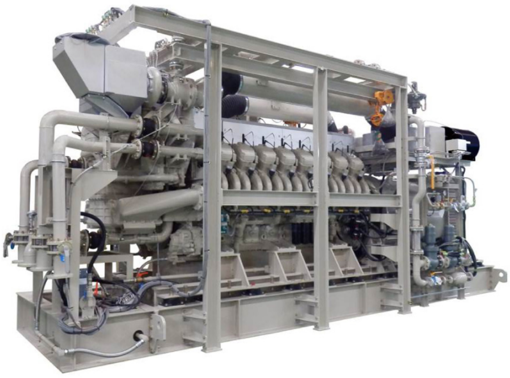
Proposal of Concept for Reducing Cycle-to-cycle Combustion Variations through Improvement of Pre-chamber Configuration in Gas Engines



TOMOHIRO KOGA[*1] DAISUKE TAKEMOTO[*1]
YUSUKE IMAMORI[*2] AKIHIRO YUKI[*3]
HIROYUKI ENDO[*4] YUTA FURUKAWA[*5]

To meet the needs for high efficiency and high power output in the gas engine market, it is important to reduce cycle-to-cycle combustion variations. In this paper, a combustion variation reduction concept derived through simulation technology (LES: Large-Eddy Simulation) that is more advanced than the conventional analysis method (1) is described. By using LES technology, we were able to analyze the phenomenon of cycle-to-cycle combustion variations, which was difficult to understand using the conventional method. This made it possible to conduct factor analysis/concept design and contributed to the development of combustion variation reduction technology.

1. Introduction

Recently, natural gas prices have decreased and demand for a low-carbon society has grown. Under these circumstances, the market for gas engines is expanding, and in particular, demand for 1 to 2 MW class engines is rising. The power generating efficiency of our G16NB 2 MW class gas engine power generator set has reached 44.7%(2), but higher efficiency for the reduction of environmental load is needed. One of the factors that interfere with the increased efficiency of gas engines is combustion variation. This is a phenomenon where the maximum pressure (hereinafter, Pmax) in the combustion chamber varies by cycle, and it is caused by an unstable state of the mixing of fuel gas and air at ignition timing, etc. Thermal efficiency is affected by the average value of Pmax, while the reliability limit is determined by the maximum value of Pmax. Therefore, if combustion variation is curbed, that is, if the difference between the maximum value of Pmax and the average value of Pmax is reduced, efficiency is improved.

To reduce combustion variation, it is necessary to understand the phenomenon occurring in the combustion chamber in detail, identify the factors of combustion variation and then find a concept for reducing combustion variation. It is difficult to understand the phenomenon occurring in the combustion chamber just by measurement, and CFD (Computational Fluid Dynamics) is also used. In the conventional approach using RANS (Reynolds-Averaged Naivier-Stokes equations), however, all eddies are modeled, and the varying state of the phenomenon occurring in the combustion chamber cannot be understood. As such, we adopted an analysis method using LES by which the phenomenon of combustion variation can be understood by directly resolving eddies that are resolvable with a mesh to identify the factors of combustion variation, propose a combustion variation reduction concept and demonstrate it.

*1 Combustion Research Department, Research & Innovation Center
*2 Chief Staff Manager, Combustion Research Department, Research & Innovation Center
*3 Manager, Combustion Research Department, Research & Innovation Center
*4 Director, Engine Technology Development Department, Engine & Energy Division, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd,
*5 Engine Technology Development Department, Engine & Energy Division, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd,

2. Factor analysis of combustion variation

First, before the factor analysis of combustion variation, we conducted non-combustion flow analysis using LES for the current configuration of the pre-chamber of the G16NB. The configuration of the pre-chamber is shown in **Figure 1**. The pre-chamber is composed of a pre-chamber body with a spark plug installed and a throat portion connecting the body and the nozzle. **Figure 2** presents the results of the flow velocity vectors. At -70 deg ATDC (After Top Dead Center), the flow in the pre-chamber forms along the flow from the throat. As the compression is proceeding, the flow from the throat turns to the left side (-60 deg ATDC, -45 deg ATDC) and then turns to flow along the throat again (-30 deg ATDC, -20 deg ATDC). This indicates that in the current configuration, the flow from the throat to the pre-chamber varies. The factor that causes such variation in the flow is interference of the flow from the throat with the tumble flow being generated in the pre-chamber as seen in **Figure 3**. It is presumed that variation in the flow in the pre-chamber causes variation of the fuel concentration in the vicinity of the ignition point, resulting in the occurrence of combustion variation. Therefore, to prevent combustion variation, the pre-chamber should be configured so that such variations can be reduced.

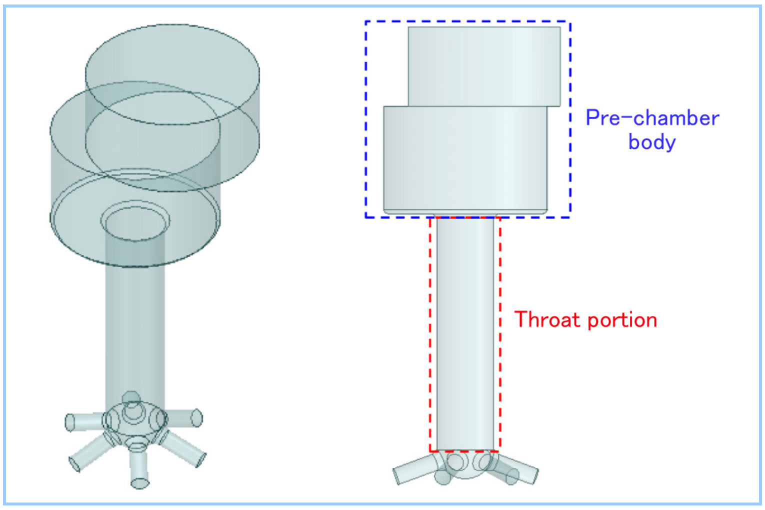


Figure 1 Configuration of the current pre-chamber for the G16NB engine

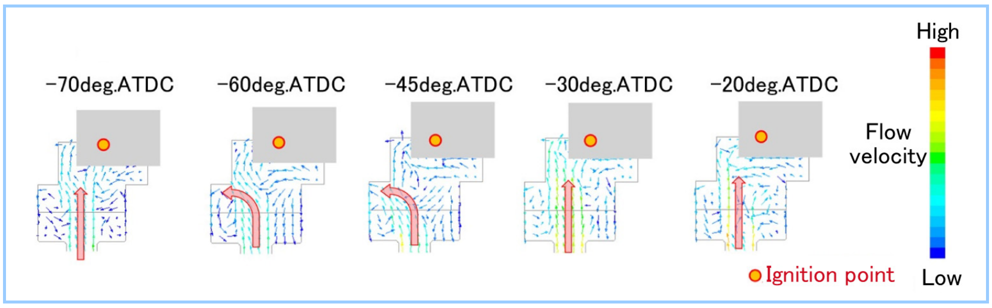


Figure 2 Flow velocity vectors in the pre-chamber body during compression process (current configuration)

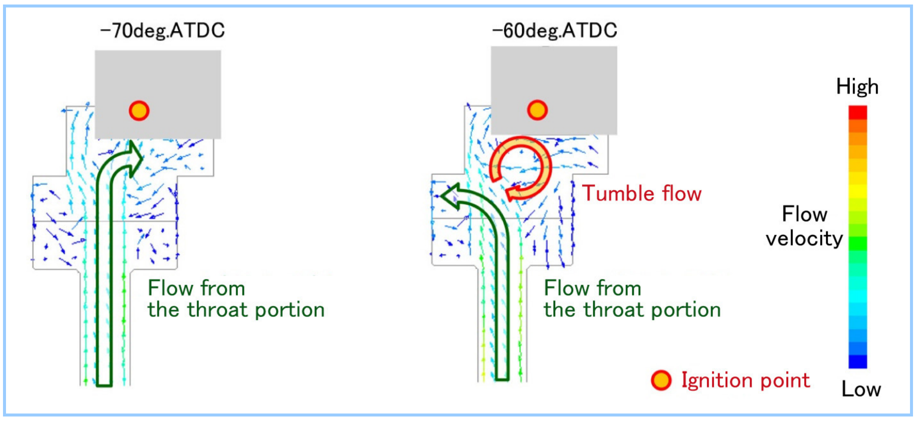


Figure 3 Mechanism of flow variation in the current configuration of the pre-chamber

3. Proposal and demonstration of combustion variation reduction concept

Based on the factors of combustion variation clarified in the previous section, we developed a concept of the pre-chamber configuration that reduces variation in the flow in the pre-chamber. In the modified configuration given in **Figure 4**, part of the pre-chamber body is eccentrically arranged so that there are no steps between the wall surfaces of the throat and the pre-chamber body to prevent the flow from the throat from turning to the left side. It is expected that this modified configuration will reduce the variation in the flow from the throat to the pre-chamber. **Figure 5** lists the results of LES non-combustion flow analysis for the current configuration and the modified configuration. In the current configuration, the flow from the throat varied during the compression process, while in the modified configuration, no variation in the flow was observed and the intended effect was obtained. **Figure 6** makes a comparison of the temporal changes in the fuel concentration in the vicinity of the spark plug. In the modified configuration, the reduced variation in the flow in the pre-chamber results in the reduction of variations in the fuel concentration distribution, and as a result, the stabilization of ignition and reduced combustion variation can be expected.

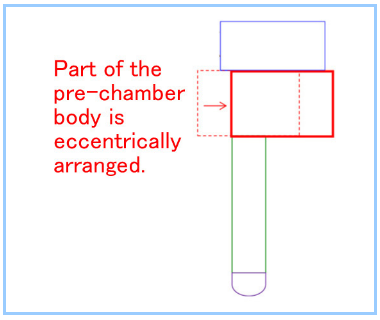


Figure 4 Schematic diagram of the modified configuration of the pre-chamber

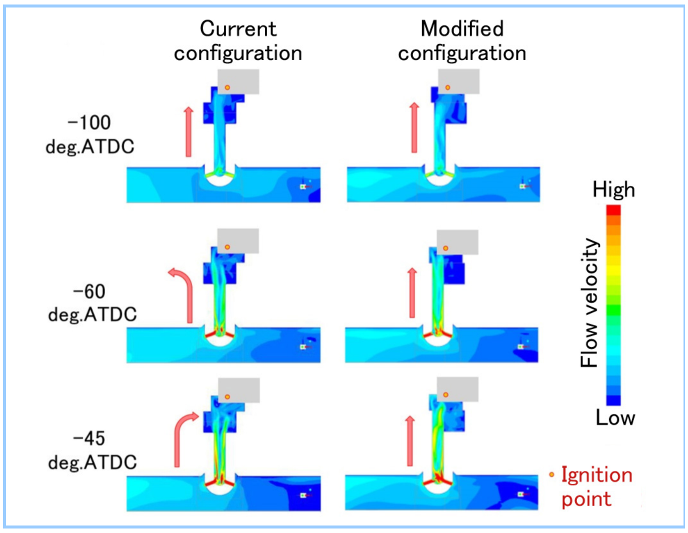


Figure 5 Comparison of the flows in the pre-chamber

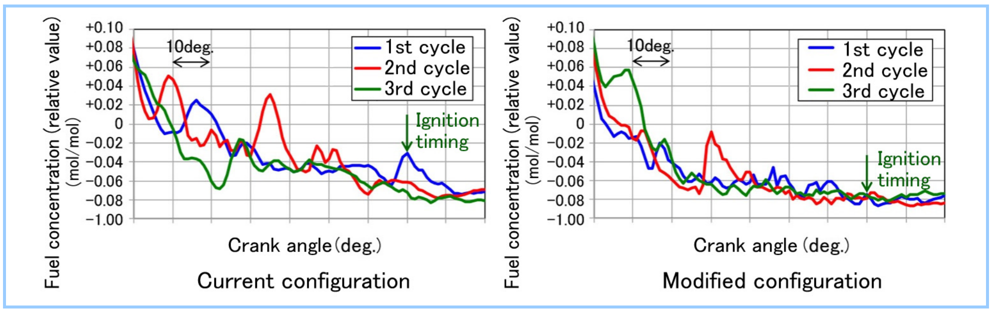


Figure 6 Comparison of the temporal changes in the fuel concentration distribution in the vicinity of the spark plug

Next, the effect of the modified configuration was checked by combustion analysis using LES. In the combustion analysis, only the combustion chamber was targeted and the analysis was conducted with different initial flows multiple times to simulate a continuous cycle calculation. As the evaluation index of combustion variation, the variation in the timing when the pressure in the pre-chamber exceeds the pressure in the main chamber, that is, the timing when combustion in the main chamber starts, was selected. **Figure 7** illustrates the temporal changes in the differential pressure between the pre-chamber and the main chamber. In a comparison of the variations in the timing when the differential pressure exceeds 0, the variation in the timing is 2.4 deg in the current configuration, while it is 1.0 deg in the modified configuration. In the modified configuration, the variation was reduced by about 58%. It is considered that the stable air fuel mixture formation around the ignition position resulted in reduced combustion variation.

The effect of the configuration provided according to the proposed combustion variation reduction concept using LES was verified by a test. **Figure 8** presents the test results. According to the pressure history in the cylinder of the 100 cycle engine, the variation of the maximum pressure was reduced by 37.5% in the proposed modified configuration. In this test, as the evaluation index, the variation in the timing when the integrated amount of heat generation in the engine cylinder exceeds 0, that is, the timing when combustion starts in the main chamber, was selected. **Figure 9** is a comparison of the temporal changes in the total amount of heat generated. Through the modification of the configuration of the pre-chamber, the range where the total amount of heat generated varied was reduced from 3.5 deg to 2.0 deg. It is considered that in the modified configuration, the stable air fuel mixture formation around the ignition position resulted in a reduction of the variation in the timing when combustion starts in the main chamber, finally leading to a reduction of the variation of the maximum in-cylinder pressure. **Figure 10** presents a comparison of the combustion variation reduction rates in the analysis results and the test results. Although the combustion variation reduction effect is overestimated in the analysis, the qualitative tendency has been reproduced.

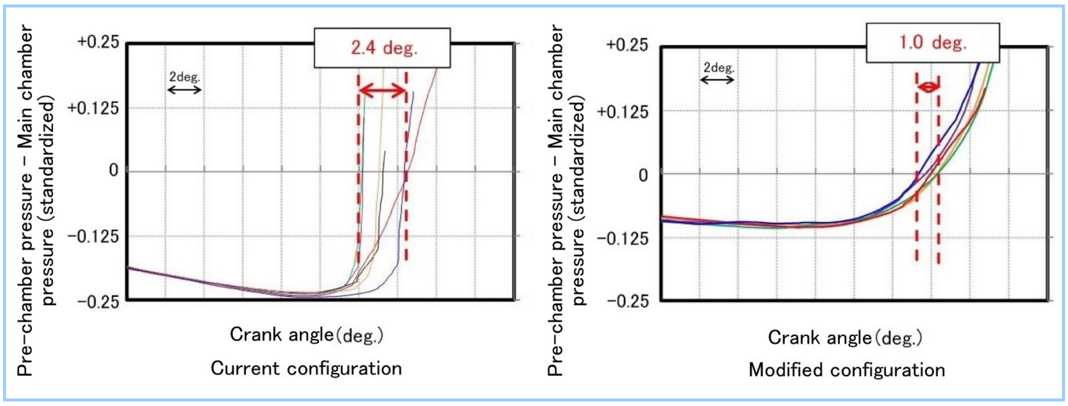


Figure 7 Comparison of the temporal changes in the differential pressure between the pre-chamber and the main chamber

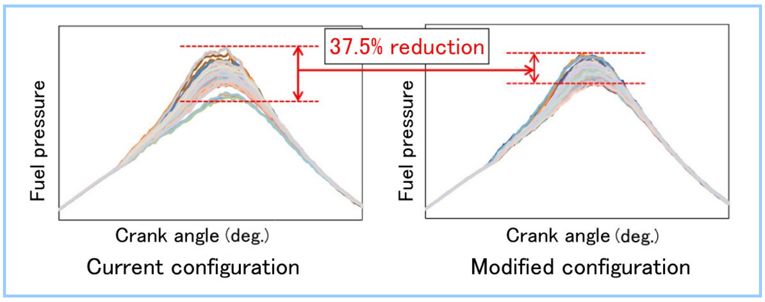


Figure 8 Comparison of the pressure histories in the cylinder for 100 engine cycles

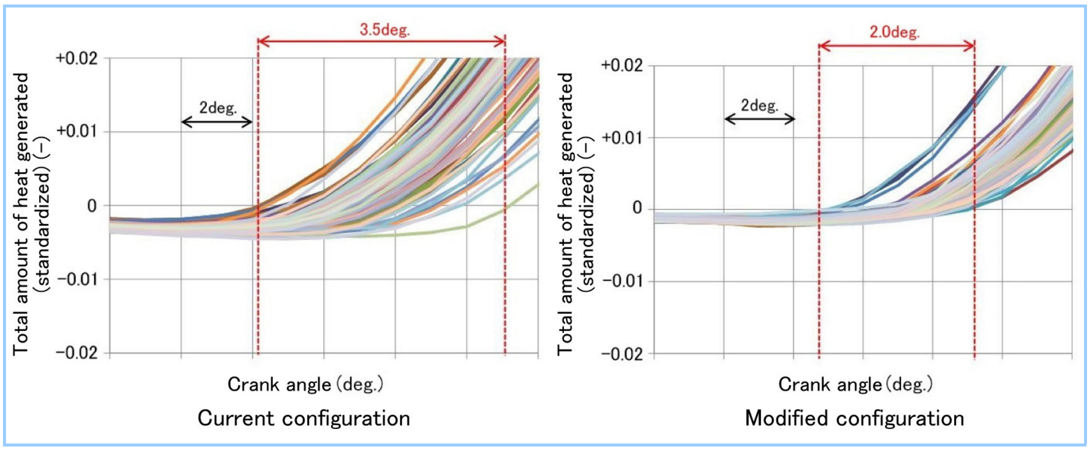


Figure 9 Comparison of the temporal changes in the total amount of heat generated

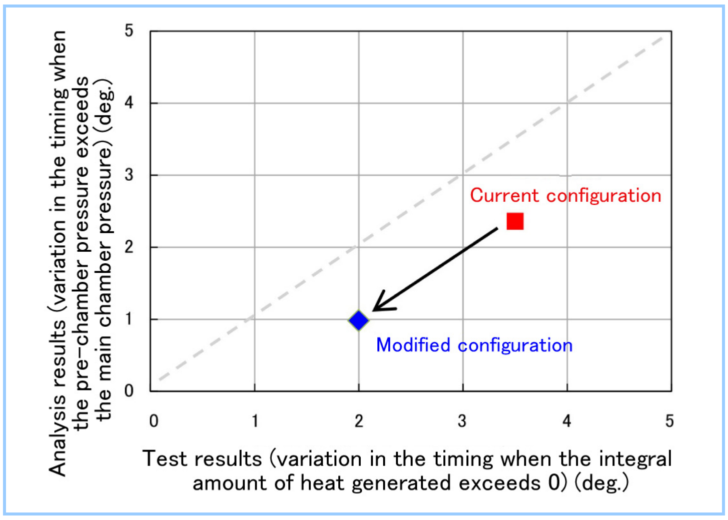


Figure 10 Comparison of combustion variation reduction rates

4. Conclusion

We identified the factors of combustion variation in the current configuration of the pre-chamber by using LES and proposed a modified pre-chamber configuration based on the combustion variation reduction concept. The combustion variation reduction effect of the proposed modified configuration was demonstrated both in the analysis and in the test. At present, evaluation is made only for qualitative tendency, but in the future, we will conduct an analysis in consideration of not only variation in the flow, but also variation in the supply of unburnt gas and gas by using a continuous cycle simulation, etc., and promote the development of technology that will allow a quantitative evaluation of the combustion variation reduction effect.

References

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