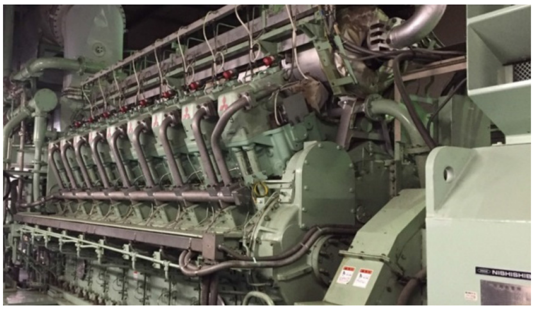
Improvement of Power Generation Efficiency by 3% Points by Remodeling Existing Gas Engines for Higher Efficiency



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Natural gas resources have been attracting attention as a major fuel in the future due to their feature of reducing environmental impact and a strongly-secured energy supply. The KU gas engine series of Mitsubishi Heavy Industries Group has pursued high efficiency and high output since the introduction of the KU30G gas engine to the market, with the total operating time already exceeding 9 million hours. The engines of this series ensure high reliability by sharing a common design for 80% of their components. This report presents technologies to make the most of the benefits of the product series to remodel a gas engine that has been in operation for a long period of time to the latest model during regular maintenance, which contributes to improving power generation efficiency and operability, while also introducing an example thereof.

1. Introduction

Mitsubishi Heavy Industries Group has continued to develop the KU gas engine series in pursuit of economy and reliability since bringing the spark-ignition KU30G gas engine to the market in 1990. This was followed by the introduction of the micro-pilot ignition KU30GA in 2001 and the release of the KU30GSI in 2009, which uses the latest technology to improve efficiency and adopts the spark ignition system. The latest model, the KU30GSI series, includes the KU30GSI, which emphasizes overall efficiency and the KU30GSI-PLUS, which emphasizes the power generation efficiency covering a generator output range of 3650 to 5750 kW[(1)(2)]. **Table 1** lists the main specifications of the KU30GSI series. The total operating time of the KU gas engine series has exceeded 9 million hours and the engines of this series ensure high reliability by sharing a common design for 80% of their components. In this way, products and services based on abundant operation and maintenance results are provided.

Table 1 KU30GSI series main specifications

Engine type		KU30GSI	KU30GSI-PLUS
Cylinders count		12 - 18	
Bore and Stroke	mm	300 × 380	
Engine speed	min^{-1}	720 / 750	
Generator output*	kW	3650 - 5750	
Power generation efficiency*	%	46.5	49.5
NOx (converted to 0% O_2)	ppm	<320	
Weight	Ton	40 - 60	

* Under ISO3046 conditions and with our recommended reference gas

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In general, in order to operate a gas engine efficiently over a long period of time, it is necessary to have an optimal maintenance program and to replace parts appropriately. As the operating time of the engine increases, the running cost increases due to the expansion of the maintenance range and the increase in the number of replacement parts caused by the occurrence of the wear of sliding parts and dirt on the cooling surface and corrosion, which becomes an operational issue. In addition, aging deterioration of auxiliary equipment such as pumps and instrumentation is a potential factor for unplanned outages.

Most of the KU30GA engines our company delivered in the 2000s have been in operation for about 15 years and the cumulative operating time of the engines has exceeded 100,000 hours. Some of these engines may require replacement or maintenance of relatively large-scale parts in order to prevent failures due to aging. Therefore, by performing remodeling work to apply the latest high-efficiency technology during regular maintenance of the gas engine, operational flexibility can be improved and stable continuous operation can be ensured in the future.

This report presents technologies to make the most of the benefits of the product series to remodel a gas engine that has been in operation for a long period of time during regular maintenance, which contributes to improving power generation efficiency and operability, while also introducing an example thereof.

2. Features and advantages of remodeling existing machine to latest engine

KU series gas engines use 80% common design for the main bodies, and 100% common design for generators and plant auxiliaries. Therefore, it is possible to remodel to the KU30GSI, which features the latest combustion technology and component reliability technology, while making the best use of the existing plant equipment. The KU30GSI has the following features and the remodeled gas engine can be expected to have the same advantages.

(1) Improved power generation efficiency

The KU30GSI achieves a higher power generation efficiency than existing engines by improving the cycle efficiency oriented to high Miller cycle through the adoption of a high-efficiency turbocharger, exhaust gas bypass control, etc., as well as by improving the combustion efficiency through the optimization of the shape of the combustion chamber and pre-chamber. The ignition system has been changed to spark ignition, which eliminates the need for ignition fuel and realized the same continuous operation time, that is, the same spark plug replacement cycle as the micro-pilot ignition system.

Figure 1 compares the ignition systems of the existing model KU30GA and the latest model, the KU30GSI.

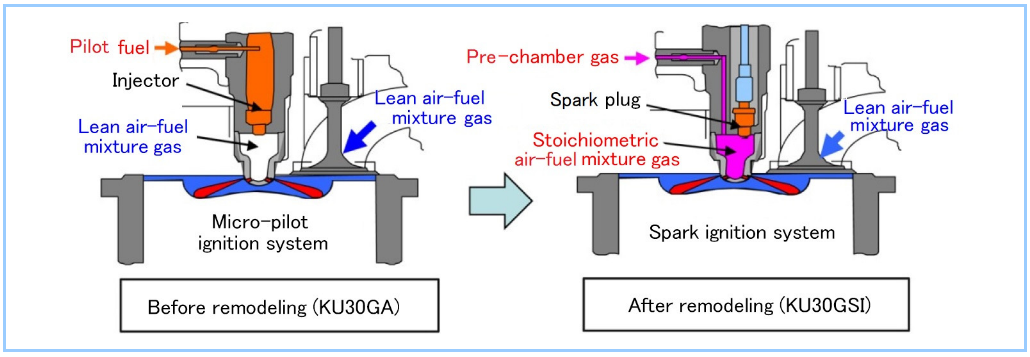

Figure 1 Comparison of ignition systems

(2) Maintaining overall efficiency and NOx emissions

Exhaust gas energy tends to decrease as the power generation efficiency improves. The KU30GSI adopts an exhaust gas bypass system for air-fuel ratio control to suppress the loss of exhaust heat recovery compared to the charge air discharge system used in the conventional model. **Figure 2** compares the air-fuel ratio control systems. In addition, the operable air-fuel ratio range is expanded with the latest combustion technology, so it is possible to minimize the decrease in the amount of steam generated to maintain the overall efficiency by raising the exhaust gas temperature and optimally adjusting the balance with the amount of exhaust gas.

NOx in the exhaust gas is lower than 320 ppm (converted to 0% O_2), which is the standard value of the latest model, due to the expansion of the operable air-fuel ratio range and it can be maintained at 200 ppm (converted to 0% O_2), which is the same level as the conventional gas engine.

The technologies used for the KU30GSI also contribute to the CO_2 emissions reduction through effective energy use and the improvement of the power generation efficiency.

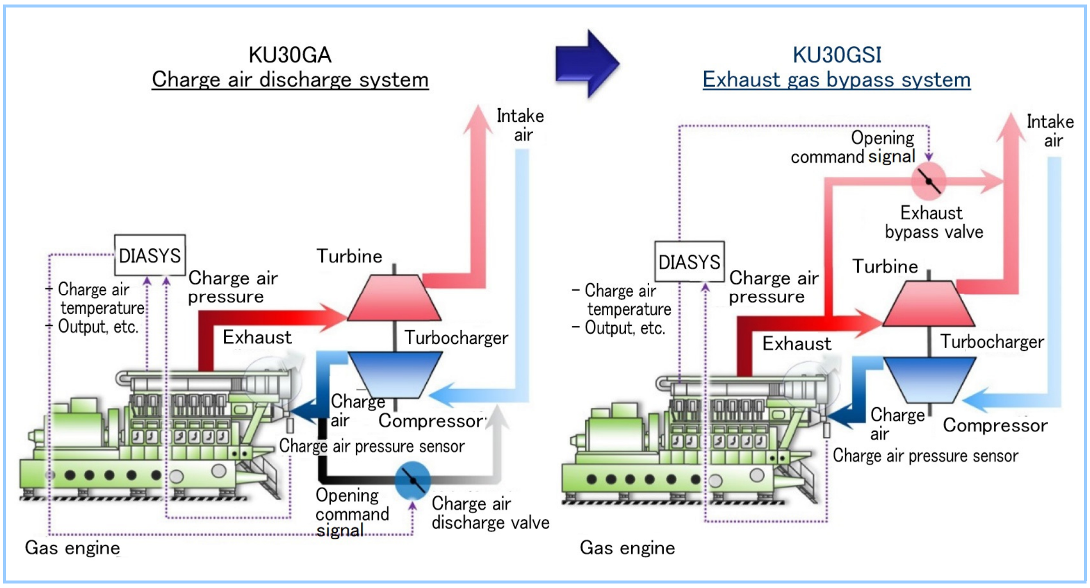

Figure 2　Comparison of air-fuel ratio control system

(3) Excellent start-up and load following characteristics

In the case of a conventional micro-pilot ignition system, the temperature of the combustion chamber and the air-fuel mixture tends to affect the ignitability of the ignition fuel, requiring a start-up time of 20 minutes or more. On the other hand, in the case of the spark ignition-type KU30GSI, the temperature of the combustion chamber and the air-fuel mixture does not significantly affect the ignitability within the actual operating range and the time from start-up to reaching the rated load is shortened to about 5 minutes by setting the concentration of the air-fuel mixture appropriately. Although it has the capability to achieve the same start-up performance level, the remodeled engine is adjusted targeting reaching the rated load from start-up within 10 minutes in consideration of the margin depending on the operation form and the site environment of the existing plant, thereby realizing a start-up time of less than 1/3 of that of the conventional engine.

(4) Extension of maintenance interval

The service life of the main parts of the KU30GSI has been significantly extended by reflecting the achievements of the KU gas engine series in the field to improve and refine the design of various parts. The parts of existing gas engines have been aging and deteriorating. By replacing parts that need to be replaced in the future with the latest parts in the remodeling work, the maintenance cycle of pistons and bearings, which was conventionally 8,000 hours, can be extended to 16,000 hours. Furthermore, the micro-pilot ignition system required maintenance of the injector, but the spark ignition system requires only replacement of the spark plug, which reduces maintenance costs and eliminates the need for the storage and management of spare parts for injector maintenance.

Extending the maintenance interval as described above reduces the maintenance cost compared with the existing engine, so the remodeling contributes to the improvement of economic efficiency in addition to the improvement of power generation efficiency.

(5) Effective utilization of existing equipment

This remodeling work not only improves the power generation efficiency, but also pays attention to economic efficiency and life cycle assessment by maximizing the use of existing equipment.

As described above, the design of the plant auxiliaries is almost same regardless of whether they are new or old, so most of the existing equipment can be used for the remodeled engine. In addition, since the change in the exhaust heat recovery is minimized due to the difference in air-fuel ratio control, it is not necessary to change the heat recovery device such as the boiler in principle.

Since not only the engine main body but also the plant auxiliaries can be reused, it is possible to flexibly remodel and update the equipment according to user needs and the initial investment can be suppressed by planning according to the actual situation of the plant. Furthermore, the devices and equipment to be reused can be replaced or updated in maintenance work before or after the engine main body is remodeled, so investment can be diversified and more flexible and efficient equipment renewal is realized compared to introducing new power generation equipment as a replacement.

3. Features of remodeling technology

3.1 Gas engine main body

The remodeling work can be made toward either specifications that focus on the overall efficiency or on the power generation efficiency. Many ordinary plants use waste heat in their operation and it is common to maintain the overall efficiency by remodeling to the KU30GSI. **Figure 3** shows the modified parts and the modification purposes.

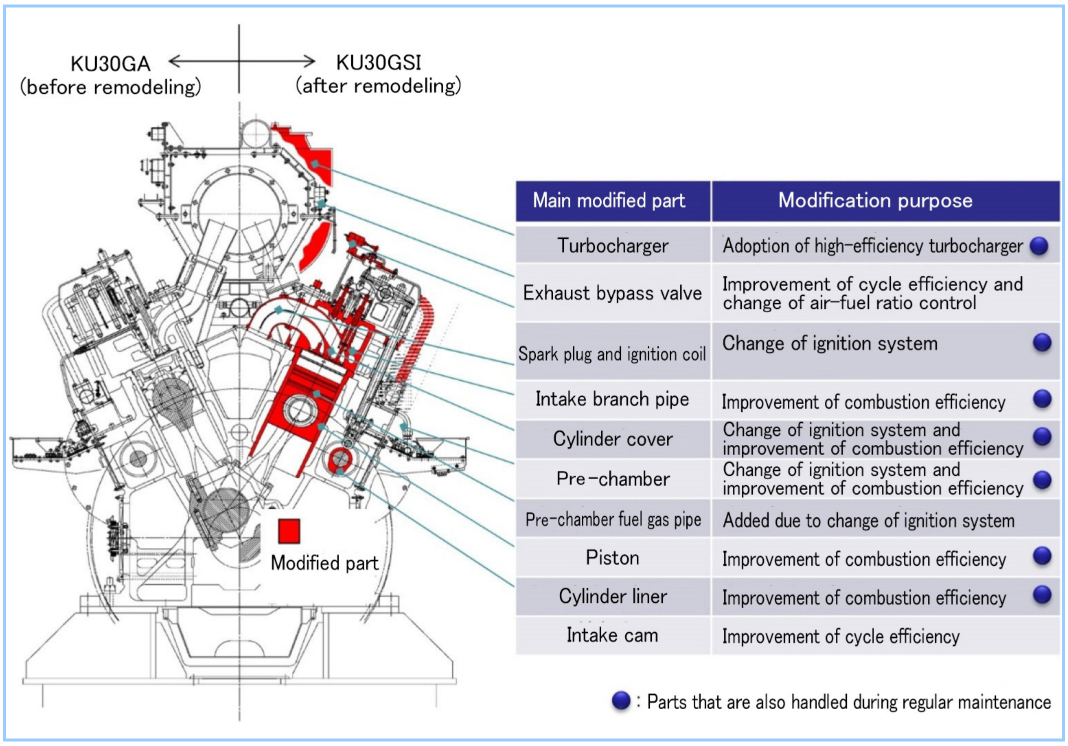

Figure 3 Modified parts and modification purpose

The remodeling of the gas engine main body is mainly the change of the parts around the combustion chamber, the turbocharger and the specifications of the fuel gas supply system. The cylinder cover, intake branch pipe, piston and cylinder liner, which constitute the combustion chamber, as well as the pre-chamber and turbocharger, are disassembled and maintained or replaced during regular maintenance. The result of changes in the combustion and performance due to aging deterioration and wear of these parts can be a factor that affects the stable operation of aged engines. Therefore, by performing remodeling work at the same time as regular maintenance work, the cost can be suppressed compared to performing the remodeling work alone, thereby eliminating deterioration by replacing the parts. The replacement parts have no major structural differences from the existing ones and have only minimum differences due to changes in the ignition system, so their handling manner remains the same after the remodeling, which is one of the advantages.

Furthermore, the parts to be modified in the engine main body are only 20% of the total weight of the engine and the heaviest part is the turbocharger. Therefore, it is unnecessary to prepare special emplacement/movement routes and large heavy machine, so almost all remodeling work can be carried out locally as long as equipment necessary for performing regular maintenance is available.

3.2 Engine control device

Figure 4 is a configuration diagram of the control system of the KU30GSI gas engine. It is necessary to change the control system, controller, etc., in order to change the ignition system, but many parts can be reused from the existing engine and the remodeling work can be performed with minimal changes.

The pilot injection controller is replaced with an ignition device. Due to this change in the combustion system, it is necessary to add a knock detector in order to detect knocking with a high degree of accuracy. On the other hand, the combustion diagnostic device and the main control device (DIASYS) can be reused, so the change to the spark ignition system can be made only by modifying the control logic and changing the set values. The gas supply controller (governor) can be reused only by changing the set value.

On the other hand, the reusable devices such as combustion diagnostic device and gas supply controller (governor) can be replaced with those of the latest specifications. The latest combustion diagnostic equipment has improved data resolution and processing capacity and the latest gas supply controllers (governors) have improved control functions. DIASYS Netmation, the latest version of DIASYS, supports remodeling without the need for changes, as will later versions. The latest DIASYS Netmation and combustion diagnostic equipment have improved operation functions and are capable of remotely changing settings in addition to remote monitoring, which contributes to the improvement of equipment maintainability.

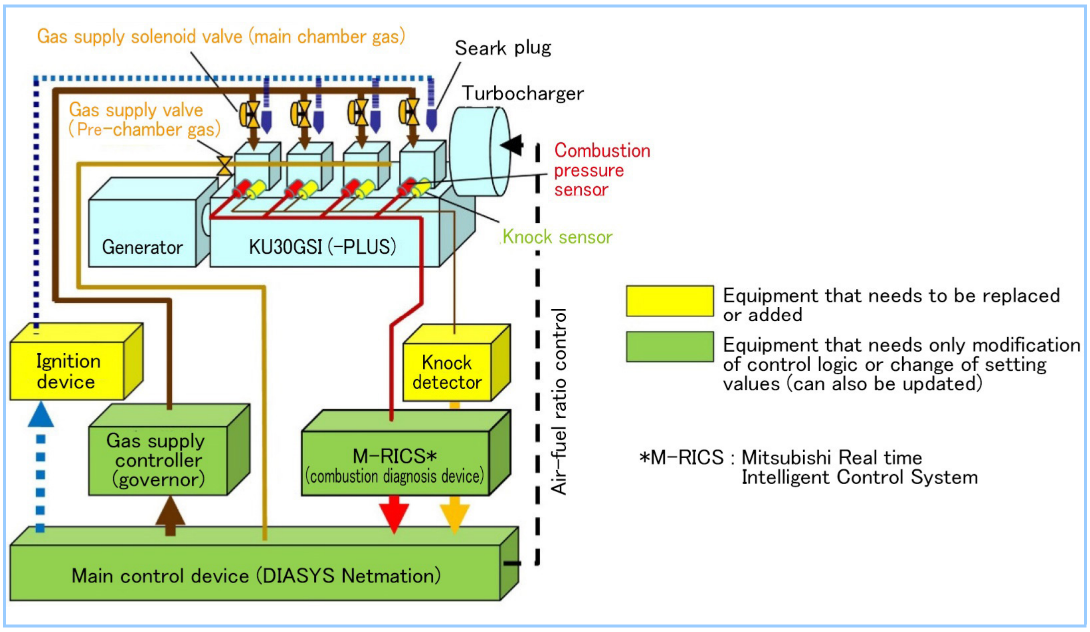

Figure 4 Configuration diagram of gas engine control system

3.3 Plant equipment and auxiliaries

Over the operation time, some plant equipment and auxiliaries also undergo unavoidable aging-related issues, such as becoming obsolete, which causes the procurement of consumable parts to be difficult and gradual performance deterioration. As a measure against these issues, replacing the cooling system pump with the latest energy-saving pump, while also taking advantage of the common design mentioned above, can eliminate operational anxiety and reduce the power consumption in the facility.

4. Example of plant remodeling

4.1 Overview of remodeled plant

Table 2 lists the specifications of a plant that was remodeled at the same time as regular maintenance. This plant is a CHP (combined heat and power plant) that uses gas engine generator output and exhaust heat and has two 18KU30GA units with a micro-pilot ignition system. Generator output is 5500 kW and the engine speed is 720 min^{-1}. This plant uses two types of fuel gas, Japanese city gas 13A and BOG (boil-off gas), in a switching manner and the change of fuel properties is dealt with by the engine setting. This power generation plant started operation in 2004 and the total operating time is about 70,000 hours[3][4].

Table 2 Specifications before and after remodeling

Item		Before remodeling	After remodeling
Engine type		18KU30GA	18KU30GSI
Engine number		2 units	←
Generator output per unit	kW	5500	←
Engine speed	min^{-1}	720	←
NOx (converted to 0% O_2)	ppm	<200	←
Engine running in year		2004	2018
Engine operating time	Hr	About 70,000	-
Fuel gas		Japanese city gas 13A and BOG	←
Ignition system		Micro-pilot	Spark ignition
Air-fuel ratio control system		Charge air discharge	Exhaust bypass valve
Startup system		Automatic turning	Slow turning

4.2 Performance after remodeling

The engine, plant, environmental performance and operating characteristics after the remodeling work were confirmed by a test run. **Table 3** presents the test run results. All results satisfied the planned expected value and the remodeled engine achieved the same performance as the KU30GSI.

Table 3 Test run results

Item		Measurement result
Generator output per unit		5500kW
Power generation efficiency (average)	Japanese city gas 13A	+3.2%pt
	B.O.G	+3.0%pt
Exhaust temperature	Turbocharger outlet	±0°C
NOx (converted to 0% O_2)		<200ppm
Startup time		About 1/3

(Notice) The measurement results of the power generation efficiency, exhaust temperature and startup time are represented as the difference before and after remodeling.

(1) Plant performance

The power generation efficiency was improved by 3.2% pt in the case of Japanese city gas 13A fuel and 3.0%pt in the case of BOG fuel at a rated output of 5500 kW. When the thermal efficiency of a gas engine improves, the amount of exhaust gas tends to decrease, but it was confirmed that due to changing the air-fuel ratio control system and adjusting the exhaust gas temperature as described above to maintain the overall efficiency combined with the exhaust heat recovery at the same level as before, the operation of the entire cogeneration facility was not affected.

By optimally adjusting the air-fuel ratio and ignition timing in the test operation, the NOx emissions in the exhaust gas were reduced to 140 ppm in the case of Japanese city gas 13A fuel and 170 ppm in the case of BOG fuel, which were well below the NOx emissions in exhaust gas from the operation using an existing gas engine (up to 200 ppm (converted to 0% O_2)) in all load ranges.

(2) Operational characteristics

As a result of the plant characteristic confirmation test conducted in the test operation, it was confirmed that it took the plant less than 8 minutes from turning on the breaker to reaching the rated load and the start-up time was shortened to about 1/3 of that before the remodeling. In addition, as a result of the load increase/decrease test, it was confirmed that the load followability was improved in a wide load range. In this way, performance that enables more flexible plant operation was realized.

The improvement of the startability and load followability is a significant operational advantage because it can easily and quickly ensure plant operation and demand followability when starting/stopping the engine or switching the fuel gas.

On the other hand, as a function that takes advantage of the spark ignition system, the remodeled engine has a mode that automatically selects and switches between "normal start" and "cold start" depending on the warm-up state at the time of starting the engine. **Figure 5** presents the time to reach load for each start mode. In cold start mode, the engine can be started even under insufficient warm-up conditions by suppressing the load following speed. This function can contribute to energy saving by eliminating the need for active warm-up during stoppage in the case the start-up time need not be short, such as in a test run after regular maintenance.

As described above, the remodeling work realized the functions of the latest model, which improves the performance of the engine and plant, improves the economic efficiency and contributes to improving the operational performance, such as enabling more flexible plant operation.

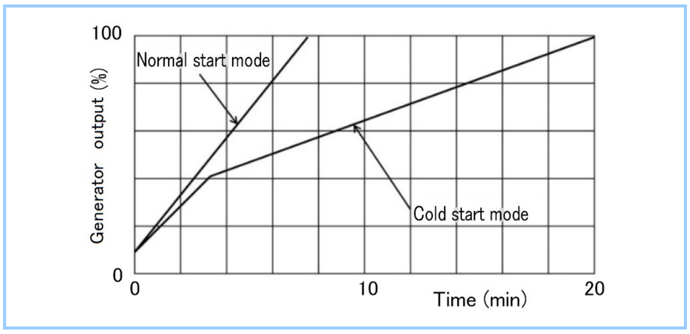

Figure 5 Time to reach load for each start mode

5. Conclusion

We established technologies to remodel existing gas engines to the latest gas engine at the same time as regular maintenance and were able to obtain good results.

Remodeling of the KU engine series, which are based on a common design, minimizes installation costs by retrofitting the latest technology to existing plants, improves the power generation efficiency and reduces the maintenance costs, while also making it possible to provide stable plant operation over a long period of time. Currently, we have completed similar remodeling work for three engines of two plants and have received an order for remodeling one engine of one plant. It is also possible to convert the KU30A diesel engine to a gas engine using the same platform. With these remodeling technologies, we would like to contribute to the extension of the operation period and the reduction of the environmental load for aged engines, the number of which is expected to increase going forward, in order to realize the effective utilization of the assets of our customers.

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