Hitachi's Gas Turbine Product Range and Development Background

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OVERVIEW: Since supplying its first gas turbine in 1966, total orders received by Hitachi to date have reached 600 units. The 1960s and 1970s were the formative years for Hitachi's gas turbine business during which it expanded sales outside Japan, primarily through technical collaborations with General Electric Company, and built up the foundations of its current business. The 1980s and 1990s saw a boom in combined cycle plants that provided Hitachi with the opportunity to expand its domestic business, including being the first Japanese vendor to supply combined cycle systems with exhaust heat recovery. In 1988, Hitachi developed its H-25 gas turbine, the first model to use its own technology throughout for everything from design to manufacturing. Hitachi has also been marketing the H-25 internationally since 2000, and this has led to the development of its current global business. Hitachi's gas turbine business can also be thought of as embodying the Pioneering Spirit that was part of what inspired the company's original formation.

INTRODUCTION

ALTHOUGH its business has faced a number of difficulties over the years, including economic recessions and appreciation of the yen, total orders for Hitachi's gas turbines since its technical collaboration with General Electric Company (GE) have now reached 600, and they can be thought of as having solidified their role as a mainstay of thermal power generation. Those gas turbines have earned a strong reputation for reliability, with some of the early Hitachi-GE units having been in operation for more than 30 years. Hitachi built up the foundations of its current thermal power generation business in the subsequent period when combined cycle technology was becoming established in Japan, during which it led the market with its experience and with the environmental technologies needed to satisfy stringent Japanese regulations. It was during this time that Hitachi developed the H-25 gas turbine using its own technology. The high performance and reliability of the H-25 have earned it a total of 151 installations. Hitachi then went on to develop the H-15 sister product and the medium-capacity (100-MW class) H-80 gas turbine.

This article looks back at the more than 40 years of Hitachi's gas turbine business, and also describes developments over recent years.

HISTORY

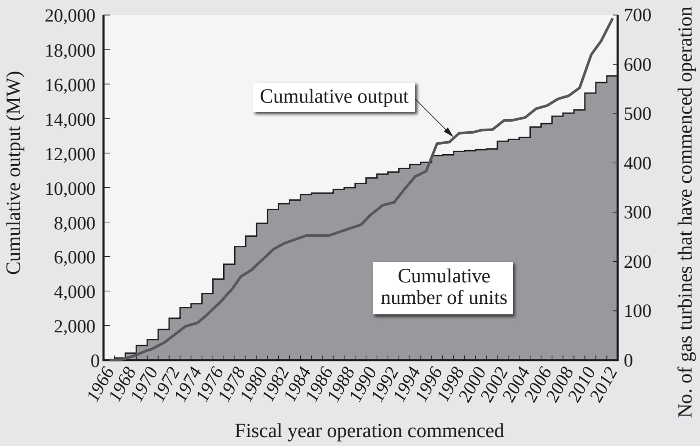
Origins of Gas Turbine Manufacturing at Hitachi

Hitachi's involvement with gas turbines dates back to 1938 and a turbocharger for a 500-HP (1 HP = 0.7457 kW) exhaust turbine built as part of experimental research commissioned by the Japanese Naval Aeronautical Technology Institution. The size of the exhaust turbine was progressively increased and a total of 800 units had been produced by the end of the Second World War in August 1945. Work also proceeded on the testing and research of jet engines, with Hitachi's role including collaboration on the manufacture of the Ne-20 and the prototyping of the Ne-230. A prototype 1,100-kW open, two-shaft, regenerative gas turbine for power generation was completed in 1954. Although this prototype had been used to make a variety of research enhancements by 1959, it did not lead to commercial production as the market for gas turbines at that time had yet to develop.

Technical Partnership with GE

(1) Manufacture of first gas turbine

In 1964, Hitachi signed a joint manufacturing agreement with GE, the world's leading gas turbine manufacturer. This led to the first Hitachi-GE gas turbine being delivered to Nippon Petro Chemicals Co., Ltd. (as it was then known) in 1966. This MS3002



Model	Output	No.
MS1002	5,050 HP	2
MS3002	15,140 HP	28
H-15	16,900 kW	6
H-25	32,000 kW	151
MS5001	26,300 kW	286
MS5002	38,000 HP	12
MS6001B	39,160 kW	28
MS6001FA	70,140 kW	4
MS7001B/E/EA	85,400 kW	31
H-80	99,260 kW	12
MS7001F/FA	171,700 kW	30
MS9001B/E	123,400 kW	6
MS9001FA	255,600 kW	4
	Total	600

* Output is under ISO conditions, fueled by gas.
* Includes supplied gas turbines purchased from GE (as of October 2012).

ISO: International Organization for Standardization GE: General Electric Company

Fig. 1—Cumulative Sales of Hitachi Gas Turbines.
The total number of gas turbines supplied since 1966 has reached 600.

two-shaft gas turbine had a rating of 6,000 kW and a turbine inlet temperature of 800°C.

(2) MS5001

The first MS5001 was ordered from GE, completed in 1967, and delivered to American Independent Oil Company (AMINOIL). Its output was 16,250 kW. It went on to be adopted around the world, becoming a mainstay of the Hitachi product range with a total of 286 units delivered (see Fig. 1).

(3) Mechanical-drive gas turbine

Hitachi has supplied a total of 12 mechanical-drive gas turbines, consisting of eight MS3002 models supplied via GE to what is now the Russian Federation in 1977, and the completion of the MS5002 for customers who included Société Nationale pour la Recherche, la Production, le Transport, la Transformation, et la Commercialisation des Hydrocarbures s.p.a. (aka Sonatrach), the Algerian national oil and gas company.

(4) Large-capacity, high-performance gas turbines

In response to growing demand for large-capacity, high-performance gas turbines, the 60-Hz MS7001 was developed based on the MS5001M, followed by the 50-Hz MS9001. The MS9001B uses air cooling for the first stage buckets and nozzles, and Hitachi received the first order for this model from the Kawasaki Thermal Power Station of what is now the East Japan Railway Company, which was delivered in 1981. This plant was the first combined cycle power plant in Japan to use exhaust heat recovery.

The MS7001E completed in 1981 included enhancements to the combustor and turbine cooling (air cooling of second stage buckets and nozzles also).

Combined cycle power plants burning liquefied natural gas (LNG) became a mainstream power source in the 1990s because of their high plant thermal efficiency and operating characteristics, and this drove demand for the gas turbines that are the major component of these plants. Three 1,100°C-class MS7001EA gas turbines were supplied to the Yanai Power Station of The Chugoku Electric Power Co., Inc. in 1990, and three more in 1992. Six MS7001E gas turbines were supplied to the Shin Oita Power Station of Kyushu Electric Power Co., Inc. in 1991. These were single-shaft combined cycle plants in which the gas turbine, generator, and steam turbine were linked by a single shaft (see Fig. 2).

Two 1,300°C-class MS7001F gas turbines were supplied for single-shaft combined cycle plants at the Yanai Power Station of Chugoku Electric Power in 1994, and two more in 1996.

It was at this time that interest was growing in the use of exhaust reheat combined cycle power plants that allowed short-turnaround repowering of existing steam-powered generation systems by adding a gas turbine. One 1,100°C-class MS9001E unit was supplied to the Goi Thermal Power Station of The Tokyo Electric Power Co., Inc. in 1994. Another focus was on achieving higher efficiency at rated load, and a multi-shaft combined cycle power plant

ACC: advanced combined cycle power plant (a combined cycle power plant incorporating a high-performance gas turbine with a combustion temperature of 1,300°C)

Fig. 2—Overview of Yanai Power Station of The Chugoku Electric Power Co., Inc.
The site consists of two 700-MW combined cycle power plants. Unit 2 is an ACC plant and was Japan's first 1,300°C-class gas turbine. Unit 2-1 commenced commercial operation in March 1994, and Unit 2-2 commenced commercial operation in January 1996.

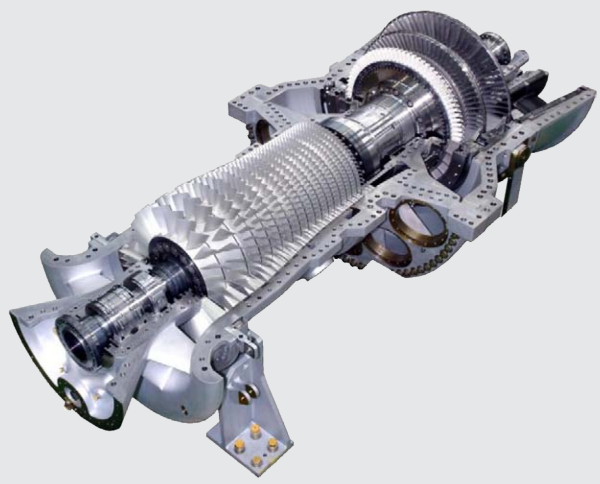


Fig. 3—H-25 Gas Turbine.
The photograph shows an overview of an H-25 gas turbine with the upper casing removed.

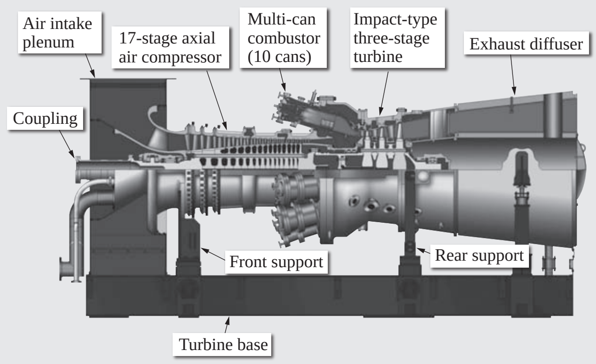


Fig. 4—Cross Section of H-25 Gas Turbine.
H-25 was the first gas turbine that was entirely developed by Hitachi. A scaled down version, the H-15, was developed three years later.

comprising three MS7001FAs and one steam turbine was supplied to the Himeji No. 2 Power Station of The Kansai Electric Power Co., Inc. in 1996. In the same year, seven MS7001FA gas turbines for single-shaft combined cycle power generation with high efficiency and excellent operating characteristics were also supplied to Kawagoe Thermal Power Plant of The Chubu Electric Power Co., Inc. Three MS7001FA gas turbines were supplied to the Shin Oita Power Station of Kyushu Electric Power in 1998. From the MS7001EA supplied in 1990, these and all other subsequent LNG-fired units used dry low nitrogen oxide (NO*x*) combustors developed in-house by Hitachi. The 1,300°C-class MS6001FA was developed jointly with GE, with the first Hitachi-made unit being supplied to the Hitachi Rinkai Power Station in 2000.

HISTORY OF GAS TURBINE DEVELOPMENT AT HITACHI

Development of H-25 Gas Turbine

As the thermal efficiency of the MS5001 (output in the 25,000-kW class) was approximately 27%, Hitachi recognized that a model with a more competitive level of thermal efficiency would be needed in the future and therefore set about developing its own highly efficient gas turbine with a similar output. Through separate development of a high-performance compressor, turbine, and combustor, Hitachi developed a high-performance 25,000-kW-class gas turbine (the H-25) with a combustor exit temperature of 1,260°C in 1988. The compressor was an axial compressor with a pressure ratio of 15 that had been scaled up from a model used for experimental testing. The first unit was supplied for use in a cogeneration power plant fueled by LPG and A-type fuel oil at the Tokuyama Refinery of Idemitsu Kosan Co., Ltd. The combustor was a standard model with a diffusion burner and steam injection (see Fig. 3 and Fig. 4).

H-25 Gas Turbine Technology

(1) Compressor

Improving the efficiency of gas turbines requires a high pressure ratio and high efficiency performance from the compressor. The challenges of compressor development include finding ways to prevent instabilities such as rotating stall and surging. It is also necessary to ensure that the compressor has the reliability to ensure stable operation over a wide range of flow rates from startup to shutdown. Hitachi embarked on its own development to establish design techniques that can achieve both performance and reliability in multi-stage axial compressors, and in 1983 achieved the performance targets it had set for a prototype 17-stage compressor with a pressure ratio of 15. These were advanced specifications for that time. Hitachi was also able to determine the characteristics of the rotating stall phenomenon based on actual measurements made on the prototype and incorporate them into its multi-stage compressor design techniques.

The axial compressor for the H-25 gas turbine was developed based on a similar design to this prototype compressor. In response to demand for further efficiency improvements, Hitachi subsequently embarked on the development of an axial compressor (with a mean stage pressure ratio of 1.19) with the aim of achieving a world-leading pressure ratio. Hitachi also built a prototype scale model including all stages in 1999 with the aim of verifying the robust reliability and aerodynamic performance of this compressor. The prototype achieved close to target performance during testing and allowed Hitachi to establish design techniques for high pressure ratios and higher loads. In addition to transonic stage design techniques, the development also sought to improve performance by utilizing multi-stage flow analysis to match the cascade of blades in the compressor (see Fig. 5).

(2) Turbine

The turbine in the H-25 gas turbine has a three-stage configuration. Fig. 6 shows the cooling configuration for the first stage. The first stage nozzles achieved high cooling efficiency using a combination of impingement cooling and film cooling with pin fin cooling on the trailing edges. The cooling mechanism for the first stage buckets used return flow cooling, which was a new technique at the time of development. The design includes a turbulence promoter on the surface in the cooling flow path to improve performance without using a large volume of cooling air.

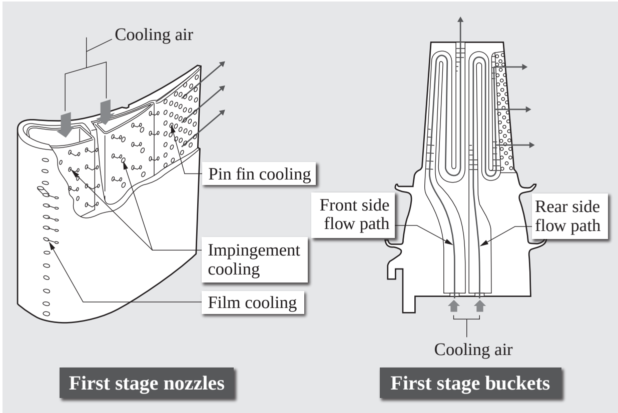


Fig. 6—Turbine Blade Cooling Mechanism for H-25 Gas Turbine.
The first stage nozzles use a combination of impingement cooling and film cooling, with pin fin cooling on the trailing edges. The cooling mechanism for the first stage buckets used return flow cooling, which was a new technique at the time of development.

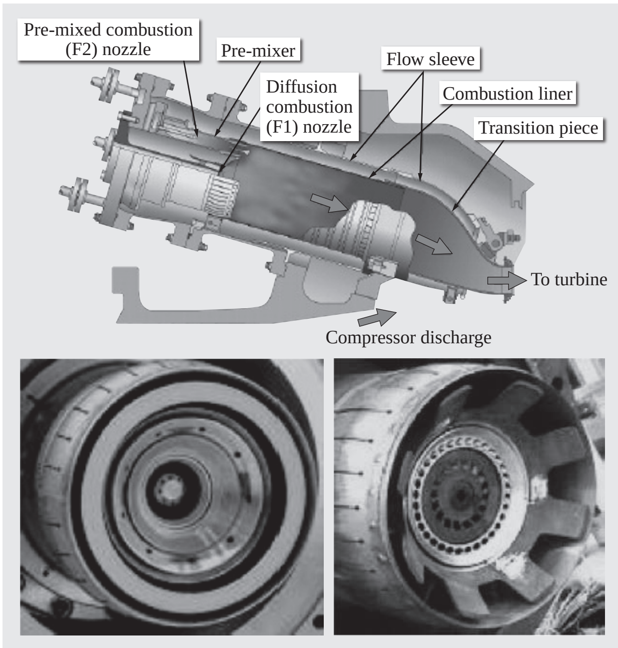


Fig. 7—LNG-fired, Low-NOx Combustor and Dual-fuel, Low-NOx Combustor.
The combustor for the H-25 gas turbine, shown here, achieved a level of NOx emissions (25 ppm or less) that was among the best in its class at the time.

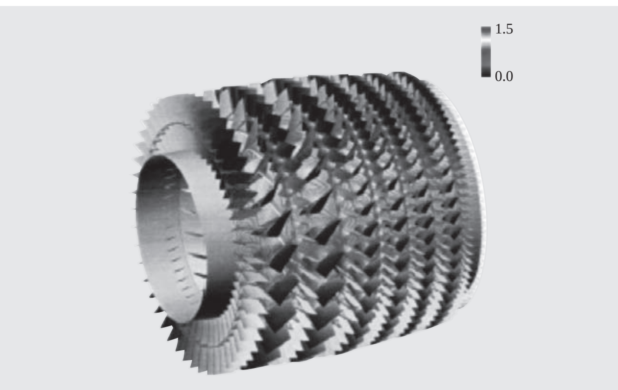


Fig. 5—Example Multi-stage Flow Analysis of Axial Compressor for Gas Turbine.
Higher compressor pressures and loads are essential to making gas turbines more efficient.

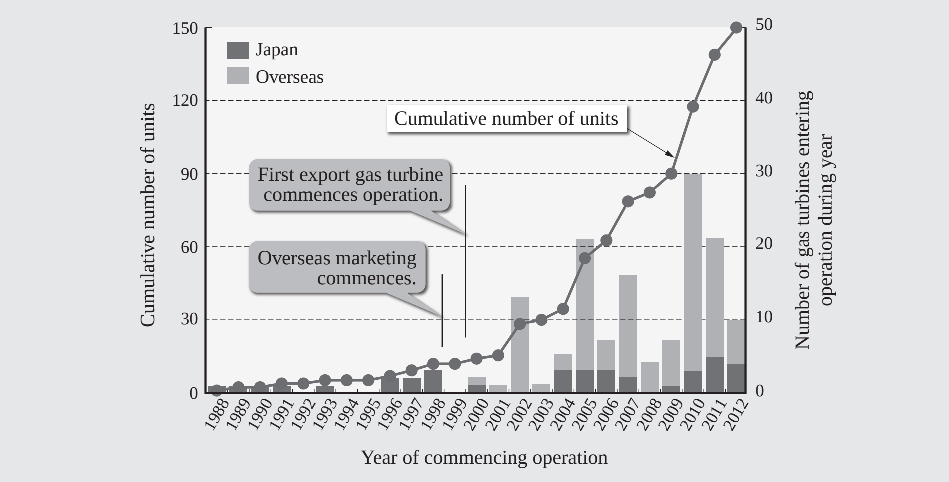


Fig. 8—History of Gas Turbine Development by Hitachi.
The graph shows deliveries of H-25 gas turbines in Japan and overseas up until May 2012. H-25 gas turbines are operating reliably in a wide range of environments, from the Russian Federation where temperatures fall as low as -48°C to the Republic of Iraq where temperatures reach up to 50°C.

(3) Combustor

Fig. 7 shows the structure of the LNG-fired, low-NO*x* combustor in the H-25 gas turbine. A downsized version of the third-generation combustor used in the 1,300°C-class gas turbine was designed, consolidating the experience and technology built up on the large models. This pre-mixed, low-NO*x* combustor with a diffusion pilot is based on a ring-shaped flame holder and achieves class-leading levels of NO*x* emissions (25 ppm or less). To allow a wider range of fuels, Hitachi has developed a dual-fuel gas/oil, low-NO*x* combustor that can burn oil and also achieve gas-fueled performance equivalent to a dedicated gas combustor. The combustor maintains a stable pre-mixed flame when fueled by gas, and has a radial type flame holder to promote mixing of oil and air when fueled by oil, ensuring stable combustion when fueled by gas or oil alone, a mixture of the two, or when switching between fuels.

EXPANSION OF GAS TURBINE BUSINESS

Expansion of Overseas Business

For about ten years after the first H-25 gas turbine was delivered in 1988, most installations were used for cogeneration at petrochemical companies in Japan. Gas turbine users typically place a high priority on a product's track record, and they can be reluctant to select new models. In particular, GE's MS5001 was the top selling gas turbine in the same class and had a large presence in the market. Accordingly, Hitachi embarked on a program to expand sales that combined marketing, technology, and design. Based on roughly a decade of experience from Japan, the first H-25 gas turbine supplied to a customer outside Japan was delivered to South Korea in 2000, and Hitachi subsequently went on to deliver a large number of units to countries around the world. The H-25 and H-15 gas turbines now have a strong reputation for high performance and reliability, with totals sales exceeding 150 units. Similarly, total operating time has exceeded 1.4 million hours, operating reliably throughout the world (see Fig. 8).

H-25 Gas Turbine Applications

A feature of the H-25 gas turbine is its wide range of applications, which extend from power companies to petrochemical companies.

One recent example of the supply of a gas turbine to a power company was the Nyíregyházi Kombinált Ciklusú Erőmű (NYKCE) Project of E.ON Hungária in Hungary that commenced operation in 2007 (see Fig. 9). The NYKCE Project is a multi-shaft combined cycle plant consisting of one H-25 gas turbine, one

Fig. 9—NYKCE Project of E.ON Hungária in Hungary.
This power plant was constructed to supply power to nearby factories through a grid interconnection while also supplying heat for space heating.

Fig. 10—Betara Project of PetroChina Co., Ltd. in Republic of Indonesia.
The plant receives gas and liquids by pipeline from several dozen nearby gas wells and performs gas-liquid separation to produce natural gas. Exhaust heat from the H-25 gas turbines is used for the high-temperature gas needed to regenerate the adsorbent (molecular sieve) used to remove the water content from the process gas.

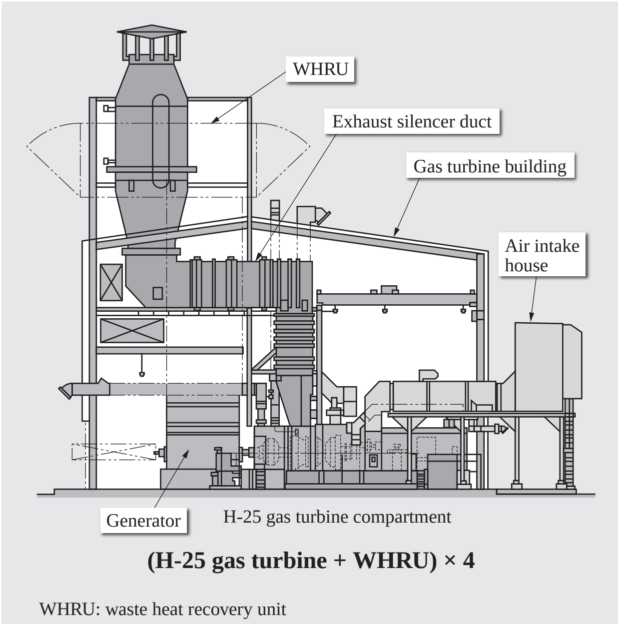


Fig. 11—Sakhalin-2 Project in Russian Federation.
This is an example of the H-25 gas turbine being deployed in a cold-climate application.

waste heat recovery unit with supplementary burners, and one steam turbine. The net combined cycle output is between 29.5 and 49.5 MW. The plant operates as a cogeneration system that uses the waste heat of the gas turbine to supply hot water for district heating, and also high-pressure (26 bar, where 1 bar = 0.1 MPa) and low-pressure (7.5 bar) steam to nearby factories. As a highly efficient plant, it achieves a cogeneration efficiency of 89.3%. In terms of its environmental performance, it features a low-NO*x* combustor with emissions of 25 ppm (dry) [15% oxygen (O_2) equivalent] or less under rated operating conditions.

An example application at a petrochemical company is the Betara gas field development project of PetroChina Co., Ltd. (see Fig. 10). Located on the island of Sumatra in the Republic of Indonesia, a long way from the electric power grid, the project uses three H-25 gas turbines to supply power with an island operation configuration. The site includes a large number of compressors driven by electric motors in the megawatt range. While compressors like these have conventionally been driven mechanically by a gas turbine in the past, the site recognized the benefits of centralizing power generation using H-25 gas turbines, which include flexibility of operation and layout, less maintenance, less spare parts, and cost savings. Switching all compressors to electric motor drive also improved the ease-of-operation of the overall system.

H-25 gas turbines are also used at the world's leading LNG facilities. A total of 12 units have been supplied to the Damietta Project in the Arab Republic of Egypt, the Sakhalin-2 Project in Russia, and the Bonny Project in the Federal Republic of Nigeria. The H-25 has a strong reputation for stable performance and reliability in the oil and gas industry (including oil refineries and fertilizer plants), and accounts for half of all orders.

The Sakhalin-2 Project in Russia is a cold-climate application where outdoor temperatures fall as low as -48°C, and the four H-25 gas turbines are installed indoors together with the waste heat recovery units (see Fig. 11). To improve plant operation, two of the four units are solely gas-fired, with dry low-NO*x* combustors, while the other two use dual-fuel (gas and oil) dry low-NO*x* combustors.

In the Middle East, Hitachi has received orders for H-25 gas turbines fueled by natural gas and light oil for the Republic of Iraq from Japan International Cooperation System as part of its aid program after the Iraq War (see Fig. 12). Three gas turbines were supplied to the Taji Gas Turbine Power Station in 2007, and two gas turbines were supplied to the Mosul Gas Turbine Power Station in 2008. As supervisory staff from Japan were not able to be sent to the Iraqi site for installation and commissioning due to security considerations, Hitachi decided to handle gas turbine installation and commissioning remotely. While on-

Fig. 12—Recovery Aid Project for the Republic of Iraq.
With supervisory staff from Hitachi unable to be sent to the site, Iraqi personnel undertook all work from installation to commissioning by themselves.

site work did not always go smoothly, the eagerness of the Iraqi personnel involved in the project to construct the plant for themselves and the desire on the side of the Hitachi engineers to help with the Iraqi recovery combined to bring the plant successfully into operation.

DEVELOPMENTS OVER RECENT YEARS

Development of H-80 Gas Turbine

Hitachi developed the H-80 gas turbine based on technology built up with the H-25. The first unit was supplied to the Shin Oita Power Station of Kyushu Electric Power in 2010 (see Fig. 13). Unit 1 at the Shin Oita Power Station was a combined cycle power generation system that commenced operation in 1991. As its efficiency was low compared to the latest power generation systems, it was mainly used for peak load. A proposal to replace the gas turbine was formulated with the aims of increasing efficiency and flexibility. This increased the plant efficiency by 3% (absolute) and also helped reduce CO_2 emissions. As the project involved improving efficiency by only replacing the gas turbine, in accordance with the customer's requirements, it had to be installed around the existing equipment and leave the shaft end output unchanged. Accordingly, a two-shaft configuration was adopted with different speeds for the compressor driveshaft (4,580 rpm) and output shaft (3,600 rpm). The H-80 is a heavy-duty gas turbine with the largest capacity of any two-shaft model in the world*.

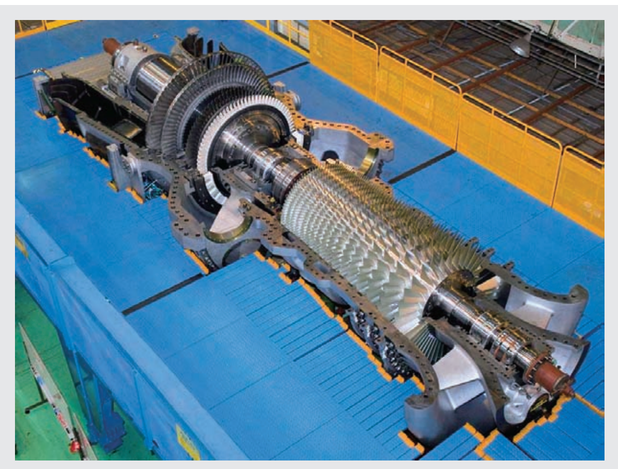


Fig. 13—H-80 Gas Turbine Supplied to Shin Oita Power Station of Kyushu Electric Power Co., Inc.
This is one of the world's largest two-shaft gas turbines. It is helping boost the efficiency of aging gas turbines.

AHAT

Hitachi is currently developing the advanced humid air turbine (AHAT), a highly efficient system with excellent operational characteristics. The AHAT is a new type of gas turbine system with an enhanced regeneration cycle that is capable of higher efficiency without increasing the pressure ratio or combustion temperature. Also, because it does not use a boiler or steam turbine, the AHAT should be capable of a rapid load changes and flexible operation. Hitachi has already confirmed the viability of the system by conducting testing on a pilot plant with an output in the 3-MW class (see Fig. 14). Meanwhile, experimental trials on a 40-MW-class demonstration system for developing specific technologies required for commercialization commenced in the end of 2011.

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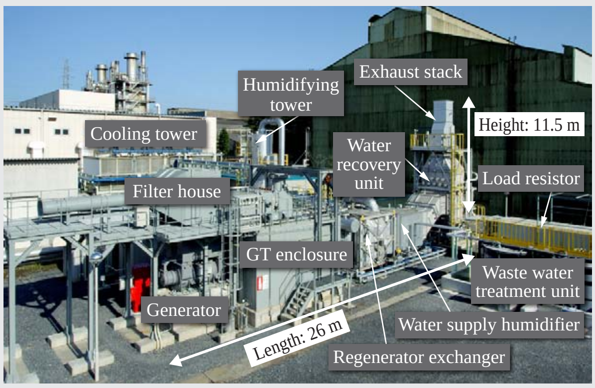
* As of October 2012, based on Hitachi, Ltd. research.



AHAT pilot plant facility (Hitachinaka City, Ibaraki Prefecture, Japan)

AHAT: advanced humid air turbine

Fig. 14—3-MW-class AHAT System Pilot Plant.
Hitachi has confirmed the viability of the AHAT system.

Hitachi aims to produce commercial models in the future in the medium-capacity class.

CONCLUSIONS

This article has looked back at the more than 40 years of Hitachi's gas turbine business, and also described developments over recent years.

The history of Hitachi's gas turbine business can be seen as a reflection of the ongoing Pioneering Spirit that dates back to the company's founding. In the future, Hitachi intends to continue taking up the challenge of greater innovation with the aim of becoming a leading manufacturer of medium-capacity gas turbines.

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