key features of the supervision and control system are summarized as follows:

(1) To achieve integrated operation over the entire power station facility, a centralized monitoring and operation scheme was developed by installing four control units (including three preexisting units) in a central control room. A centralized supervision and operations environment with good visibility and that can be run by a small number of operators was achieved with one central large-screen panel for monitoring boilers, turbines, and generators [the BTG (boiler, turbine and generator) supervision panel], and six CRT (cathode-ray tube) operator consoles (see Fig. 5).

(2) The HI (human interface) of the supervision and control system leverages the latest computer technologies to provide advanced human-machine functions and supports sharing of information using a four-panel multi-screen display on a high-visibility 100-inch large-screen LCD (liquid crystal display). The HI of CRT operations has also been significantly upgraded by merging warning, monitoring, and operations functions, and installing advanced CRTs with multi-window, multi-host capabilities.

(3) Instrumentation renovation work was rationalized by sharing detectors, and cable deployment work was reduced by installing a remote transmission system between on-site equipment and the supervision and control system. A transmission interface was also implemented that monitors control/monitoring signals from about 700 points using a total of 15 remote I/O (input and output) panels installed on the first and second floors of the turbine room, and in the metal-clad switchgear and electric room in the control center. Electronic instrumentation renovation work was also rationalized and reliability enhanced by installing redundant signal transmission lines and power supplies.

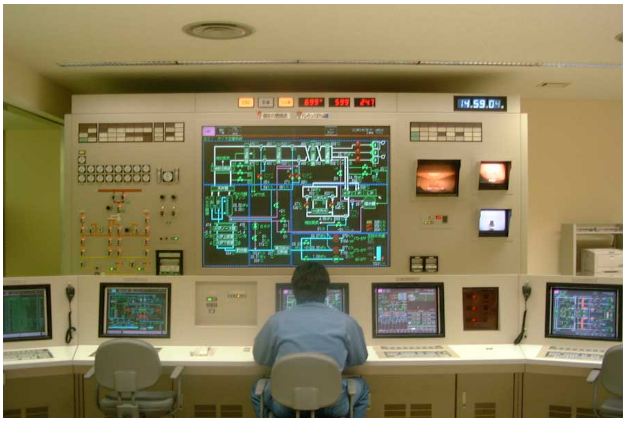

Fig. 5—Central Supervision and Control Panel in Tomatoh-Atsuma Power Station Unit No. 4.
An excellent visibility human interface is achieved by combining a large-screen display with CRT operation consoles.

(4) Digital control systems — the main turbine control equipment, automatic voltage regulator, auxiliary sequence controller, etc. — were implemented as a functional unit distributed system based on Hitachi Integrated Autonomic Control System 7000 (HIACS-7000), a compact system providing advanced capabilities and high speed processing. Finally, the

system provides excellent plant-wide cooperation and responsiveness because the interface connecting these systems and equipment is implemented with high-speed, high-capacity fiber-optic cable (100 Mbit/s and fully redundant).

TRIAL OPERATION PERFORMANCE

Construction of the plant began in earnest in March 2001, and the initial firing of the boiler took place in October 2001. After first steaming and initial connection of the generator to the transmission system in December 2001, the turbine reached its full rated output of 700 MW in January 2002. The turbine was subjected to extensive testing over the next five months, and after verifying all safety, reliability, and operability criteria, the turbine entered commercial service in June 2002.

Plant Performance

Our planned design objective for the No. 4 system was to achieve 44.2% efficiency, the highest level generating efficiency of any coal-fired power plant. By applying the various performance enhancing technologies described in this paper, Hitachi was trying to reach a thermal efficiency of 49.83% in its turbine plant commissions, the highest level ever achieved for this kind of power plant.

Based on the technologies outlined above, the steam turbine performance trial results during trial operations exceeded the planned efficiency target at the rated output of 700 MW. The results for the gross thermal efficiency including the boiler also exceeded the planned value, thus demonstrating that this plant operates at the world's highest level of efficiency for a coal-fired thermal power plant.

Plant Startup Characteristics

Plant startup characteristics were evaluated during the trial operation by assessing how long it took for the plant to reach its rated output when starting after being shut down for eight hours. The planned startup time based on automatic startup by the unit computer was 180 minutes, but the actual startup took only 174 minutes. It was also found that the actual test startup time results either met or exceeded the planned times under various other startup modes for varying shutdown times.

CONCLUSIONS

This article gave an overview and described the performance of the No. 4 turbine genertor unit at Hokkaido Electric Power Co., Inc.'s Tomatoh-Atsuma Power Station, a highly advanced and efficient coal-fired thermal power plant. The application of advanced technologies raised the efficiency of the plant, which also helps to suppress the volume of CO_2 emissions. Hitachi remains committed to enhance the efficiency of thermal power plants even more in the years ahead to minimize adverse effects on global warming.

Finally, the authors gratefully acknowledge the guidance and support of the various members of Hokkaido Electric Power Co., Inc. throughout the planning and trial operations phases of the Tomatoh-Atsuma Power Station No. 4 unit.

REFERENCES

(1) S. Moriya et al., "High-Efficiency Coal-Fired Power Plant," *Hitachi Hyoron* **79**, pp. 255-260 (Mar. 1997) in Japanese.
(2) F. Fukumoto et al., "Completion of World's Largest Variable Pressure Operation Coal-Fired Power Plant," *Hitachi Hyoron* **76**, pp. 687-692 (Oct. 1994) in Japanese.

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