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Mitsubishi MF-111

Outlook

- MF-111 apparently out of production for some years
- Reported sales appear to be of secondhand gas turbines
- Upgrade kits available for MF-111s still in service
- Technology developed for MF-111 still in use on other gas turbines

Orientation

Description. The MF-111 is a 50-Hz, single-shaft, axial-flow industrial gas turbine machine developing 12-15 MW.

Sponsor. The MF-111 was privately developed by the prime contractor.

Power Class. The MF-111B (ISO base-rated) output is 14.57 MW when firing natural gas and 14.13 MW when firing fuel oil.

Status. The MF-111B remains in production. The MF-111A was retired in 1998.

Total Produced. A total of 61 MF-111 machines were manufactured and installed for customers in nine countries worldwide.

Application. Applications include utility and industrial power generation, including combined-cycle power generation, repowering, and cogeneration. No orders for the machine have been placed for mechanical drive duty.

Price Range. The MF-111B's price in 2015 U.S. dollars is estimated at $6.6 million to $6.8 million.

For electrical generation, the genset price covers a single-fuel skid-mounted gas turbine, electric generator, air intake with basic filter and silencer, exhaust stack, basic starter and controls, and conventional combustion system.

Competition. The MHI MF-111B competed against the Solar Titan 130 and the GE Energy LM1600.

Contractors

Prime

Mitsubishi Hitachi Power Systems, Takasago Machinery Works	http://www.mhi-global.com, 1-1 Shinhama, 2-chome, Arai-cho, Takasago-shi 6760008, Hyogo, Japan, Prime
Turbomach SA	http://turbomach.cat.com, Via Campagna 15, Riazzino CH-6595, Ticino, Switzerland, Tel: + 41 91 851 15 11, Fax: + 41 91 851 15 55, Email: contact@turbomach.com, Packager

Mitsubishi MF-111

Subcontractor

Alcoa Howmet	http://www.alcoa.com/howmet/, 145 Price Rd, Winsted Industrial Park, Winsted, CT 06098 United States, Tel: + 1 (860) 379-3314, Fax: + 1 (860) 379-4239 (Blade, Stage 1-3)
VT Group plc	Woolston Shipyard, Victoria Rd, Woolston SO9 5GR, Southampton, United Kingdom (Control)
Vogt Power International Inc	http://www.babcockpower.com/products/heat-recovery-systems/vogt-power-international, 1000 W Ormsby Ave & 10th St, PO Box 1918, Louisville, KY 40201-1918 United States, Tel: + 1 (502) 634-1511, Fax: + 1 (502) 637-7344 (HRSG - Shell Philippines, through SFL)

Technical Data

Dimensions.

	Metric Units	U.S. Units
Length	5.6 m	18.38 ft
Width	2.7 m	8.86 ft
Height	2.5 m	8.21 ft
Weight	22,000 kg	48,502 lb

Performance.

	Natural Gas	Fuel Oil
Generator Power	14,570 kW	14,130 kW
Heat Rate LHV	2,778 kcal/kWh	2,811 kcal/kWh
Heat Rate LHV	11,627 kJ/kWh	11,763 kJ/kWh
Efficiency	31.0%	<31.0%
Pressure Ratio	15.0:1	15.0:1
Turbine Speed	9,660 rpm	9,660 rpm
Exhaust Flow	56.36 kg/sec	56.42 kg/sec
Exhaust Temperature	530°C	530°C

All performance data is at S/L, 15°C; 60 percent RH; 75mm x 75mm H_2O inlet/exhaust losses.

Design Features. The Mitsubishi Heavy Industries (MHI) MF-111 gas turbine machine incorporates advanced cooling technology and advanced technology in the combustor to attain a continuous high-level operating temperature of 1,250°C. The unit's thermal efficiency of 31 percent in simple-cycle operation and 44-45 percent in combined-cycle operation (when mated with an exhaust HRSG), combined with the very high operating temperature, makes it suitable for cogeneration plant applications and for repowering existing steam turbine units.

MHPS developed new materials for the MF-111 designed to be superior to existing popular materials. These included MGA1400 for the blade, MGA2400 for the vane, and Tomilloy for the combustor. Compared to IN738LC, MGA1400 exhibits the same high-temperature creep strength at 30°C higher, and if it is incorporated for the directionally solidified (DS) blade, it has the same strength at 50°C higher. Compared to the ECY-768, the Ni-based MGA2400 has the same high-temperature creep strength at 20°C higher, while maintaining weldability.

Application of these new materials was not an easy process, requiring various tests during the R&D stage. In addition, MHPS applied the materials to actual engines and verified performance over long operations. MHPS has been applying these materials to the MF-111 engine since 1994, together with thermal barrier coating (TBC). Following excellent results, MHPS started to apply the materials to both the F and G series. Currently, the MGA1400 and MGA2400 are playing important roles in the improvement of hot parts life after being applied to the uprated F series. MHPS is also active in R&D for the casting process, such as with DS and single crystal (SC) processing.

To attain the high temperatures, metal temperatures of the hot gas path components are kept constant through the use of advanced cooling technologies, including the use of turbine Row 1 vanes with blunt leading edges and efficient impingement/film cooling, turbine Row 1 blades with multi-pass cooling air passages, and laminated fin wall combustor design.

Compressor. The axial compressor design features 15 stages (MF-111A) or 16 stages (MF-111B). Variable inlet guide vanes are provided. Compression ratio is 13:1 to 15:1. Rated speed is 9,660 rpm, but reduced to 3,600 rpm (60 Hz) or 3,000 rpm (50 Hz). Blade rings are removable with the rotor in place.

Combustor. Eight cannular-type combustors, featuring a laminated fin wall cooling configuration, were developed to produce low NOx. The basket is made of Hastelloy X, the transition piece of Tomilloy. Combustor outlet temperature is 2,282°F (1,250°C). Steam injection and water injection methods are incorporated into the fuel nozzle design. Dual-fuel nozzles are available.

Turbine. Three-stage axial-flow air-cooled turbine. Discs are of IN718. Row 1-2 vanes are of ECY-768; Row 3 is of X-45. All blades are of IN738LC (blades and vanes are precision investment-cast). Row 1 vanes have impingement and film-cooling schemes. Turbine casing is horizontally split. Curvic couplings are used to connect the turbine discs. Blade rings and rotating blades are removable in place.

Bearings. Two-bearing design.

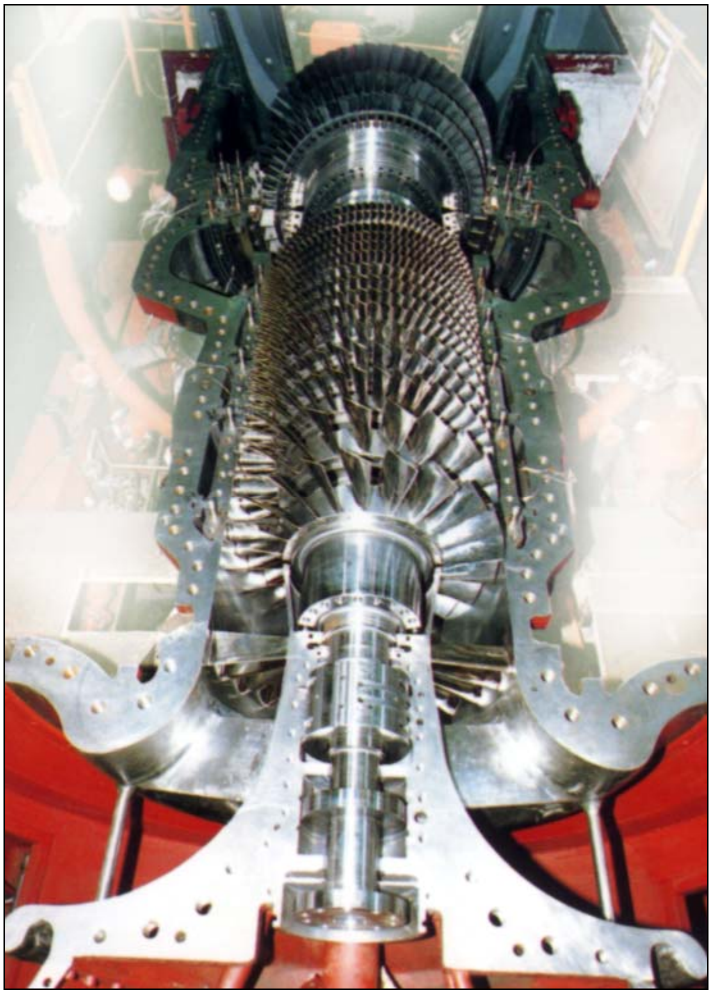
Accessories. Features output shaft reduction gearing designed to allow front-mounted shaft (cold-end drive), allowing the exhaust flow to be directed either horizontally or vertically to mate with various heat recovery boiler designs.

Operational Characteristics. To meet environmental regulations, a lean-diffusion flame combustor with steam or water injection was developed and installed in the machine. The combustor can burn versatile fuels such as #2 distillate oil, natural gas, and, with slight modification, low-Btu gas. It can simultaneously burn two different fuels and can change over between fuels on line. The machine has achieved a NOx emission level of 25 ppm at 15 percent O_2 via steam injection when burning natural gas at full load and 42 ppm at full load with water injection.

The gas turbine power system can be divided into two modules: a gas turbine package and a generator and auxiliary package, with each package assembled on a common baseplate structure.

Stable firing of a gas turbine combustor is essential to ensuring reliability and availability, and to achieving maximum component life capability. Combustor instabilities can trigger high-pressure fluctuation and are generally due to sudden changes in operating condition such as in fuel calorific value, fuel quality, and ambient temperature, or sudden changes in operating load. To minimize the impact of such combustor instabilities, MHPS developed a monitoring and protection system known as the Combustor Pressure Fluctuation Monitoring (CPFM) system. Following this, MHPS developed the Advanced Combustor Pressure Fluctuation Monitoring (ACPFM) system, which incorporates on-line monitoring and protection functions to automatically adjust the air bypass valve and the main and pilot fuel nozzles to maintain the appropriate fuel/air ratio based on the flame conditions. These airflow controls successfully prevent flameout, combustion oscillation, and flash back under various modes as well as unexpected disturbances in the combustion process. This ACPFM system has been tested at Mitsubishi's in-house power plant.

Mitsubishi MF-111



Mitsubishi MF-111

Source: Mitsubishi Heavy Industries Ltd

Variants/Upgrades

MF-111A. The MF-111A was a 15-stage axial compressor machine introduced in 1985. Power output was 12.22-12.61 MW at generator terminals. Thermal efficiency was about 30.3 percent. Overall compressor pressure ratio was 13:1. The MF-111A was retired in 1998.

MF-111B. The MF-111B is a 16-stage axial compressor machine introduced along with the MF-111A in 1985. Power output is 14.13-14.57 MW at generator terminals. Thermal efficiency is at least 31 percent. Overall compressor pressure ratio is 15:1. At 200 psia (13.79 bar), 400°F (204°C) steam is produced at a flow rate of 78,000 pounds per hour (1,633 kg/sec).

MF-111 Upgrade Package. By 2005, early units from the MF-111 production program were beginning to experience power output loss due to continuous use. Mitsubishi elected to address this problem with an upgrade program that introduced a showerhead for the Row 1 turbine vanes and a pre-swirl nozzle that reduced the rotor pumping work for the blade-cooling airflow. These modifications increased power output by 4 percent.

Program Review

Background. Mitsubishi Heavy Industries Ltd has long been involved in the design, manufacture, delivery, and setup of power systems equipment, including gas turbine machines for combined-cycle power generation, repowering, and cogeneration. It has accumulated abundant experience in all facets of power generation. In February 2013, MHI and Hitachi Ltd announced their new joint venture, Mitsubishi Hitachi Power Systems Ltd (MHPS), which combines the thermal power generation operations of both companies.

In the recent past, activity focused on the development of technologies in new arenas such as energy conservation, oil substitution, and new and renewable energy and environmental protection. Success was attained in the creation and production of large-capacity high-efficiency gas turbines, combined-cycle power plants, high-efficiency steam turbines, ultra-supercritical boilers, and large-capacity high-head reversible pump turbines. In the area of environmental protection, high-temperature flue gas DeNOx systems have emerged.

The Mitsubishi gas turbine line includes 10 products spanning the power band from 5.925 MW for the MF-61 to 334.2 MW for the Model 701G2. The MF-111B gas turbine, at about 14.57 MW (natural gas fuel), evolved from a demand for energy savings in electric and industrial utilities. The MF-111 machines are produced in Japan at Mitsubishi's Takasago Machinery Works, Takasago City, and Hyogo Prefecture.

Moonlight Origins

Mitsubishi was an active participant in the Japanese Moonlight Project, aimed at creating a very high-efficiency gas turbine machine of 120 MW. It built the HP turbine and compressor, part of the LP turbine, and the high-temperature developing unit, and also assembled and tested the entire pilot plant. Technology and processes from that effort undoubtedly found their way into the MF-111.

Packagers Aplenty

US Turbine Corporation. In March 1988, Mitsubishi and then-US Turbine Corporation (USTC, now a subsidiary of Rolls-Royce Energy Systems) signed an agreement whereby USTC would package the MF-111. It obtained rights to market the gas turbine to cogeneration plants, independent power companies, and industrial customers throughout North America. USTC provided power generation equipment, including cogeneration systems, for electrical output needs in the range of 660 to 51,180 kWe. In 1990, USTC shipped two MF-111-based generator sets to the University of Colorado for operation starting in September 1992; waste heat boilers were part of the overall installation.

In 1992, a contract for two MF-111B-based generator sets was placed with USTC on behalf of Fluor Daniel in the U.S. for installation at the Pilipinas Shell Petroleum Corporation in Makati, Metro Manila, the Philippines; those units began operation in September 1994.

USTC delivered at least five MF-111s. USTC is no longer involved with the MF-111.

Turbomach SA. In the summer of 1989, Mitsubishi and then-TUMA Turbomach SA (now Turbomach SA, Switzerland) signed an agreement under which Turbomach would package the MF-111 for electric power generation and cogeneration applications in Europe. The Swiss-based firm could get the bare gas turbine from Japan. It could handle package design and fabrication, as well as procurement of the package's gearbox, controls, auxiliaries, and related equipment from firms in the countries in which packages were to be located.

In 1990, Turbomach sold one MF-111B-based generator set to AK Enerji in Turkey for a cogeneration plant; the plant began operations in August 1992. The machine burns natural gas as its primary fuel and #2 distillate as its secondary fuel; it is used for baseload power. In 1994, a contract was awarded for three MF-111B-based generator sets for PTWP in Karawang, Indonesia, with two of the machines used in a cogeneration plant.

In 1998, the MF-111A was retired and it appears that the MF-111B was as well. Corporate literature does not refer to any sales of the MF-111 after 1998 and the gas turbine is no longer mentioned in company data. While some sources do report a scattering of sales, it is notable that the MF-111 frequently appears as a secondhand sales item. It is therefore likely that these reported sales, if accurate, are of previously owned gas turbines.

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Timetable

Month	**Year**	**Major Development**
	1984	Development of MF-111 announced
	1984	Contract for first machine awarded
Aug	1986	First MF-111 begins operation in Japan
Mar	1988	Mitsubishi/USTC agreement signed
Mid-	1989	Mitsubishi Turbomach agreement signed
	1990	First machines ordered through USTC
Sep	1992	First USTC-supplied units begin operation in U.S.
Mid-	1993	Higher heat rate (LHV) made available
Sep	1994	Two USTC-supplied units begin operation in the Philippines
	1995	First machines installed in Indonesia
Oct	1995	One unit in Italy begins operation (acquired from Turbomach)
Feb-Mar	1998	Two units in Slovakia begin operation (acquired from Turbomach)
End	1998	MF-111 retired
	2005	Upgrade package for MF-111A and MF-111B introduced

Worldwide Distribution/Inventories

The following information is extracted from Forecast International's **Industrial & Marine Gas Turbine Installations Database**.

Country	**MF-111A**	**MF-111B**
Germany		1
Indonesia		7
Italy		2
Japan	32	9
Philippines		3
Spain		2
Switzerland		1
Turkey		2
United States	2	0
Total	**34**	**27**

Forecast Rationale

The MF-111 adopted many advanced key technologies that were necessary for future large-capacity engines. Numerous MF-111s have been installed in Japan, making it one of the best selling engines in the home market for low-power industrial gas turbines. The engine also served as a testbed for many of the technologies that were subsequently used in other Mitsubishi gas turbine designs. However, it appears that this gas turbine was discontinued some years ago, and that any reported sales since then have been of used engines being sold on the secondhand market.

This being the case, it appears that no forecast can be made for these gas turbines. Unless there is a significant change in this situation, this report will be archived next year.

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