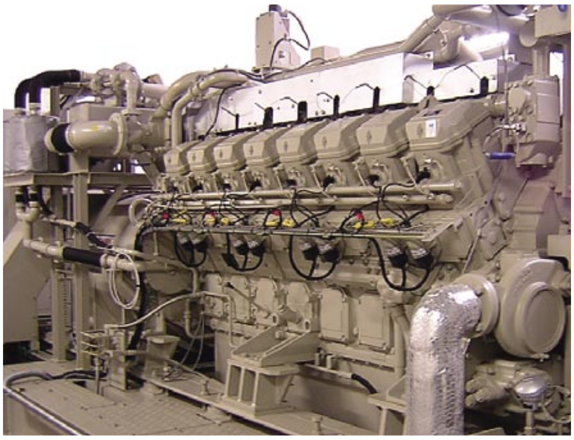

The Development of 1 MW Class Gas Engine and Its Application to Cogeneration Systems

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Since the end of the 20th century, gas engines fueled by natural gas, known as "clean energy," have attracted attention as outstanding power generation systems in addressing global environmental issues. They are increasingly in demand because they emit less carbon dioxide (CO_2), which causes global warming, sulfur oxides (SOx), which are responsible for acid rain, and nitrogen oxides (NOx), which lead to environmental problems. With this background, Mitsubishi Heavy Industries, Ltd.(MHI) has developed a commercial highly efficient 1 MW class (280–1000 kW) gas engine, which is friendly to the global environment.

1. Efficiency improvement of gas engines

1.1 Features of gas engines

The main fuels for gas engines are natural gas and city gas (13A). They generate less carbon dioxide (CO_2), which causes global warming, because the main component methane (CH_4) contains four times more hydrogen atoms (H) than carbon atoms (C), which is over twice the ratio of petroleum fuels. Hydrogen becomes water when combusted. They also do not emit sulfur oxides (SOx), which cause acid rain, because the fuel does not contain sulfur atoms. Moreover, natural gas and city gas contain no particulate matter (PM) and emit fewer nitrogen oxides (NOx), both of which are detrimental to human health.

1.2 History of efficiency improvements in MHI's gas engines

In 1993, MHI introduced a gas engine that adopted an ultra-lean-burn system whose generating efficiency at that time was 34.3–35.5%. Subsequently, in 2000, MHI marketed a gas engine (GSR Miller) that adopted the Miller cycle for a precombustion chamber-type lean-burn engine developed jointly with Osaka Gas. The Miller cycle gas engine had the world's highest generating efficiency of 40% for that class (280, 560, and 740 kW) at that time. In 2002, the company developed the Advanced Miller cycle gas engine (GSR Advanced Miller; 305, 610, and 815 kW) by improving the efficiency and increasing the output of the Miller cycle gas engine, attaining what was then the world's highest generating efficiency of 40.4% (305 kW) to 40.8% (610 and 815 kW). With subsequent improvements, MHI has attained a generation efficiency of 41.4% at 815 kW. Joint development efforts with Osaka Gas continued, and in 2005, a middle-sized GS6R2 Miller cycle gas engine with the world's highest generating efficiency of 41.5% (380 kW) was marketed. Furthermore, a 1000 kW Miller cycle gas engine with a generating efficiency of 41.7% will be introduced in the near future. **Figure 1** shows the history of the efficiency improvements. While this figure shows products for the 60-Hz region, the following development efforts were also made for the 50-Hz region:

- GSR Miller: Generating efficiency 39% (320, 635, and 845 kW), 2002
- GSR Miller: Generating efficiency 40% (635 and 845 kW), 2006
- High-powered GSR Miller: Generating efficiency 40% (700 and 930 kW), 2006

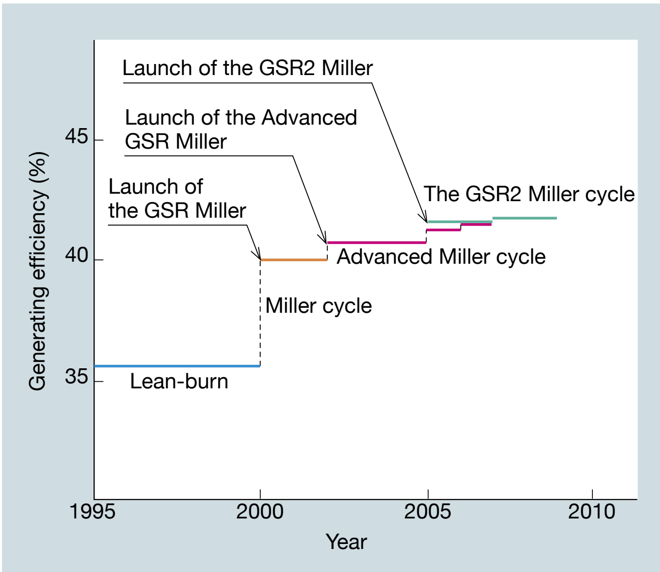

Fig. 1 History of MHI's improvement of gas engine efficiency

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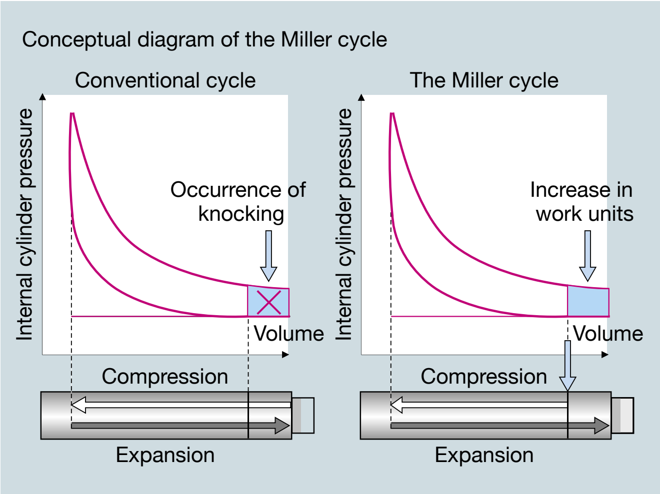

Fig. 2 Conceptual diagram of the Miller cycle
This technology prevents knocking by decreasing the compression ratio and improves the cycle efficiency by increasing the expansion ratio.

• GS6R2 Miller cycle gas engine: Generating efficiency 41.6% (315 kW), 2007

The GSR Miller, Advanced GSR Miller, and High-powered GSR Miller together have a delivery record of over 220 units across the country, earning a high reputation among customers.

2. Gas engine cogeneration system

Cogeneration is a system that uses energy effectively by generating multiple types of energy, such as electricity, hot water, and steam, from a single energy source such as natural gas. Due to the higher-energy efficiency and resultant reduction in greenhouse gas emissions as represented by CO_2, this system is expected to bring about positive economic effects such as energy cost reductions.

2.1 System configuration

The component devices of the cogeneration system include engines, generators, pumps, heat exchangers, silencers, boilers, and gas compressors, combinations of which can further expand the available selection. Therefore, marketing required standardizing the basic system to readily satisfy customer specifications. Cogeneration systems with a gas engine as their core can be divided into hot water recovery systems and hot water and steam recovery systems. The difference between these two types is whether the heat from the engine exhaust gas is recovered in the form of hot water or steam. To facilitate the production of the two types, the components common to both, such as the engine, generator, starting battery, lubricating oil tank, control panel, gas valve equipment, and gas compressor, were integrated into one package as the power generation unit. Simultaneously, the components that could not be used in common were

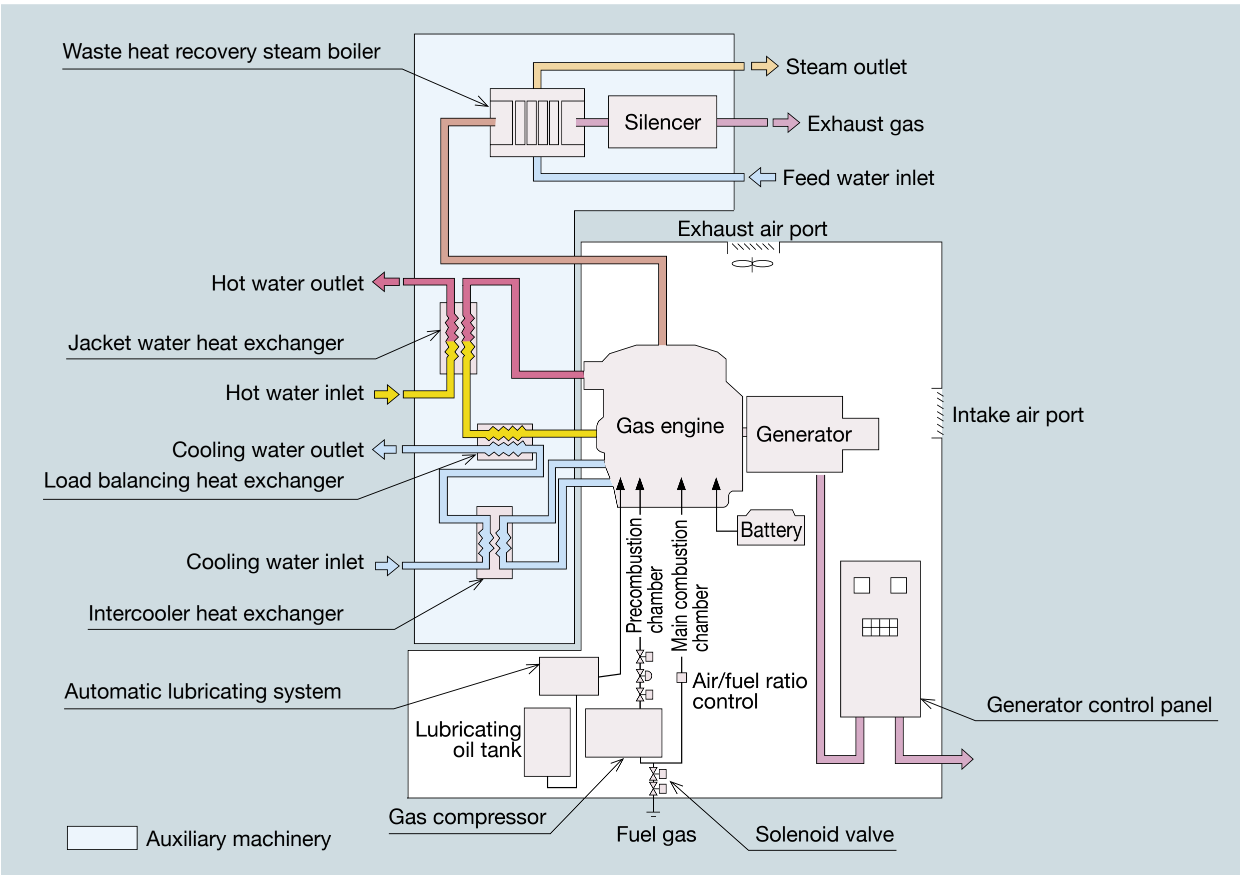

Fig. 3 Block diagram of the hot water and steam recovery system

Fig. 4 The Advanced Miller GS16R-815kW hot water and steam recovery system in operation

integrated as auxiliary machinery incorporating heat-recovery devices to meet the two specifications separately. In designing the package, a compact layout was realized, while maintainability was considered. Furthermore, by adopting this cogeneration package configuration, site installation requires simply combining these units, shortening the work period for site construction.

2.2 Hot water and steam recovery system

Figure 3 shows a block diagram of the hot water and steam recovery system. A waste heat recovery steam boiler is located above the auxiliary machinery. This system recovers the heat from the engine exhaust gas in the form of steam and recovers the heat from the engine cooling water in the form of hot water by using a heat exchanger (total efficiency 73.2–76.4%). The hot water recovery temperature is set to a normal temperature range (83°–88°C, i.e., the temperature range required for an absorption chiller and for a Gen-link). **Figure 4** shows an example of the hot water and steam recovery scheme of the GS16R Advanced Miller cycle system (815 kW).

2.3 Hot water recovery system

Figure 5 shows a block diagram of the hot water recovery system. In this system, which has a total efficiency of 73.5 to 77.6%, hot water is recovered through the following two lines.

- Heat from the engine exhaust gas is recovered in the form of hot water by the waste heat recovery water heater above the auxiliary machinery.
- Heat from the engine cooling water and the hot water from the exhaust gas are recovered in the form of hot water by the jacket water heat exchanger.

The temperature value of the hot water recovery system is the same as that of the hot water and steam recovery system. Optionally, this system can be used at higher recovery temperatures (83°–90°C). **Figure 6** shows an example of the hot water recovery scheme of the GS6R Advanced Miller cycle system (305 kW).

2.4 Examples of other applications

When exhaust gas is led directly into an absorption chiller for heat recovery, heat radiation devices are installed above

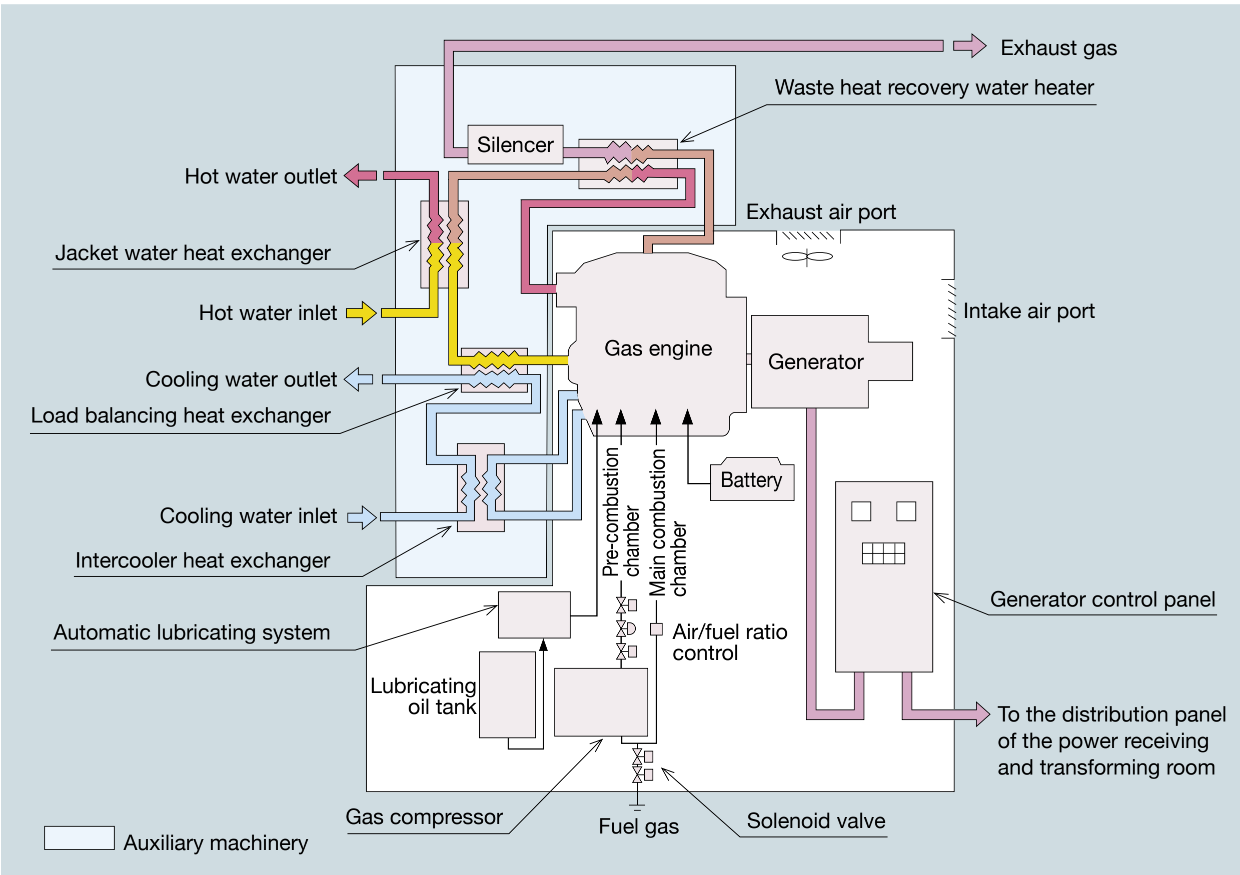

Fig. 5 Block diagram of the hot water recovery system

Fig. 6 The Advanced Miller GS6R-305kW hot water recovery system in operation

the auxiliary machinery so that the system can introduce exhaust gas through the gas duct directly. Several of these units have already been delivered to customers.

3. Conclusions

The GSR Miller cycle gas engine cogeneration package has attracted attention by attaining a generating efficiency of 40% for the first time in this class. It has contributed to shortened delivery time and cost reductions, which were realized by using the standardized package for each engine model, as described above. As a result of these efforts, the number of orders has increased steadily. As the need for cogeneration is expected to rise in the future due to rising energy prices and increasing demands for CO_2 emissions reduction, MHI is considering expanding production beyond the existing range based on an accurate understanding of customer needs. In addition, MHI intends to develop the high-efficiency technology that the company has cultivated over the years further and to continue introducing products that can help prevent global warming.

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