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Characteristics of Turbulent Flow in a Cylinder of Pre-Combustion Chamber Spark Ignition Engine

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Abstract

The characteristics of gas flow such as mean velocity and turbulence during a compression and expansion strokes in the main combustion chamber of a spark ignition engine are very important factors effected to the burning velocity and flame propagation. The flow characteristics in the engine with pre-combustion chamber were studied and the results showed that the turbulence changed with the cut-off frequency. The specific cut-off frequency should be fitted in narrow range of crank-angle. The curve-fitting method can analyzed the turbulence in wide range of frequency compared with cut-off frequency method. The mean velocity in main combustion chamber swirled during a compression stroke and the variation of velocity distribution become large due to the torch jet flow during the expansion stroke. The turbulence intensity during expansion stroke increased rapidly when the torch jet flow closed to the measuring position. The spatial distribution of turbulence intensity totally different from the mean velocity. The integral length-scale decreased during compression stroke as crank-angle closed to TDC, due to the gas in the main cylinder compressed in the clearance volume.

1. Introduction

The characteristics of gas flow such as mean velocity and turbulence during a compression and expansion strokes in the main combustion chamber of a spark ignition engine are very important factors effected to the burning velocity and flame propagation. The flow characteristics are necessary for an estimation of combustion characteristics and simulation of combustion process of the engine. A spark ignition engine with pre-combustion chamber is designed in order to reduce the emission of pollution gases and increase the combustion efficiency. There are a number of researches on the flow characteristics of a spark ignition engine with a conventional combustion chamber, and in this paper will present the study of flow characteristics of the pre-combustion chamber spark ignition engine.

In general, the turbulence is defined as the higher frequency components of the velocity above a certain cut-off frequency, and frequency spectrum analysis is performed to obtain the mean velocity and the turbulence intensity for each cycle. However, it is difficult to decide the cut-off frequency for the method above called cut-off frequency method. Although there are many ideas to select the cut-off frequency, the unanimous method has not been established. In this paper, a simple method called curve-fitting method, is proposed for separating the turbulence from the instantaneous velocity. From these methods, the changes of mean velocity with time and spatial distributions, turbulence intensity and integral length-scale in the main chamber of pre-combustion chamber engine were made clear and they were compared with the results obtained by the conventional cut-off frequency method. The proposed method can obtained reasonable results compared with ones by cut-off frequency method.

2. Experimental conditions

Figure 1 and 2 showed a schematic diagram of experimental apparatus and cross section of a test engine. The experimental conditions are shown in Table 1. The instantaneous velocity of gas in the main chamber of an engine driven by an electric motor is measured by Laser Doppler Anemometer (LDA) during a compression and expansion strokes. The LDA measurements are made at several locations of main chamber diameter $(Y/R = -1\ to\ +1)$. The engine rotational speed of 600, 1300 and 2000 rpm were operated in this test. The measurement point is varied from $0 \sim \pm 0.75$

Table 1
Experimental conditions.

Engine speed N (rpm)	600, 1300, 2000
Volumetric efficiency	80%
Torch nozzle area, An (mm^2)	55 mm^2
Measurement points Y/R	0, $\pm$ 0.25, $\pm$ 0.50, $\pm$ 0.75

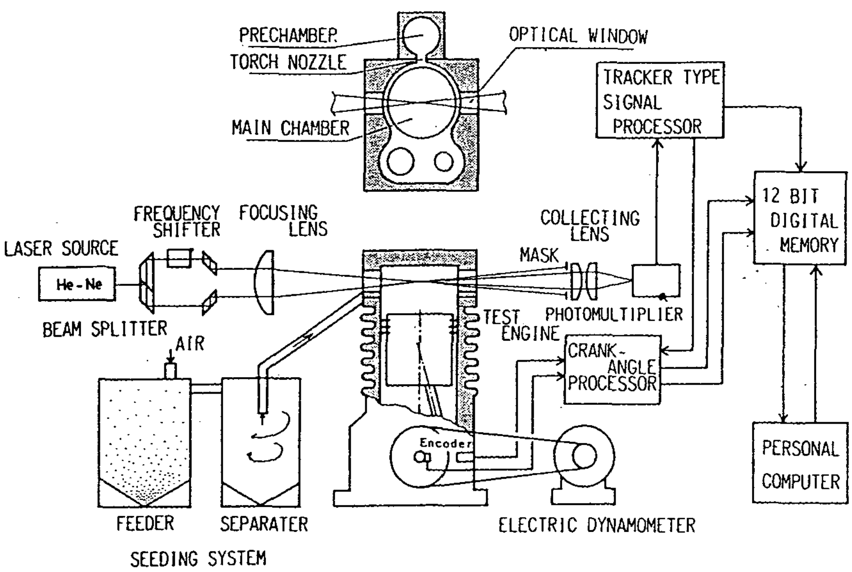


Fig. 1 Schematic diagram of experimental set-up.

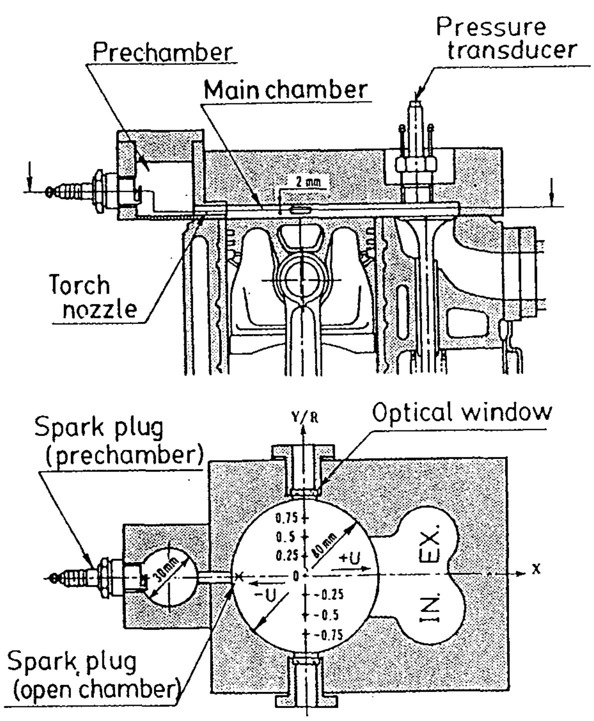


Fig. 2 Cross section of test engine.

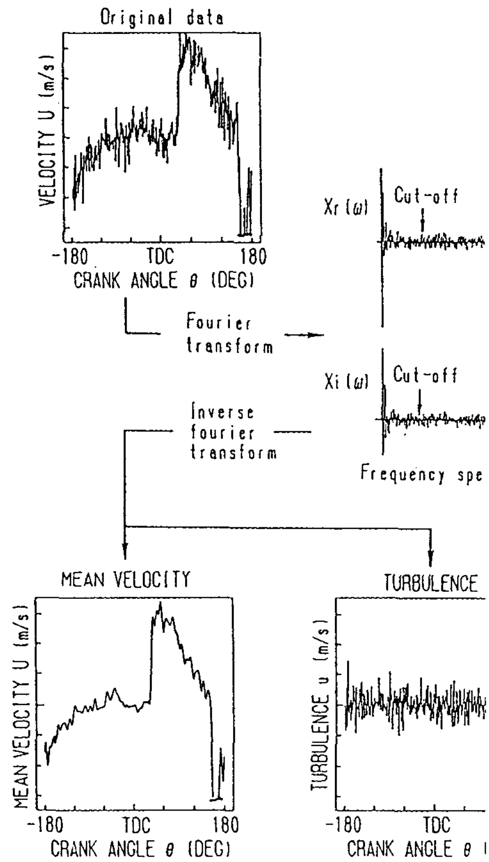


Fig. 3 Separation of mean velocity and turbulence by using cut-off frequency method.

3. Results and Discussions

(1) Separation between turbulence and mean velocit

Figure 3 showed the method to separate the me velocity and turbulence by using the cut-off frequen method. Figure 4 showed the results of measu instantaneous velocity and the mean velocity obtained the curve fitting method which is smoother than the c off frequency method.

In order to determine the cut-off frequency by usi the cut-off frequency method, there are two conditic should be consider as follows. (a) Ensemble turbulence which calculated by using the cut- frequency method is equal to zero or smaller compa with the value of turbulence intensity. (b) Ensemble mean velocity which obtained by this method are alm same value.

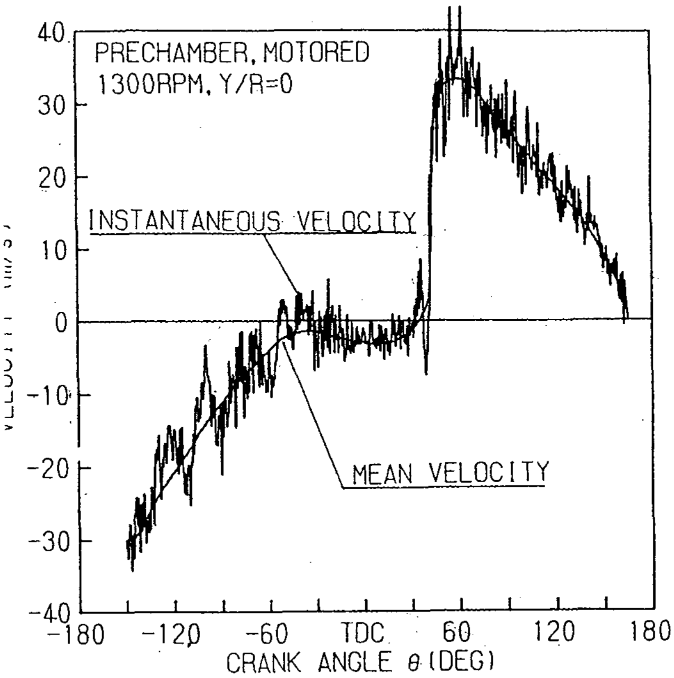


Fig. 4 Measured instantaneous velocity and mean velocity which obtained by curve fitting method.

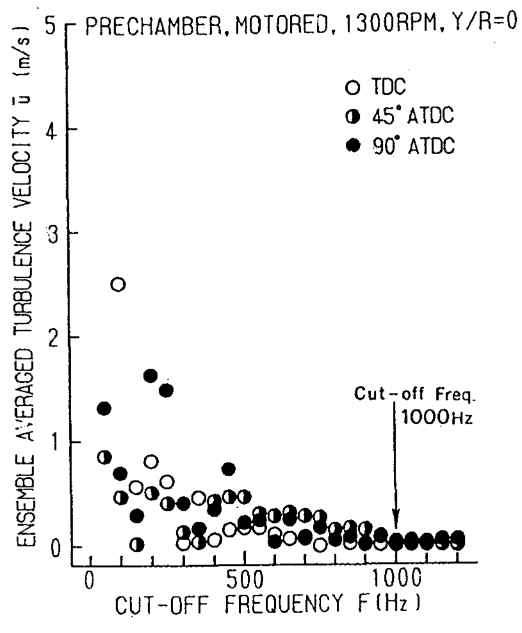


Fig. 5 Ensemble of averaged turbulence velocity.

Figure 5 showed the relationship between the values of cut-off frequencies and ensemble of averaged turbulence velocity which calculated by using the cut-off frequency method at top dead center (TDC), 45° and 90° after top dead center (ATDC) under the condition of the engine speed of 1300 rpm. The results showed that ensemble of averaged turbulence velocity gradually decreased as increasing of a cut-off frequency. The effect of the cut-off frequency on mean velocity at any crank angles is shown in Figure 6. Generally, a 1000 Hz is selected as a cut-off frequency in order to separate the turbulence and mean velocity. However, the values of cut-off frequency changed with the operating condition of engine and the measuring position as shown in Table 2.

Table 2
Cut-off frequency obtained under each experimental conditions.

(a) Changing speed condition at $Y/R=0$

Engine Speed, rpm	600	1300	2000
Cut-off frequency, Hz	330	1000	1700

(b) Changing measurement position at N = 1300 rpm

Y/R	-0.75	-0.50	-0.25	0	0.25	0.50	0.75
Fc	600	600	800	1000	600	400	600

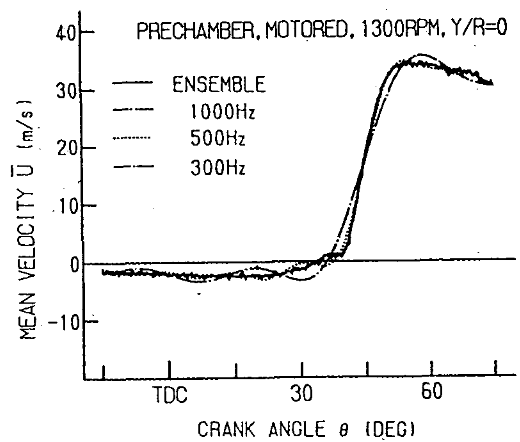


Fig. 6 Effect of cut-off frequency on mean velocity.

Figure 7 showed the comparison between the mean velocity and turbulence by using the cut-off frequency method and the curve fitting method at the center of main chamber $(Y/R=0)$ and cut-off frequency of 200, 600 and 1000 Hz. It was found that at the cut-off frequency of 200 Hz, the mean velocity curve does not follow to the instantaneous velocity at crank angle $30°-60°$ ATDC when the velocity increased rapidly due to effect of torch jet flow from pre-combustion chamber to main chamber. The curve of mean velocity with cut-off frequency of 600 Hz, 1000 Hz and the curve-fitting method are the same tentative. In regard to the turbulence, the results of the cut-off frequency of 200 Hz and the curve-fitting method are similarly and there are a turbulence with undulation appeared in the instantaneous velocity. The results of the cut-off frequency of 1000 Hz and 600 Hz do not include the undulation in the curve of turbulent. It was reported that the turbulence with frequency of $100\sim200$ Hz played an important roles in combustion of an internal combustion engine. From this viewpoint, the cut-off frequency of 1000 Hz which satisfied with two conditions of (a) and (b) as described above may be too much value. And also the cut-off frequency of 600 Hz will has the same problem.

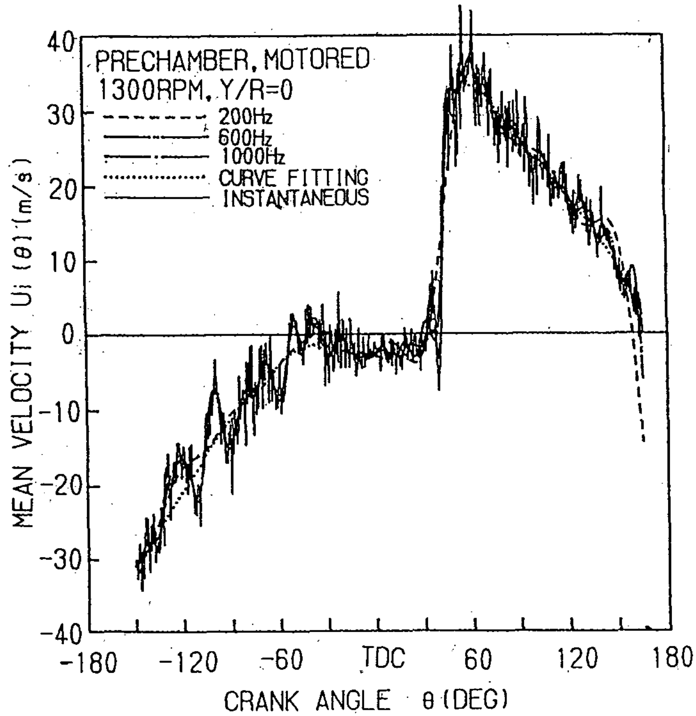


Fig. 7 Comparison of mean velocity obtained by cut -off frequency method and curve fitting method.

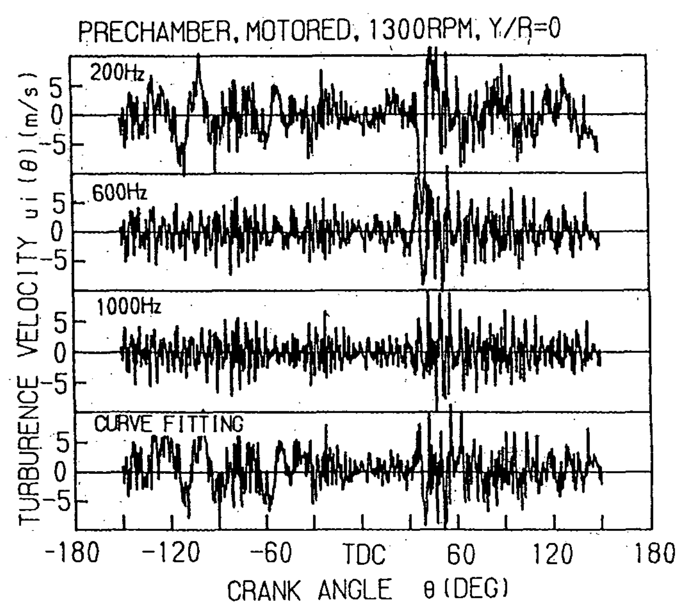


Fig. 8 Comparison of turbulence obtained by using both methods.

Figure 9 showcd the power spectra of the turbulence obtained by both methods. The value from the curve-fitting method has many low frequency components. Ensemble averaged turbulence velocity in Figure 10 showed the validity of curve-fitting method with condition of (a) and (b). Ensemble averaged turbulence velocity by the curve-fitting method has rarrowed fluctuation compared with cut-off frequency o 200 Hz. It was found that the curve-fitting method more satisfied with the condition (a) compared with cut-off frequency 1000 Hz, because the turbulence intensity by the former method is relatively larger than this method.

Figure 11 showed ensemble the mean velocity obtained by all methods. The curves by the method with cut-off frequency of 600 Hz and 1000 Hz and the curve-fitting method are almost similar, while the method with cut-off frequncy 200 Hz is difference from the others. The curve fitting method can satisfy the condition of (a) and (b) and it can analyzed all frequency components from the low to the high compared with the cut-off frequency method.

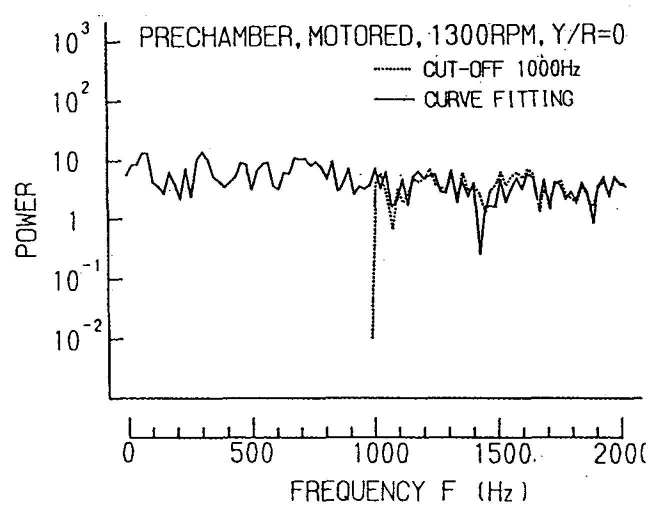


Fig. 9 Comparison of power spectra of turbulence obtained by both methods.

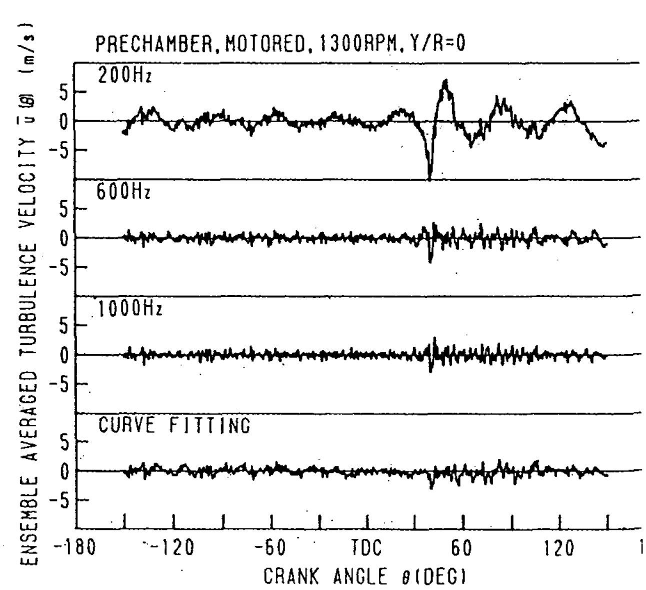


Fig. 10 Comparison of ensemble averaged turbulence obtained by using both methods.

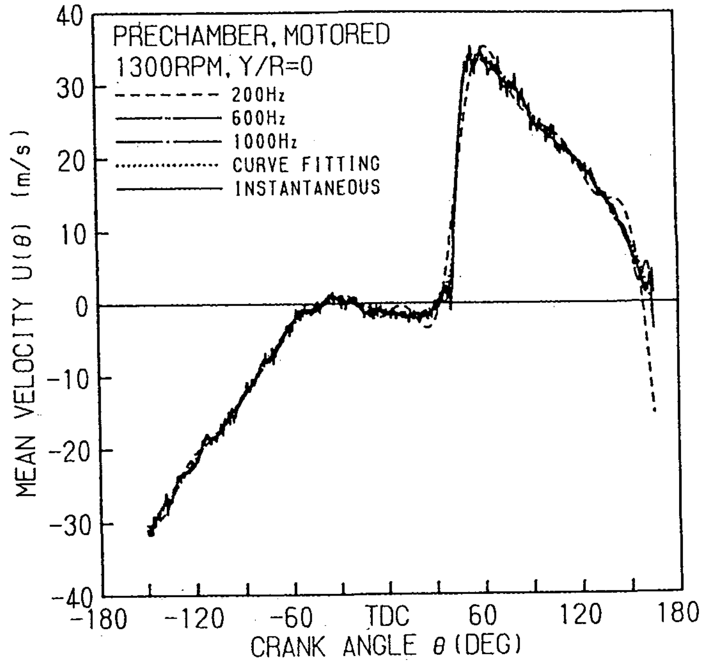
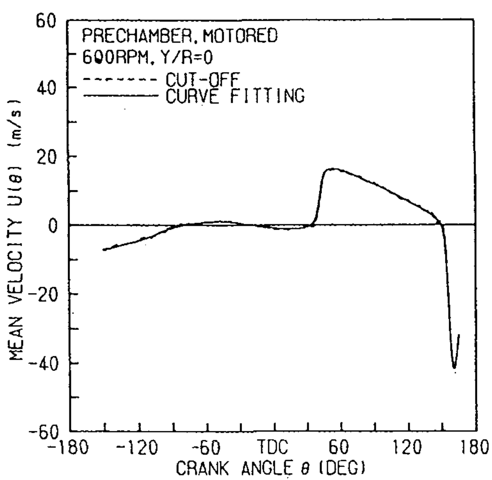


Fig. 11 Comparison of ensemble averaged velocity obtained by using both methods.

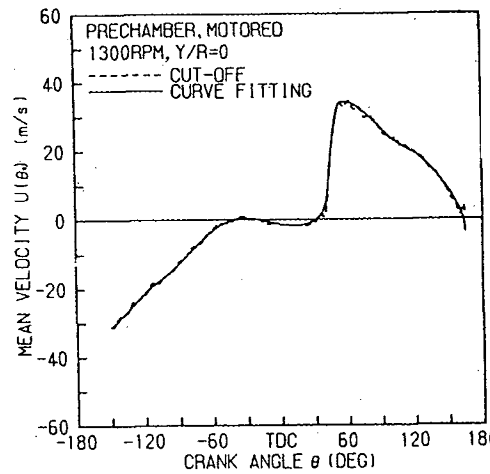


(a) at 600 rpm

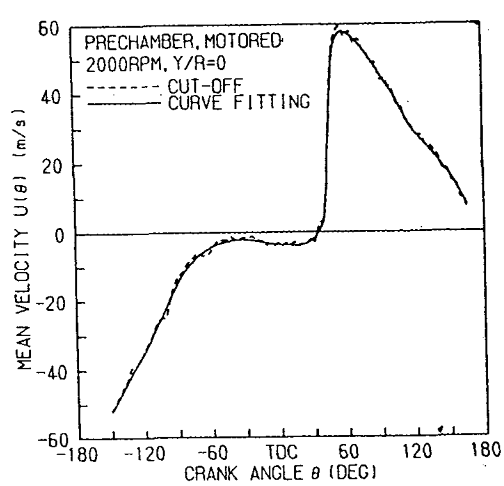
Fig. 12 Comparison of mean velocity obtained by both methods under different engine speed.

(2) Variation of turbulent characteristics with crank-angle and its spatial distribution in the main chamber

Figure 12 showed the comparison of the mean velocity at the center of main chamber by both methods with crank angle at diferenlt engine operating speed 600, 1300 and 2000 rpm. It was found that the results of both methods are almost same and a condition of (a) is satisfied whenever engine speed is changed. The distributions of mean velocity by both methods also has same tendency with each others at different crank-angles during a compression and expansion strokes as shown in Figure 13. At crank-angle before 40° BTDC, the flow which came from intake valve was in the direction between the torch nozzle and the pre-combustion chamber and after that, the swirl flow is produced in the main chamber and at the center of the swirl where its velocity was zero gradually moved from center to the wall of the main chamber. After 40° ATDC, the velocity distribution was changed by the flow which ejected from the torch nozzle and its pattern is held for some crank-angles.



(b) at 1300 rpm



(c) at 2000 rpm

Fig. 12 Comparison of mean velocity obtained by both methods under different engine speed. (continue)

$(Y = \pm 0.25)$. These due to the reverse flow at both sides of torch jet flow.

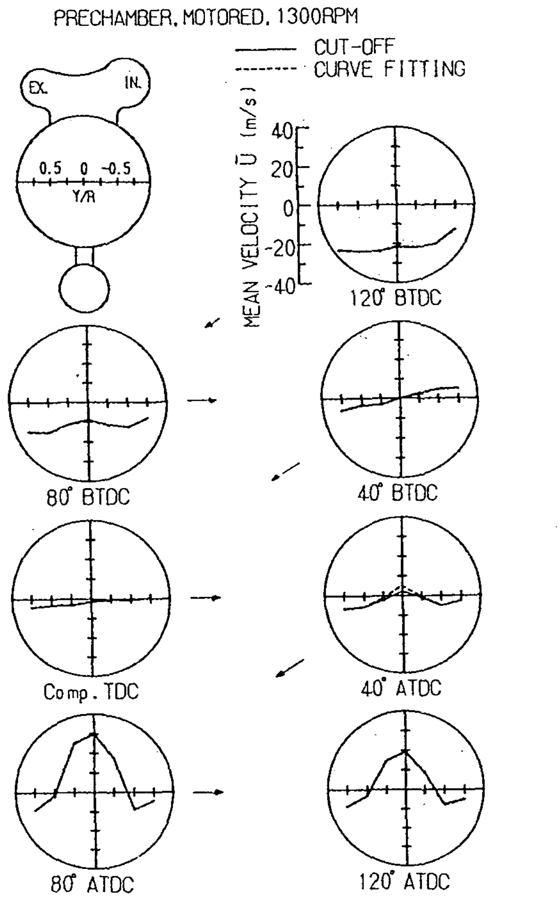


Fig. 13 Distribution of mean velocity during compression and expansion strokes.

Figure 14 showed the comparison of the turbulence intensity of all the methods at the center of main chamber during the compression and expansion strokes. The curve-fitting method and the cut-fitting frequency of 200 Hz method have larger turbulence intensity than other two cut-off frequency during the compression stroke. But in case of cut-off frequency of 200 Hz method the turbulence intensity increased rapidly before the jet ejected from pre-combustion chamber. The results of curve-fitting method and cut-off frequency method of 1000 Hz showed a similar pattern, but value of curve-fitting method is larger than the cut-off frequency method except at top dead center (TDC). Figure 13 showed the uniform distribution of the mean velocity at any measuring position (Y/R) until 80° BTDC, while the distribution of turbulence intensity in Figure 15 is non-uniform distributed. In the expansion stroke the turbulence intensity at the center start to increase by the jet flow and then increased at both sides of it

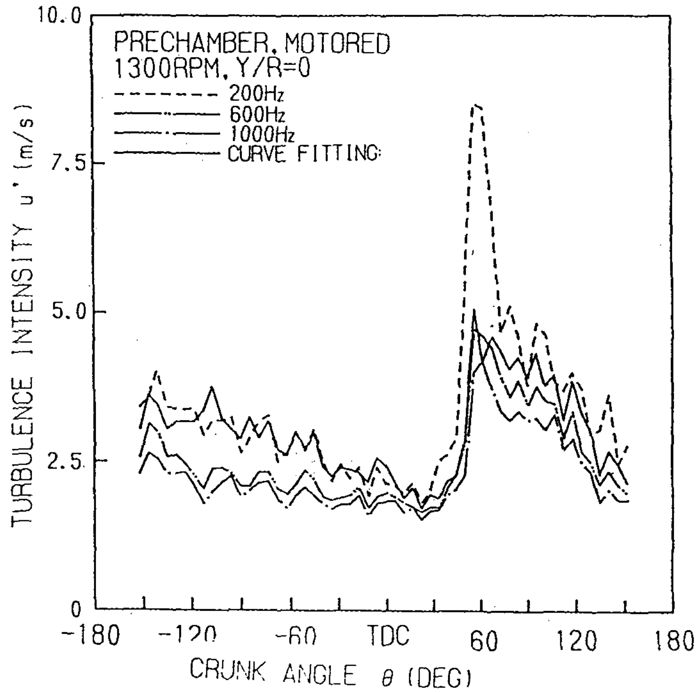


Fig. 14 Turbulence intensity during compression and expansion strokes.

Figure 16 showed the variation of the integral length-scales in main chamber by all methods at various crank-angle during the compression and expansion strokes. The integral length-scale decreased during compression stroke as the crank-angle increased close to the top dead center (TDC) because of the gas in the main cylinder is compressed as the piston move upward. During the expansion stroke the integral length-scale are rapidly increased at almost same stage when the torch jet flow reached the measuring position except in case of cut-off frequency method of 200 Hz. The distribution of the length-scale in the main chamber by the curve-fitting method and cut-off frequency method 1000 Hz are shown in Figure 17. The difference between the results by both methods become large at crank-angle of 120° BTDC and $Y/R = -0.25 \sim +0.25$ but after that it will be small.

The following conclusions are summarized from above results.

1) The turbulence are changed with the value of cut-off frequency. Furthermore, the specific cut-off frequency will be fitted in narrow range of crank-angles, because the suitable cut-off frequency is existed for each crank-angle of engine rotation.
2) Curve-fitting method does not have the limitation for selection of frequency and it can be analyzed the turbulence in wide range of frequency compared with cut-off frequency method.
3) The swirl of the mean velocity in the main combustion chamber was produced during the compression stroke and the variation of velocity distribution become large due to the torch jet flow

during the expansion stroke. The turbulence intensity during expansion stroke increased rapidly when the torch jet reached the measuring position and the spatial distribution of turbulence intensity was different from that of the mean velocity.

4) The integral length-scale decreased during the compression stroke when the crank-angle closse to TDC, due to the gas in the main cylinder was compressed by the piston which move upward to the TDC. During the expansion stroke the integral length-scale are rapidly increased at almost same stage when the torch jet flow reached the measuring positon.

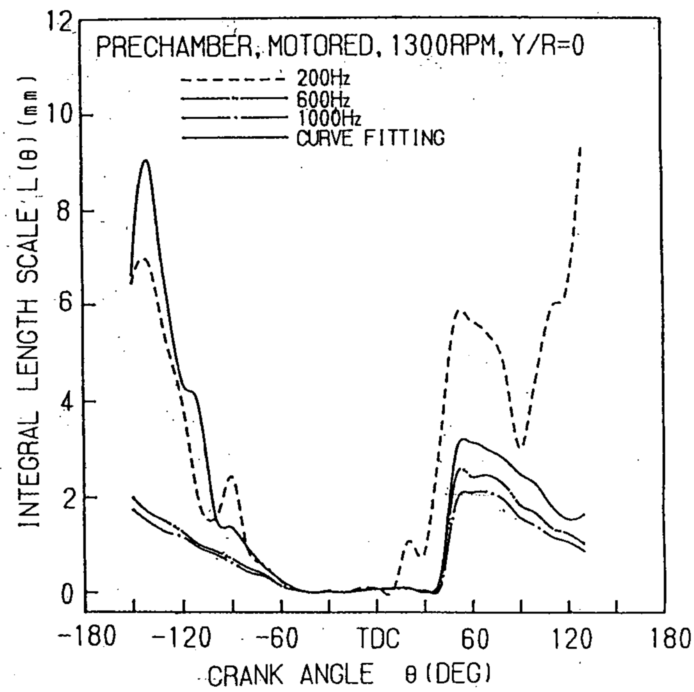


Fig. 16 Integral length-scales during compression and expansion strokes.

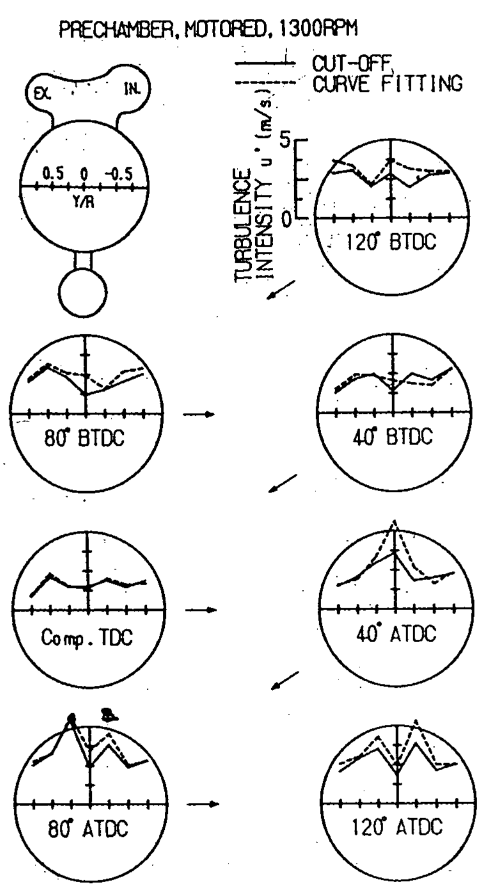


Fig. 15 Distributions of turbulence intensity during compression and expansion strokes.

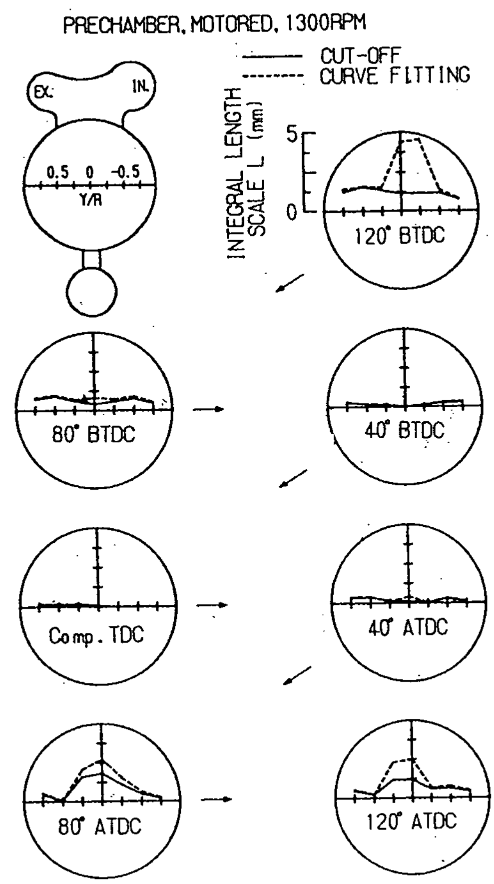


Fig. 17 Distributions of integral length-scale during compression and expansion strokes.

Reference

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