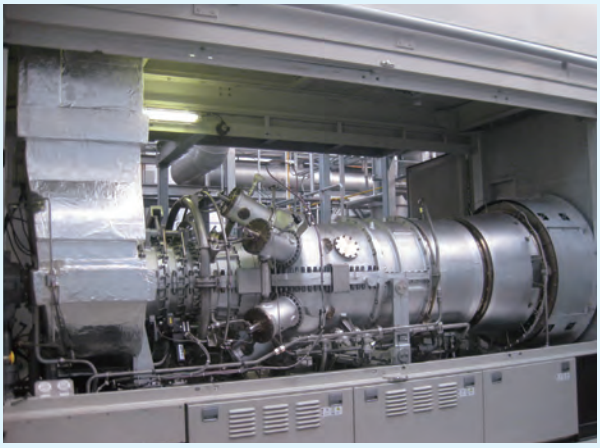
Modification of 8 MW class gas turbine, M7A-03



Over 30 orders have been received for our 8 MW class high-efficiency gas turbine, the M7A-03, which first appeared on the market in 2007. Those units are running smoothly with an accumulated equivalent operating time of more than 200,000 hours. To respond to the need for further performance enhancement, continuous efforts have been directed at improving performance of the M7A-03. This paper presents our approach to performance improvement with the M7A-03.

Preface

In addition to the interest drawn from increased environmental awareness, gas turbine-based cogeneration systems are considered to be increasingly important hardware as distributed power supplies. The gas turbines that form the core of such cogeneration systems are required from an environmental viewpoint to have environment-friendly exhaust gas characteristics (CO_2 and NOx emissions reduction) based on the use of natural gas and high efficiencies from an economic perspective.

The M7A-03 is a low-environment-loading, high-efficiency gas turbine, and is the latest model of Kawasaki's M7A series, which has an impressive track record of more than 100 units delivered. we continue the effort for performance enhancement of the M7A-03 in response to the needs described above.

1 Overview of the M7A-03

We internally developed the M7A-01 1) gas turbine (6 MW class) and equipped it with a full-scale axial flow compressor, putting it on the market in 1994. Following this, We developed the M7A-02 gas turbine (7 MW class) in which transonic compressor technology was applied to increase output power through an increase in the intake air flow volume and pressure ratio, with sales started in 1998. Aiming at scaling up the M7A while maintaining its basic structure, we applied the latest technology in developing a high-efficiency gas turbine in the L20A 2) (18 MW class) Sales were launched in 2000.

The M7A-03 3) which retrofitted the M7A-02 with the latest technologies of the L20A to improve performance characteristics, has been on the market since 2007. Fig. 1 shows the M7A-03, and Table 1 presents its specifications.

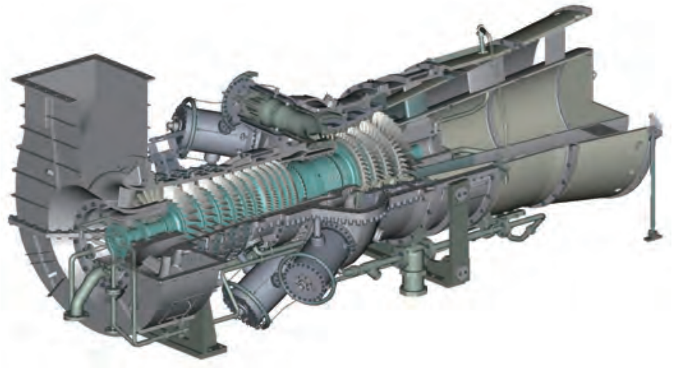


Fig. 1 Overview of M7A-03 gas turbine

Table 1 M7A main specifications

Structure	Open cycle, Single shaft
Compressor	Axial flow, 11 stages
Combustor	Can-type, 6 cans
Turbine	Axial flow, 4 stages
Number of revolutions (min^{-1})	13,790
Bearing specification	Journal bearings, Thrust bearing

(a) Unit for Japanese use

(b) Unit intended for use in Europe

Fig. 2 M7A-03 gas turbine generator package

2 Operational track record of the M7A-03

We have received orders from both Japan and abroad for over 30 cogeneration facilities equipped with the M7A-03 gas turbine. The total working time is over 150,000 hr in terms of the actual operating time and over 200,000 hr in terms of the equivalent operating time. Fig. 2 shows an example of a typical gas turbine generator package.

In terms of the combustion scheme, most of the delivered gas turbines are equipped with Dry Low (NOx) Emission (DLE) combustors to meet environment requirements. Three gas turbines equipped with an ultra-low (NOx) DLE combustor with an NOx emission density of 15 ppm (15% O_2 conversion) continue running without a problem. On the other hand, in regions such as Southeast Asia where infrastructure for natural gas is unreliable, gas turbines equipped with a dual fuel combustor that can be fired temporarily on liquid fuel are used.

With the M7A-03 having roughly the same basic structure as the M7A-02, the M7A-03 can replace the M7A-02 installed on a generator package. Fig. 3 shows how the generated output changes as a result of a replacing the M7A-02 with the M7A-03. By replacing the M7A-02 with the M7A-03, the generated output can be increased by 700 kW without other substantial modifications.

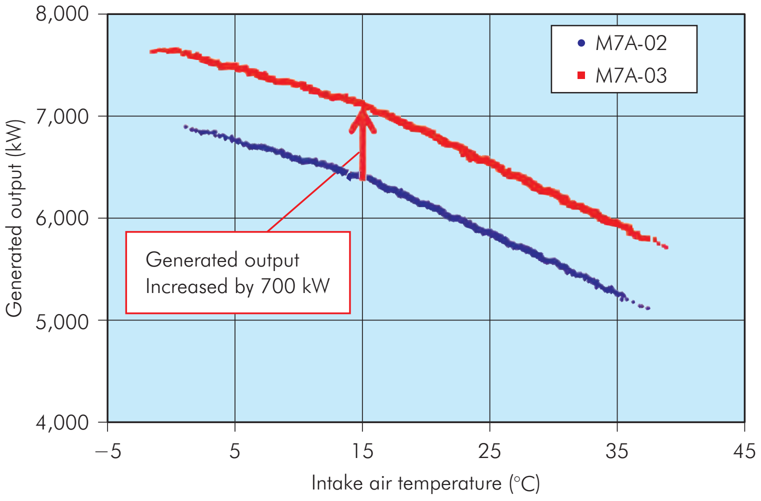


Fig. 3 Benefits of output power by switching to M7A-03

3 Efforts for higher performance

In response to market requirements for higher efficiency, we have continued efforts toward higher performance. Some of those efforts are presented below.

(1) Improvement of element efficiencies and reduction in ineffective air

In the development of the M7A-03[3], a substantial increase in performance was attained by improving the efficiencies of each element such as the compressor and turbine, and reducing air that was not effectively used to produce power. By the way, we continue efforts to improve these factors to achieve even higher performance.

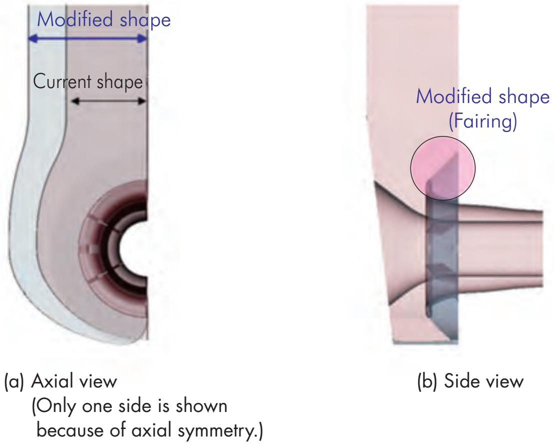
(i) Reduction in pressure loss in the inlet collector

The passage through which air is taken from the outside of the generator set and channeled to the gas turbine inlet is shaped as a collector. An improperly shaped inlet collector causes distorted flow at the compressor inlet resulting in increased pressure loss. In addition, this inlet flow distortion affects the element efficiency of the compressor and blade vibration characteristics.

A modification was made to make the flow at the compressor inlet uniform. Fig. 4 shows the shape before and after the modification, and Fig. 5 shows the results of CFD analysis on the outlet of the inlet collector (namely, the compressor inlet). The modification has brought about a reduction in pressure loss of about 10%.

(ii) Reduction in the tip clearance of the turbine

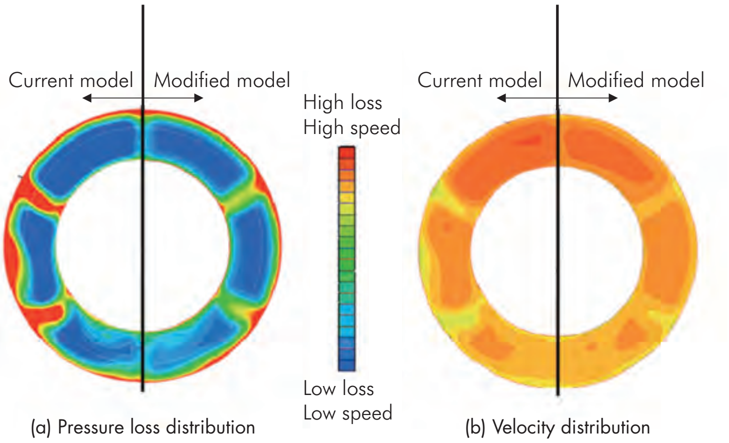
The gap between the turbine rotor blades and turbine shroud, is called the "tip clearance." Because it governs the quantity of working fluid bypassed to the face and the back of a blade, this tip clearance affects the element efficacy of the turbine greatly.



(a) Axial view
(Only one side is shown because of axial symmetry.)

(b) Side view

Fig. 4 Modified inlet collector profile



(a) Pressure loss distribution

(b) Velocity distribution

Fig. 5 Results of CFD analysis at collector outlet (Cross-section downstream of bellmouth)

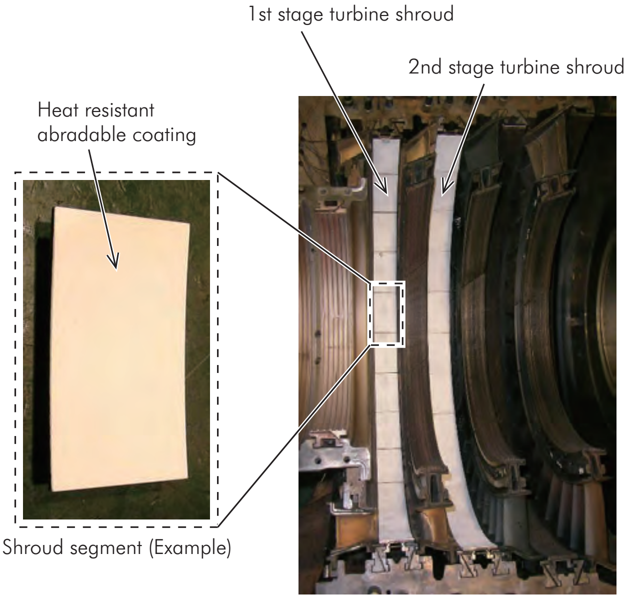


Fig. 6 Heat-resistance and abradable coating

The tip clearance becomes the smallestin a transient operation such as start up. The clearance in nominal operation is determined so as to prevent the rotor blades and stationary shroud from being damaged by hard rubbing in a transient operation.

With the aim of making the clearance during normal operation still smaller, a heat-resistant abradable coating that is easily worn by contact with rotating metal is applied to the shroud so that any possible contact of the rotor blade with the shroud during transient operation does not result in serious damage. Fig. 6 shows a shroud with the heat-resistant abradable coating.

(iii) Reduction in ineffective air

Pressure at the outlet of the compressor in a gas turbine is very high. For this reason, if gaps are present in spaces of high compressed air, air leaks will occur and compressed air cannot be used effectively. But, it is difficult to eliminate gaps completely because of processing tolerances and the differences in thermal expansion during operation.

With the aim of minimizing gaps that occur during operation and thereby reducing leaking air, heat-resistant plastic cord seals were inserted into the gaps. Fig. 7 shows how a cord seal is inserted.

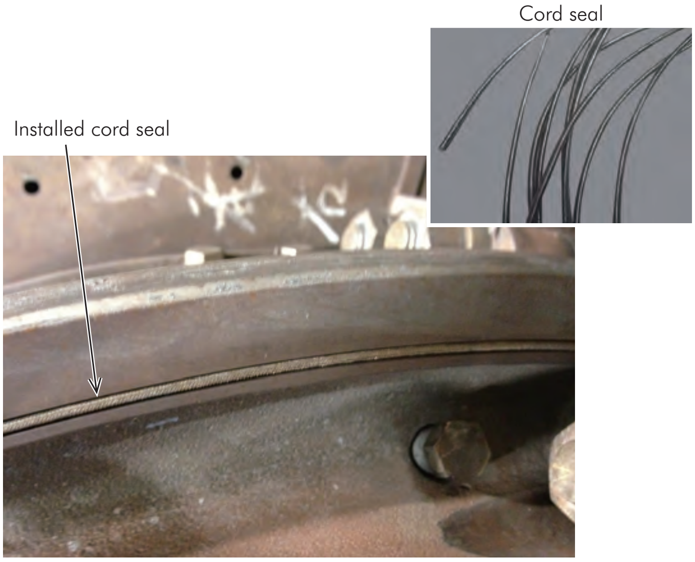
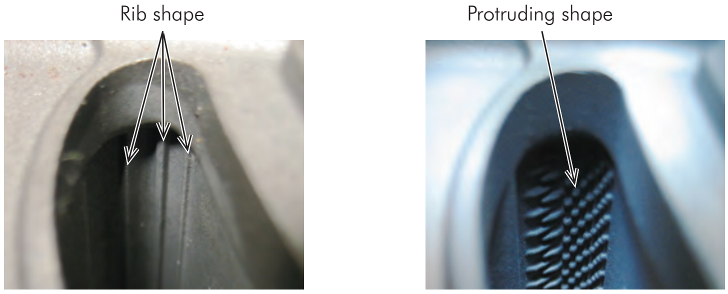


Fig. 7 Gap minimization by applying cord seal



(a) Conventional blade

(b) Modified blade

Fig. 8 Cooling structure on leading edge

(2) Re-examining the heat cycle

The ways of increasing performance in terms of the heat cycle characteristics of a gas turbine include increasing the pressure ratio and raising the gas temperature at the turbine inlet. The former requires the compressor be redesigned and hence a substantial change in the structure. For this reason, the latter means of raising the gas temperature at the turbine inlet was adopted to attain higher performance.

An increase in the temperature of turbine parts affects the life of hot section parts and consequently the reliability of gas turbine. What becomes important to ensure reliability is cooling technology for the hot parts when the turbine inlet temperature (TIT) is raised, and temperature measuring technology to verify the effect of the former.

(i) Cooling technology

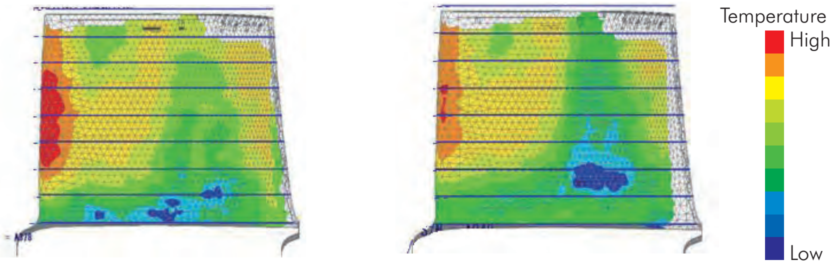
With compressed air from the compressor outlet used to cool turbine blades, saving this cooling air minimizes compression work, contributing to an improvement in performance of the gas turbine. Also, when the TIT is raised, improving the cooling performance of blades is important to maintain, with a minimal increase in cooling air volume, the turbine blades at about the same temperature as when the TIT is not raised.

In order to improve the blade cooling performance at the highest thermally loaded leading edge of the 1st stage turbine stationary blades, which are exposed to the highest gas temperature, the leading edge cooling structure was changed from the conventional rib structure to a protruding structure that increased the heat transfer area on the cooling side. Fig. 8 shows the difference in the cooling structures.

(ii) Temperature measuring technology

Among the rotor blades of the M7A-03, the 1st and 2nd stage blades adopt a cooling structure. The temperature of the blade material is one of the very important factors in assessing the life of turbine blades. But, it is difficult to accurately estimate temperatures over the entire cooling blade at the time of design, and for this reason, it is extremely important to measure temperatures across the blade on an actual machine in operation.

To retain the reliability of blades in terms of strength, the basic structure of the cooling blade was kept identical to that of a conventional blade. On the basis of this idea, the objective was set not to allow the temperature of the blade material to rise as a result of an increase in the cooling air to the blade if the TIT rises. In the design phase, studies were conducted to maintain the temperature of the



(a) Before modification
(Conventional TIT)

(b) After modification
(Raised TIT)

Fig. 9 1st blade surface temperature measured by pyrometer (Brade pressure side) turbine blade material with a minimum increase in cooling air volume in consideration of the effect on engine performance.

To verify the appropriateness of the increase in cooling air volume based on this design, the temperature of blade materials on an actual machine was measured. To measure the temperature of the rotary blades, an infrared radiation temperature measurement system (pyrometer)4) that had a proven track record was used. Fig. 9 shows the results of measurements on the 1st stage turbine rotor blades. This confirms that the temperature of the material of the turbine blades is held below the same temperature of conventional blades even if the gas temperature at the inlet rises.

4 Performance of the modified model

The modified model is being subjected to field tests at our Akashi Works No.7 power plant to verify the reliability of each of the modifications since June 2012. Table 2 shows the performance of the improved M7A-03 to which the current modifications have been applied.

Concluding remarks

We have received brisk orders for the M7A-03 since the first unit was marketed in 2007, and continues favorable operation.

The improved M7A-03, which aims at still higher performance, has been undergoing field tests at the energy center of Kawasaki's Akashi Works since June 2012.

We will do its best to continue making improvements with the aim of providing its customers with gas turbines of higher performance and reliability.

Table 2 Performance of improved M7A-03

	Modified	Conventional
Output, generator end (kW)	7,780	7,420
Efficiency, generator end (%)	33.5	33
Exhaust gas temperature (°C)	523	510
Pressure ratio	15.6	15.6
Air flow rate (kg/s)	27	27

No inlet and exhaust duct loss; fuel: methane (100% CH_4)

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