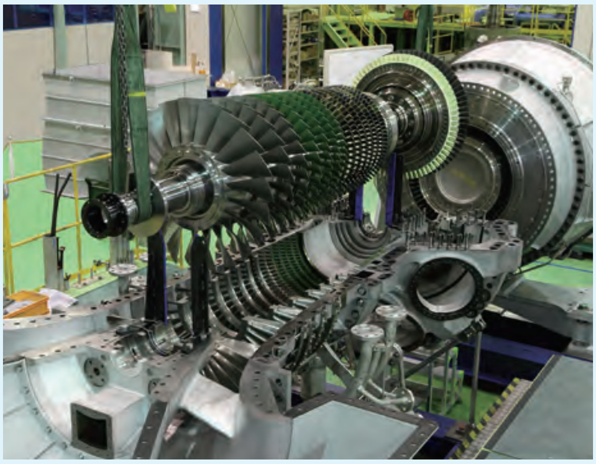
Technical Description

Highly efficient 30 MW class gas turbine, L30A



From the viewpoint of reducing environmental loads and being aware of a growing demand for distributed power generation and an economy-driven need for high-efficiency power generation, we have developed the L30A gas turbine that boasts the world's highest efficiency in the 30 MW class. This paper describes the design concepts, basic structure, general design, and other features of the engine.

Preface

Amid society's mounting awareness of electricity conservation, the demand for distributed power generation is increasing with the aim of obtaining a stable supply of electric power. Because of this and economic considerations such as the reduction in running costs, high efficient power generation is coming to the forefront. In addition, expectations are growing in less environment-loading renewable energy and energy conservation from the viewpoint of preventing global warming and CO_2 emissions. Under these circumstances, combined heat and power plants (CHP/CCPP) using high-efficiency, environment-friendly industrial gas turbines are attracting the greatest attention in the fields of energy conservation.

We have developed the L30A, a new highly efficient 30 MW class gas turbine, in response to such requests from society.

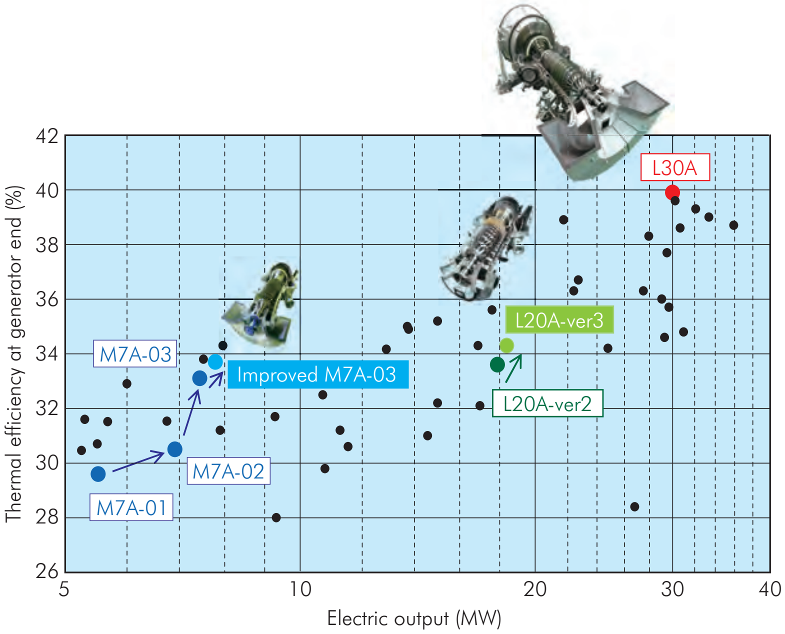


Fig. 1 Performance trend of 5-35 MW class industrial gas turbine

1 Overview

Figure 1 shows the performance characteristics of 5 to 35 MW class industrial gas turbines. With one of the development targets set at an efficiency of 40% or more, the world's highest in the 20 to 35 MW class gas turbines, which are the most needed, and with the petroleum and gas markets and turbines for mechanical drive units in sight, we started development of the two-shaft L30A gas turbine in 2007[1)].

Table 1 shows the main specifications of the L30A and Fig. 2 gives an overview of it.

The L30A gas generator module adopts a multistage axial-flow compressor, a multi-can combustor, and a horizontal split casing structure that were employed in products of our proven M7A and L20A series. For the power turbine module, a ring structure that resists deformation and allows for greater efficiency was designed after proven two-shaft type gas turbines — our small-sized gas turbine, the M1F series, and the Super Marine Gas Turbine (SMGT) developed under a national project.

Table 1 L30A main specifications

Type	Simple open cycle, two-shaft
Output (MW)	30.9
Thermal efficiency (%)	41.3
Compressor	Axial flow 14-stage
Combustor	8-can
Gas generator turbine	Axial flow 2-stage
Power turbine	Axial flow 3-stage
Gas generator revolutions (min^{-1})	9,330
Power turbine revolutions (min^{-1})	5,600
Mass flow rate (kg/s)	86.5
Pressure ratio	24.5
Exhaust gas temperature (°C)	470

ISO conditions (at power turbine shaft end; Fuel: natural gas)

2 Features

(1) World's highest efficiency in 30 MW class gas turbines

With the aim of achieving the world's highest efficiency among gas turbines of the same class, the L30A employed a design philosophy of increased compressor pressure ratio, improved element efficiencies, and state-of-the-art turbine cooling technology. In our existing gas turbines, the pressure ratio of a compressor used to be about 18, but the L30A achieves 24.5, which dramatically surpasses conventional characteristics. For the compressor, a blade profile optimization tool was applied and, at the same time, inter-stage matching was adjusted via Computational Fluid Dynamics (CFD) across all stages. For the turbine, Kawasaki's patented technologies for film cooling and conjugate heat transfer and flow (CHT flow) analysis were applied to grasp detailed temperature distributions on turbine blades to improve the design accuracy.

(2) Low emissions

Along with the CO_2 emissions reduced through an increase in engine efficiency, the dry low NOx combustor that had produced satisfactory results in the M7A and L20A series (third generation) was adopted as design concepts[2)]. With a pre-mixing lean-burn type fuel nozzle, three kinds of burners are used to enable Dry Low Emission (DLE) operations across a wide range.

(3) Ease of maintenance

Inspection holes are provided at suitable locations so that all flow path faces can be inspected without disassembly. As in existing Kawasaki models, the high-temperature section of the gas generator module is structured as a horizontally split casing and a multi-can combustor with the aim of shortening the maintenance time for periodic replacement. In addition, a modular structure design enables easy and fast replacement work in overhauls.

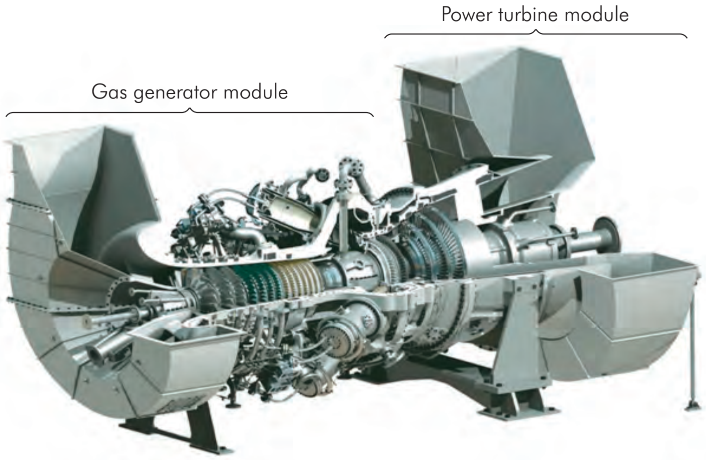


Fig. 2 L30A gas turbine

Table 2 Failure modes and effects analysis of L30A

Item (Critical parts)	Failure modes	Assessment in each validation phase				
		Design	Manufacture or assembly	Engine test		Rig test
				Short-term	Long-term	
245 (Number of cases)	6,473	4,300	1,866	4,095	4,071	170
Gas generator 1st stage rotor blade	Creep rupture	CHT flow analysis	Flow rate test	Pyrometer measurement	Metallurgical inspection	Pre-swirl nozzle rig test
Axial-flow compressor	Inter-stage mismatching or surge	Multi-stage 3D-CFD	Blade tip clearance measurement	Wall static pressure measurement	—	Scale compressor rig test
DLE combustor	Exceeded allowable emissions	3D-CFD	(Checking of ease of assembly)	NOx measurement		Actual scale rig test

3 Development process

Prior to the start of the engine development, we conducted Failure Mode and Effects Analysis (FMEA) to predict problems such as potential accidents and failure risks in the design stage. Table 2 lists representative failure modes of a higher probability of occurrence. Detailed analyses and rig tests were conducted in advance to assess their possibilities.

(1) Advanced analysis

(i) Conjugate heat transfer and flow analysis

With the aim of enabling turbine rotor blades to reach an allowable metal temperature and thereby meet the design creep strength, the flow outside the blade from the combustor and the flow of cooling air inside the blade were computed simultaneously. On the basis of these calculations, CHT flow analysis was conducted on the rotor blade to optimize the arrangement of cooling holes and the shape of the cooling passage.

(ii) Non-linear vibration response analysis

All rotor blades of the power turbine have a tip-shroud, with a vibration damping structure based on a Z-shaped notch. For this reason, vibration response analysis that took into consideration frictional force and damping at the notch contact section was conducted to identify vibrations during operation. It was found that the blades had a sufficient margin of strength for vibrations including higher harmonics modes and random vibrations.

(2) Rig tests

(i) Compressor tests

Before the engine test, a 63%-scale compressor rig test was conducted (Fig. 3). Using a rig test facility, the compressor characteristics such as the startup behavior, inter-stage matching, compressor map, and variable stator blade schedules were checked and optimized to reduce the risk of failures[3].

(ii) Combustor tests

Actual-scale rig tests under the same pressure and temperature conditions as for the engine in operation were conducted in the test facility at RWTH Aachen. Combustion characteristics such as the ignition performance, emissions and durability based on the measurement of the liner wall temperature were checked. This also reduced the risk of failure before the engine test.

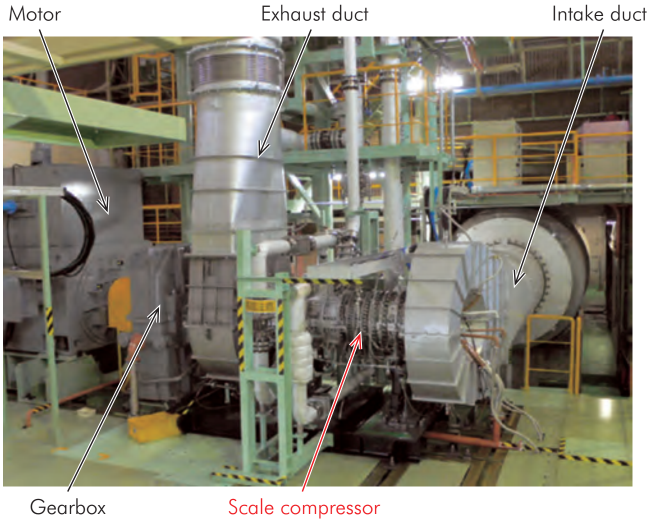


Fig. 3 Scaled-compressor rig test facility

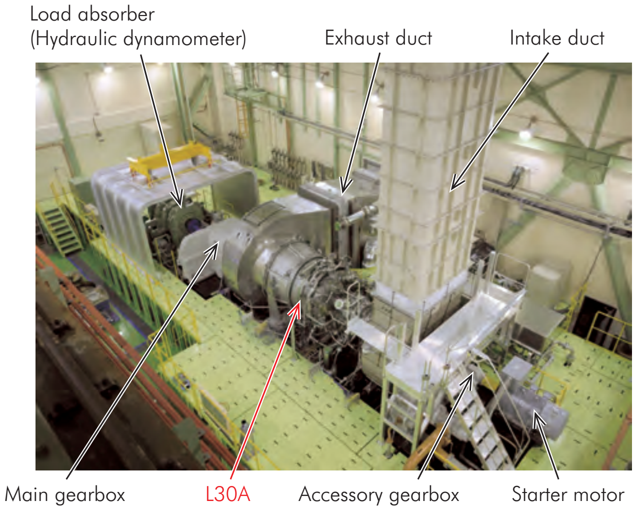


Fig. 4 L30A test facility

(3) Establishing special production processes

We have established conditions for various special processes such as how to cast and coat rotor blades, and electron beam welding, and have developed systems that allow these conditions to be applied to the production of parts beginning with the first unit.

4 Results of operation tests

We have constructed a new operation test facility for the L30A in our Akashi Works and, at the same time, built a new satellite for the natural gas storage tank. Fig. 4 shows the layout of the operation test facility for the L30A.

The in-house validation tests were conducted roughly in four stages.

(1) Startup test and load input test

Figure 5 shows a typical trend graph from startup to the maximum load condition in the early phase of development. The engine startup process was completed without problems after adjustments of the fuel schedule and so forth. It was further confirmed, by monitoring the engine running state during the load input period, that the engine exhibited stable operating characteristics up to the time when the maximum load condition was reached.

(2) Performance tests

The performance characteristics of the L30A are obtained by converting pieces of test data measured during the engine operation into ISO-based values using our own performance calculation system. Fig. 6 plots the performance characteristics of the L30A along with its

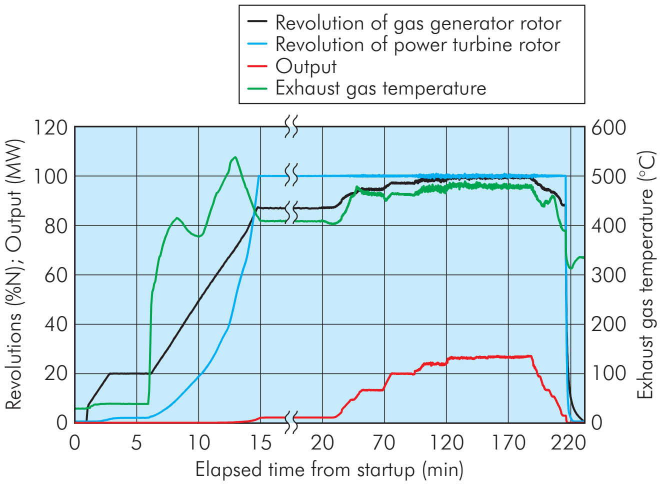
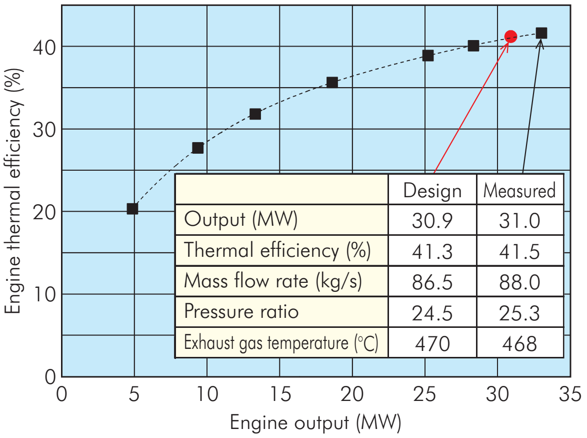


Fig. 5 Typical trend graph from startup to full load



	Design	Measured
Output (MW)	30.9	31.0
Thermal efficiency (%)	41.3	41.5
Mass flow rate (kg/s)	86.5	88.0
Pressure ratio	24.5	25.3
Exhaust gas temperature (°C)	470	468

Fig. 6 L30A performance test results

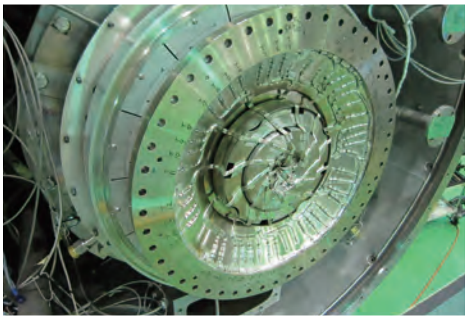


Fig. 7 Telemetry system for power turbine and vibration measurement test results

design values. The target for the engine thermal efficiency against the engine output was achieved.

(3) Durability confirmation tests

Using a telemetry system with multiple channels, blade vibrations in the compressor and the turbine were measured to prevent the rotor blades from resonating and breaking in operation (Fig. 7). At the same time, tip-timing blade vibration measurements were also conducted and both measurements verified that all the blades were within the allowance in terms of vibration.

Since turbine blades are exposed to a high-temperature atmosphere while in operation, the blade metal temperature was directly measured by means of an infrared radiation measurement system (pyrometer)4). Measurement data was used to confirm that no problems existed with the durability of the rotor blades and to assess the compatibility with the CHT flow analysis verified beforehand, with the usefulness of both techniques confirmed.

In addition, clearance and other items were measured and the initial clearance for assembly was determined on the basis of the measurement data for the purpose of engine restarting, and so on.

(4) DLE combustor tests

The combustor is composed of three burners (pilot burner, main burner, and supplemental burner). During the operation in the DLE mode, the pilot burner plays the roll of maintaining the minimum flame. And, as the load increases, the ratio of the fuel for the supplemental burner is increased, with a low NOx level maintained in this way.

The test results of a combustor installed on an engine showed that, as in the preliminary rig tests that were conducted in advance, the NOx value in exhaust gas attained the target of the world's lowest level of 15 ppm or less (15% O_2) for 50-100% loads.

5 Combined heat and power generation using the L30A unit

As an example of application, the performance characteristics of a plant that introduced the L30A unit in a cogeneration system were calculated. Table 3 shows that

Table 3 Specifications of L30A combined heat & power plant

Electric power output (MW)	28.4
Steam production (t/h)	46.2 Saturated steam (Pressure: 0.83 MPaG; Temperature: 177°C)
LHV thermal efficiency (%)	38.8
Total LHV thermal efficiency (%)	83.1
Intake air temperature (°C)	15
Intake/Exhaust loss (kPa)	0.98/3.43
Fuel	Natural gas (Lower heating value = 40.6 MJ/Nm^3)

Fig. 8 Panoramic view of L30A package PUC300D and CHP plant

the cogeneration system is capable of generating 28 MW of electric power and 46 t/h of saturated steam, and that the overall thermal efficiency reaches 83.1%.

Recently, it was decided to operate commercially the first combined heat and power plant of this type in a chemical plant in Western Japan, with the on-site demonstration tests started in October 2012. Fig. 8 depicts the L30A package, named as the PUC300D, along with the entire view of the CHP plant.

Concluding remarks

The development and application to power generation of the L30A, a gas turbine boasting the world's highest efficiency among 30 MW class gas turbines, has been completed. And, commercial operation of L30A units has been started, thereby contributing to CO_2 emissions reduction and energy conservation. We will continue development efforts for applications in mechanical drive units aimed at the petroleum and gas markets, with efforts directed at increasing sales of the L30A, which contributes to environmental conservation with its high performance.

References

1) R. Tanaka, K. Take, M. Ryu, A. Matsuoka, and A. Okuto: "Verification Test of Newly Developed High Efficient 30MW Class Gas Turbine, The Kawasaki L30A," ACGT Paper ACGT2012-7138 (2012)
2) T. Oda, M. Ogata, K. Matsumoto, S. Aoki, A. Horikawa, and K. Hirano: "DLE combustion technology for enhancing the environmental performance," Kawasaki Technical Review, No.173, pp. 51-56 (2013)
3) T. Ikeguchi, A. Matsuoka, Y. Sakai, Y. Sakano, and K. Yoshiura: "Design and Development of a 14-stage Axial Compressor for Industrial Gas Turbine," ASME Paper GT2012-68524 (2012)
4) T. Taniguchi, R. Tanaka, Y. Shinoda, M. Ryu, N. Moritz, and K. Kusterer: "Application of an Optical Pyrometer for Newly Developed Industrial Gas Turbine," ASME Paper GT2012-68679 (2012)

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