PIV/LDV Combination for Optimum Turbulence Generation Scheme to Spark Ignition in Wide Operating Condition of SI Engine

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Lean burn and high exhaust gas recirculation (EGR) rate combustion have been applied to spark ignition (SI) engines to improve the fuel economy. However dilution of mixture by air of exhaust gas leads to unstable ignition and low flame propagation speed and engine operating limit is determined due to these issues. In-cylinder turbulent flow field and its control is the one of the most important factors to determine flame propagation following ignition.

During intake process, intake air flows into cylinder and initial bulk flow is generated. After the intake valves closing, the bulk flow transits to turbulence by cascade transition during compression stroke. Figure 1 shows a hypothesis about optimum flow transition during compression stroke. At ignition timing, bulk flow is fully transit to turbulence, turbulent intensity is maximized and turbulent scale is minimized. Higher momentum of initial bulk flow is required to increase turbulence intensity at ignition timing. The other important things are intensity and transition timing of small scale strong turbulence and its control. In order to optimize turbulence flow field at ignition timing, it needs to be understood about generation of in-cylinder bulk flow during intake process and cascade transition during compression stroke.

In this study, in-cylinder flow transition and turbulence characteristics near the spark location during compression stroke were measured and evaluated by using particle image velocimetry (PIV) and laser Doppler anemometry (LDV). Spatial distribution of in-cylinder flow characteristics were evaluated by PIV and time-frequency analysis of flow at local point was made by LDV. Two dimensional velocity distribution and qualitative turbulent distribution are obtained from PIV measurement. On the other hand, time series velocity fluctuation and qualitative turbulent intensity at local point are obtained from LDV measurement. Both techniques are used to evaluate the bulk flow inside the cylinder and turbulent characteristics around the spark location.

A single cylinder optical engine (bore diameter: 86 mm, stroke length: 86 mm, displacement volume: 500 cc) was used. This engine has quartz windows at the side of pent roof position, cylinder sleeve and piston top. Laser sheet for PIV measurement was introduced from the bottom of the cylinder through the quartz piston top. For LDV measurement, small LDV probe (φ14mm) was inserted into spark plug hole. The tip of the spark plug hole, an optical window was installed. Two direction velocity components were obtained by changing attachment orientation of LDV probe.

At first, velocity distribution during the intake stroke was measure by PIV. At bottom dead center (BDC), strong intake flow from upside of the intake valves was observed at left hand side and this flow was toward to the piston top. Intake flow from downside of the intake valves was also toward to the piston top. These two flows were interfered with each other around the piston top. Bulk flow of tumble flow was generated in a counterclockwise direction. This flow was pushed up toward pent roof region by piston motion. Velocity became higher at higher engine speed conditions, but these flow patterns were similar. At BDC, strong tumble flow from intake side to exhaust side was observed. In-cylinder flow once decayed and then increased due to the flow with piston movement around top dead center (TDC) and strong turbulence distribution was generated near the spark location. From these results, qualitative turbulent characteristics can be measured by PIV.

The time change of velocity, turbulent intensity and time scale near the spark location was measured by LDV. Around BDC, strong turbulence generated with intake flow remained. Turbulent intensity decayed during early stage of compression stroke. During late stage of compression stroke, turbulent intensity increased due to turbulence generation with tumble flow breakdown as shown in Fig. 1. Turbulence time scale of both direction (u and v) decreased during the compression stroke with tumble flow breakdown.

Combination of PIV and LDV enables to evaluate time change of in-cylinder flow, distribution of qualitative turbulent intensity and quantitative evaluation of turbulence intensity and scale at local point. These data are valuable for engine design (such as intake port, piston, and intake valves), control optimization and CAE validation.

![Figure 1 Turbulent intensity (U component)](image-url)