

Development of Technology for Ultra-High-Efficiency Natural Gas Engine Combined System

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1 . Introduction

Since July 2005, the Japan Gas Association (JGA) and Mitsubishi Heavy Industries, Ltd. (MHI) have collaborated in a joint project with New Energy and Industrial Technology Development Organization (NEDO) entitled Development of Technology for Ultra-High-Efficiency Natural Gas Engine Combined System. The project aims to develop technology capable of achieving target levels of power generation efficiency (see Chart 1). This paper reports on JGA activities in fiscal 2006 and sets out plans for fiscal 2007.



Operation and tests were carried out at MHI's Nagasaki R&D Center

Chart 1: Development Targets for 8 MW-Class Gas Engine

| | Item | Development Target |
|----------------------------------|----------------------------|--|
| Gas engine (cogeneration system) | Output | 8 MW-class |
| | Generation efficiency | 48% (LHV) or higher |
| | Overall efficiency | 80% (LHV) or higher |
| | NOx emission concentration | 320 ppm (O ₂ = 0% equivalent) or less |
| Combined system | Generation efficiency | 50% (LHV) or higher |

| | Single cylinder | 18 cylinder trial unit |
|---|------------------------|------------------------|
| Combustion system | Sub-chamber gas engine | |
| Ignition system | Micropilot ignition | |
| Cylinder diameter (mm) | 300 | 300 |
| Stroke (mm) | 420 | 380 |
| Revolutions (rpm) | 679 | 750 |
| Output (kW) | *285 | 5750 |
| Indicated mean effective pressure (MPa) | 2.13 | |

*Output if indicated mean effective pressure is same as trial unit

Figure 1. Outline of Single Cylinder Test Engine

2. Report on Fiscal 2006 Activities

Development of ultra-high-efficiency gas engine: establishment of technology for enhancing efficiency through new combustion system.

Overall JGA Activities

Confirmed combustion improvement effects of new combustion system (which combines concentration distribution control with exhaust gas recirculation) using single cylinder test engine, and obtained results indicating targets can be achieved.

Results achieved by each JGA team are reported below.

Flow Analysis Team Activities

Evaluated gas pipe scheme aimed at practical application of air supply flow system and reflected results in design of single cylinder test engine. Analyzed distribution of air-fuel mixture in the cylinder for sub-chamber gas supply system and

high pressure gas jet system, and used results of this analysis to project that the following concentration distribution controls would be possible for each fuel supply method (see Figures 2 and 3).

- Sub-chamber gas supply system: center rich
- Air supply flow system: completely homogeneous, center rich or center lean (see Figure 4)
- High pressure gas jet: center rich

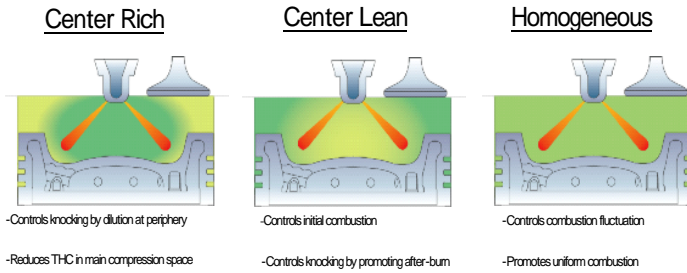


Figure 2: Concept of New Combustion System

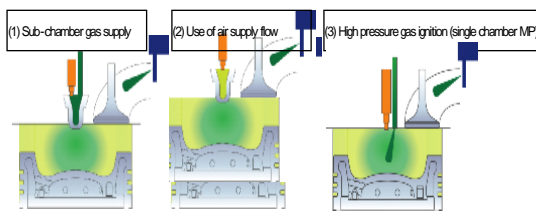


Figure 3: Concentration Distribution Control Methods

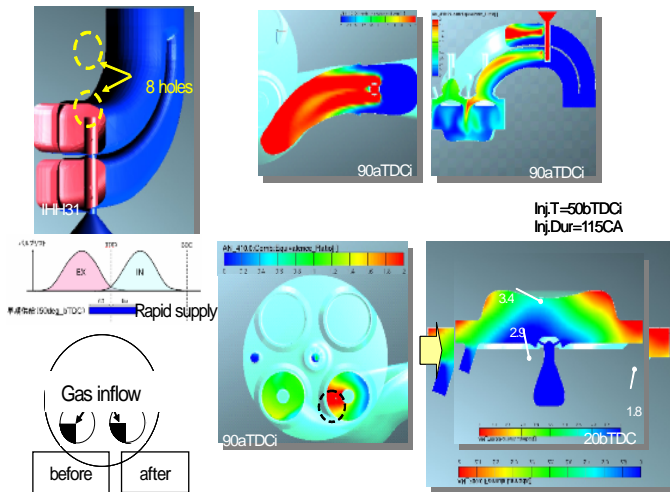


Figure 4: High Swirl/Center Lean Concentration Distribution Control by Air Supply Flow System

Concentration Distribution Analysis Team Activities

High-speed FID was used to measure the composition of concentration distribution in the cylinder via three methods: completely uniform mixture, use of air supply flow and auxiliary chamber gas supply (see Figure 5). These measurements were compared with concentration distribution projections made by CFD analysis and the accuracy of the CFD analysis was verified.

This provided data necessary for studying the new combustion system and enabled evaluation of its impact on engine performance (see Figure 6).

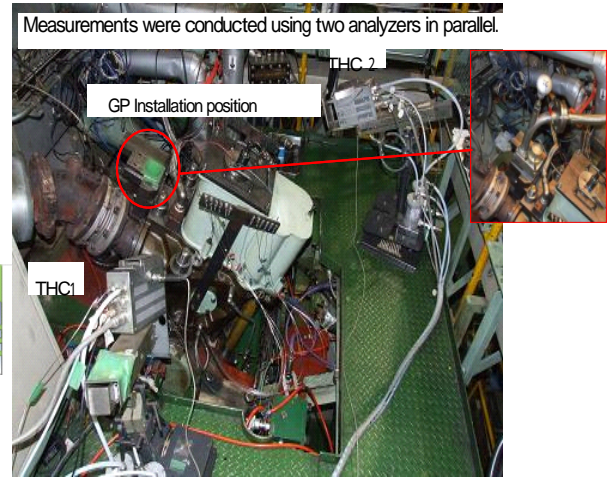


Figure 5: High-speed FID Measurement Method

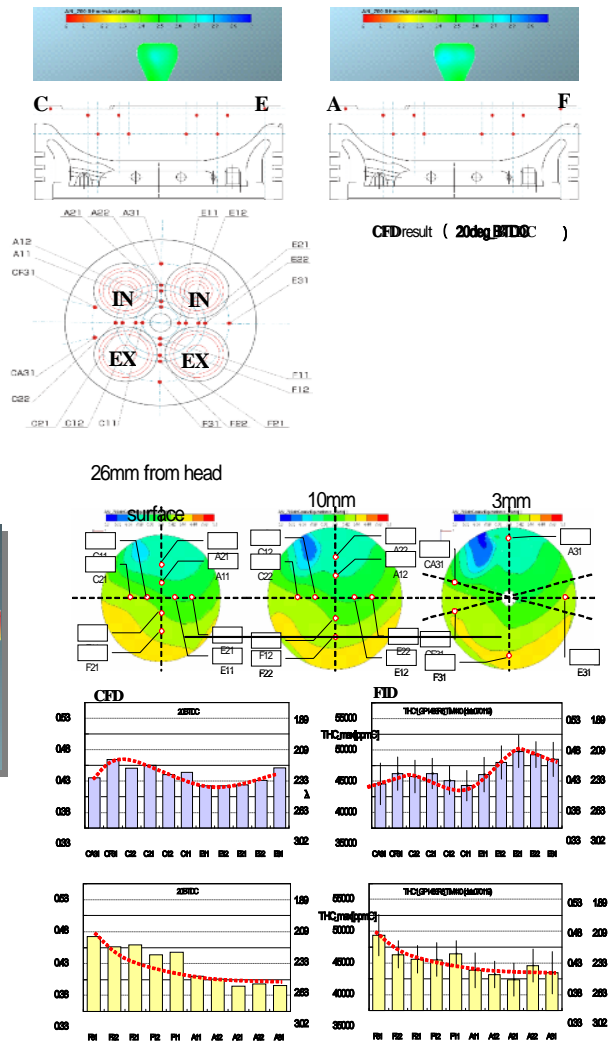


Figure 6: High-Speed FID Test Results and Comparison with CFD Analysis (Center Lean)

Combustion Optical Analysis Team Activities

The Combustion Optical Analysis Team used an in-cylinder optical combustion analysis device (Visio-Tomo) to conduct optical combustion analysis of tests using different mixture compositions and evaluate the location of knocking (see Figures 7 and 8). It also examined flame initiation and reflected the results in adjustments to engine operation.

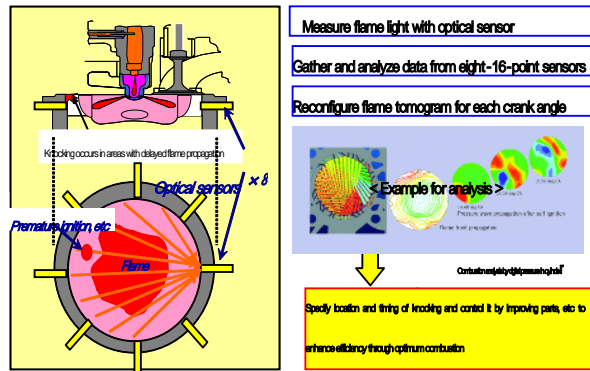


Figure 7: In-Cylinder Combustion Visualization Measurement Method

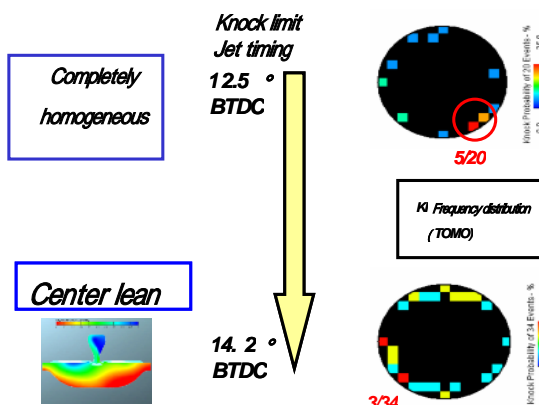


Figure 8: Example of Knocking Location Analysis Method

3. Summary of Fiscal 2006 Activity Report

- Using CFD analysis, high-speed FID and Visio-Tomo, it was determined that use of air-supply flow is the most effective of the three concentration control methods (sub-chamber gas supply, use of air-supply flow and high pressure gas jet).
- In terms of the concentration distribution concept, it was determined that the center-lean formula is effective in enhancing resistance to knocking.
- Specifications for the trial unit were selected based on results of engine specification optimization tests and from the perspective of concentration distribution control.
- The new combustion system has opened up the prospect of achieving target levels of power generation efficiency.

4. Fiscal 2007 Activity Plan

The trial unit, which has already been designed and manufactured, will be tested to verify the engine's target levels of power generation efficiency. The combined system selected will be incorporated into the trial unit to verify target levels of power generation efficiency. Using the trial unit head, single cylinder tests will be conducted with the aim of adjusting the new combustion system, and data will be gathered and evaluated.