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The Latest Development of High Performance Gas Engine

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Abstract

The gas engine is employed for power generation from a long time ago due to the characteristic of clean exhaust emission. And it is expected to be promising resource of generation because of its advanced thermal efficiency and worldwide gas supply stabilization in recent years. On the other hand, in the sphere of emergency power generation, the performance from startup to load application and high load following performance are remarkably required. In addition, the power systems should supply the electricity stably to specific essential service in case of lightning damage on transmission grid is occurred. Because of the combustion of gas engine is significantly affected by mixture density, the gas engine is subject to unstable operation like the knocking and misfiring behavior. Thus the gas engine was regarded as unsuitableness for resources of emergency power generation. To overcome this disadvantage and apply the eco-friendly advantage of gas engine on every power generation, Niigata has developed a new gas engine.

Emergency power generation (Dynamic response): The facilities like a hospital, airport and data center equip the emergency power generation to recover the electricity immediately when the power transmission is cut off in case of blackout. To meet Japanese regulation for emergency power generation, the performance from starting to application of load at rated voltage within 40 seconds and application of load of 30% are required. Thus the engine is operated with remarkable sudden load changes and the sufficient air mass control system is necessary on the gas engine. The developed gas engine has air recirculation system before cylinders in order to obtain optimum air fuel ratio for every engine loads.

Improvement of thermal efficiency: The fluctuation of in-cylinder pressure with cycle to cycle and/or cylinder to cylinder is one of the factors in deterioration of thermal efficiency. The origin of the fluctuation is unstable combustion like knocking or misfiring and the reinforcement of ignition source makes high stability engine operation. The design of pre-combustion chamber is optimized by using CFD simulation technology and the benefit of stronger ignition source in efficiency is verified experimentally.

In this paper, the result of improvement of dynamic response and thermal efficiency are described.

***Keywords**:* Gas engine, Power generation, Load acceptance and Thermal efficiency.

1. Introduction

The gas engine is employed for power generation from a long time ago due to the characteristic of clean exhaust emission. And it is expected to be promising resource of generation because of its advanced thermal efficiency and worldwide gas supply stabilization in recent years [1, 2]. In Japan, as an alternative power resource of diesel engine, gas engine has become the faction in power, which is applied for 1-6 MW class land power generating facilities. Niigata has continuously strived to develop gas engines to comply with the needs of the times [3, 4, 5]. In particular, its gas engines designed for large continuous power generating systems have received favorable reviews not only for high economic efficiency, but also for environmental friendliness and safety.

On the other hand, in the sphere of emergency power generation, the performance from startup to load application and high load following performance are remarkably required. In addition, the power systems should supply the electricity stably to specific essential service while the damage on transmission grid is occurred. Because of the combustion of gas engine is significantly affected by mixture density, the gas engine is subject to unstable operation like the knocking and misfiring behavior. Thus the gas engine was regarded as unsuitableness for resources of emergency power generation. To overcome this disadvantage and apply the eco-friendly advantage of gas engine on every power generation, Niigata has developed a new gas engine.

In this paper, the result of improvement of dynamic response and thermal efficiency are described.

2. Gas Engine for Land Power Generation, and its Requirements for Dynamic Response

Usually, gas engine is applied as a base load power in the factory, and which is coupled with commercial electricity. The variations in power demand of the factory will be absorbed by purchasing power of the commercial electricity, thus gas engine can be operated on constant load. However, depending upon the running cost of the gas engine, it is also possible to cope with variations in power demand of the factory by varying the output from the gas engine, in order to reduce the high cost of commercial electricity. In this case, the engine is required to have a high load following performance that conforms to the change in power demand.

In addition, another application of gas engine is for the survivor of essential services at the time of the blackout. Electric power generated by a gas engine is used as a base load power during normal operation in the factory. However, at the time of the blackout, electric power is supplied only to predetermined essential services, thus preventing a serious accident. With these incidents, if a gas engine power generating facility supplies power while operating in parallel with the commercial electricity, electric power immediately becomes insufficient, that will prevent the electric power from being supplied to the essential services. For this reason, before supplying electricity it is necessary to cut off the gas engine power generating facility and the essential services from the commercial electricity system. Here, in order to instantly change the condition from which the engine was operated for base load power supply (rated load), to for only essential services supply (low load), operation with no engine stall and no load fluctuation are required. In other words, it is required that the engine have high dynamic response.

Furthermore, for an emergency power generation facility, it is necessary to recover the electricity immediately when the power transmission is cut off in case of blackout. In Japan, the performance from starting to application of load at rated voltage within 40 seconds and application of load of 30% are required.

Now, in Japan, where earthquakes are frequent, in order to enable economic activities to be continued even when a deficiency of electric power causing by the earthquake occurs, many manufacturers are considering introducing cogeneration systems using gas engines as a dispersion type power source. Especially after the devastating earthquake in 2011, there is raising demand for gas engine based cogeneration systems as a power source for the above-mentioned emergency use and for disaster prevention use.

The background of the increasing application of gas engines to the above-mentioned power generating facilities are the better availability and depreciation of fuel gas due to worldwide development of fuel gas. Another factor was the promotion of technical development aimed on improvement of fuel consumption and load following performance in gas engine. However, while the affordability of fuel gas is increasing, it is likely that various kinds of fuel gases with different compositions will appear in the market. Fig. 1 shows the Methane Number (MN) for each natural gas production region [6]. Natural gases produced in Northern Europe and North America has a relatively high value of MN, which means it has a high anti-knocking characteristics. Those produced in the Middle East have a relatively low value of MN and thus a higher tendency toward engine knocking. So it is necessary to develop combustion control technology to realize a constant engine output and load following performance, even when fuel gases with inferior combustion characteristics are supplied. In this paper, the design and validation of combustion control technology was developed while assuming the use of low methane number fuel gas which has inferior anti-knock property.

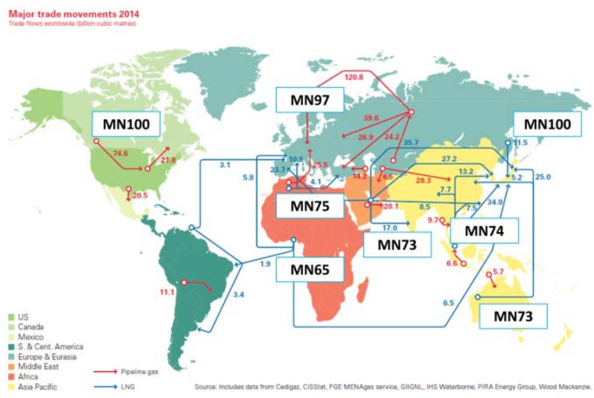

Fig. 1 Methane number (MN) for each natural gas production region

3. Development of Technology for Improving Dynamic Response in Niigata Gas Engines

There are two kinds of combustion methods in gas engines, one is stoichiometric combustion and the other is lean burn combustion. From the perspective of exhaust emission and thermal efficiency, Niigata applies lean burn combustion in its gas engine in which the excess air ratio (λ) is adjusted to about 2, thus simultaneously realizing high output, high efficiency, and low nitrogen oxide emission. In lean burn combustion, because of the adjustment range of the excess air ratio is strictly restricted, it is required to control the quantity of air charged into the cylinder according to the load. Fig. 2 shows the range of the excess air ratio can be adjusted according to the load. It can be seen that the higher output is, the wider knocking and misfiring zone are, thus the adjustable range of excess air ratio becomes narrower and narrower.

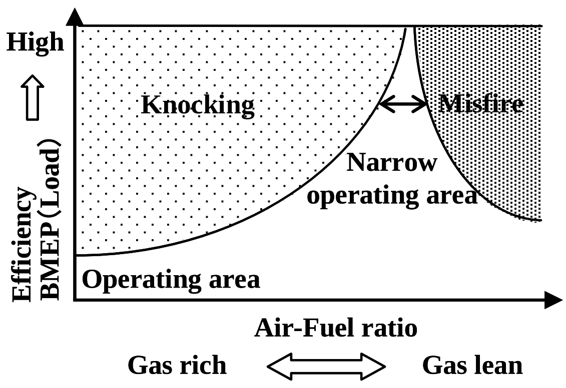

Fig. 2 Relationship between air-fuel ratio and load

3.1 Technology for Stabilizing Combustion during Load Operation in Gas Engine for Power Generation

For the gas engine used for power generation, to maintain an appropriate combustion condition, it is necessary to control the air-fuel ratio in an appropriate range, especially during the load operation. As mentioned above, Niigata controlled the excess air ratio to about 2 in its gas engine. Because the quantity of fuel gas is adjusted by the fuel supply system according to the engine output, then the air-fuel ratio control is mean to control the quantity of the air that be charged into the cylinder. Niigata ensures the charge air quantity control by adjusting the air pressure and the air temperature in its gas engine.

However, in a reciprocating engine with a turbocharger, there is a turbo lag due to the operation delay of turbocharge when the engine load abruptly changes. For this reason, the engine cannot get an appropriate quantity of air as being acquired in case of rapid load operation. In the case of a gas engine, unstable combustion will be caused. To make the engine operation be maintained, usually, the load operation speed is restrained. In the case of a diesel engine, lack of air quantity will occur as well, so the exhaust smoke concentration is likely to increase, and also the exhaust gas temperature may rise temporarily. However, the setting range of the air-fuel ratio that can be acquired to ensure that the engine operates stably is wide, and also the extent of the effect of the charge air temperature on the combustion condition is small, so abnormal combustion will not occur.

In order to secure the necessary load following performance, the charge air pressure in Niigata gas engine is monitored while charge air temperature is maintained in a constant condition, and the charge air pressure is controlled according to the load. This method enables an appropriate air-fuel ratio to be obtained, thus suppressing the occurrence of unstable combustion. And a method is called charge air bypass (Fig. 3) is accepted in Niigata gas engine, in which the compressed air at the air cooler exit is bypassed to the air intake side of the turbocharger, in order to control the charge air pressure.

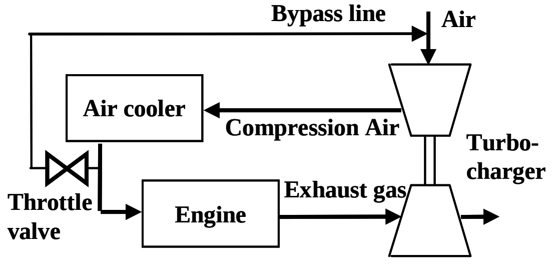

Fig. 3 Charge air bypass

3.2 Technical Issues of Dynamic Response and Load Operation in Gas Engine

In a gas engine, when the air-fuel ratio is low and the charge air temperature is high, a phenomenon called knocking, in which the mixed gas remaining in the cylinder to the very end automatically ignites. Violent knocking will cause damage to the engine, so it is necessary to avoid knocking even if the engine output has to be restricted. For this reason, knocking is the main cause of poor loading following performance. The condition under which knocking occurs is realized by a deficiency of air quantity, so in order to improve the load following performance of the gas engine, it is necessary to improve the operation speed obtained by using the abovementioned method which maintains the charge air condition constant.

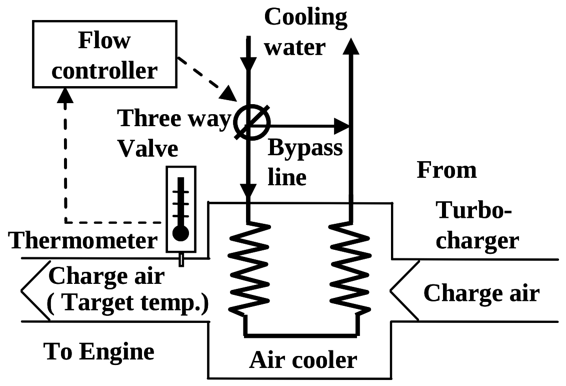

Fig. 4 Charge air control system

The charge air temperature is controlled to the target value by operating the cooling water three-way valve so as to control the quantity of cooling water that enters air cooler, while monitoring the signal emitted from the temperature sensor installed in the exit of air cooler, as shown in Fig. 4. In cases where the load operation is rapidly, the output from the temperature sensor sometimes differs from the actual temperature due to the thermal capacity of the temperature sensor, making it difficult to appropriately adjust the water quantity. As a result, the charge air temperature rises, which may cause abnormal combustion to occur. Furthermore, when the charge air pressure changes along with the engine load, the charge air temperature at the air cooler entrance changes as well, so the necessary quantity of cooling water need to be changed. Consequently, an important technical issue here is the question of how best to improve the charge air temperature following performance.

Because of the gas engine adjusts the excess ratio by controlling charge air pressure as mentioned above, it is necessary to correctly adjust the charge air pressure during a transient condition as well. In order to maintain the excess air ratio constant while the load is being increased, it is necessary to increase the load following performance of the turbocharger. However, in recent years, with the aim of high efficiency and low nitrogen oxide emissions, the Miller cycle which necessitates high-pressure turbocharging has been used more and more. Consequently, in order to correctly adjust the excess air ratio, it is necessary to increase the setting of the target charge air pressure. In this connection, the load following performance of the turbocharger has become more important than ever before. The discrepancy between the target charge air pressure and the actual pressure becomes large, particularly when the engine is operating on a low load.

3.3 Improvement of Dynamic Response in Niigata Gas Engines

In order to resolve these technical issues mentioned above, Niigata upgraded the response speed of the charge air control which has been used up to now and also redesigned the turbocharger system. For the charge air control, Niigata improved the accuracy of the charge air bypass control together with upgrading the control speed of the charge air temperature, thereby succeeded in suppressing knocking greatly during the engine load increasing. Meanwhile, a variable turbine geometry turbocharger is adopted in the exhaust gas system, and it permits fine setting of the boost pressure possible.

Fig. 5 shows the results of the transient test. As a result of using combustion control technology mentioned above, it is confirmed that the load operation characteristics and load acceptance characteristics required in a land power generating engine have been realized. It also has a function of important load survival operation which is in great demand in Japan, as well as a rated output voltage establishment performance of within 40 seconds which should be provided for both emergency use and disaster prevention use.

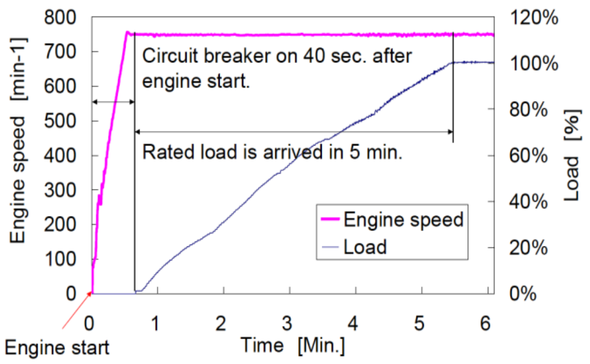

Fig. 5 Startup to load application characteristics

4. Development of Technology for Improving the Thermal Efficiency in Niigata Gas Engines

As well as the excellent dynamic response, high thermal efficiency is also demanded for a land power generating engine. For the spark ignition type gas engine is classified according to the Otto cycle from the viewpoint of the thermodynamic cycle, consequently, in order to improve the thermal efficiency, it is necessary to increase the degree of constant volume while shortening the combustion period and reducing exhaust loss. On the other hand, while the combustion condition is over-activated, the temperature of the mixture gas in the cylinder will rise excessively, and knocking will occur. Therefore, it is important to optimize the formation of the pre-mixed gas and the combustion conditions. Furthermore, in the case of a multi-cylinder engine, manufacturing errors in each component cause the formation of pre-mixed gas and the combustion conditions to differ for each cylinder. Consequently, there are cases in which abnormal combustion occurs in a specific cylinder, preventing the target output and efficiency from being obtained.

This research focuses on ensuring stable combustion and shortening combustion period by using a stronger ignition method to take aim at improving the degree of constant volume and minimizing the difference between the cylinders, and finally, succeeds in obtaining high thermal efficiency.

To gain the stronger ignition source, the design of pre-combustion chamber (PCC) is optimized by using CFD simulation technology, and the parameters of PCC volume, PCC nozzle hole diameter and PCC nozzle hole numbers etc. are specified. Fig. 6 shows a result of the flame jet from the PCC to the main combustion chamber (MCC) of combustion CFD analysis. From the figure, it was confirmed that after the optimum shape design of PCC, the flame jet, which is the ignition source for the MCC, has been stronger. The stronger ignition source helps us not only on gaining a stable combustion which results in minimizing the difference between cycle to cycle and/or cylinder to cylinder, but also on shortening combustion period which results in improving the thermal efficiency, and the benefit of stronger ignition source in efficiency is verified experimentally.

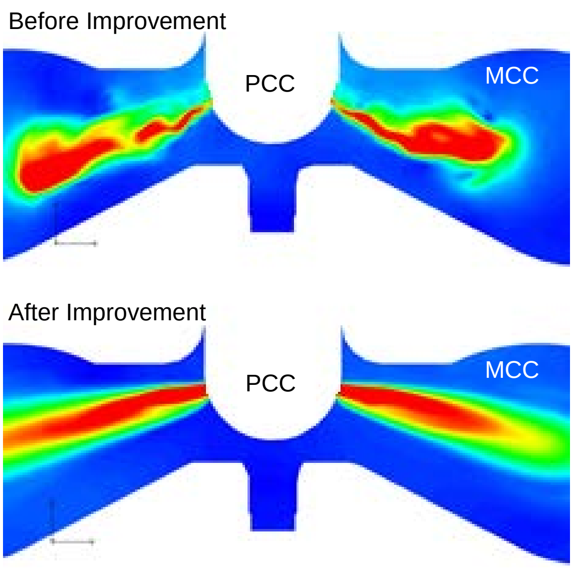

Fig. 6 Flame jet from PCC to MCC

As a result of examination in the actual engine, it was verified that the coefficient of variance (COV), which indicates the degree of random variation in combustion, is reduced by 30%.

As another result of examination in the actual engine, Fig. 7 shows the change of in-cylinder pressure before and after improvement. From the figure, it can be seen that the maximum in-cylinder pressure (Pmax) of after improvement is bigger than that of before improvement. It is thought that the minimizing the difference between cycle to cycle and/or cylinder to cylinder makes the engine can be operated on higher Pmax condition stably, and the higher Pmax operation benefits for the efficiency improvement.

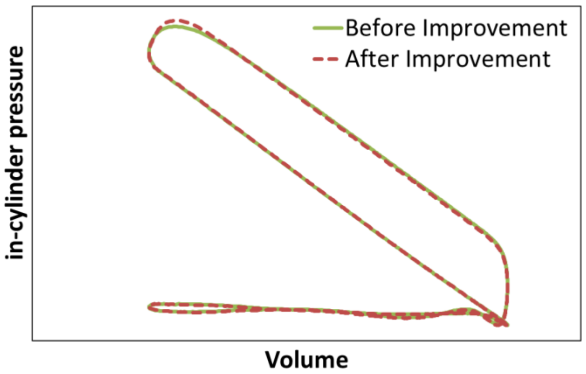

Fig. 7 in-cylinder pressure before and after improvement

5. 28AGS Series Gas Engine Developed by Niigata

Finally, the 28AGS series are the latest developed gas engine by Niigata. The construction of the combustion chamber is shown in Fig. 8.

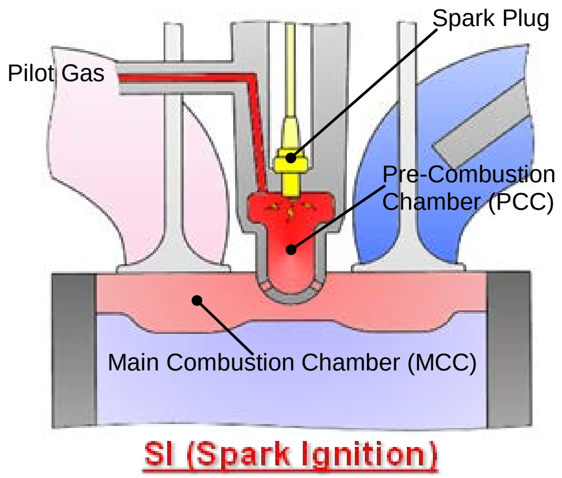

Fig. 8 Combustion chamber section

28AGS series engines are equipped with a pre-combustion chamber and spark-ignition system, which was developed based on our performance improvement technology during this research.

The composition of the lineup of 28AGS series is shown in Fig. 9. The lineup consists of 6 and 8-cylinder L-type, 12, 16 and 18-cylinder V-type engines, covering 1-6 MW in output. And the specification of 28AGS series is shown in Table. 1.

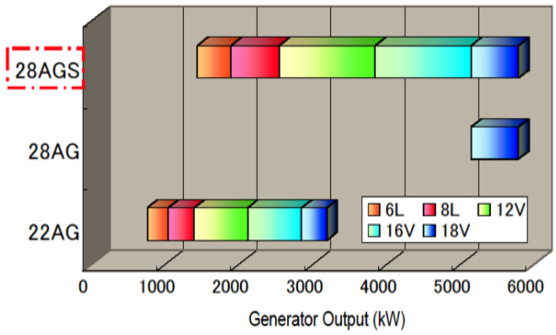

Fig. 9 Lineup of 28AGS series

Table. 1 Specification of 28AGS series

Cylinder Bore (mm)	295	
Stroke (mm)	400	
Number of Cylinders	18	
Engine Speed (min^{-1})	720	750
Generator Output (kWe)	5750	6000
B.M.E.P. (MPa)	2.0	
Mean Piston Speed (m/s)	9.6	10.0
Ignition Method	Spark Ignition	
Combustion method	PCC	
Starting Method	By Air Motor	
Applied Fuel	Natural Gas, LNG	
Note: Output based on ISO standard reference conditions and generator power factor 0.9, natural gas at LCV of 41.6 MJ/Nm^3; MN = 65		

28AGS series are designed based on gas engines with high reliability supplied by Niigata up to now; advanced air-fuel ratio control technology and combustion control technology are adapted to realize high generating efficiency and high load following performance, while maintaining low NOx emissions, which is satisfied with the requirement of World Bank guideline (200mg/Nm^3) .

Especially, the L-type engines for power generating systems of 2MW output class have attained the world's highest thermal efficiency about 45.6% of power generation efficiency with a tolerance of +5%.

Also, thanks to our excellent combustion control technology, 28AGS series have a high robustness on the variety of gas fuels. The natural gas fueled to the gas engines varies in compositions depending on the area of its production, and unfortunately, this has a large effect on the satisfying conditions for causing knocking. But fortunately, 28AGS series can run on international fuel gases of various properties without affecting the rated output. It has been confirmed that the newly developed 28AGS series realize stable combustion even when using low methane number natural gas, which has inferior anti-knock property. As a result confirmed, 28AGS series can run while maintaining a constant output corresponding to the conditions of methane number 65 or higher.

Furthermore, 28AGS series are compatible with a radiator cooling system that enables these engines to be used in many regions throughout the world. Compared to conventional models, the newly developed 28AGS series can be used under much severer environmental conditions.

6. Conclusion

To apply the eco-friendly advantage of gas engine on every power generation such as for emergency use and for disaster prevention use. Niigata has developed a new gas engine with the dynamic response technology and thermal efficiency technology improved. The following conclusions were obtained.

1. By upgrading air-fuel ratio control and charge air temperature control technology, the latest developed gas engine is optimally matched to Japanese market demands and attains performance satisfied for disaster prevention power generation in Japan.
2. The reinforcement of ignition source makes high stability engine operation and the stronger ignition source benefits in efficiency improvement.
3. Combining the technologies developed, the newly developed 28AGS series have a high robustness on the variety of gas fuels, and can run while maintaining a constant output corresponding to the conditions of methane number 65 or higher, without any de-rating.

In terms of environmental preservation, applying of gas fuel is much expected. Niigata will continue to develop and supply gas engines that can meet the needs of the market and are safe and easy to handle.

7. References

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