ADDED VALUE ENHANCEMENT FOR 1,000KW-CLASS CHP SYSTEM

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Abstract

The performance and added value of the natural gas CHP system can be improved by increasing the total efficiency and the first step loading ratio for the emergency power source.

We improved the first step loading ratio from 20% to 35% of the rated output power by the development of integrated control system and the optimum control parameters of air-fuel ratio and pre-chamber gas quantity. The total efficiency is improved largely to 80.3% by the development of the new heat recovery system in comparison with 74.1% of the conventional system.

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1. Introduction

In recent years, various environmental protection activities aiming for saving energy have been taking place. Since the first commitment period for the fulfillment of the reduction of greenhouse effect gas established by Kyoto Protocol became effective in 2008, much discussion regarding CO2 emission trading scheme is ongoing in Japan as well and addressing CO2 reduction is expected to further accelerate. Natural gas CHP system has had keen attention for its high overall efficiency, functional capability to serve as a decentralized power system for local power needs and superiority of clean emissions by using natural gas for fuel. In future, it is expected that the demand of natural gas CHP system as a system that contributes to CO2 emission reduction will further increase.

Not only as an energy-saving system, a natural gas CHP system is also drawing great attention for its added value as a power source now. The system can contribute to saving energy as a CHP system in daily use and also it can serve as a continuous electrical power source by fuel delivery via gas pipeline in case of power failure. Comparing to an emergency generator, a CHP system requires less cost and space for installation. Furthermore, CHP systems ensure higher reliability for power supply as they are daily operated and serviced unlike emergency generators.

OSAKA GAS CO., LTD. and MITSUBISHI HEAVY INDUSTRIES, LTD. have jointly developed high efficiency natural gas CHP system [(1)]. Approximately 290 sets of gas engine CHP systems employing Miller Cycle (300-1000kW class) have been sold until 2010 (Figure 1), and the total capacity reaches as high as 200MW. Recently, both companies have jointly succeeded in developing a new 1000kW-class high efficiency natural gas CHP system of which added value as a power source greatly enhanced. Figure 2 shows the appearance and specifications of the gas engine that is integrated in this 1000kW (60Hz) CHP system.

In the next passage, explanations on how improving the first step loading ratio that is the critical performance basis for CHP system operation as a power source during power stoppage was made possible and outline of the development for total efficiency improvement by increasing the amount of heat recovery which is as important as output as a CHP system are given.

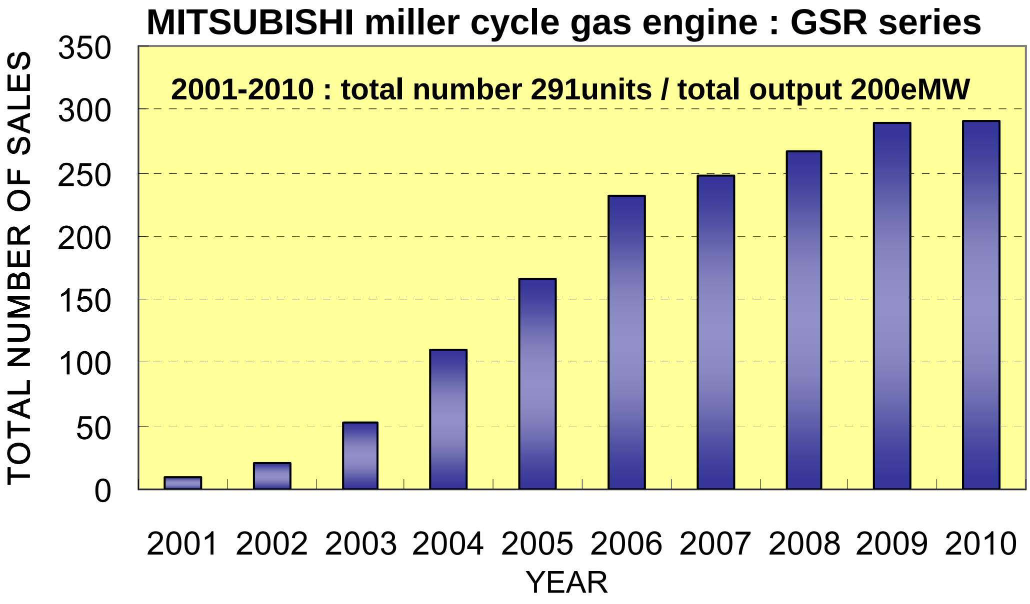

Figure 1 Total number of sales of MITSUBISHI miller cycle gas engines

Engine model	GS16R2
Output power	1000kW
Engine speed	1200min^{-1}
No. of cylinder	16-V type
Displacement	79.9L
Cylinder bore	170mm
Cylinder stroke	220mm
Gen. efficiency	41.7%
Total efficiency	74.1%
NOx (O2=0%)	< 100ppm (after de-NOx catalyst)

Figure 2 The appearance and specifications of GS16R2 gas engine

2. Improvement of the first step loading ratio

What makes the performance difference of a CHP system to be used as a power source at the time of a power outage is the first step loading ratio of the system. First step loading ratio is the percentage of load to the rated power that can be applied on the system as the first step load after the start-up. The higher percentage the system has, the more power is supplied from the system to loads. For the purpose of improving the first step loading ratio; (1) Improvement of Control System and (2) Improvement for more stable combustion were addressed in this joint development.

(1) Improvement of Control System

Control System which is used on conventional Mitsubishi Gas engine is shown in Figure 3. In order to achieve high power generation efficiency and low NOx emission, Pre-Combustion Chamber system lean burn is selected as the combustion strategy. By electronically controlling gas quantity to Main Combustion Chamber, flow rate of mixed gas and gas quantity to Pre-Combustion Chamber, stable combustion in various operating conditions is secured.

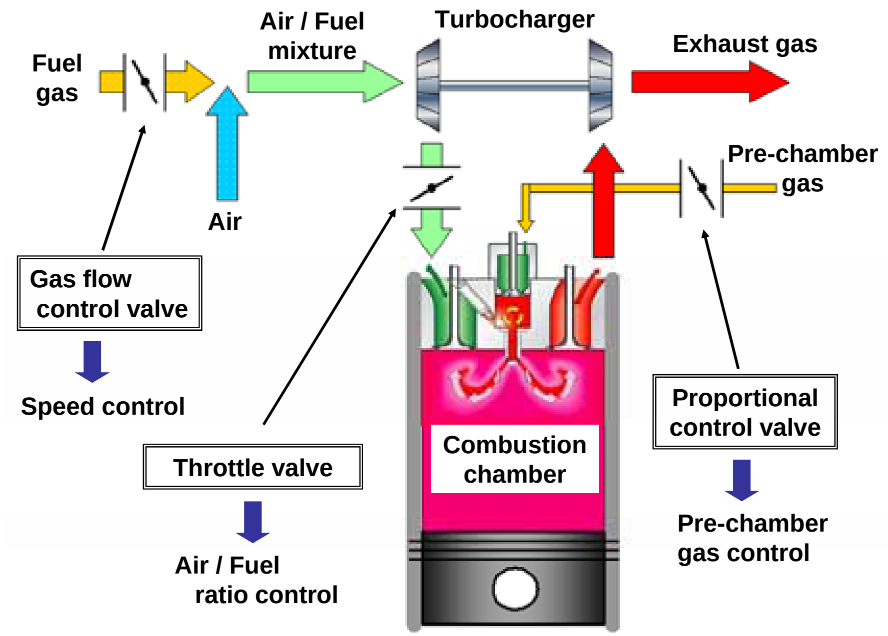

Figure 3 The appearance and specifications of GS16R2 gas engine

The improvements added in the control system by this joint development are shown in Figure 4. On conventional engines, commercially available controllers were used to control air fuel ratio, power and gas quantity to Pre-Combustion Chamber respectively via independent control. On the other hand in the new development, they are integrated into one single controller with Mitsubishi's own control logic uniquely developed for this CHP system. Control valves which have been used on Mitsubishi engines for long remain almost completely as it is. By reducing the number of controllers, cost reduction is also achieved.

	Conventional system	Developed system
Controlled object	Controller	Controller
Air / Fuel ratio	Air / Fuel ratio controller	Integrated controller
Speed Output power	Governor	
Pre-chamber gas flow	Pre-chamber gas controller	

Figure 4 The development of the integrated controller

Securing high power generating efficiency, low NOx emission and stable combustion in various operating conditions that were achieved in conventional control system, the newly developed integrated controller made it possible to drastically improve response performance compared to conventional control in various transient conditions such as starting, loading and load rejection through more precise cooperative control of air-fuel ratio and gas quantity to Pre-Combustion Chamber.

Figure 5 shows a rough outline of how response performance is improved by compensation control during loading. In the conventional individual speed control, engine speed was controlled to return to the rated speed in response to the speed drop from loading. By contrast, compensation control that increases fuel gas amount in response to load signals is newly employed in the latest development of the controller integration and speed drop is decreased compared to the conventional control.

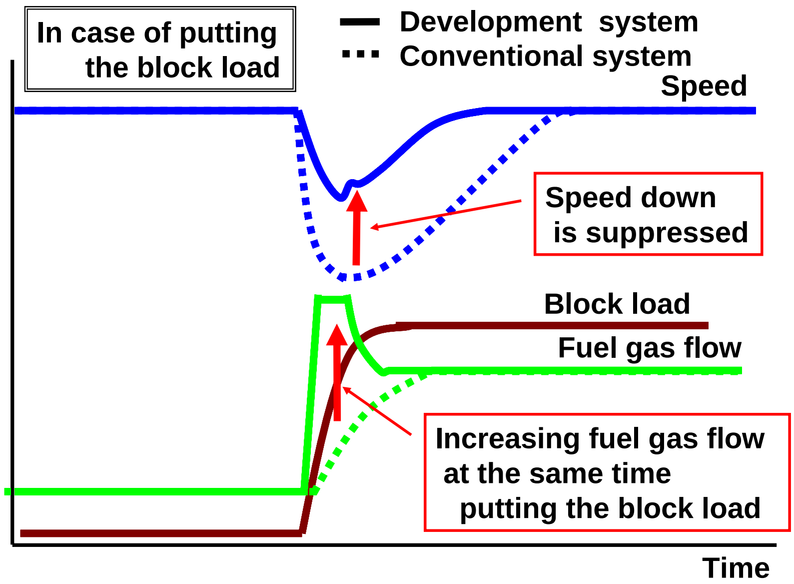

Figure 5 The compensation control during loading of the integrated controller

In order to utilize this new control system more effectively to improve transient response performance, it is necessary to properly adjust parameters such as air-fuel ratio and PID gain to actual gas engine behaviors in transient condition. Gas engine behaviors such as response and combustion differ in hot condition and cold condition. Therefore, each parameter adjustment requires balancing in various conditions. In the next passage, details of the adjustment in the severest condition, first step loading after cold start, are explained.

In order for a generator to serve as an emergency power source at the time of power stoppage, Japanese emergency generator regulation requires a generator to be ready for loading within 40 seconds after the start. Speed behaviors of a gas engine when it is initially loaded 40 seconds after the engine start in cold condition are shown in Figure 6. Both the speed drop from loading ((3) in the figure) and the time required until speed becomes stable ((2) in the figure) must be within the standard. The standard here is 15% or less speed change from the rated speed and within 15 seconds until the speed stabilizes to +/-1.5% of the rated speed.

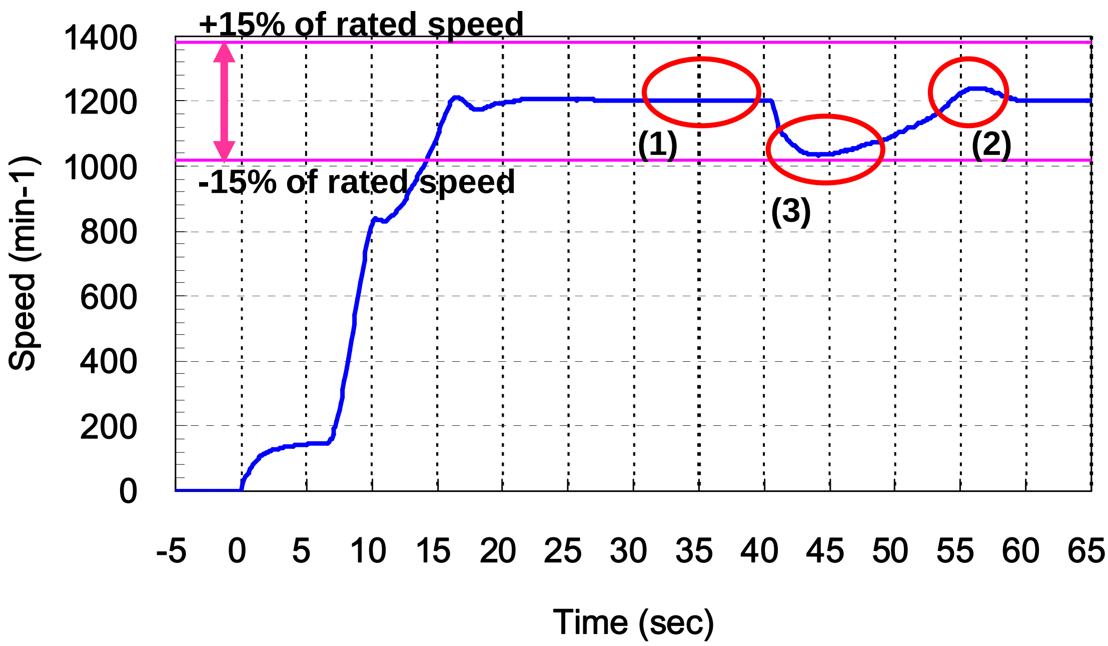

Figure 6 The engine speed behavior of the first step loading from starting

Here, higher first step loading ratio would be achievable if the speed drop could be minimized by the aforesaid compensation control to increase fuel gas quantity and PID gain adjustment to shorten the time to recover stable speed. However, it is known that how much quantity of gas may be increased is subject to the air-fuel ratio during stand-by without load ((1) in the figure). Careful adjustment is required because it could cause degradation in response performance because of misfire and engine stall if gas increase is excessive, and it may cause backfire in the worst case.

Normally, air-fuel ratio during no-load stand-by is adjusted to the point where the combustion is the most stable or the concentration of the unburned gas (exhaust THC) is the lowest. However, in this development, after optimization with gas quantity increase compensation control, slightly lean air-fuel ratio is selected in order to improve engine speed control performance during loading. As a result, exhaust THC concentration during no-load stand-by became slightly worse but succeeded in minimizing speed drop from loading. This first step loading ratio improvement greatly contributes to enhancement of the product competitiveness.

(2) Improvement of combustion stability

In order to improve first step loading ratio, it is important to maintain stable combustion even during stand-by with no load and stabilized engine speed so that compensation control to increase gas quantity during loading are carried out more effectively. To verify stable combustion, installed a cylinder pressure sensor for each cylinder and observed the combustion during loading. In this test, Kistler sensors model 6052C were used and the signals from the sensors were amplified by Charge Amplifiers (8 amplifiers with 2 channels each, 16 channel in total in a case) to analyze in a combustion analyzer. Ono Sokki's DS Series which is capable of analyzing up to 20 channels was selected to analyze all 16 cylinders of the engine at one time. The pictures in Figure 7 are combustion analyzer and cylinder pressure data on a monitor.

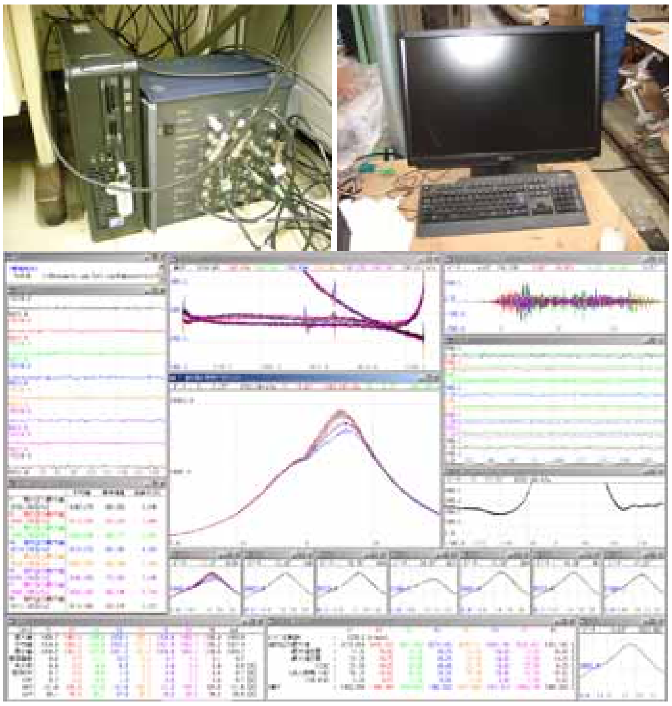

Figure 7 The combustion analyzing system

Figure 8 shows the data of cylinder pressure during the first step loading. The chart shows the engine speed transition from engine start, speed drop due to loading at 40 seconds from the start and stable speed after recovery. In the chart, speed drop is 17.6% and time required until speed recovery is 26.6 seconds, which are great deviations from the standard and do not satisfy the requirement. In this case, cylinder pressure data show multiple fluctuations between no-load stand-by until speed recovery. It is assumed multiple misfiring in many cycles occurred which resulted in unstable combustion. This unstable combustion is considered to have caused the large deviation from the standard regardless of the compensation control for gas quantity increase during loading.

On the other hand, Figure 9 shows the engine speed and cylinder pressure data from engine start through the first step loading that were taken after adjusting each parameter to the parameter conditions in Figure 8. Although misfiring occurred immediately after loading, it did not occur during stand-by with no load and speed recovery after drop unlike the case of Figure 8 judging from the cylinder pressure data, and the overall combustion was stable. Consequently, it is assumed that speed stability at the time of loading was within the standard.

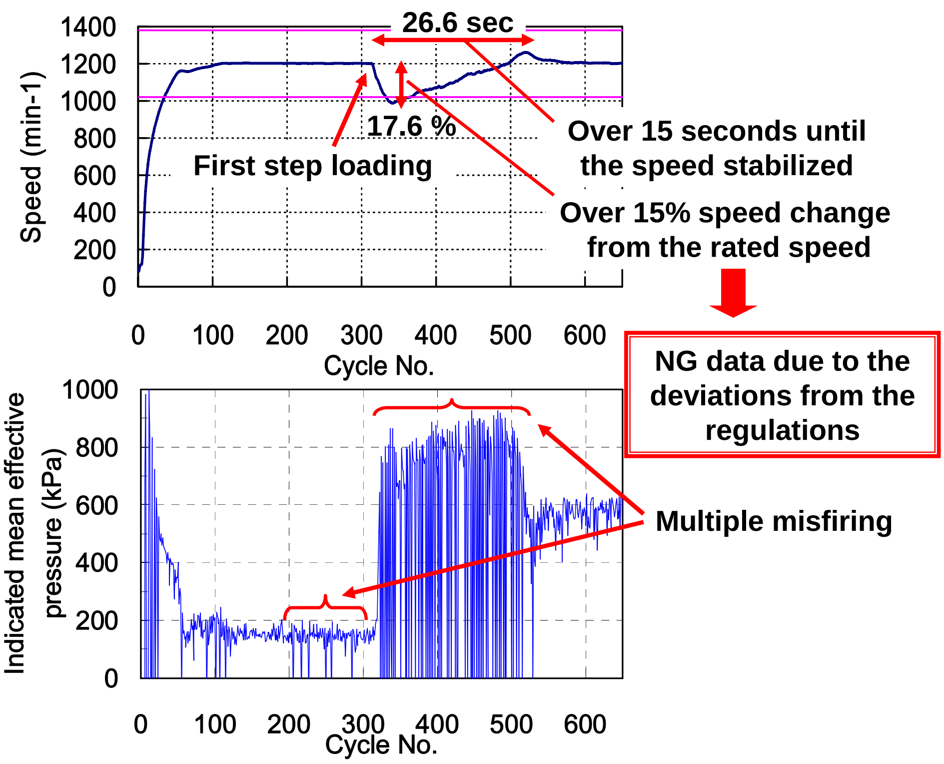

Figure 8 NG data of the first step loading (before adjusting engine parameters)

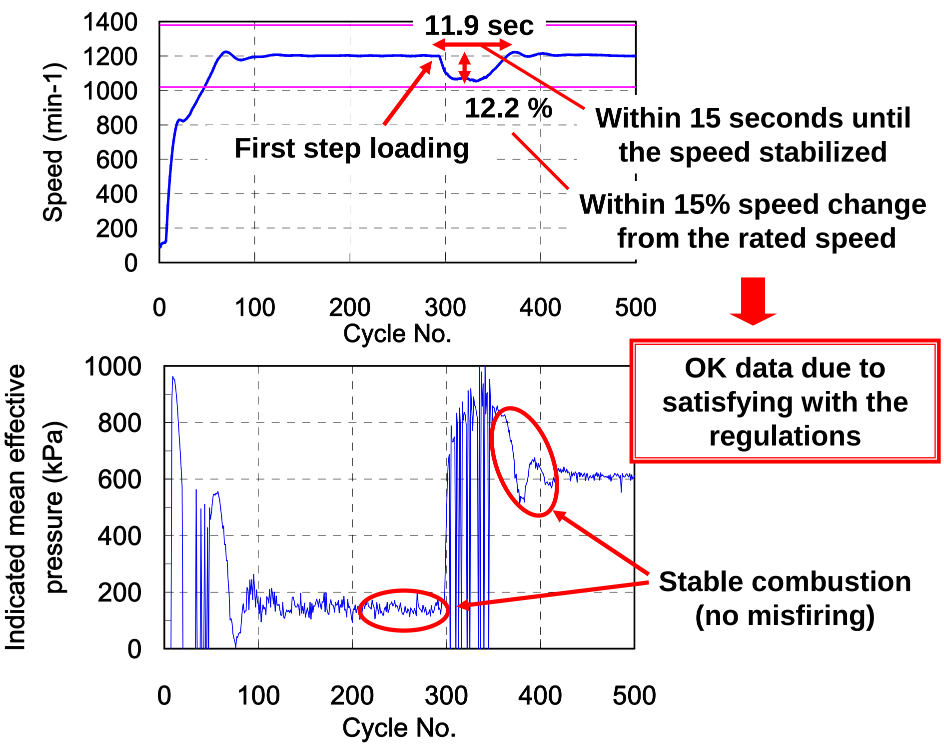

Figure 9 OK data of the first step loading (after adjusting engine parameters)

Based on above, it was identified that stabilizing the combustion while the system is stand-by state without load and maintaining the stable combustion from loading until speed recovery are very effective for first step loading ratio improvement. Utilizing this method, engine speed control performance has been improved by setting the optimum air-fuel ratio control parameter and gas quantity control parameter for Pre-Combustion Chamber. Furthermore, unburned THC concentration has also been reduced in this development by improving combustion stability in all cylinders.

As a result of the control system integration and matching for combustion stabilization, the first step loading ratio which was 20% in the conventional control system has been drastically improved to 35%. Figure 10 represents the step loading results in case of a power failure. Following the first step loading ratio of 35%, 15% of second loading and successive 10% loading in every 15 seconds are possible, which greatly enhances the value as an emergency power source.

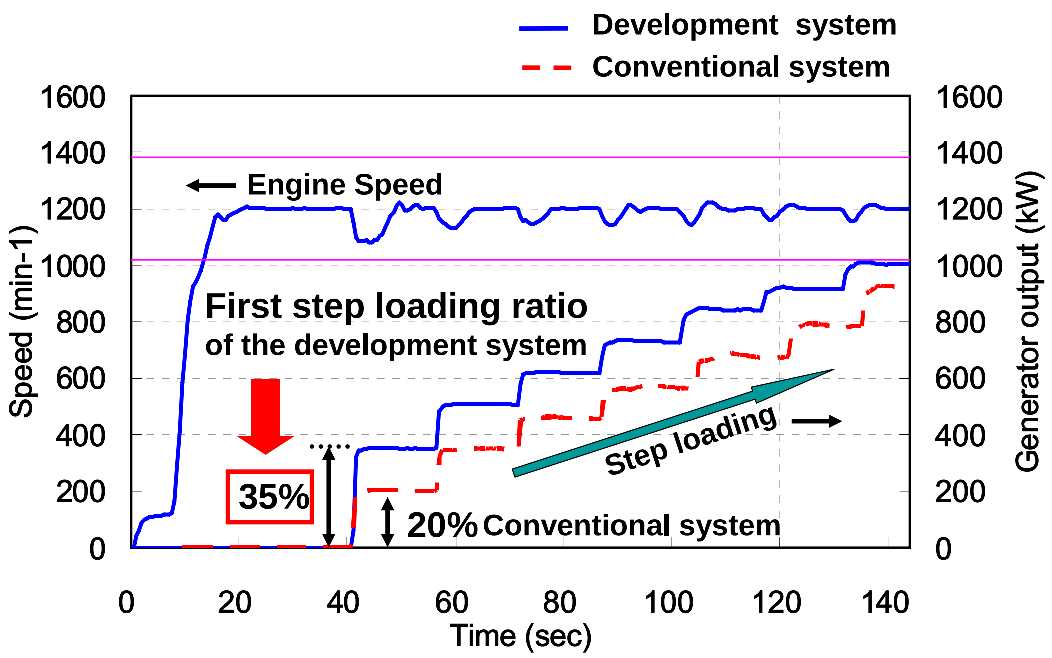

Figure 10 Step loading results in case of a power failure

3. Improvement of total efficiency

Improving total efficiency contributes to reduction of CO_2 emission as well as economic efficiency. Previously, recovered heat from Intercooler and Oil Cooler was released by Radiator. In this development, heat recovery system that enables the cascade use of the recovered heat for higher temperature and lower temperature is adopted (2-stage system). Figure 11 indicates the coolant flow of the high and low temperature systems and Figure 12 shows how 2-stage Intercooler looks on the engine.

Waste heat energy is recovered at Oil Cooler (high temperature side: 1st stage) and the Intercooler (high temperature side: 1st stage) by exchanging heat with the jacket water. The heat from Oil Cooler (low temperature side: 2nd stage) and Intercooler (low temperature side: 2nd stage) is radiated by a

Radiator as is conventionally done. In this way, the heat which was released in the conventional system is additionally recovered, which brings in better total efficiency.

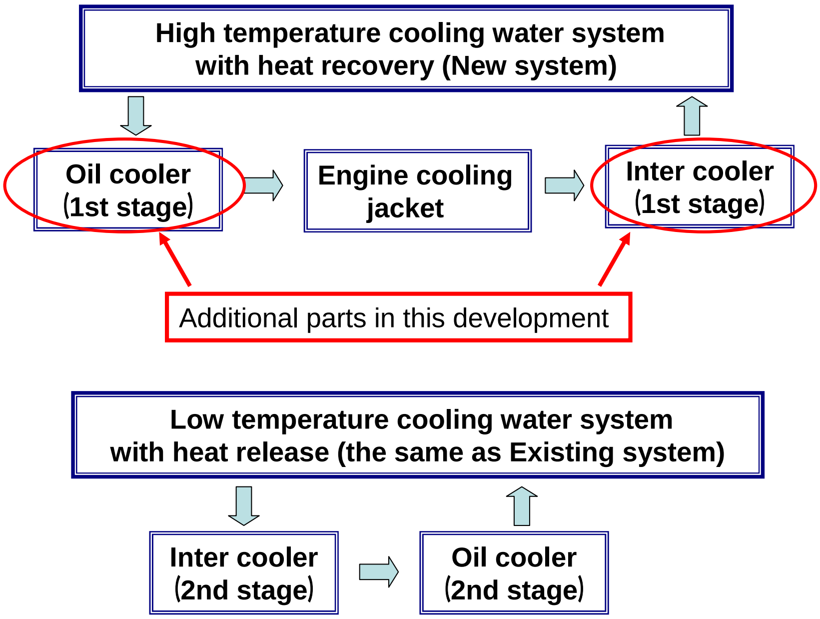

Figure 11 The development of new heat recovery system

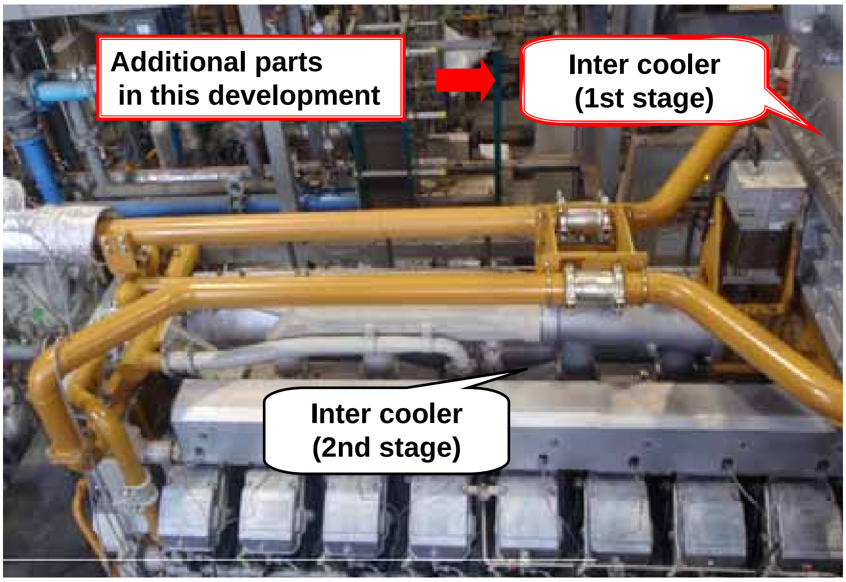

Figure 12 The development of new heat recovery system (2-stage inter cooler)

Figure 13 represents the total efficiency improvement result by this development. By this 2nd stage cooling to partly recover heat from Intercooler and Oil Cooler that was previously released, total efficiency has been improved from 74.1% to 80.3%.

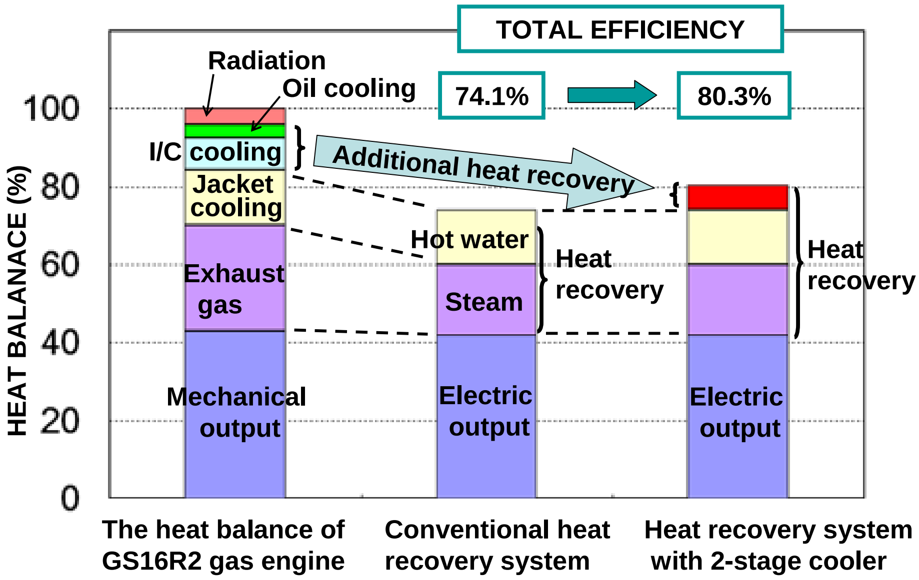

Figure 13 The total efficiency improvement result by this development

4. Wrap-up

The following developments are added to 1000kW-class high efficiency natural gas CHP to increase its added value;

(1) By integrating control system and stabilizing combustion, the first step loading ratio which was 20% in conventional control system is drastically improved to 35%, which contributes to adding value as an emergency power source.

(2) By partly recovering heat which was released into air in the conventional system from Intercooler and Oil Cooler using 2-stage cooling system, the total efficiency which was 74.1% in the previous system has been improved to 80.3% achieving the world's best standard for 1000kW class CHP system.

Figure 14 MITSUBISHI 1000kW-class CHP package

5. Closing

Customers' expectations for natural gas CHP systems demanding multiple functions such as operation as an emergency power source and effective equipment for CO_2 emission reduction are becoming high. Further performance improvements will be addressed focusing on total efficiency of CHP system and adding greater values as energy saving equipment and emergency power source.

References

(1) DEVELOPMENT OF HIGH EFFICIENT MILLER CYCLE GAS ENGINE,
Yoichi Matsushita and Nagatomo Tsuji, IGRC 2004

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