

Technology for Improving Combustion Reliability of High Speed Engines



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In order to meet the market needs for high efficiency and high power output, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd. (MHIET) has been working on the development of the new G16NB gas engine for generator use. The features of this new gas engine in terms of its performance were introduced in detail in Mitsubishi Heavy Industries Technical Review Vol. 52 (achieving power generation efficiency of over 44.7%, etc.). This paper will focus on the following outcomes relating to endurance testing and technologies for improving the combustion reliability; (1) total verification testing hours reaching 4,700 hours (as of November 2016), (2) excellent results of endurance testing for overloading/overspeed, (3) improvement in the accuracy of knocking detection by about 30 to 40%, (4) reduction in the combustion variation by 20%, and (5) increased reliability of the pre-chamber gas supply valve (reduction of the flowback by 76%).

1. Introduction

Recently, gas engines for generator use are expected to achieve high efficiency and high power output at the same time. In order to meet such market needs, MHIET has been working on the development of the new G16NB engine for generator use. While an increase in the combustion pressure/temperature is essential for realizing high efficiency and high power output, it is also necessary to ensure the reliability in terms of the structure, sliding and combustion.

In Mitsubishi Heavy Industries Technical Review Vol. 52, the following outcomes of the G16NB development were described, focusing mainly on the engine performance.

- The power generating efficiency of the engine is increased by +4% points due to the utilization of a two-stage turbocharging system and increased maximum combustion pressure, achieving the world's top level efficiency of 44.7% or higher.
- The break mean effective pressure (BMEP) is increased by +0.5MPa compared with existing models. (The power output is increased by 33% compared with the existing models of the same engine displacement and speed.)

This paper will describe the details of endurance testing and technologies for improved combustion reliability as an update on the G16NB development.

- Knocking (abnormal combustion) detection/control technology
- Combustion variation reduction technology
- Technology for increasing the reliability of the pre-combustion chamber fuel gas supply valve

The principal specifications of the 16NB engine are provided in [Table 1](#).

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Table 1 G16NB Principal specifications

Cylinder diameter	mm	170
Stroke length	mm	220
Rated speed	min ⁻¹	1500
Number of cylinders	—	16
Rated output (Generator terminal)	kW	2000
Ignition method	—	Spark ignition

2. Endurance test

Currently, endurance testing is carried out utilizing an independent test engine, as well as a fully-equipped power generation unit. The total test operation time has reached as many as 4,700 hours (as of November 11, 2016).

With the independent engine unit, endurance testing was carried out particularly under the condition of overloading/overspeed. In the overhaul inspection after testing, we confirmed that the individual parts and components were in good order. As a couple of examples from the inspection results after endurance testing, pictures of the crankpin metal, main metal and cylinder liner from the main sliding portion are shown in [Figure 1](#).

The power generation testing unit has actually been operating during the verification period as part of our co-generation facilities that supply electricity and steam to MHIET plants, greatly contributing to effective energy use by handling the Demand Response.

MHIET will continue to carry out reliability testing through the long-term operation of individual testing units.

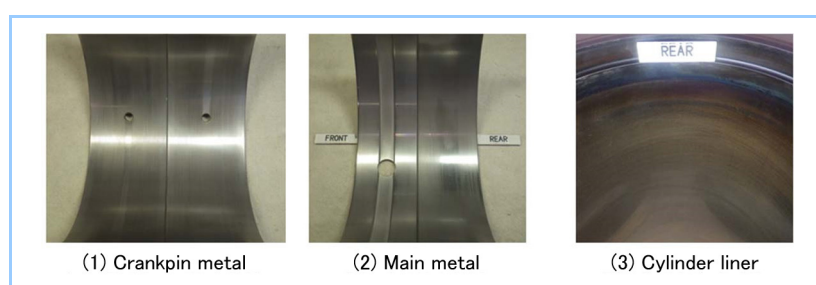


Figure 1 G16NB parts inspection

3. Technology for improving reliability

3.1 Knocking (abnormal combustion) detection/control technology

Generally speaking, there is a possibility of abnormal combustion called knocking occurring in gas engines. It is known that knocking is highly likely to occur when a gas engine operates under conditions of high thermal efficiency, which has a high risk of causing engine damage. Therefore, knocking detection/control is an essential feature for achieving high engine efficiency. In 2 MW class gas engines, knocking detection is generally carried out by the acceleration sensor. In existing model gas engines, knocking detection systems installed therein were manufactured by other companies. However, in order to perform advanced detection/control, MHIET developed its own controller that includes knocking detection/control functions, and utilized it in the G16NB engine. The system overview is illustrated in [Figure 2](#).

Our in-house controller focuses on improved detection accuracy and is designed to select the location where the acceleration sensor is arranged, to optimize the internal circuit and to perform the derivation of robust detection logic, based on a structural analysis. [Figure 3](#) shows the correlation confirmed between the values detected with an in-cylinder pressure sensor (referred to as the true knocking values*) and those detected with an acceleration sensor, which was conducted as part of the knocking detection accuracy test. According to the results, we learned that detection with our own controller demonstrated a coefficient of correlation with the true knocking values that was about 30% to 40% higher in comparison with existing products, indicating high knocking detection accuracy. Under various conditions including loads, ignition timings, fuel types and engine specifications, it has been confirmed that MHIET's in-house controller demonstrates

excellent detection accuracy. Consequently, the possibility of achieving high-efficiency operation while securing reliability looks immensely promising.

- * Detection based on the in-cylinder pressure results in high knocking detection accuracy as it directly measures the pressure inside the combustion chamber.

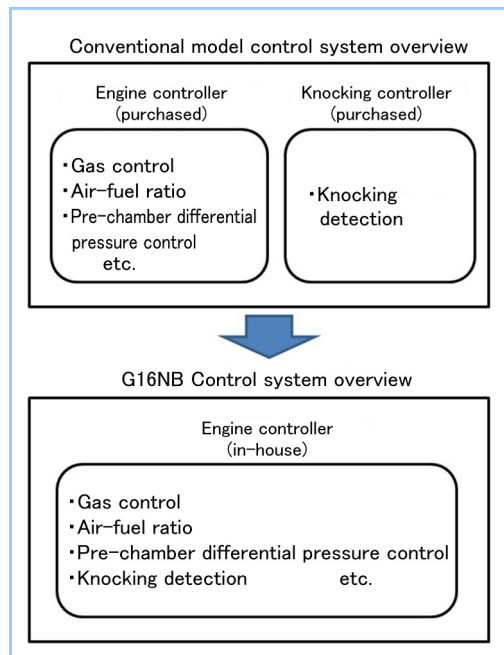


Figure 2 G16NB control system

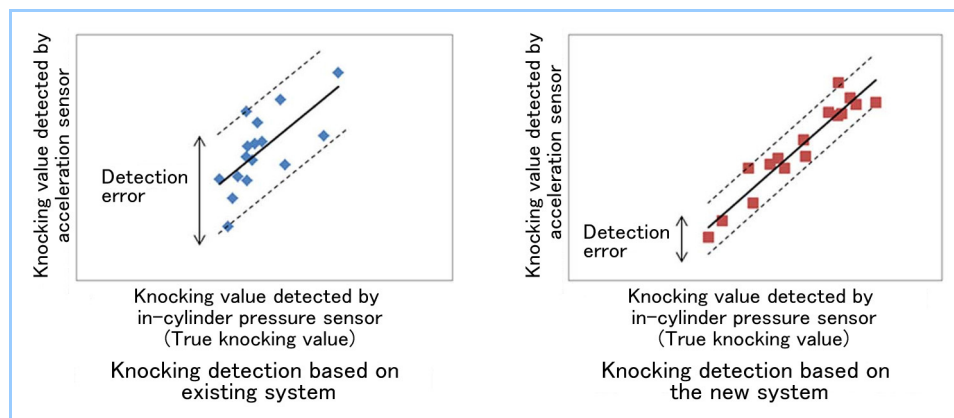


Figure 3 Comparison of knocking detection accuracy

3.2 Combustion variation reduction technology

Generally speaking, gas engines have, in comparison with diesel engines, wider variation in peak firing pressure per cycle. This combustion variation could be a possible cause of misfires or knocking, and would interfere with the improvement of efficiency. Therefore, control over combustion variation would be crucial for securing engine reliability.

The G16NB engine utilizes pre-combustion chamber (hereinafter referred to as the "pre-chamber") style combustion, which enables control over combustion variation by stabilizing the combustion in the pre-chamber. Figures 4 and 5 illustrate the structure of the pre-chamber and the pre-chamber combustion style, respectively. In a pre-chamber gas engine, "(i) The process where fuel gas is supplied into the pre-chamber," "(ii) The process where the lean mixture from the main combustion chamber (hereinafter referred to as "main chamber") flows into the pre-chamber in order to create a mixture at the stoichiometric ratio," "(iii) The process where the spark plug ignites the mixture in the pre-chamber to initiate combustion" and "(iv) The process where the flame in the pre-chamber shoots into the main chamber in order to burn the lean mixture therein" occur in one cycle, which repeats combustion. Since a stable flow inside the pre-chamber is very important for combustion stability, MHIET optimized the shape of the pre-chamber based on combustion flow analysis in the pre-chamber.

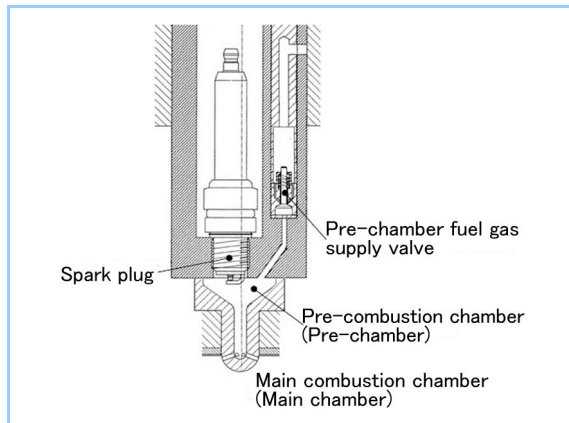


Figure 4 Pre-chamber structure

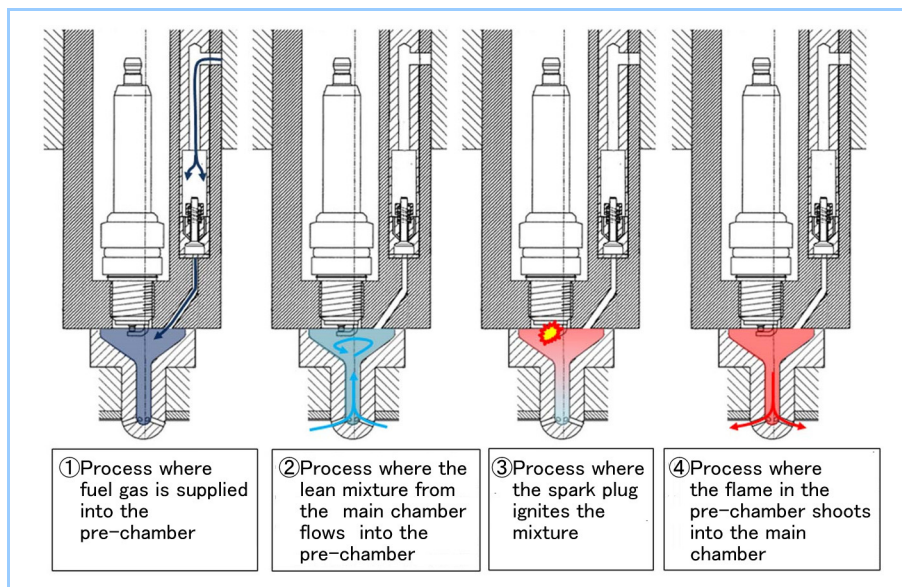


Figure 5 Pre-chamber combustion method

Figure 6 shows the results of a combustion variation assessment test. Compared with the initial design, the utilization of the upgraded configuration, which realizes the generation of a lean mixture in the pre-chamber in a more stable manner, successfully reduced the combustion variation ratio by 20%. Furthermore, a verification test was carried out utilizing parts that simulated the changes in configuration due to a long-term operation, which indicated that combustion variation would not deteriorate even after more than 8,000 hours of operation.

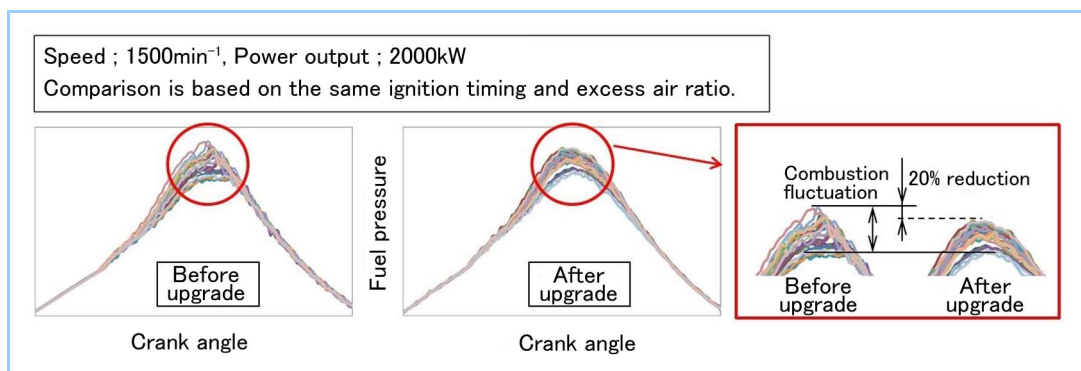


Figure 6 Reduction of combustion variation

3.3 Technology for increasing the reliability of the pre-chamber fuel gas supply valve

It is important to secure the reliability of the structural parts of the combustion chamber as the pressure and temperature there become quite high in high-efficiency/power output gas engines. In particular, the lean mixture which burns inside the pre-chamber is closer to the stoichiometric

ratio than that in the main chamber, which makes the temperature even higher. Therefore, the reliability of the parts and components arranged in the pre-chamber requires special care. Parts and components placed in the pre-chamber include a pre-chamber fuel gas supply valve (hereinafter referred to as a "check valve"). The structure of the check valve is illustrated in **Figure 7**.

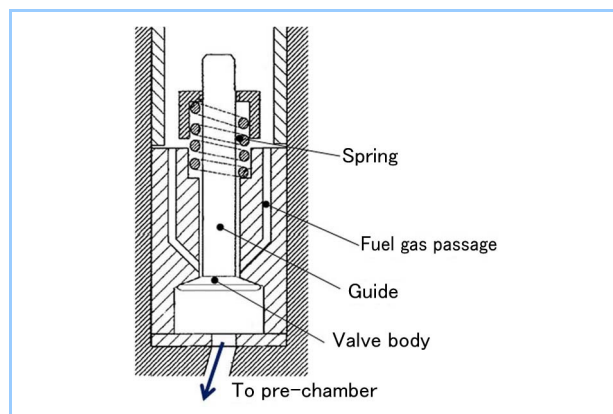


Figure 7 Structure of pre-chamber gas supply valve

As mentioned in the combustion process (i) in 3.2 above, fuel supply is necessary in the pre-chamber. In this regard, a check valve is installed to stop the combustion gas from flowing back into the fuel supply line. The check valve is activated by a spring, which involves the risk of the combustion gas flowing back due to response lag and other factors. When flowback occurs, the temperature of the spring placed upstream could increase and soot may attach to the sliding portion, which could cause breakage or failure of the check valve. MHIET analyzed the check valve behavior in order to optimize its individual design parameters.

The results of the behavioral analysis are shown in **Figure 8**. Compared with the initial design specifications, the valve response has improved in the optimized check valve specifications, reducing the amount of flowback by 76%.

Furthermore, the details of inspection conducted after operation are provided in **Figure 9**. Compared with the initial design specifications, it was confirmed that there was almost no soot adhered upstream.

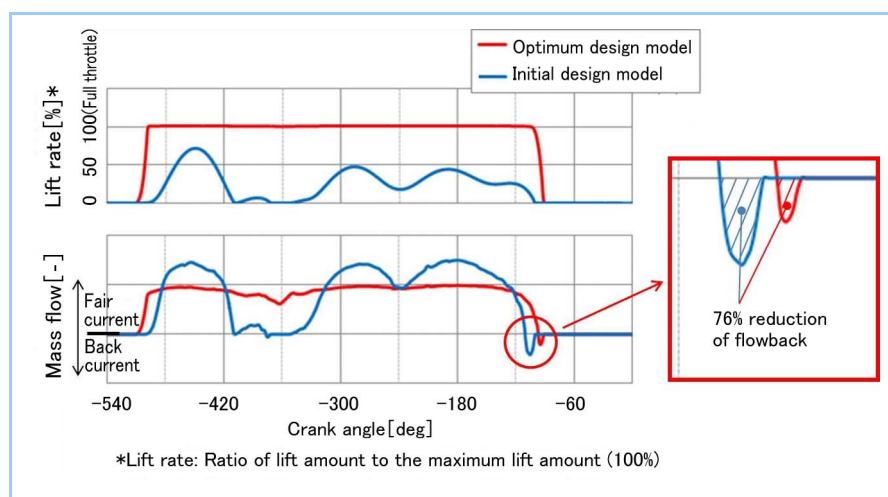


Figure 8 Pre-chamber gas supply valve simulation

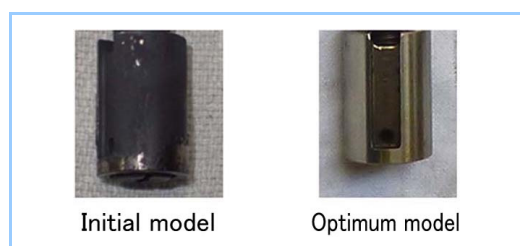


Figure 9 Pre-chamber combustion method

4. Conclusion

MHIET conducted the following attempts as part of reliability testing for the G16NB gas engine for generator use, from which positive outcomes were obtained. Testing is currently being carried out.

- Total test operation time of 4,700 hours utilizing an independent test engine, as well as a fully-equipped power generation unit
- Endurance testing under the condition of overloading/overspeed, as well as post-testing inspections

Development of technology for improving the combustion reliability resulted in the following outcomes.

- Increased accuracy in knocking detection/control (The correlation coefficient against the values detected by the in-cylinder pressure was improved by about 30 to 40%.)
- Combustion variation reduction (reduced by 20% after improvement in the configuration of the pre-chamber)
- Increased reliability of the pre-chamber gas supply valve (reducing 76% of the flowback of the gas supplied to the pre-chamber)

MHIET will continue testing until the launch of the new G16NB engine for generator use on the market.