Effect of Uniformity in Mixture Strength and Unburned Gas Temperature on Knock in a Spark Ignition Engine

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ABSTRACT

Mixture concentration distribution in combustion chamber is visualized by Laser Induced Fluorescence (LIF) and Coherent anti-stokes Raman spectroscopy (CARS) temperature measurements in the unburned end gas ahead of the flame front have been carried out in a spark ignition engine under two different fueling methods. One is uniform fueling method and another is nonuniform fueling method. In order to study the effect of nonuniformity and uniformity in mixture concentration and the unburned gas temperature on knock in a spark ignition engine, knock intensity and unburned gas temperature just before knock were measured under both operate conditions. In order to obtain nonuniformity in mixture condition, the fuel was injected to the intake port directly, while to obtain uniformity in mixture condition, the fuel was injected to the electrical heated mixchamber. The results show that knock was hard to occur under nonuniformity in mixture condition although the unburned gas temperature under nonuniform mixture condition was higher than that under uniform mixture condition. The results concluded that the fuel system has a significant effect on the occurrence of knock.

Introduction

Knocking is a complicated and unrevealed phenomena, which suppress engine output performance. In order to suppress knocking, it is necessary to know quantitatively the correlation between unburned gas temperature and engine parameters such as compression ratio, oil and water temperature and so on, which are experimentally known to be strong correlation to knocking. As knocking is due to autoignition in unburned gas area, the reason of occurring knock is thought to be due to unburned gas temperature evolution, pressure evolution, mixture concentration, residual gas and so on. However, combustion in an internal combustion engine is complicated and fast phenomenon, it is difficult to study knock and reports are few.(1)(2)

Our previous results of knocking research are reported .CARS is applied to the actual engine and the temperature increase in unburned area before knocking are known under high compression ratio(3)(4), the temperature field by measuring temperatures at several points in unburned gas area are obtained(5). These studies revealed that temperature difference between knocking and nonknocking gets bigger where the measuring point locates in final combustion period. In another study, the temperature effect of residual gas on the occurrence of knocking in unburned gas was made clear with skip cycle method(6).

In this report, anti-knocking characteristic is examined under two different fueling methods(7). One is uniform fueling method and another is nonuniform fueling method. To make clear that the difference of the anti-knock characteristic under these conditions, unburned gas temperatures was measured by

CARS and mixture concentration distributions in combustion chamber was visualized by LIF under two different fueling methods.

EXPERIMENTAL APPARATUS

Engine specification, fueling methods and knock intensity measurement

To know the effect of the nonuniformity of mixture concentration on the occurrence of knocking and its intensity, two fueling methods shown in figure 1 are prepared. In order to mix well air and gasoline, one of them has the fuel evaporation chamber with electric heater and the heated temperature sets to 190 degree Celsius corresponds to the final evaporation temperature of gasoline. The four times injection per one cycle is performed and a baffle plate is used. This chamber sets 80 cm from the intake valves. Fuel from an injector hits against the heated wall and then introduced to the baffle plates space. This fueling method is named CM, Complete Mixing. Another is a common method called port injection method. Injector sets to the head face and aims at the center of a intake valve and the injection timing sets to the induction stroke and the compression stroke. The former fueling method is named DFIS, Directed Fueling during Induction Stroke and later are DFCS, Compression Stroke, respectively. Induced gas is heated in both fueling because of the temperature of the induction gas being same.

In table 1, engine specifications of the engine used for this experiment is shown. Engine used in this study is sold in market and has two intake, two exhaust valves and the configuration of the combustion chamber is pent roof. To obtain knock occurrence time and its intensity, the time of knock occurrence was quantified from the rise time of the high-frequency component of the combustion pressure oscillations induced by knocking. Knock intensity was found by calculating the ratio of heat released under autoignition to the heat released under normal combustion(8).

Measurement of unburned gas temperature

CARS is used to measure the unburned gas temperature. An outline of the CARS experimental apparatus used in this work is shown in fig.2. Employed as the light source was a 532 nm second harmonic of a YAG laser. Part of the 532 nm laser radiation was also used to pump a broadband dye laser system centered at 607 nm. The laser beams were focused on the combustion chamber using convex lenses. The CARS signal generated at the focal point which corresponds to the measurement point was transmitted to a 1 meter double monochromator, which separated the spectral components for detection by a multichannel analyzer. Because the collinear type of optical alignment was used, band-pass filters were placed at the inlet and outlet of the combustion chamber to suppress the CARS light and the excited laser beam respectively. These filters thus served to eliminate any CARS light that did not

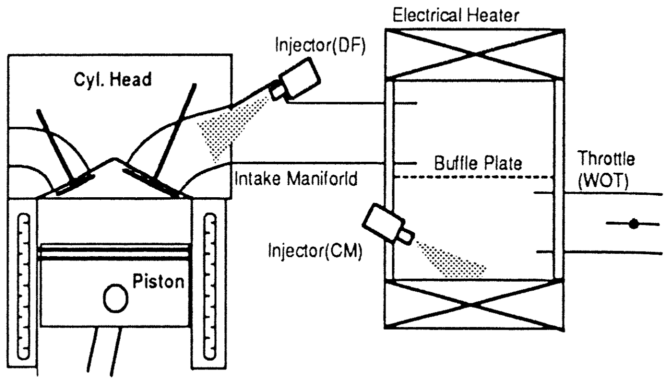

Fig. 1 Schematic Diagram of Fueling System

Table 1 Test Engine Specifications

Bore & Stroke	**86mm&86mm**
Displacement	**500cm^3**
Compression Ratio	**9.5:1**
Combustion Chamber	**Pent Roof**

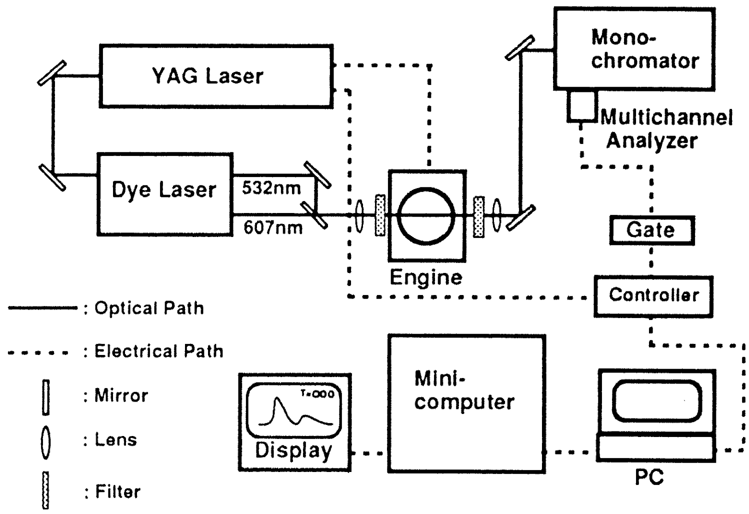

Fig. 2 CARS Experimental Diagraml

originate from the measurement point.

Fig.3 shows the measuring point of unburned gas in combustion chamber. As the final combustion aria of two intake valve engine locates near intake valve experimentally, the measuring point was decided to be 3.2 mm from cylinder wall and 4 mm from the face of the cylinder head. To obtain the same condition of knock intensity under CM and DFIS, the ignition timing sets to 3 degree BTDC. As the mean occurrence time of knocking is 20 degree ATDC, the measurement time of temperature is set to 20 degree ATDC.

Visualization and quantification of mixture concentration

To estimate the anti-knock characteristic, it is necessary to obtain the mixture concentration in an actual combustion chamber. In this study, LIF is used to visualize mixture concentration distribution of the plane vertical to the cylinder axis and 5 mm far from the face of the cylinder head. The thickness of the plane is sets to 2 mm with a cylindrical lens. LIF experimental diagram is shown in fig.4. Number 2 cylinder combined to the elongated monocylinder is used for the visualization and this four cylinder head is the same head used for the experiment of anti-knock characteristics. Wavelength of 248 nm, output power of 400 mJ KrF Excimer laser is oscillated and synchronized with the engine operation. Laser beam is divided by a half mirror and two laser sheets are made with cylindrical lenses and then introduced into the cylinder head in the opposite side of the cylinder wall through quartz windows. To obtain fluorescence from the mixture in the combustion chamber laser sheet is introduced to the high sensitive camera with image intensifier (I.I.) via mirror, and band-pass filter through a transparent piston crown. Optimized fuel and additive material's density for obtaining the good S/N image of A/F field is isooctane and N,N-Dimethyl Aniline(N,N-DMA)(9), the density of DMA is 0.2 volume % for isooctane. Boiling temperature of isooctane is 90 degree centigrade and this value is roughly same with the average distillation temperature of gasoline.

In fig.5, the fluorescent spectra of the previous stated mixed fuel and gasoline are shown under induction and compression stroke, 450 degree.and 690 degree ATDC, respectively. Isooctane with 2% N,N-DMA shows strong fluorescent intensity and the wavelength of its peak stands at around 330 nm. This wavelength is far from the fluorescent of window material, quarts. Peak intensity at the compression stroke gets weaker than that of induction stroke and the value of it is around 80% of the induction stroke.

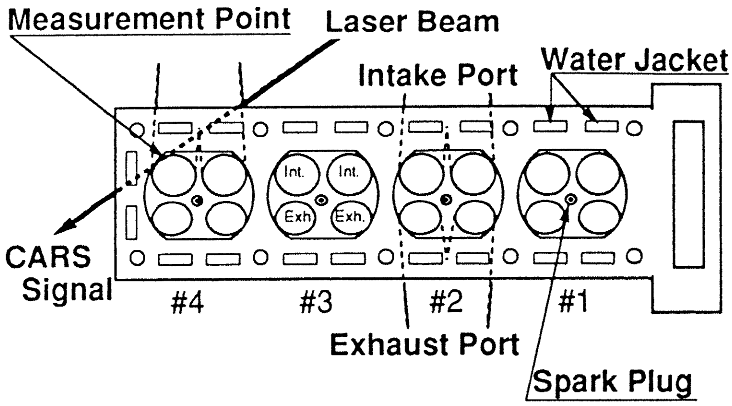

Fig.3 4 Valve Production Engine Cylinder Head Configuration

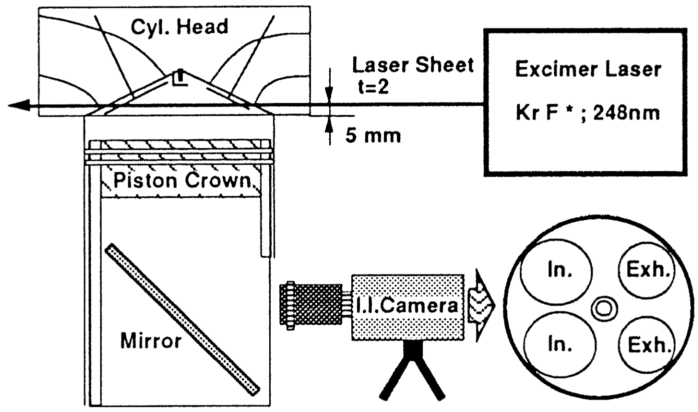

Fig. 4 Schmatic Combustion Chamber and Optical System of LIF

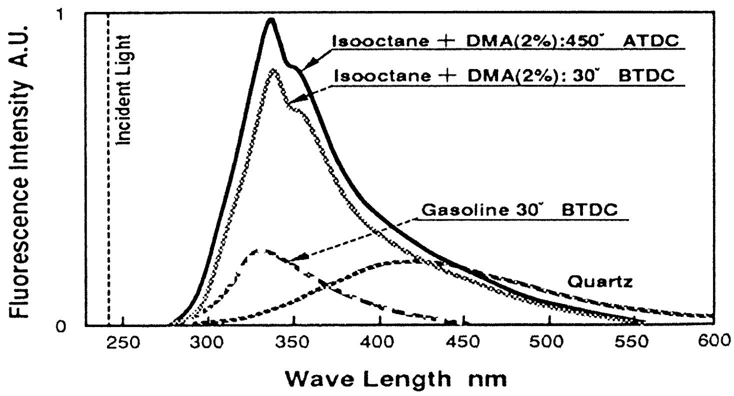

Fig. 5 Fluorescence Spectra of Fuel and Quartz

Fig.6 shows the peak intensity value of this fuel under the different concentrations of N,N-DMA and two timings of fluorescent measurement, induction stroke of 450 ATDC and compression stroke of 30 BTDC. Below 2 %, the peak value difference between two stroke timing is small and above 2% the difference of peak value gets bigger as the concentration of DMA gets higher. During induction stroke, peak value of fluorescence gets bigger linearly against the DMA concentration. Under the high pressure, high oxygen concentration and high DMA mass fraction, fluorescent intensity is strongly effected by these conditions and resulted in decrease. Fluorescent intensity difference between two timings below 2% may be due to the oxygen quenching effect and peak value difference above 2% may be due to oxygen and DMA quenching effect. Finally, the concentration of N,N-DMA was fixed to 0.2 volume % with restriction of the two dimensional image obtaining.

EXPERIMENTAL RESULTS and DISCUSSION

Knock characteristic under the different fuel method

Driving conditions are shown in table 2. In the case of DF, fueling time is chosen among the four stroke periods by changing the injection timing. The injection timing of DFIS is chosen as the most effective injection timing for the anti-knock performance and that of DFCS is chosen as ineffective. Fig.7 shows the anti-knock characteristic under CP, DFIS and DFCS fueling methods. Under these condition, ignition timing was changed to obtain knock intensity and the mean effective pressure Pi. The ignition timing of DFIS for trace knock is advanced to CP and knock intensity rises later than the case of CP against the ignition timing. Pi of DFIS is bigger than that of CP under trace knock condition. This results shows that DFIS fueling method is effective for anti-knock performance. In the case of DFIS, as most of the injected fuel comes into combustion chamber directly and mixture seems to be nonuniform, the nonuniformity seems to suppress the knock occurrence. Moreover the knock intensity depends on the air fuel ratio A/F. Fig.8 shows that the knock intensity characteristic under the different A/F. The knock intensity becomes strongest at stoichimetric A/F. This result explains nonuniformity in

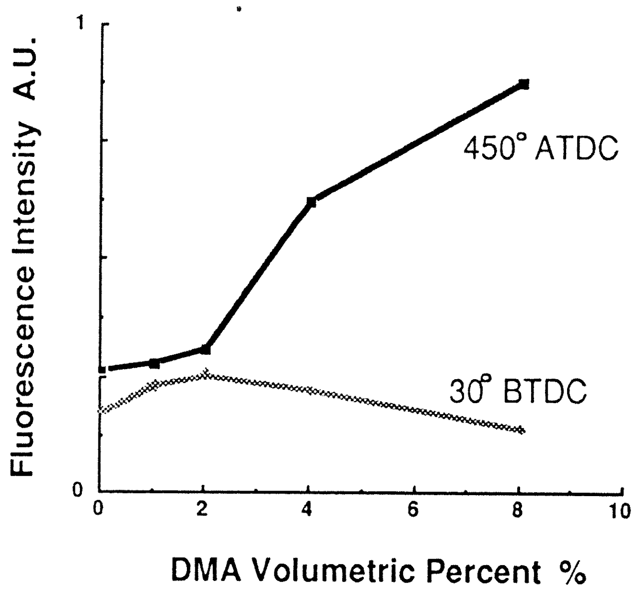

Fig. 6 Relation between DMA Mass Fraction in Isooctane and Fluorescence Intensity

Table 2 Engine Driving Conditions

Engine Speed	1200 rpm
Φ	1.18(A/F=12.5)
η_c	72%
RON	89.9

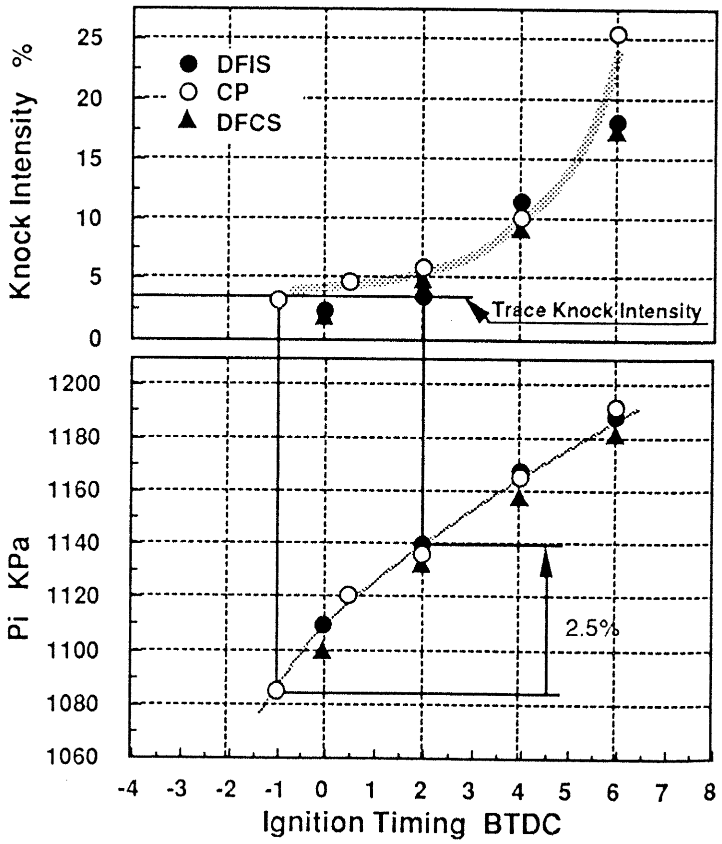

Fig. 7 Knock Characteristics for Different Fuel Supply System

unburned gas seems to change knock intensity.

Unburned gas temperature measurement

Fig.9 shows the unburned gas temperature distribution difference between CP and DFIS measured at 20 degree ATDC. As these data belong to the knock occurred cycle, these data don't belong to the occurrence of knocking yet. The mean temperature of DFIS is 955K and higher than that of CP. Using the t-test, a judgment was statistically made as to whether there was any difference between the mean values of the two groups of temperatures. It can be safely estimated that a temperature difference existed under the knock occurred cycle. Moreover, it can be also estimated that there was not a temperature difference under the nonknock cycle using t-test. As knock is easy to occur under high temperature condition in general, the converse result was obtained. This reason was studied in view of the mixture concentration in the next chapter.

Visualization and quantification of mixture concentration

Fig.10 shows the mixture concentration fields obtained by a high speed shatter camera with I.I.. These pictures were digitalised and also compensated the effect of the incident light intensity decreasing due to the laser beam absorption along the optical path by means of Digital Image Processing system. The measurement time is TDC and the ignition timing is 1 degree ATDC to

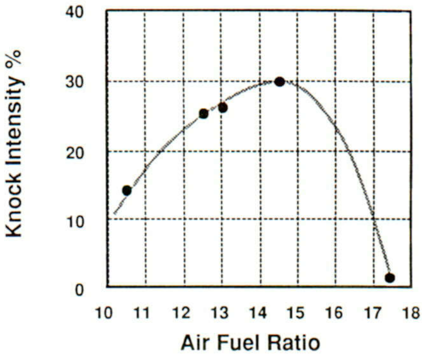

Fig. 8 Relation between Knock Intensity and Equivalent Ratio

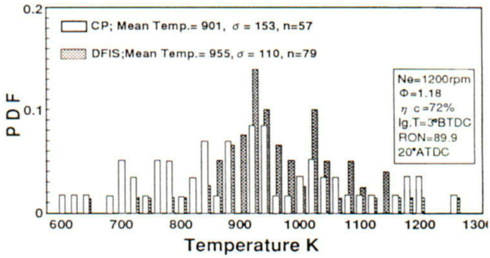

Fig.9 Temperature Distribution Difference between CP and DFIVO

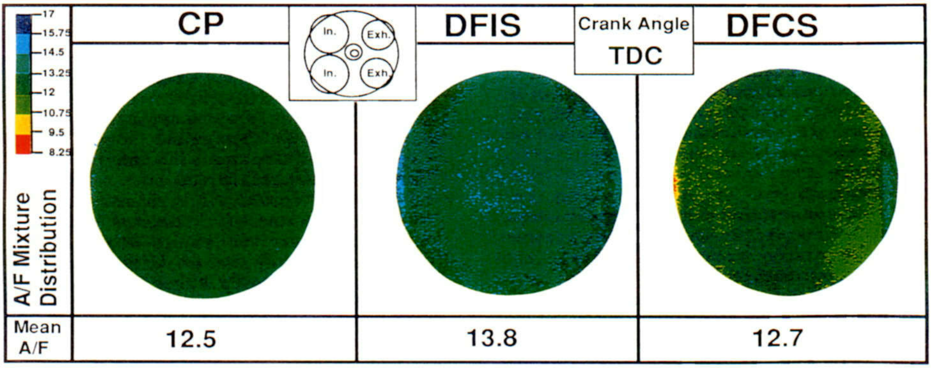

Fig. 10 Mixture Concentration Distribution for Different Fuel Supply System

avoid the influence of flame for this visualization and quantification of mixture concentration. To obtain the actual value of A/F from fluorescent intensity, perfect uniform mixture, which belongs to the different A/F, are prepared before the experiment. Correlation between fluorescent intensity and A/F are calibrated at each pixel in the observing area. Finally, these calibration curves were used to give the A/F values for each pixel. These observing areas don't include the area near the cylinder wall, but the A/F distribution in the outside of the observing area seems to be kept the similar distribution of the inside continuously.

Three kind of pictures in fig.10 show the mean A/F of the accumulated 20 cycles. In the case of CP, the mixture is uniform and the mean A/F that means the mean value of each pixel in the area of quantification is 12.5 and this value is same as that in this driving condition. While in the case of the DFIS, the mixing of air and fuel is not done well. The mean A/F in the area of quantification is 13.8 and this value shows that the mixture concentration in this section is leaner than that in this driving condition. In the case of DFCS, the mean A/F in the area of quantification is 12.7 and this value is similar to that in this driving condition. The mixture distribution in the case of DFCS seems to be the middle mixture distribution between CP and DFIS.

Two kind results of unburned gas temperature and mixture concentration are summarized. In the case of DFIS, as fuel droplets that comes into combustion chamber directly have the penetration, bigger droplets seem to impinge on the piston crown and cylinder wall. As a result, the rich mixture seems to be located near the piston crown at TDC and the mean A/F measured in the visualized section becomes lean in the case of DFIS. To change the words, the concentration gradient seems to exist along the cylinder axis and the rich mixture which value is above 12.5 should be located near the piston crown. In general, the autoignition occurs far from the ignition plug. The area near the corner of the cylinder wall and the piston crown which corresponds to the area far from the ignition plug is located below of the section visualized by laser sheet. Finally under this condition, knock intensity becomes weak as shown in fig.8 in spite of the higher temperature condition shown in fig.9. Incomplete mixing such as DFIS results in weak knock intensity and lower occurrence rate of knock.

CONCLUSION

Uniformity of mixture was visualized by LIF and temperature in unburned gas was measured by CARS. An analysis of the experimental results by means of both measurement techniques made clear the following points.

(1) Spatial distribution of A/F concentration effects on the occurrence of knocking significantly.

(2) In the case of DFIS, the existence of nonuniform A/F distribution results in the decreasing of knocking intensity.

(3) Existence of nonuniform mixture can suppress knock under the high temperature.

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REFERENCES

1. J.J.Marie and M.J.Cottereau, S.A.E.870458
2. R.lucht et al., Comb.Sci.and Tech.,Vol55,(1987)
3. T. Nakada et al., Transactions of JSAE(in Japanese with English summary)Vol.23 No.1,January 1992.
4. T.Nakada et.al., COMODIA 90,393-398.1990.
5. T.Nakada et.al.,Trans.of 9th Joint Symposium on Internal Combustion Engines(in Japanese with English summary),July 1991,p.63.
6. T.Nakada et.al.,S.A.E.Paper 932644
7. Qi-Ming Zhu et.al., Trans.of 9th Joint Symposium on Internal Combustion Engines(in Japanese with English summary),July 1991,p.67.
8. Y.Takagi et.al,SAE Paper 880196
9. R. Shimizu et. al, S.A.E.Paper 922356