Design and Operation Experience of Most Advanced Combined Cycle Plant—Construction of Unit No.4-1 Higashi Niigata Thermal Power Station of Tohoku Electric Power Co., Inc.—

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High thermal efficiency power plants are being installed world-wide to meet requirements for energy resource saving and global environmental conservation. Advanced combined-cycle power plants are attracting attention due to their high thermal efficiency. Mitsubishi Heavy Industries, Ltd. (MHI), installed a large-capacity, high-efficiency 1 090 MW combined-cycle power plant as Unit No.3 in the Higashi Niigata Thermal Power Station of Tohoku Electric Co., Inc, in 1984. We also installed an advanced combined-cycle power plant using M 701G gas turbines as Unit No.4 at the same site. In July 1999, 805 MW Unit No.4-1 began commercial operation, combining excellent performance with high reliability.

1. Introduction

A power generation plant, which is basic to any modern human society, is required to save energy resources and have excellent environmental capability as well as high reliability.

In order to meet these requirements, the Unit No.4-1 Higashi Niigata Thermal Power Station was constructed using the latest technology LNG-fired high-efficiency combined-cycle power plant, having a total power output of 805 MW. This plant is equipped with a 1 450℃ class large-capacity high-efficiency M 701 G type gas turbine which had been designed both on the basis of fully proven technology and also developed by applying state-of-the-art technology shown in **Fig. 1**.

In addition, a heat recovery steam generator and a steam turbine able to operate under a high-temperature and high-pressure steam condition were adopted for the steam cycle. As a result, the plant achieves a thermal efficiency of over 50% [higher heating value (HHV) base], the worldly highest level, at the generator terminals. Furthermore, the steam-cooled low-NOx combustor adopted for the M 701 G type gas turbine demonstrated an excellent environmental performance.

This report is intended to introduce the design outline and actual operation results of this combined cycle plant.

2. Plant design outline

2.1 Plant outline

Unit No.4-1 Higashi Niigata Power Station is a heat recovery type combined-cycle plant equipped with two large-capacity and high-efficiency gas turbines (M 701 G type) as the core equipment which operate at a combustor outlet temperature of 1 450℃, the highest in the world. The plant is a multi-shaft type combined-cycle plant consisting of two gas turbines and one steam turbine, which are connected to their respective generators, and having a unit overall output of 805 MW. The plant schematic diagram is shown in **Fig. 2**. In July 1999, Unit No.4-1, which has the half capacity of Unit No.4, commenced commercial operation.

2.2 Features

(1) High plant efficiency

The adoption of the 1 450℃ class M 701 G type gas turbine and the high-temperature and high-pressure steam condition produced by the high-temperature gas turbines improved the thermal efficiency by about 2% in above that of a conventional 1 350℃ class gas turbine. As a result, a

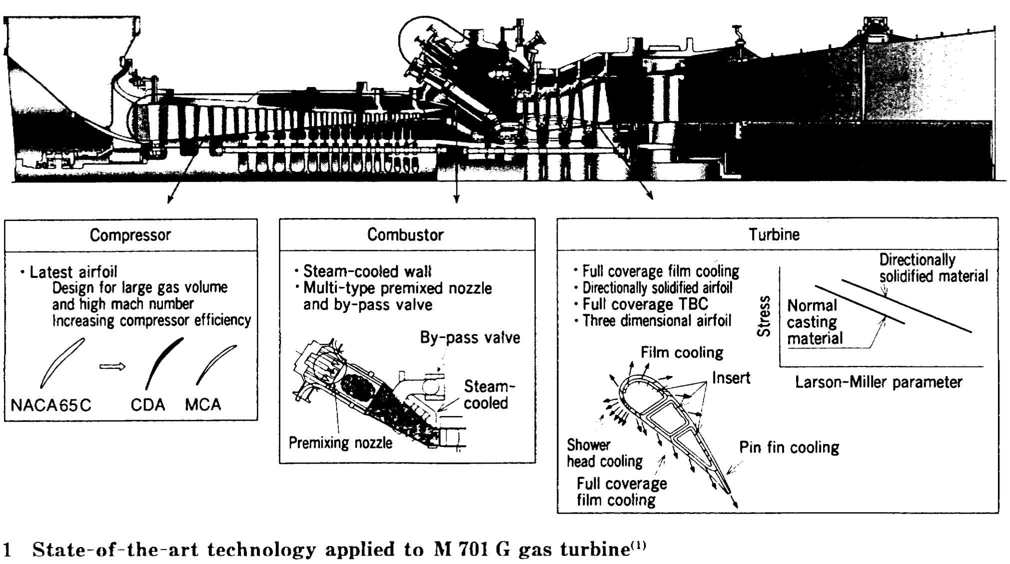

Fig. 1 State-of-the-art technology applied to M 701 G gas turbine(1)
This figure shows the state-of-the-art technology applied to the worldly first 1 450℃ class gas turbine for electric utility.

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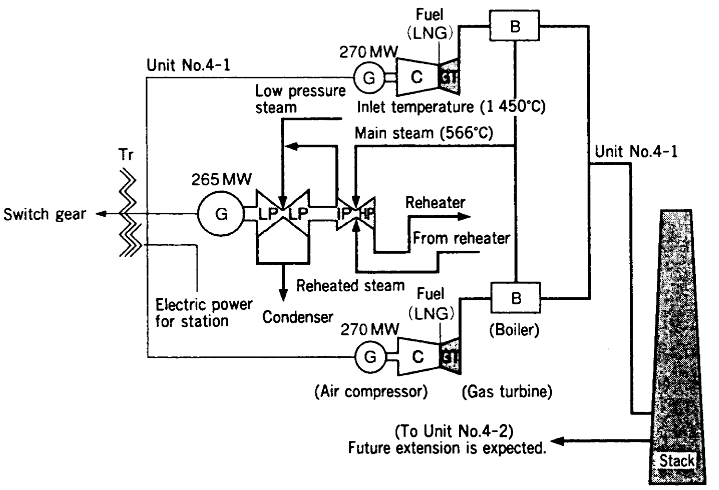

Fig. 2 Plant schematic diagram[2]

plant thermal efficiency exceeding 50% was actually demonstrated.

(2) Environmental conservation

In order to prevent an increase of NOx due to increasing the combustor outlet gas temperature to 1 450℃, in addition to the conventional premixed type, a low-NOx combustor with a steam-cooled system was adopted to make combustor-wall cooling air unnecessary. The combustor construction is shown in **Fig. 3**. Furthermore, the environmental regulation criteria can fully be satisfied by a dry-type de-NOx system having the capability to eliminate all nitrogen oxides from the waste gas.

(3) Excellent operational capability

The start, stop, and output control of the plant are automated. The plant is designed so as to be operated at a low load by stopping one gas turbine to improve the plant thermal efficiency.

(4) Compact plant layout

The plant site area is efficiently utilized by increasing each component unit capacity and adopting of a vertical gas flow type heat recovery steam generator.

Because the gas turbines and steam turbine have their own respective shafts, the foundations and buildings are optimized by the proper arrangement of their installation levels.

2.3 Plant rated performance and equipment specifications

(1) Plant rated performance

Unit No.4-1 Higashi Niigata was designed as a plant meeting an approved output of 805 MW. Each gas turbine generates 270 MW and the steam turbine 265 MW at an atmospheric temperature of −1℃. The design plant efficiency is 50% (at the generator terminals and the higher heating value base).

(2) Equipment specifications

Considering the output characteristic and the controllability of the whole combined cycle plant, every component is specified to operate smoothly. The particulars of the major components are shown in **Table 1**.

3. Characteristics of major components

3.1 Gas turbines

The M 701 G gas turbine has been developed and designed by applying the latest technology fostered through various elemental research carried out by MHI, as well as following the basic construction of the M 501 F/701 F gas turbine with its long experience and high reliability. The manufacturing schedule is shown in **Fig. 4**.

For the high-temperature components such as the combustor and the first and the second stage turbine blades and vanes, it was decided that their basic dimensions were to be the same as those of the M 501 G gas turbine (for 60 Hz) having been operated in advance.

Thus, these high temperature components could have the merit of inheriting the proven results together with the reliability of the M 501 G turbine.

The design concept that turbines for both 50 Hz and 60 Hz have their high temperature components in common has already been used for F-type gas turbines.

3.2 Steam turbine

In this plant, in order to improve the combined cycle plant efficiency, the main steam and reheat steam temperatures were chosen to be 566℃, as the steam condition corresponding to the

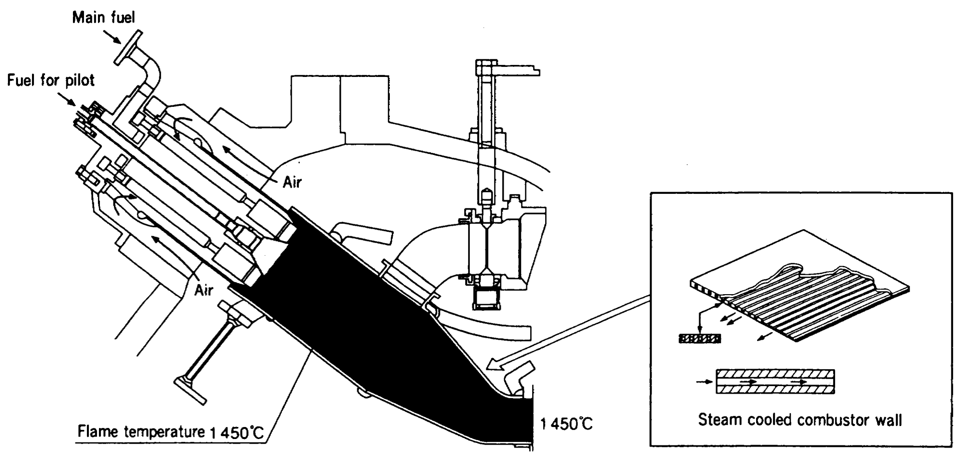

Fig. 3 Structure of steam cooled combustor
The newly developed combustor with recovery type steam-cooled system for achieving low NOx at a combustor outlet temperature of 1 450 is shown.

Table 1 Specifications of major components

Gas turbine	
Number	Two sets
Type	Single-shaft open-cycle type (M 701 G)
Fuel	LNG vaporized gas
Output	270 000 kW (at an atmospheric temperature of −1℃)
Inlet gas temperature	1 450℃
Rotation speed	3 000 rpm
Exhaust heat recovery boiler	
Number	Two sets
Type	Waste-heat-recovery triple-pressure, natural-circulation type
Steam quantity (HP)	281 t/h
Steam quantity (IP)	75 t/h
Steam quantity (LP)	65 t/h
Outlet pressure (HP)	14.1 MPa
Outlet pressure (IP)	5.2 MPa
Outlet pressure (LP)	0.64 MPa
Outlet temperature (HP)	569℃
Outlet temperature (IP)	295℃
Outlet temperature (LP)	270℃
Steam turbine	
Number	One set
Type	Comb-shaped double-flow exhaust reheat mixed-pressure condensing type (TC2F-40.5)
Output	265 000 kW (at an atmospheric temperature of −1℃)
Inlet pressure (HP)	13.7 MPa
Inlet pressure (IP)	4.1 MPa
Inlet pressure (LP)	0.49 MPa
Inlet temperature (HP)	566℃
Inlet temperature (IP)	566℃
Inlet temperature (LP)	267℃
Condenser vacuum	4.27 kPa
Rotation speed	3 000 rpm
Generator	
Number	Three sets
Type	Horizontal-shaft tubular rotary field type
Capacity	332 000 kVA
Voltage	23 000 V
Power factor	90% (delay)
Frequency	50 Hz
Rotation speed	3 000 rpm

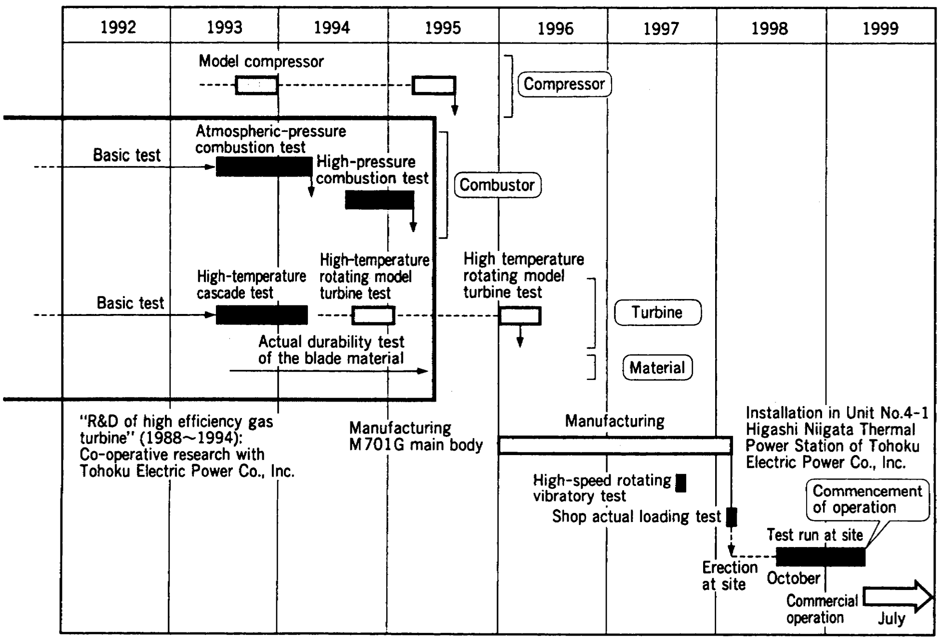

Fig. 4 Schedule of M 701 G gas turbine development and manufacturing
The M 701 G type gas turbine is a highly reliable and highly capable high-temperature gas turbine designed so as to fully reflect the results of various elemental tests.

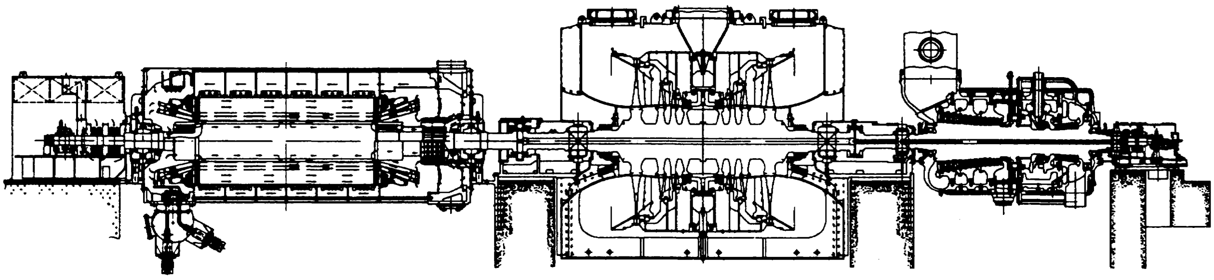

Fig. 5 Longitudinal sectional drawing of the steam turbine

waste gas condition of the M 701 G high temperature gas turbine.

For the steam turbine, a two-casing turbine was chosen, because it has been proven for commercial use and is suitable to the quantity of the steam produced in the heat recovery steam generator (**Fig. 5**).

Furthermore, the high efficiency reaction blades designed by means of the latest three-dimensional flow analysis and the 40.5 inch ISB end blades were adopted to achieve a high turbine efficiency.

3.3 Heat recovery steam generator

The heat recovery steam generator was designed so as to make the steam cycle highly efficient by adopting a multi-shaft triple pressure reheat system, raising the turbine inlet steam temperatures to 566℃/566℃ (first achieved in Japan) owing to the increased temperature of the waste gas from the high temperature gas turbine, and increasing the steam pressure to 13.7 MPa at the high pressure turbine inlet.

Because IP steam is used for cooling the gas turbine combustor, for the plant design, it is essential to assure that the IP steam amount required for the cooling is provided.

At the same time, the heat transfer areas were decided, taking into consideration the profitability of the plant.

For the heat recovery steam generator, a vertical gas flow type natural circulation boiler was adopted because of its advantages such as its compact construction and fewer inspection points.

Before adopting the steam generator, careful verification had been carried out by the visualization test of the circulating properties under the high-pressure condition.

The heat recovery steam generator was split into the right and left large scale modules for transportation[3] and they were unified and installed at site, so that the quality control could be improved and the erection schedule shortened.

4. Test run results

The test run of Unit No.4-1 corresponding to a half capacity of Unit No.4 Higashi Niigata Thermal Power Station demonstrated excellent results, satisfying all the intended specifications for plant performance, environmental capability, and operational capability.

4.1 Plant performance

The rated unit output was ensured at an atmospheric temperature of −1℃ and a plant thermal efficiency of over 50% was achieved. Also even in a partial load, high thermal efficiencies were obtained as shown in **Fig. 6**.

4.2 Environmental capability

The steam-cooled type low NOx combustor and NOx control technology by the dry-type de-NOx system demonstrated stable operation in low NOx. The NOx concentration in the exhaust gas emitted from the stack was below the guaranteed figure of 9.5 ppm (converted by O_2=16%).

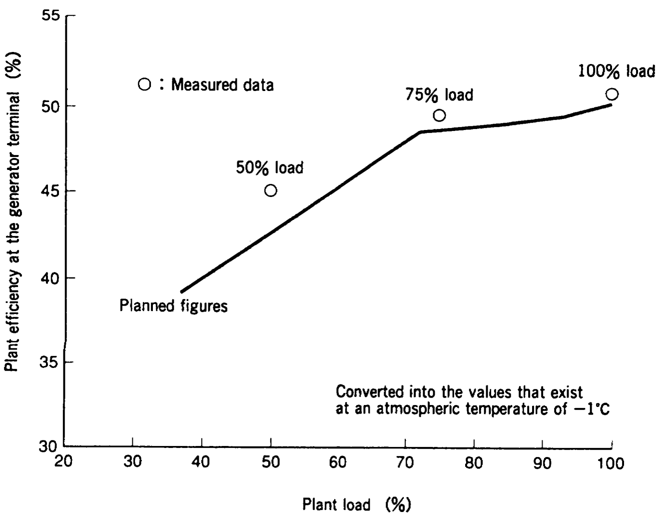

Fig. 6 Thermal efficiency characteristics (measured data)
High plant efficiencies are actually obtained even at partial loads.

Table 2 Special measurement items

Measured items	Performance	Inlet flow rate Inlet gas temperature & pressure Waste gas temperature & pressure Fuel flow rate Generator output Turbine element performance
	Metal temperature	Combustor Turbine first stage blade Turbine1st, 2nd, 3rd vanes Bearings Casings Blade rings Exhaust diffuser compressor vanes
	Pressure & vibration	Compressor vanes Combustor Rotor shaft vibration Rotor torsional vibration
	Others	Cooling air: flow rate Cooling air pressure & temperature Thrust Exhaust gas characteristics Elongation difference of rotor/casing Tip clearance Noise Lubricating oil temperature

4.3 Operational capability

The following tests concerning the plant capability were carried out during the test run and the plant was verified to have the operational capability as planned.

- Automatic start and stop function test
- Automatic output control function test
- Run back function test for auxiliary machinery stop
  Load variation test, etc.

4.4 Gas turbine

In advance of the test run at site, in order to check the performance and reliability of the gas turbines, a shop actual loading test had been performed in spring, 1998. In this loading test, the items shown in **Table 2** were measured and the efficiencies and reliabilities were confirmed to be as high as planned.

Continuing from the shop actual loading test, after the turbines were installed in Unit No.4-1, special measurements were carried out for the metals of the high-temperature components at site, and their high reliability was also confirmed.

5. Conclusion

Unit No.4-1 Higashi Niigata Thermal Power Station of Tohoku Electric Power Co., Inc. was constructed as a combined cycle plant and the expected results were achieved. The achievement of the higher plant performance and the improved environmental capability is noticeable, the technology development is especially worthy of close attention. Continuously, new plant systems including steam cycles are being studied and developed to meet future social requirements.

We believe the valuable results obtained from this plant will contribute greatly to future large-scale and high-efficiency plant projects. Also, it is expected that this Unit No.4-1 will contribute largely to reliable and stable electric power supply.

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