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Modernization and Upgrade Programs for Mitsubishi Heavy-duty Gas Turbines

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ABSTRACT

Mitsubishi Heavy Industries, Ltd. (MHI) has been applying many significant advances in gas turbine technology to new unit production, culminating in its latest production engine the 1,500 ^{o}C class "G"-series gas turbine. These proven and advanced technology features have been arranged in Modernization and Upgrade (M&U) packages which retrofit existing fleets to increase combined cycle power output, increase combined cycle efficiency, extend hot parts life, and decrease NOx emissions.

MHI developed many M&U products to meet its customer needs. To provide adequate flexibility and customization, some M&U products can be retrofitted individually or can be combined or consolidated to provide substantial savings to its customers. Economic evaluation will justify one of the available M&U packages to a customer at the next major overhaul.

Combined cycle power output and efficiency are improved by increasing firing temperature, applying improved sealing system technologies, applying advanced abradable coatings, using a regenerative fuel gas heating system, and applying high efficiency air intake filters to the gas turbine. By applying advanced cooling configurations and materials to turbine blades, vanes and ring segments and to combustor parts, hot parts life is kept even with increased firing temperatures.

MHI pioneered and introduced into a production engine the world's first lean premix dry low NOx combustor. To reduce emissions, advanced combustion systems are applied in its M&U products.

This paper summarizes M&U programs available for MHI's heavy-duty gas turbines with special emphasis on programs for M501D/701D engines. Such programs create substantial savings to customers, and are key to maintain competitive advantage in the power generation market.

1. INTRODUCTION

Recently, environmental restrictions are becoming strict. On the other hand, the deregulation of electric utilities is in progress. At the free electricity market, pool electricity prices are governed by the lowest price.

From such a background, the power plants having environmental friendliness and higher power output, efficiency are strongly demanded in order to reduce CO_2, NOx emissions as well as to generate electricity with competitive market price.

On the contrary, it is difficult for the existing power plants to keep the competitiveness. Because the performance and environmental characteristics are same level as in those days they were installed and it is also difficult for existing gas turbine power plant to avoid deterioration.

From those facts, there is a need to bring the existing fleet of gas turbines to the latest technical state of the art, so that this generating equipment can produce competitively.

This paper describes a summary of Modernization & Upgrade (M&U) options that are available for M501D/701D gas turbines. Those options apply the latest technologies that were developed for F, G and H gas turbines that have much higher firing temperatures. There are significant benefits from the standpoint of performance and reduced repair/ maintenance costs from the transfer of those advanced technologies.

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2. CIRCUMSTANCE OF GAS TURBINE AGED DEGRADATION

The typical circumstance of the aged degradation in the gas turbine is shown in figure 1. After several tens of thousands hours of operation, more than several percent of degradation could be occurred. The principal factor is listed below.

Compressor

-Increase of the surface roughness by the erosion of the flow pass as the whole including the casing and the rotor surface

-The increase of the clearance due to deformation

Turbine

-Increase of a leakage air with the increase of clearance which accompanies the deterioration other than the hot parts.

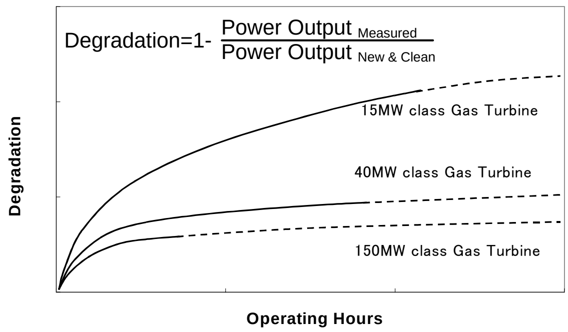


Fig.1 The typical gas turbine aged degradation in power output

Those permanent aged degradation used to be considered as unavoidable, but gradually the recovery of degradation becoming important from the point view of effective utilization of existing facility.

Thus, the recovery program of aged degradation is becoming desired.

3. D-SERIES GAS TURBINE MODERNIZATION & UPGRADE PROGRAM

3.1 D-series gas turbine

The "D-series" gas turbines were developed in 1980's to serve the electricity both for 60 and 50Hz. The M501D was designed to serve 60Hz electricity and M701D to serve 50Hz electricity.

The first M701D gas turbine was started commercial operation in 1984 with an output of approximately 137MW and a turbine inlet temperature of 1,150 °C (Turbine row 1 vane inlet). In various development steps, the current upgrade version has achieved an output of 144MW at a turbine inlet temperature of 1,250 °C (Turbine row 1 vane inlet).

3.2 The operating experience of D-series gas turbine

The operating experience of D-series gas turbines is shown in Figure 2. To date, 92 turbines are in service. The longest operational unit exceeds operating hours of 120,000 hours and number of start and stops exceeds 1,200 times. The accumulated operating hour logged more than 4,400,000 hours / 30,000 times

Overall reliability exceeds 99.8% or more.

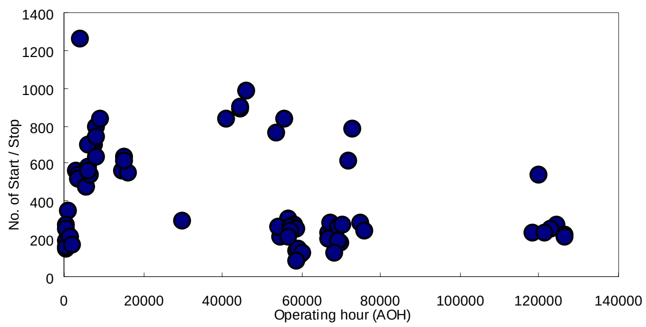


Fig.2 The operating experience of D-series gas turbine

3.3 The Modernization & Upgrade Program for D-series gas turbine

Lots of gas turbine modernization & upgrade products are available. For simplification, those can be categorized to effect the following:

(1) Performance (power output & heat rate),
(2) Emission and
(3) Reliability & availability.

Typical M&U programs are shown in Figure 3. In the figure, ①-a～⑤ (red color) modifications target performance increase, ⑥ (green color) are for emission reduction, ①-b (yellow green) for reliability improvement.

The M&U applicable for "D-series" gas turbines are listed in Table 1 below.

Table 1 M701D & M501D Modernization & Upgrade

	Modification	Remarks
①-A	Firing temperature increase	Increased firing temperature + upgraded hot parts + upgraded low emission combustion system = **performance (power output, heat rate)** and improved reliability.
①-B	Reliability Enhancement	Upgraded hot parts + upgraded low emission combustion system **= Reliability improvement.**
②	Improved seal technologies	Advanced sealing technologies (i.e., Brush seals, E-seals) reduce leakage air loss significantly resulting in **performance (power output, heat rate) benefit.**
③	Abradable coating	Abradable coating on ring segments (facing rotating blades) reduces hot gas leakage between blade tips and stator significantly resulting in **performance (power output, heat rate) benefit.**
④	FGH(Fuel Gas Heating) system	Waste heat from the turbine cooling air cooler is utilized to heat the fuel gas, resulting in **a heat rate improvement**.
⑤	Air intake filter	MHI designed HEPA filter effectively removes dusts from inlet air.Provides significant benefit on **gas turbine performance deterioration** as compared to conventional filters.
⑥	DLN (Dry Low NOx) combustion system	**Emissions are reduced** significantly without water/steam injection by multi-premixed combustion system. In addition, cooling effectiveness is reinforced with the MHI patented cooling scheme "MT-FIN."

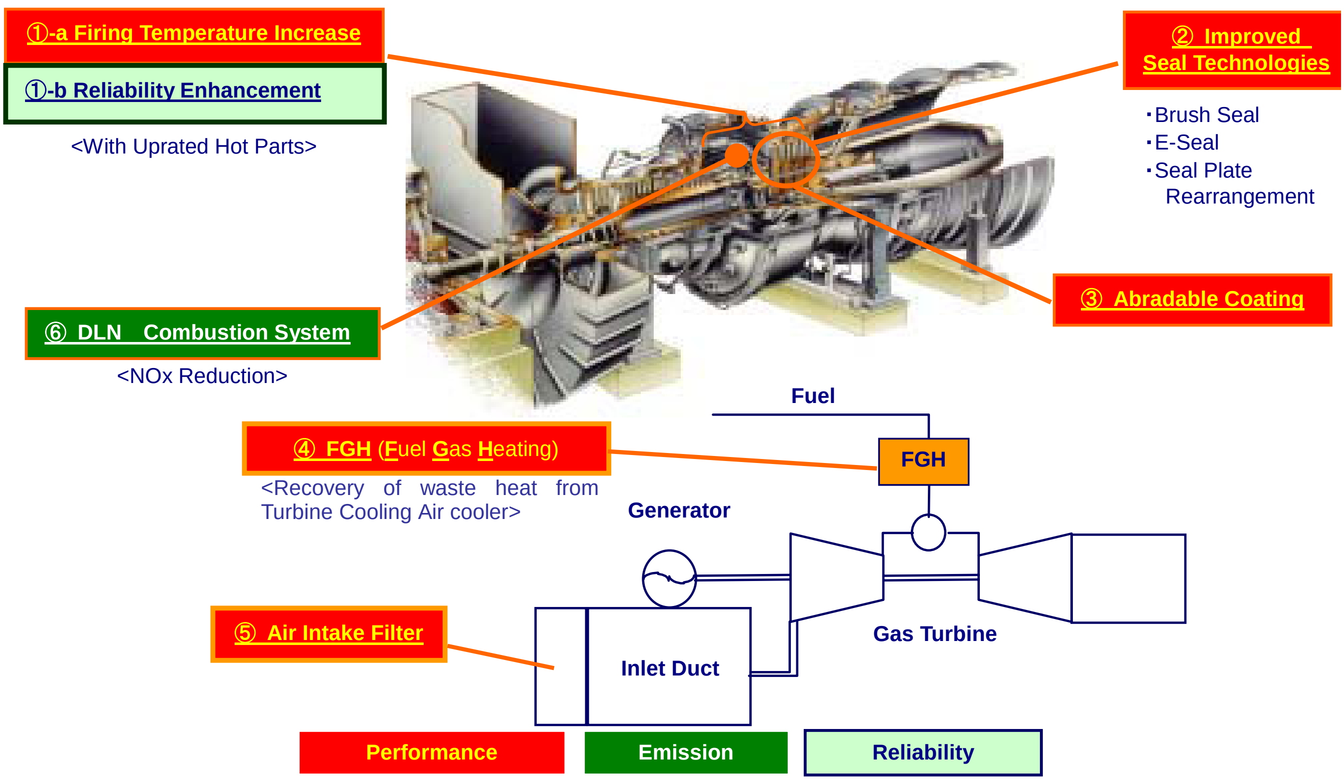


Fig.3 Typical Modernization & Upgrade Options

①-A FIRING TEMPERATURE INCREASE

With uprated hot parts and the low emission combustion system, the firing temperature can be increased and consequently performance (power output, heat rate) as well as reliability will be improved. To increase Turbine Inlet Temperature (TIT), the following modifications are required as shown in Figure 4.

- Upgrading turbine Row 1 to 3 vanes and blades
- Upgrading turbine Row 1 ring segments and isolation ring
- Upgrading combustor to increase TIT and reduce emissions.

In spite of the TIT increase, reliability can be maintained same as original by applying advanced cooling, material and coating technologies. Typical benefits of TIT increase can be quantified as follows(All values are relative improvement):

- G/T Power: 5.2% better
- G/T Heat Rate: 1.3% better
- C/C Power: 5.0% better
- C/C Heat Rate: 1.2% better

①-B RELIABILITY ENHANCEMENT

Same modification as ①-a is applied. However, turbine inlet temperature is kept as original in this case. Thanks to the advanced cooling, material and coating technologies, reliability can be enhanced as follows.

- Hot Parts Life: 1.0～1.5 times better

② IMPROVED SEALING TECHNOLOGIES

By applying advanced sealing technologies, leakage air is significantly decreased. Therefore, performance (power output, heat rate) is improved without higher level of firing temperature. As an improvement on the "D-series" Row 1 and Row 2 vane seal arrangement, MHI has developed a new configuration of seal technology. This seal arrangement includes a replacement of the seal structure from labyrinth seals to brush seals and E-seals. The required modifications are summarized below: (see Figure 5).

· Brush seals are applied to Row 2 rotor-stator seals with partial replacement of labyrinth seals.
· E-seals are inserted between Row 1 vane stationary parts with combination of seal plate re-arrangement.

Typical benefits of applying improved sealing technologies can be quantified as follows:

- G/T Power: 1.7% better
- G/T Heat Rate: 0.7% better
- C/C Power: 1.5% better
- C/C Heat Rate: 0.5% better.

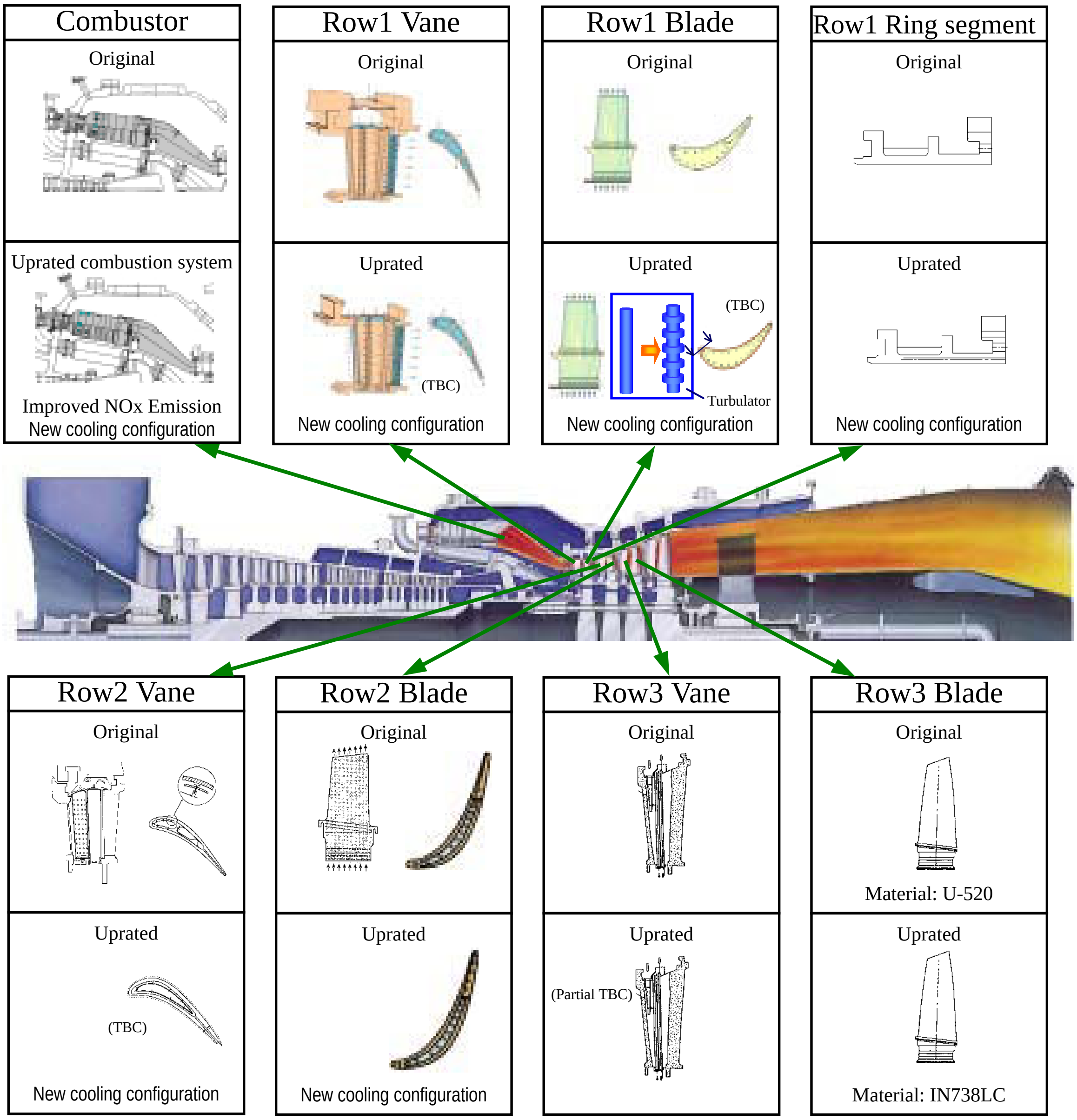


Fig.4 Modification for TIT increase

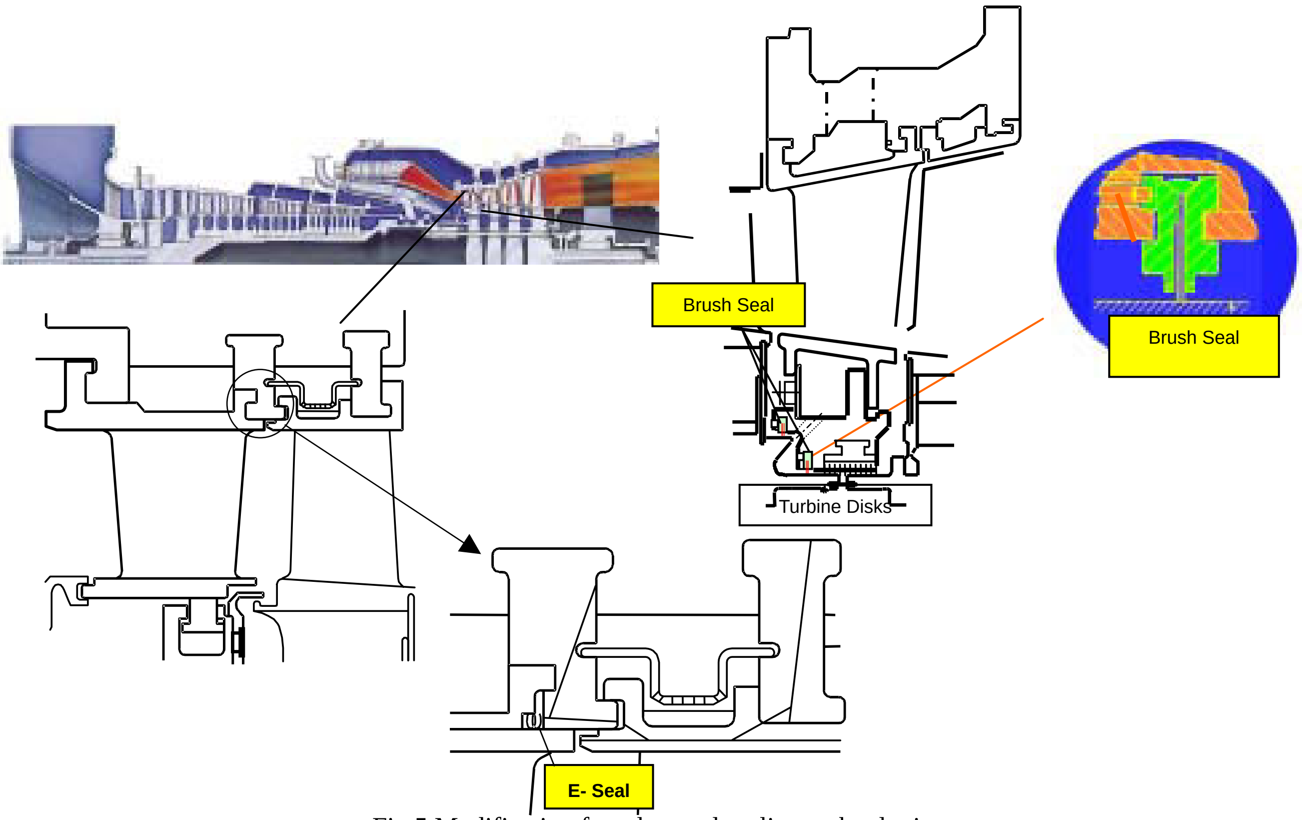


Fig.5 Modification for advanced sealing technologies

③ **ABRADABLE COATING**

Clearance between the rotor blade and ring segments is a critical factor because it allows combustion gas to leak over the tip of the blade, which causes significant performance loss.

Lots of researchers have been investigated the relationship between turbine stage efficiency and tip clearance (Dunham & Came, 1970, Kacker & Okapuu, 1982, Helmers & Klingmann, 2002). Generally, a 1% blade height of clearance lowers approximately 2% of turbine stage efficiency in heavy-duty gas turbine blade level.

However, a certain clearance is required for the heavy-duty gas turbines to account for conditions that can result in heavy rubbing due to casing oval deformation, misalignment and so on.

By applying abradable coating on ring segments facing rotating blades, a leakage of hot gas between blade tip and stator is significantly decreased. This product has been demonstrated to improve combustion turbine power output and heat rate. Therefore, performance (power output, heat rate) is improved. The required modification is shown below.

· Abradable coating on Row 1 and Row 2 ring segments

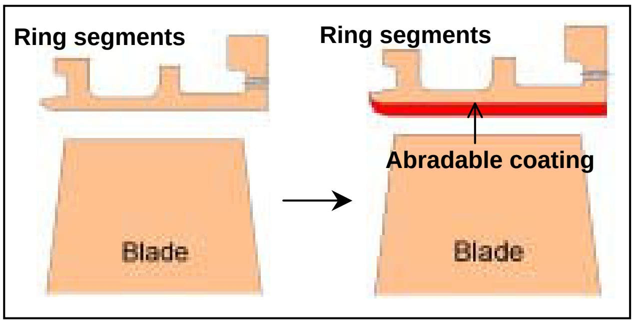


Fig.6 Abradable coating on ring segments

Based on successful "F-series" design, abradable coating has been applied to Row 1 and Row 2 turbine ring segments to reduce turbine blade tip clearances. By reducing the tip clearances, the power output and efficiency of the turbine have been increased.

Typical benefits of applying this product are shown below.

- G/T Power: 1.3% better
- G/T Heat Rate: 1.3% better
- C/C Power: 0.4% better
- C/C Heat Rate: 0.4% better

④ **FUEL GAS HEATING SYSTEM**

With this system, waste heat from the Turbine Cooling Air (TCA) cooler is utilized to heat the fuel gas, resulting consequently in a heat rate improvement. In addition to installing a fuel gas heater, some piping route modification is required.

In both simple and combined cycle, waste heat from compressed rotor bleed air can be used to heat fuel gas improving the heat rate of the gas turbine. In the current system, the rotor-bled air is cooled down to an optimum designed temperature by the TCA cooler. A large quantity of air is used to cool the rotor cooling air; consequently a large amount of heat is lost into the atmosphere. By using an FGH system, part of that waste heat is transferred directly to the fuel gas (see Figure 7).

Typical benefits of applying this product are shown below.

- G/T Power: 0.0% better
- G/T Heat Rate: 0.6% better
- C/C Power: 0.0% better
- C/C Heat Rate: 0.6% better

⑤ **AIR INTAKE FILTER**

This upgrade product utilizes High Efficiency Particulate Air filter (HEPA filter) to improve the gas turbine's availability by reducing fouling on compressor blades. The HEPA filter effectively removes dusts from inlet air. It can be installed as the third stage air intake filter, resulting in a very effective countermeasure against gas turbine performance deterioration experienced when conventional filters are used. See Figure 8 for details.

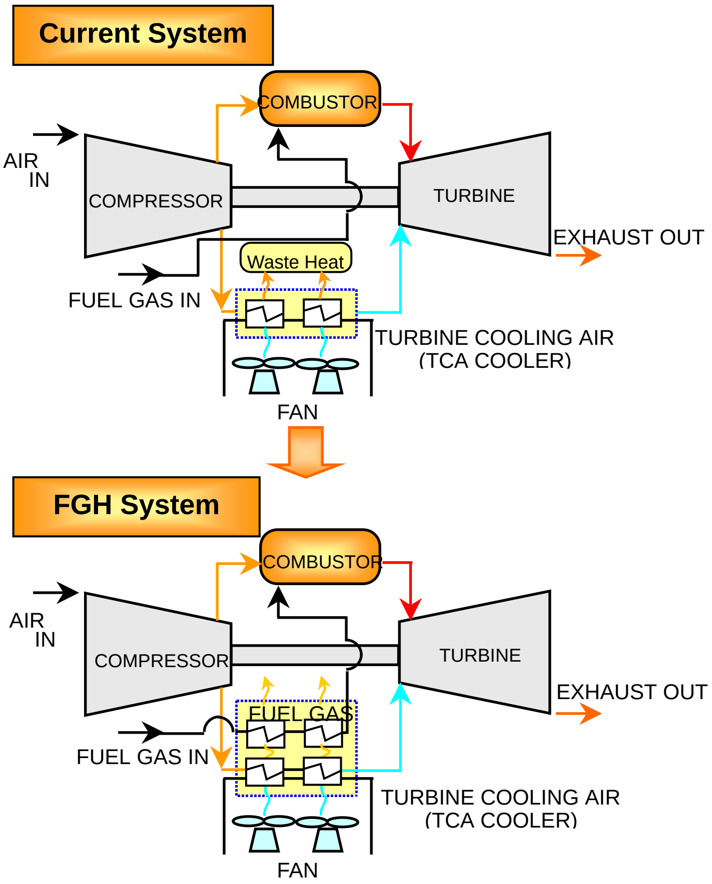


Fig. 7 Fuel Gas Heating (FGH) system

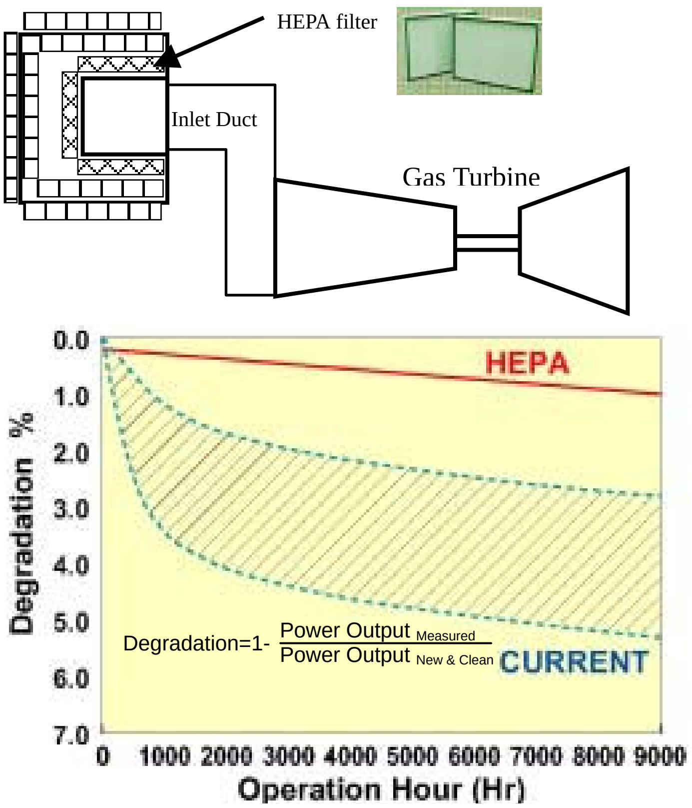


Fig. 8 Modification for air intake filter

⑥ **DLN (Dry Low NOx) combustion system**

Emission is reduced significantly without water/steam injection by the multi-premixed combustion system. In addition, cooling effectiveness is reinforced with MHI patented cooling scheme "MT-FIN"

The DLN combustion system has been demonstrated to reduce NOx emissions. This system includes the premix lean-burn hybrid combustor (see Figure 9). This combustor reduces maximum firing temperature while keeping turbine inlet temperature basically unchanged. Therefore, NOx emission level is decreased.

Typical benefits of applying this product are shown below.

- NOx: 25ppmVd with Gas firing, Dry

MHI is the first gas turbine manufacturer that developed the premix lean-burn hybrid combustor and demonstrated it. The hybrid combustor features a two type burner assembly and air bypass valve which directs a portion of the compressor delivery air directly into the transition piece to enhance flame stability during starting and to maintain desired fuel to air ratio during loading. This unique valve system is modulated to full close at full load. MHI owns a patent for this valve system.

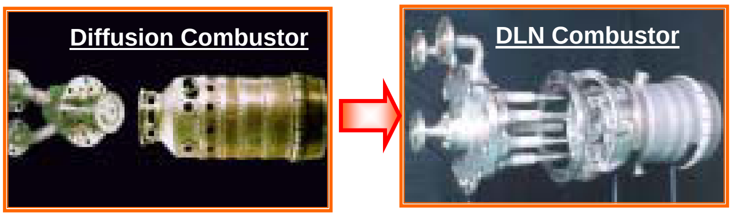


Fig. 9 Modification for DLN combustion system

PLANT OPTIMIZATION

Gas turbine power output (Generator capacity) and exhaust gas temperature (HRSG capability) can be increased by M&U package.

It may be necessary to conduct a plant re-optimization study. Figure 10 shows the major components of the combined cycle power plant for which engineering evaluation is necessary. (integrating all components and system for the combined cycle power plant).

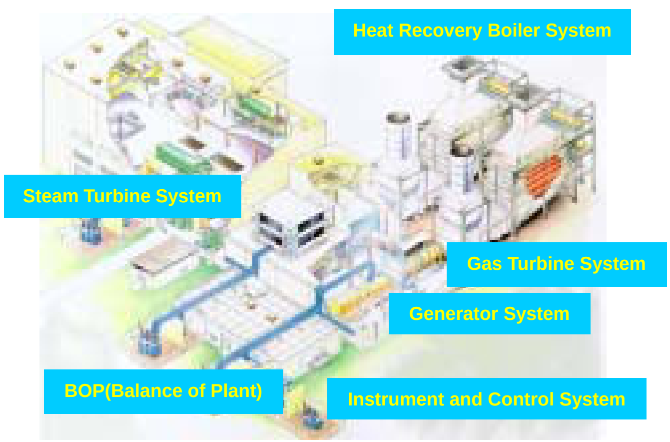
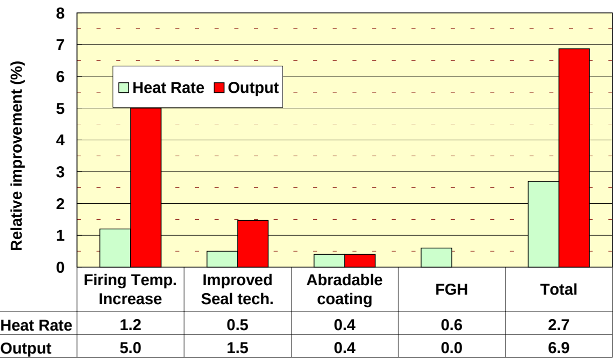


Figure 10. Combined Cycle Power Plant Elements

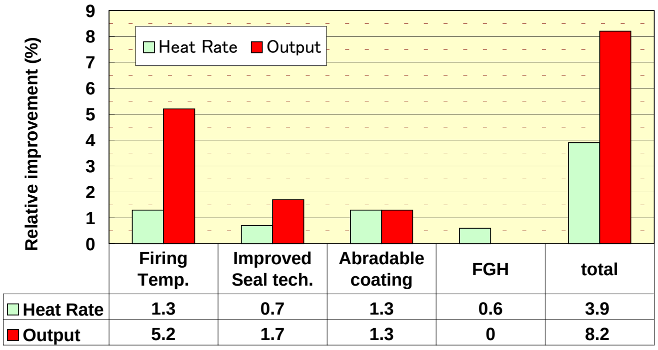
4. SUMMARY OF D-SERIES M&U

Performance improvements of "D-series" gas turbines using the various M&U options are summarized in Figure 11 for Combined Cycle and Figure 12 for the gas turbine only. In addition to performance improvements, the M&U products offer emission improvements and availability improvements.



	Firing Temp. Increase	Improved Seal tech.	Abradable coating	FGH	Total
Heat Rate	1.2	0.5	0.4	0.6	2.7
Output	5.0	1.5	0.4	0.0	6.9

Fig.11 Improvements in C/C performance by D-series M & U products



	Firing Temp.	Improved Seal tech.	Abradable coating	FGH	total
Heat Rate	1.3	0.7	1.3	0.6	3.9
Output	5.2	1.7	1.3	0	8.2

Fig.12 Improvements in G/T performance by D-series M & U products

Other improvements can be summarized below.

-Extended hot parts life: 1.0 ~ 1.5 times better
-NOx: 25ppmVd with DLN (w/o water/steam injection)
-Performance improvement by HEPA filter

Some of the M&U packages may require a plant re-optimization study.

By applying appropriate selections of the M&U options the power output and heat rate of a combined cycle could be increased up to 6% and 2.5% respectively. Likewise, there is the advantage of extending existing plant life with the abovementioned upgrade.

5. CONCLUSION

To keep the competitiveness of existing gas turbine plants, it has great importance for the existing plant to seek the performance (power output and heat rate), RAM (Reliability, Availability and Maintainability) and environmental friendliness.

MHI has developed advanced technologies of culminating in latest production, which have been proven in its fleets.

And also MHI has developed the applications of advanced technologies which retrofits for existing fleets.

Those applications are called Modernization & Upgrades (M&U) products. These products can provide significant savings to customers due to improved heat rate and increased power output and improved RAM. Those products also include reduction of emission levels helping the users to comply with stringent regulatory requirements.

Some M&U products require plant re-optimizations. The plant optimizations will adjust cost impact and modification. M&U products should be selected carefully according to plant needs.

By applying M&U products and plant re-optimizations, power output and heat rate of combined cycle could be not only recovering the deterioration but increased significantly.

This paper described D-series M&U products mainly. However, M&U products for F-series – having higher firing temperature levels and for small gas turbines are also available.

MHI consider M&U will be use for extending existing plant life

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