25—35 MW Class High-Performance Gas Turbine MF-221

Kenichiro Takeishi*1 Hidetaka Mori*1
Keizo Tsukagoshi*2 Naoyuki Seki*2
Masayuki Takahama*2

From the viewpoint of utilizing energy most effectively, cogeneration plants in which gas turbines are the main power producers are being spotlighted due to their excellent overall thermal efficiency. To date, the excellent performance of the MF-111 gas turbine has been verified in more than 30 cogeneration plants. To meet a variety of needs, Mitsubishi Heavy Industries, Ltd. developed the 25—35 MW class high-performance gas turbine MF-221. The performance and reliability of the prototype engine were verified in a full load shop test carried out in 1994.

1. Introduction

From the viewpoint of utilizing energy most effectively, cogeneration plants in which gas turbines are the main power producers are being spotlighted due to their excellent overall thermal efficiency. These cogeneration plants generate steam by recovering the exhaust heat of gas turbines. This steam is used as process steam as well as for steam turbines. Through this system, the overall thermal efficiency of the cogeneration plant can be improved and energy savings of the plant can be expected. Moreover, further energy savings can be realized by utilizing the higher gas temperature of the gas turbine.

Mitsubishi Heavy Industries, Ltd. (MHI) started development of the 12—16 MW class MF-111 gas turbine in 1983 in order to utilize the higher gas temperature of the gas turbine[1]. Advanced cooling techniques have been applied to the MF-111 type gas turbine in order to enable it to be continuously operated at a turbine inlet gas temperature of 1 250°C. This type of gas turbine has exhibited excellent performance primarily in the cogeneration plant field, and MHI has already delivered more than 30 units.

To meet a variety of needs, MHI developed the 25—35 MW class high-performance gas turbine MF-221. The MF-221 was designed with a turbine inlet gas temperature of 1 250°C. In order to realize high reliability, MHI made the best use of techniques obtained through the production of the MF-111 gas turbines. The advanced technology and the higher gas temperature technology have been incorporated into its design to achieve high performance. The performance and reliability of the prototype engine were verified in a full load shop test carried out in 1994.

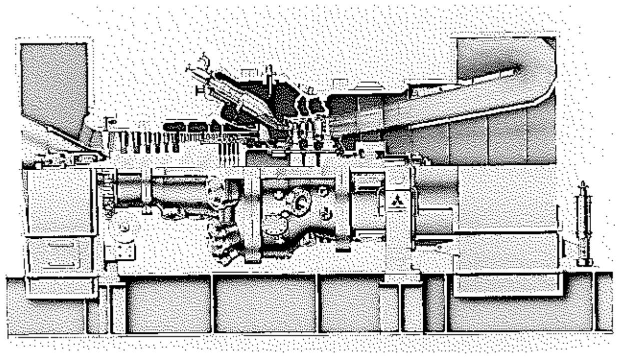

Fig.1 MF-221 gas turbine longitudinal cross-section
Full load tests of the prototype engine were conducted in July 1994, and its performance and reliability were verified.

Table 1 MF-221 gas turbine design feature

	MF-221	MF-111 B
Compressor		
Number of stage	17	16
Pressure ratio	16	15
Number of bleed stage	3	3
Combustor		
Type	Cannular	Cannular
Number	10	8
Turbine		
Number of stage	3	3
Air cooled stage	1st and 2nd	1st and 2nd
Rotor		
Structure	Stacked disk	Stacked disk
Rotating speed	Approx. 7 200 rpm	Approx. 9 700 rpm

2. Features of the MF-221 gas turbine

The MF-221 retains the fundamental structure of the MF-111 accumulating operation results and high reliability. The advanced technology obtained in the basic research and the higher temperature technology of the 501 F and the 701 F were applied for the MF-221[(2)-(5)].

2.1 Overall structure

The fundamental structure of the MF-221, as shown by the longitudinal cross-section in **Fig.1**, is a scale ratio of 1.35 times that of the MF-111 and has the features in line with design concepts used in Mitsubishi gas turbines as their horizontal two-piece housing structure, two bearing support, and a compressor-shaft-end drive system. **Table 1** shows the design features of the MF-221. It has a design rotating speed of 7 200 rpm and drives a generator through reduction gears.

2.2 Compressor design

The efficiency of the compressor has been improved through the use of high-performance blades. A direct support system from the cylinder cover was not employed for seventh and subsequent stage of vanes, but rather a support system using blade ring was employed. Also, an abradable coating is applied to the blade ring. Improvements in the efficiency of the elements were attained by keeping the tip clearance of the blades at a minimum.

2.3 Combustor design

The combustor has been designed with a scale ratio of 0.67 times that of the DF-42 diffusion type low NOx combustor for the MW-501 D 5/MW-701 D, and has also been improved to

*1 Takasago Research & Development Center, Technical Headquarters
*2 Takasago Machinery Works

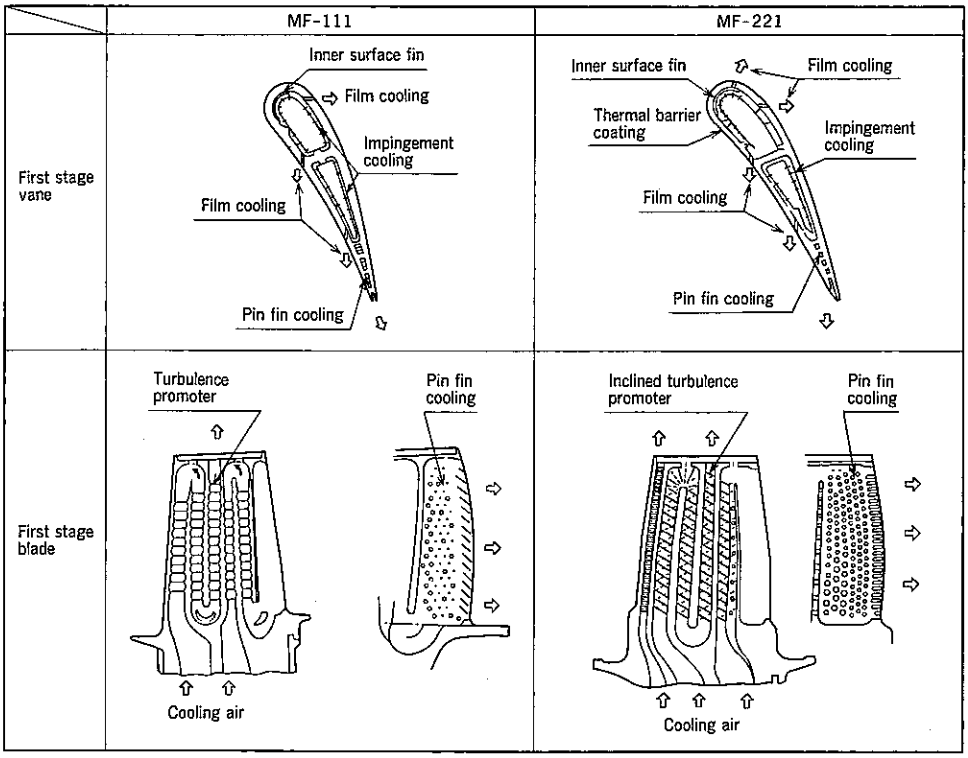

Fig.2 Improvement of cooling scheme
The cooling performance of the first stage turbine blades and vanes has been improved by incorporating the advanced cooling scheme into the design.

Table 2 Turbine blade and vane materials

	Vane	Blade
1st stage	ECY 768	MGA 1400
2nd stage	ECY 768	MGA 1400
3rd stage	X-45	MGA 1400

meet higher turbine inlet gas temperatures. The cooling structure for the combustor wall surface has been changed from a conventional film cooling type to a plate fin cooling type with the objective of lowering NOx generation by decreasing the amount of cooling air and increasing the amount of combustion air. As a measure to lower NOx generation, when gas and oil are burned, a water/steam injection method has been employed.

2.4 Turbine design

Though the turbine has been designed in a fashion that is basically similar to the MF-111 gas turbine, blade profiles have been optimized through the use of a fully three-dimensional flow analysis. The annulus area of the last turbine stage has been made relatively larger than that of the MF-111 in order to decrease exhaust loss. Blades with integral "Z" tip shrouds, which have excellent vibration resistance, have been used for the third-stage blades. The high-strength material MGA-1400, developed by MHI, has been used for all stage blades as shown in **Table 2**.

2.5 Air cooling system/Air cooled blade and vane design

Turbine blades and vanes are cooled with air bled from each stage of the compressor. The first stage vanes are cooled with the compressor discharged air, while the second vanes are cooled with the compressor 13th stage bled air. Blades and the rotor are cooled with the compressor discharged air after cooling it with an external cooler down to 200°C in the same way as large-sized gas turbines. The cooling scheme of the first stage turbine vane is such that the structure of the impingement cooling of the inner surface using two inserts, the film cooling of the vane surface, and the pin fin cooling of the trailing edge parts is optimized. Also a thermal barrier coating is applied to all gas path surfaces of the first stage vanes, as shown in **Fig.2**. Thus, the reliability of the vanes has been improved. Air cooled blades have been used for the first and second stage turbine blades. The cooling scheme of the first stage blade is such that cooling air passages of the leading edge, center and trailing edge parts are independent of each other, and they effectively cool parts having large thermal flux. Its cooling performance has also been improved through the use of inclined turbulence promoters inside.

3. Component tests

Component tests were conducted, and various design data were obtained during the basic design stage of the MF-221 gas turbine. Test results were incorporated in the detailed design stage.

3.1 Combustion tests

The performance of the combustor used in the MF-221 gas turbine, to which the scale design of the DF-42 diffusion type low NOx combustor for the MW-501 D 5/MW-701 D gas turbines was applied, was tested using an intermediate pressure combustion test unit. It was verified through this test that the test combustor NOx emissions versus fuel/air ratios (weight ratios) characteristic approximately coincided with that of the DF-42 when gas/oil were burned and that there was no problem with its combustion stability and metal temperature.

3.2 Rotating vibration tests

The rotating vibration test was conducted using an actual rotor for compressor and turbine blades. A non-contact measuring method using optical sensors was applied to the first

Table 3 Gas turbine performance

		Design values
Power output	(kW)	30 000
Thermal efficiency	(%)	32.0 or more
Exhaust gas temp.	(°C)	530
Exhaust gas flow	(kg/h)	363 600

Conditions: ISO, Fuel: natural gas

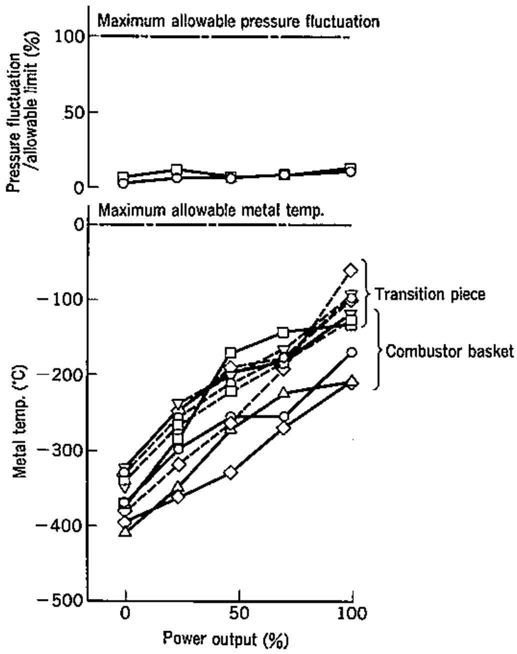

Fig.3 Combustor metal temperatures and pressure fluctuations
Metal temperatures measured by burying thermocouples at various positions are within allowable limits, and the results of pressure fluctuation measurements of the combustor also are within allowable limits.

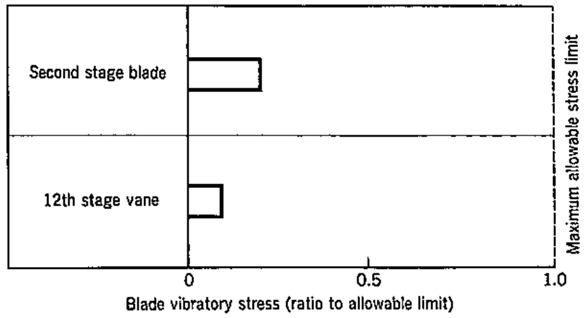

Fig.4 Compressor blade and vane vibratory stresses
Each measured vibratory stress was sufficiently lower than its respective allowable limit.

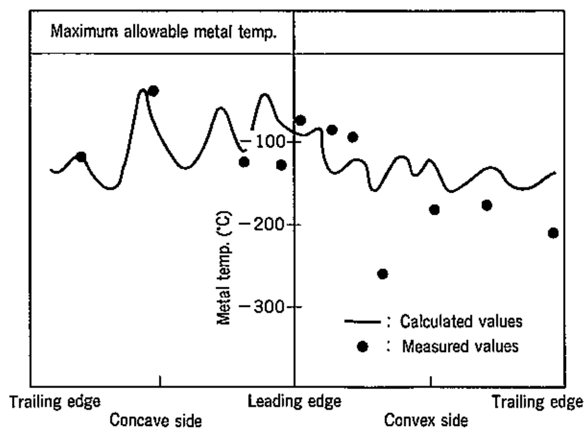

Fig.5 First stage turbine vane metal temperatures
Metal temperatures were measured by burying thermocouples into the surface of the vanes. Metal temperatures measured at a vane height of 50% were measured and the results were compared with calculated values.

and fifth stage compressor blades. The natural frequencies and vibration damping characteristics of the first, second and third stage turbine blades were measured by a non-contact system in which a strain gauge was fitted to each blade and signals from it were transmitted through the use of a telemeter.

As a result, it was verified that the vibration characteristic of each blade was excellent and that the damping effect of the third stage blade shrouds was adequate.

4. Full load shop tests

The prototype MF-221 gas turbine engine was completed in July 1994, and verification tests of its performance and reliability were conducted using a full load verification test unit at the Takasago Machinery Works of MHI.

4.1 Performance

The overall performance of the MF-221 was analyzed by conducting a heat balance on the basis of measurement results of the inlet air flow, cooling air flow, fuel consumption, power output of generator, and the temperature and pressure of the various part. As a result, it was verified that both power output and thermal efficiency of the gas turbine were superior to the design performance specifications shown in **Table 3** under full load conditions.

4.2 Combustor

During the full load shop tests using kerosene as fuel, environmental pollutants in the exhaust gas such as nitrogen oxides (NOx) and carbon monoxide were measured under various load conditions. It was verified through these measurements that the NOx reduction effect versus the amount of injected steam approximated expected values.

Metal temperatures, pressure fluctuations, and vibratory stresses were measured to verify the reliability of the combustor. Metal temperatures were measured by burying thermocouples in the combustor basket and the transition piece. As can be seen in **Fig.3**, it was verified that the metal temperature at every position was lower than the allowable limit. Pressure fluctuations, which are a source of the vibratory stress of the combustor, were measured by mounting a high-temperature pressure fluctuation sensor in the combustor basket. These measurements confirmed that the results were excellent. It was also verified that the vibratory stress of each part of the combustor was sufficiently lower than the allowable limit.

4.3 Compressor and turbine blades

Natural frequencies and vibratory stresses of two blades were measured by a non-contact method using optical sensors for the second stage compressor blade and by fitting strain gauges on the 12th stage compressor vane. As a result, it was verified that each measured vibratory stress was sufficiently lower than its respective allowable limit as shown in **Fig.4**.

Metal temperatures of the first and second turbine vanes were measured by burying thermocouples into the surface of the vanes. **Fig.5** shows a comparison between the calculated values and the actual measured results of metal temperatures of first stage vanes on a section of mean radius under full load conditions. The actual results coincided almost completely with the calculated values, and the maximum metal temperature complied with allowable limits.

4.4 Mechanical properties

The reliability of the thrust bearing and journal bearing was verified by measuring thrust force and metal and discharged oil temperatures for the former, and metal and discharged oil temperatures for the latter.

The measurements, were found to be satisfactory and within expected values.

5. Conclusion

MHI has developed the 25—35 MW class high-performance gas turbine MF-221. The MF-221 retains the fundamental structure of the MF-111 accumulating operation results and high reliability. The performance of this gas turbine has been enhanced by applying the advanced technology obtained in the basic research and the higher temperature technologyof the 501 F and the 701 F. The performance and reliability of the prototype engine were verified in a full load shop test carried out in 1994. The MF-221 gas turbines are expected to contribute to further energy savings of cogeneration plants, serving as their main power producers.

References

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