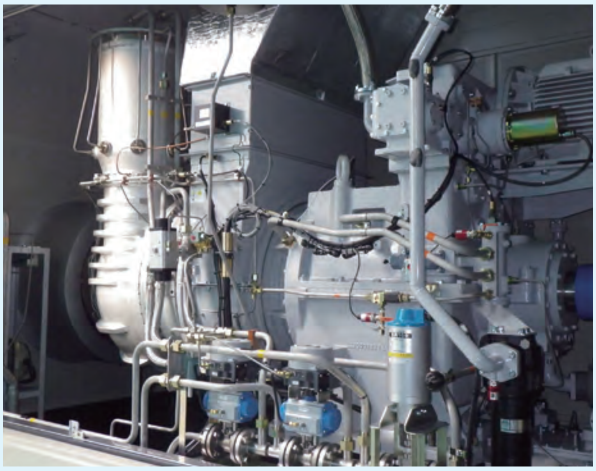
1.7 MW class high efficiency and low emission gas turbine, M1A-17



We have been developing and manufacturing power generation-use gas turbines for a long time ever since pioneering the manufacture and sale of the first such unit in Japan. Based on this rich experience, we developed a new 1.7 MW class power generation-use gas turbine, the M1A-17, with latest analysis technology. Its generating-end efficiency is of the world's highest class at 26.0%, while NOx emissions are 52.5 ppm converted on an O_2=0% basis (15 ppm converted on an O_2=15% basis), also the world's highest performance achieved. The field test machine started operation in a power generation facility at our plant in April 2010, and marketed units started operation all over the world, including Japan, in 2012.

Preface

Recently, the importance of distributed power sources has increased from the viewpoint of ensuring power supply against the loss of power and power service interruptions in disasters. In addition, regulations on exhaust gas are increasingly stricter from the viewpoint of global environment preservation. A reduction in NOx emissions from power generation-use gas turbines is also demanded.

Since successfully developing Japan's first domestically built industrial gas turbine in 1972, we have put various models of gas turbines on the market. Fig. 1 shows the lineup of our industrial gas turbines. The M1A-13, developed in the latter half of the 1980s, boasts a track record of deliveries of about 400 units for continuous generating power use both in Japan and overseas.

Developed on the base of the proven M1A-13, the M1A-17[1)] not only integrates the development history and basic technologies of Kawasaki but also is endowed with a substantial improvement in efficiency and exhaust gas performance while still preserving the reliability of the M1A-13. The M1A-17 has exhibited a generating-end efficiency of 26.0% and an overall thermal efficiency of 80% with the boiler included, achieving the top-level performance indexes of this class.

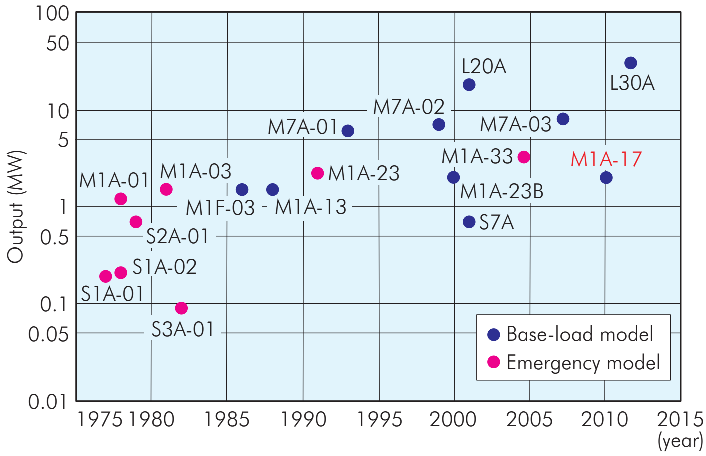


Fig. 1 Lineup of industrial gas turbines

1 Overview of the M1A-17

The M1A-17 is composed of a two-stage centrifugal compressor, a three-stage axial flow turbine, and a single can-type combustor as its main components. The model can be equipped with a diffusion combustor or a dry low emission (DLE) combustor; the model equipped with a DLE combustor is distinguished as the M1A-17D. Fig. 2 shows a cut model of the M1A-17D and Table 1 the main characteristics and cogeneration performance data. The features of the M1A-17 are described below.

(1) High efficiency

Thanks to measures to improve the efficiencies of individual elements described hereafter, the M1A-17 has achieved the world's top level of generating-end efficiency at 26.0%. And, since the exhaust gas temperature is on the same level as that of conventional machines, it has attained a high overall thermal efficiency of 80% as a cogeneration system that produces, in addition to electricity, steam by using the exhaust gas.

(2) Low emission

The DLE combustor incorporates Kawasaki's proven system used in the M7A, inheriting the high reliability of the model. Equipped with a DLE combustor, the M1A-17 has achieved the world's top-level of low NOx performance at 15 ppm (O_2=15%).

(3) High reliability

The basic structures of the rotor and casing of the M1A-17 are the same as those of the highly reliable M1A-13. To carry on the overall system reliability from the predecessor model, the same number of revolutions and the same bearings as the M1A-13 have been adopted; the peripheral devices were proven on other models.

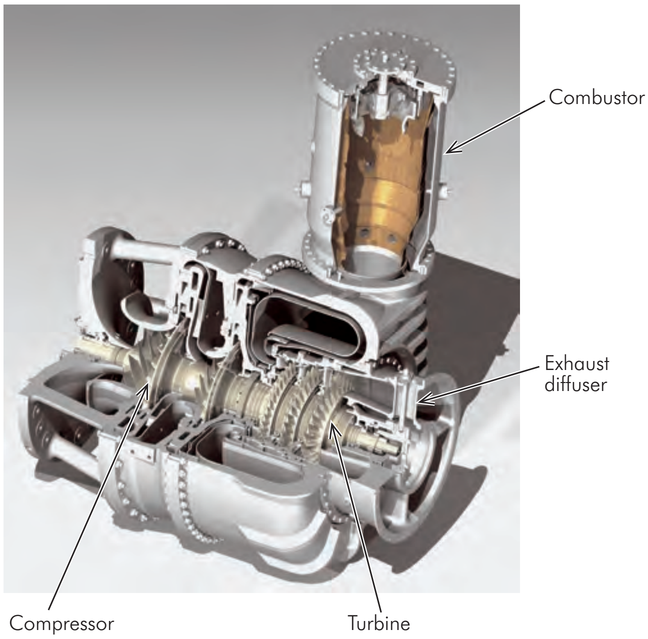
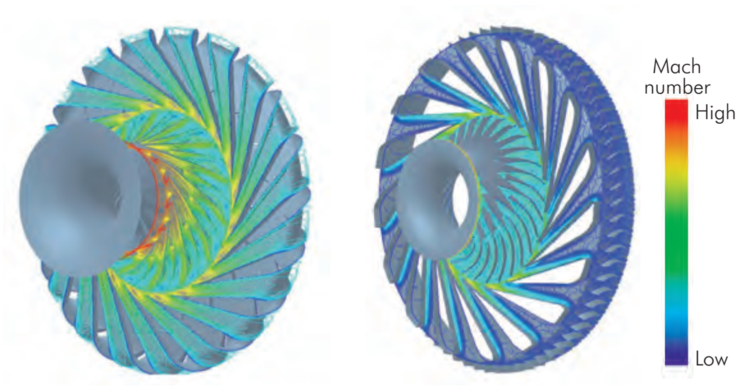


Fig. 2 Cut model of M1A-17D gas turbine

Table 1 Main specifications and performances of M1A-13D and M1A-17D

Model	M1A-13D	M1A-17D
Type	Simple open cycle, single-shaft type	
Compressor	Two-stage centrifugal type	
Turbine	Three-stage axial flow type	
Combustor	Single-can-type (DLE)	
Generating-end output (kW)	1,450	1,630
Fuel consumption (m^3N/h)	617	629
Quantity of steam supplied (kg/h)	5,100	5,000
Generating-end efficiency (%)	23.6	26.0
Heat recovery efficiency (%)	56.1	54.1
Overall thermal efficiency (%)	79.7	80.1
NOx value (ppm, O_2=15%) (Operating range)	NOx<25 (85～100%)	NOx<15 (70～100%)
CO value (ppm, O_2=15%) (Operating range)	NOx<50 (85～100%)	NOx<80 (70～100%)

<Conditions for calculating performance values>
Intake temperature: 15°C
Atmospheric pressure: 101.3 kPa (At 0 m elevation)
Intake/Exhaust pressure loss: 0.98/2.45 kPa
Fuel: Methane 100%
Generator efficiency: 95%
Measures for NOx: Lean premixed combustion
Heat recovery steam generator: Steam pressure 0.83 MPaG; Water supply temperature: 80°C



(a) 1st stage compressor (b) 2nd stage compressor

Fig. 3 CFD results of compressor internal flows

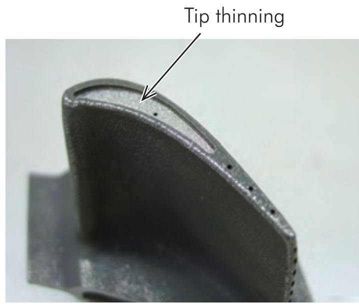


Fig. 4 Tip thinning structure

2 Design improvements of individual elements

(1) Compressor

This model adopts a two-stage centrifugal compressor. In the past, the application of CFD analysis was limited to the design of impellers, which are rotating bodies. This time, however, CFD analysis was applied to parts on the stationary side to carry out an integrated analysis of rotating and stationary bodies for the purpose of optimizing the passage shape so as to prevent reverse flow in the passages of stationary bodies. Fig. 3 shows examples from an analysis of internal flow in the first and the second stage. Using this analysis technology has made it possible to maximize the efficiency of centrifugal compressors.

(2) Turbine

The turbine is a three-stage axial flow type and provided with cooling blades in the first stage. In designing this turbine, a tip* thinning structure (Fig. 4) was adopted as a structural feature for reducing leak loss, while a low expansion material was adopted for the turbine casing as a material feature for minimizing the tip clearance** in rated operation. This helped reduce leaking from the blade tips, allowing more fluid energy to be recovered by the turbine. In terms of aerodynamics, the latest CFD tools were used to separately analyze the individual stages, and then all stages were analyzed with the aim of optimizing the passage shape and distribution of work between the stages. Fig. 5 shows the result of the CFD analysis on all stages.

* Tip: Tip of turbine blade

** Tip clearance: Clearance between the tip of blade and the turbine shroud that covers the blade

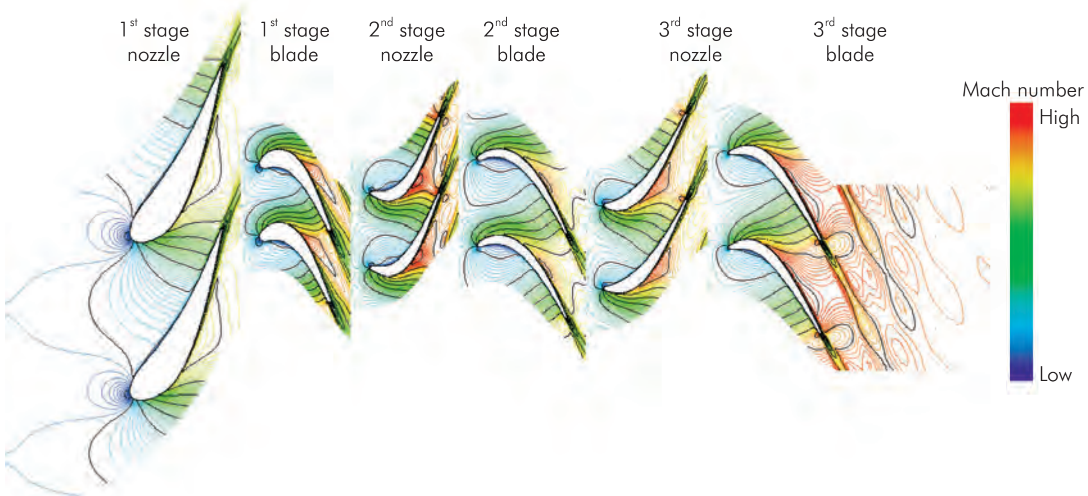
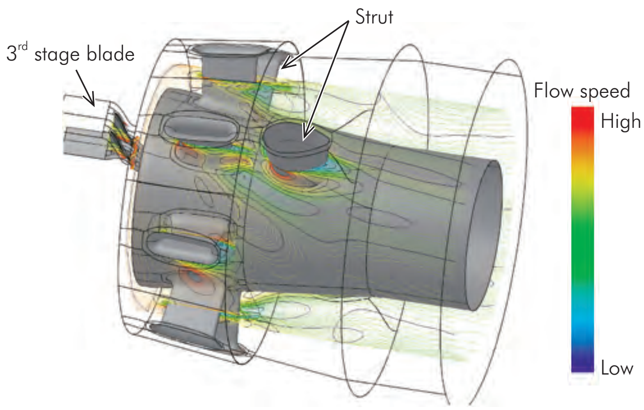
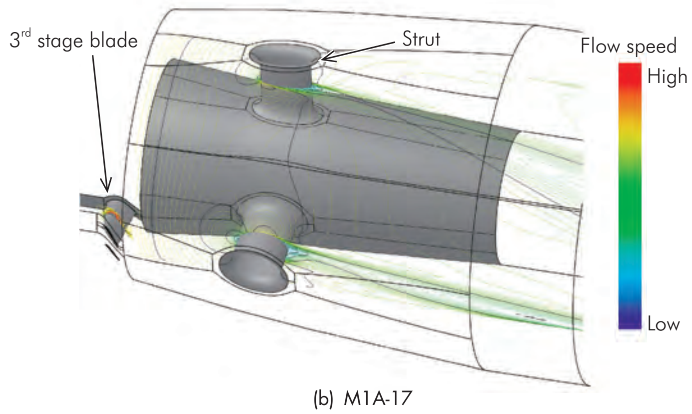


Fig. 5 CFD results of all turbine stages



(a) M1A-13



(b) M1A-17

Fig. 6 CFD results of exhaust diffuser

(3) Exhaust diffuser

The exhaust diffuser is used to discharge exhaust gas while expanding the flow passage to reduce the flow speed and recover static pressure. Struts are provided in the flow passage to hold bearing parts and others arrayed on the inside diameter side. Since the struts are provided in the exhaust gas passage, their shape, number, and arrangement affect the performance of the exhaust diffuser greatly. In the M1A-17, CFD-based flow analysis was used to study the arrangement and shape of the struts, while the pressure loss was reduced by minimizing the reverse flow domain. Fig. 6 shows examples from the CFD-based analysis of the exhaust diffuser used in the M1A-13 and M1A-17. The illustration shows a smaller separation of flow and areas of reverse flow in the M1A-17 than in the M1A-13, which comes as a result of reducing the number of struts and other measures.

(4) DLE combustor

The combustor is based on lean premixed and a supplemental combustion method, both of which have been proven with our products. The combustor has three burners: a pilot burner, a main burner, and supplemental burners (Fig. 7). The pilot burner is used mostly for ignition and low load, while the main burner and the supplemental burners are used at low NOx operation. Keeping the fuel concentration distribution as homogeneous as possible in the combustion zone is effective towards reducing

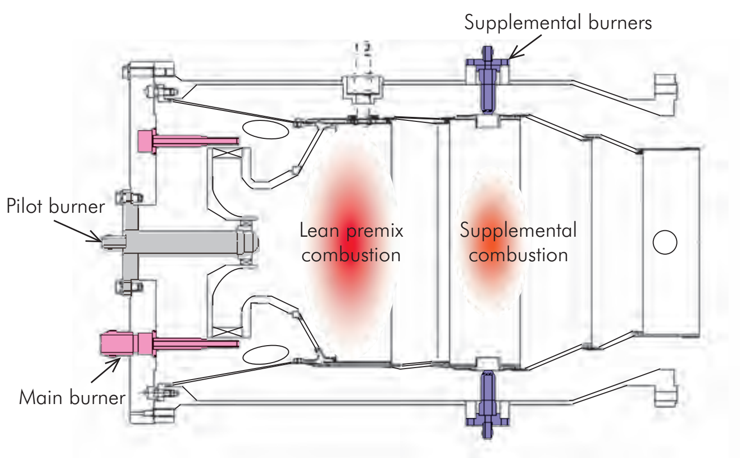


Fig. 7 Dry Low Emission combustor

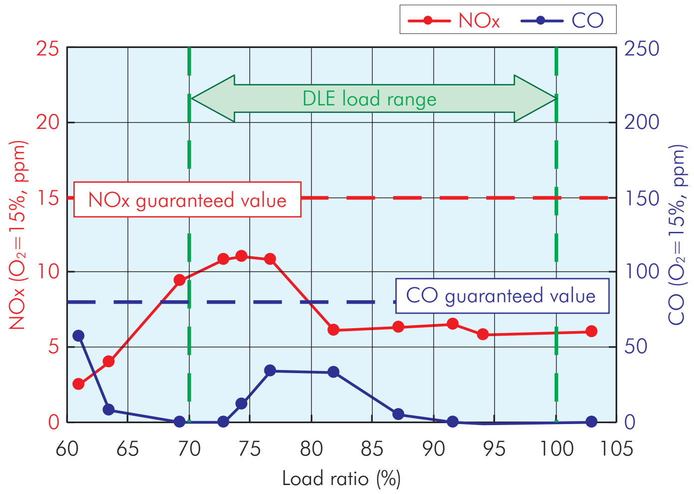


Fig. 8 NOx emission characteristics

Fig. 9 Electric power plant at Akashi Works

emissions. For this purpose, CFD analysis was used to optimize the shape of the burner and flow passage so that air and fuel are mixed efficiently in the burner section. In combustor unit tests and engine tests, an NOx value no greater than 15 ppm (O_2=15%) was attained, thus improving NOx exhaust performance by about 50% in comparison with the M1A-13D. Fig. 8 shows the NOx exhaust characteristics.

3 Field test

To determine the reliability of the M1A-17D, a field test was started at a power station in one of our plants in April 2010 (Fig. 9). The turbine is operated with the DLE combustor. Operation exceeded 8,000 hours in August 2012 and continues smoothly without problems.

Table 2 M1A-17D track record of deliveries

Delivered to	Country name	Fuel	Waste heat utilization
Energy supply company A	Switzerland	Natural gas	Boiler
Energy supply company B	USA	Natural gas	Boiler
Chemicals manufacturing company	Germany	Natural gas	Boiler
Food processing company A, No.1 unit	Germany	Natural gas	Boiler
Food processing company A, No.2 unit	Germany	Natural gas	Boiler
Metal manufacturing company	Germany	Natural gas	Boiler
Paper manufacturing company	Japan	City gas	Boiler
Construction materials manufacturing company A, No.1 unit	Japan	City gas	Drying oven
Construction materials manufacturing company A, No.2 unit	Japan	City gas	Drying oven
Construction materials manufacturing company B	Japan	City gas	Drying oven

Fig. 10 M1A-17D package (Switzerland)

4 Mass-production units

The M1A-17 was put on the market in April 2010. Since the first mass-produced unit was commissioned in April 2012, 10 units have been shipped as of June 2012. Table 2 shows the track record of deliveries, and Fig. 10 the package of the first mass-produced unit destined for Switzerland.

Concluding remarks

Carrying on the reliability proven in its predecessor machines, the M1A-17 incorporates state-of-the-art performance-enhancing technologies and substantially improves thermal efficiency through an improvement in efficiency performance of individual elements. The turbine also has realized a low emissions level of the world's top class. We will continue demonstrating the reliability of its products in field tests, as well as striving for further improvement with the aim of contributing to the effective use of energy and the reduction in environmental loading.

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Reference

1) Y. Hosokawa, M. Gouda, Y. Yamasaki, and A. Norimoto: "Development of 1.7 MW Class High Efficiency Gas Turbine, M1A-17," Asian Congress on Gas Turbines, 2012.