

Development of High Thermal Efficiency PFI Lean-Burn Engine(1st report)

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This study investigated the improvement of combustion stability and thermal efficiency through enhanced in-cylinder flow in a port fuel injected (PFI) lean-burn engine for series hybrid applications. In the baseline configuration, the lean limit was restricted to $A/F = 32.5$ due to an increase in the coefficient of variation of indicated mean effective pressure (COV_{IMEP}). As a result, the operating range satisfying both combustion stability and NOx emission requirements was limited.

To improve lean-burn combustion, the intake port and piston crown geometries were redesigned to strengthen tumble flow and maintain the flow structure until near top dead center (TDC). The improved configuration employed an intake port that generated a curved flow guided along the cylinder liner after passing through the intake valve. In addition, a cylindrical feature was incorporated into the piston crown to preserve in-cylinder motion during the compression stroke. CFD analysis showed that the improved configuration increased the tumble ratio from the compression stroke to TDC compared with the baseline configuration (Fig. 1).

Combustion analysis at $A/F = 32.5$ revealed a shorter initial combustion duration (MBF IG-10) and reduced cycle-to-cycle variations in both the initial and main combustion durations (MBF 10-90), indicating improved combustion stability (Fig. 2). Figure 3 compares the COV_{IMEP} and NOx emissions as a function of A/F for the baseline and improved configurations. The enhanced tumble flow suppressed the increase in COV_{IMEP} under leaner conditions, extending the lean limit from $A/F = 32.5$ to $A/F = 34$. Consequently, the operating range satisfying both the combustion stability criterion and the NOx target was expanded. In the operating region representative of HEV applications, the indicated thermal efficiency exceeded 45%, reaching a maximum of 46.6%, while NOx emissions remained below 35 ppm (Fig. 4). Furthermore, ultra-lean combustion at $\lambda = 3$ ($A/F = 44$) was achieved in a limited operating region.

These results demonstrate that enhancement and preservation of tumble flow effectively improve combustion stability under lean-burn conditions, enabling extension of the lean operating limit while simultaneously achieving high thermal efficiency and low NOx emissions.

1. Enhanced and sustained tumble flow reduced the initial combustion duration and cycle-to-cycle combustion variability, resulting in improved combustion stability and an extension of the lean limit. Ultra-lean combustion at $\lambda = 3$ was successfully achieved in a limited operating region.
2. In the HEV operating range, indicated thermal efficiency exceeded 45%, with a maximum value of 46.6%, while NOx emissions were maintained below 35 ppm, demonstrating the compatibility of high thermal efficiency and low NOx emissions.

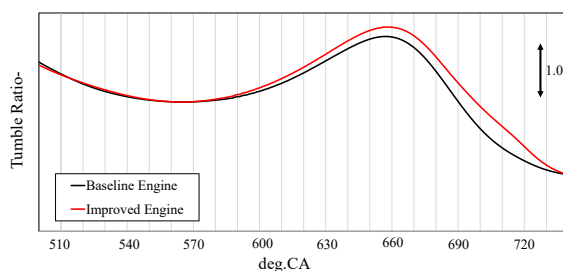


Fig. 1 Comparison of Tumble Ratio versus Crank Angle

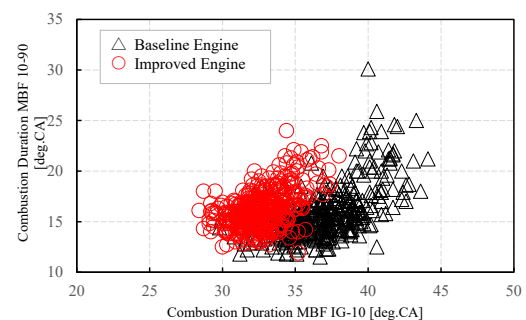


Fig.2 Relationships between MBF IG-10 and MBF 10-90

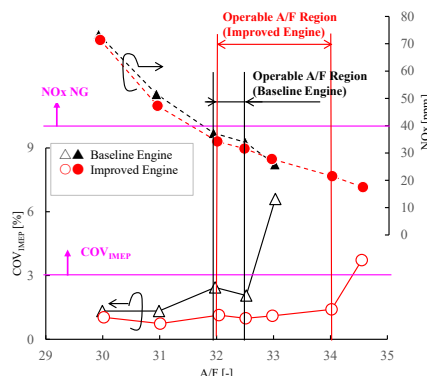


Fig. 3 Operable A/F region (2000rpm, IMEP=760kPa)

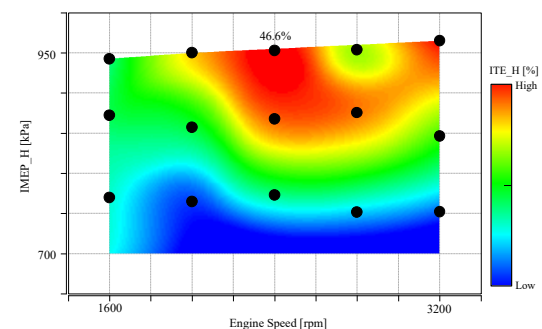


Fig.4 Indicated Thermal Efficiency Map [%]