Spark plug-in Fiber LDV for turbulent intensity measurement of practical SI engine

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ABSTRACT
A compact fiber LDV has developed in order to measure turbulent intensity near the spark plug. An optical parameter of the FLDV was designed to have high data rate and spatial resolution without any consideration of seeding particles. The developed FLDV (Fig. 1) was installed in the casing which fits M14 instead of the conventional spark plug (Fig. 2). The measurements were carried out in a practical engine under motoring condition. The test engine is the production engine, no special treatment was added. (Fig. 3)

The measurement results demonstrate that turbulent intensity near the spark plug changed before/after TDC dramatically. The data rate was over 5kHz and cyclic variation of the engine operations were demonstrated.

1 Introduction
It is well known that a high turbulence near spark plug can increase turbulent combustion speed, which contributes to stable and lean engine combustion over a wide range of engine operation conditions. Many measurements by LDV (e.g. Durst et al., 1976 and Obokata et al., 1987) and visualization (Melling,
1997 and Fujikawa et al., 1995) are required to understand turbulent characteristics near a spark plug in both constant-volume combustion chambers (Morikawa et al., 1999) and model engines (Hamamoto et al., 1993). Flame propagation characteristics have been discussed in research on visualization (Fujikawa et al., 1995). On the other hand, LIF can demonstrate the two-dimensional fuel concentration distribution before ignition (Kakuhou et al., 1999 and Zhao et al., 1994). This is very useful information in controlling mixture formation, although it is hard to understand the time-varying characteristics.

Direct turbulent measurement near the spark plug is necessary to understand flame propagation and its relation to turbulence intensity for various engine speeds. The purpose of this present study is to develop a fiber LDV system that can be used instead of spark plugs in a standard engine without any modification. The first step is to demonstrate this measurement in a practical engine and understand the flow behavior and turbulence intensity measurement under non-combustion conditions.

2 Optics design of LDV

LDV optics should be installed in an M14 casing where there are no spark plug units. The optical parameter is determined in order to measure at a very high data rate for cycle-resolved analysis. The developed optical component is shown in Fig. 4. The measurement location is 5mm from the optical window, which was determined to be the same location as the spark plug gap. The measurement volume size and optical parameter were determined in consideration of band width of signal processor, measurable dynamic range, the accuracy, the data rate, ease of cleaning, ease of setting up, pressure, vibration, and so on. The fringe spacing was determined to be over 2µm for sufficient visibility and a seeding particle diameter of 1-2µm (Menon et al., 1991 and Ikeda et al., 1992). For high data rate measurement, the scattered light from the measurement volume can be increased with a smaller measurement volume size, but the particle concentration and passing percentage becomes low. Then, the measurement volume diameter was first set up around 50µm and the measurement volume depth was less than 500µm. The output beam diameter from the collimate lens was then determined. We used W18 (NSG, selfoc lens: W18, 0.248P, AR coating) for 514.5nm.

Here, the SNR parameter (Durst, et al., 1976) was used to evaluate the LDV’s performance. We tried to achieve more than 4.5 × 10⁻⁵, which is much higher than those commercially available (Ikeda et al., 1990) and our previous experimental results (Ikeda et al., 1992 and Ohira et al., 1995). The developed Fiber LDV is shown in Fig. 5. As shown, the size was for M14 and is easy to install in a practical engine. Figure 6 shows the practical installation in the practical SI engine used in the experiment.

All optical parameters were determined in these processes. The final dimensions of the measurement volume are also shown in Fig. 4.
**Optical parameter**

- **Wave-length**: $\lambda = 514.5 \text{ nm}$
- **Focal length of front-lens**: $F_f = 31 \text{ mm}$
- **Working distance**: $W = 5 \text{ mm}$
- **Effective diameter of receiving-lens**: $D_a = 5.74 \text{ mm}$
- **Space of laser beams**: $D = 7.5 \text{ mm}$
- **Diameter of laser beam**: $D_{in} = 0.4037 \text{ mm}$
- **Measurement volume dimension**: $d_f = 50.3 \text{ mm}$, $d_z = 415.8 \text{ mm}$
- **Fringe spacing**: $d_f = 2.142 \text{ mm}$
- **Fringes number**: $N_f = 23.65$

**AOM**

- **40 MHz**

**SNR parameter**

$\text{SNR parameter } = \left( \frac{D_a \cdot D_{in}}{f^2} \right)^2 = 45.24 \times 10^{-6}$

**SNR parameter**

- **TSI(9273)**: $0.64 \times 10^{-6}$
- **KANOMAX(8835)**: $11.11 \times 10^{-6}$
- **DANTEC(60x17)**: $2.28 \times 10^{-6}$

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**Fig. 4 Optical parameter**

**Fig. 5 LDV probe**
3 Experimental Apparatus

The engine used in this experiment was a practical 1000cc four-cylinder engine [bore x stroke = 71 x 80.5mm:NISSAN]. The measurement system is illustrated in Fig. 7. An Ar-ion laser and a Burst Digital Correlator [BDC (Ikeda et al., 1990)] were used for the measurement. The test engine was operated in normal motoring conditions, and the developed FLDV was installed into one of the cylinders instead of a standard spark plug, as shown in Figs 6 and 7. The measurement location was at the center of the cylinder shown.

The seeding particle used in the measurement was MSF (Nishigaki et al., 1992) and a constant feeding system was used.
4 Results and discussion

The measurement results are shown in Fig. 8, which shows LDV data in three consecutive cycles. The figure indicates two data rates calculated from the short period and wide period. A high data rate of over 5kHz can be measured in each cycle. The direction U means from intake to exhaust and V was perpendicular to U. The results show that both velocity traces indicate large velocity fluctuations, but the fluctuating ranges are similar. The fluctuating range near TDC is about −4m/s to 7m/s. Since this developed FLDV was designed to measure turbulence intensity, it is found that the measured data can provide sufficient turbulence information near TDC. It is understood that a constant and high level of turbulence can increase turbulence combustion speed just after ignition, so that formation of constant turbulence around ignition time and TDC should be clearly understood for optimum engine operation control and reduction of UHC in exhaust gas. In this paper, we do not discuss the detailed flow characteristics, because the purpose of this study is to develop a fiber LDV that can be installed in a practical engine. Although the present measurement data can only provide the evaluation results of the present system, it was found that the velocity fluctuation in the expansion stroke is much larger than the compression stroke near the spark plug. A large reverse flow was found at BDC on the compression stroke.

The ensemble average velocity was compared to one of an instantaneous cycle, as shown in Fig. 9. The rms value is very small in this experiment. The window size used was 0.5°CA and the sample number distribution indicated that the particles can travel the measurement volume sufficiently around TDC.

![Fig. 8](image)

Fig. 8 Cycle-resolved LDV measurement
5 Conclusions

We have developed a fiber LDV that can be installed in a practical engine instead of a standard spark plug. The evaluation was done under motoring conditions. The design process and the results can be proved to achieve high data rate measurement in practical engine conditions. The measurement results show that the data rates near ignition timing and around TDC were sufficient to determine the turbulent flow characteristics in real time and cycle-resolved measurement can be demonstrated.

References


2) "Applications of Laser Techniques to Fluid Mechanics", 5th Int. Symp. on Application of Laser Techniques to Fluid Mechanics, (1990)


