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APPLICATION OF FLAME MEASUREMENT TECHNIC BY DENSELY INSTALLED ION-PROBES ON 2-STROKE GASOLINE ENGINE

Tomoaki YATSUFUSA*, Kentaro TAKATANI*, Shinsuke MIYATA*
***Hiroshima Institute of Technology**

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Abstract

Ion-probe is relatively inexpensive and physically strong method to detect the flame in confined chamber. A new technic to measure the propagating flame precisely by using densely installed multiple ion-probes has been developed. This measuring method using multiple ion-probes can obtain the information of dynamic and spatial behavior on propagating flame that cannot be realized by single ion-probe.

Our group investigated the suitability of this method for precise measurement of high-intensity and pulsatile combustion, such as knocking in gasoline engine, and destructive oscillating combustion in burner or gas turbine. In such environment, optical measurement or pressure measurement are often utilized. However, optical observation is generally utilized only for limited conditions because of the strength of observation window. Compare to the visualization, pressure sensor is much stronger, but it can only capture indirect information of combustion. In contrast, ion-probe is physically and thermally strong enough to endure such environment.

In the present study, three ion-probes were installed on the cylinder head of the 2-stroke gasoline engine on chainsaw, and the output signals from those installed ion-probes were investigated. Idle and WOT (wide open throttle) operating conditions were tested. In idle condition, circumstantial evidence clearly showed that ion-probes could detect the existence of the flame. However, detailed information of propagating flame in engine cylinder could not be obtained. The problem to be solved had been clarified by the series of experiments.

1 Introduction

1.1 Difficulty of combustion measurement in reciprocating engines

Measurement of combustion in reciprocating gasoline engine has a difficulty in measurement, because it's pulsatile high pressure caused by high-intensity and explosive combustion [1,2]. In general, such a combustion in reciprocating engine is measured experimentally by visualization and pressure measurement of combustion field in piston-cylinder.

The visualization-technique inside of a reciprocating piston engine generally uses an optically-accessible transparent window [3,4] at engine development in laboratories [5-9] and manufactures [10,11]. In general, materials chosen for transparent window are quarts, sapphire, or toughened glass. However, general optical accessible windows are not strong enough for pulsatile high-pressure by high-intensity and explosive combustion in actual engine operational conditions even if such strong and expensive materials are chosen. Therefore, engine operation with visualization are generally forced to be under the low-load conditions.

On the other hand, pressure measurement can only infer the combustion conditions indirectly from the temporal changes in internal pressure, although the mechanical strength of pressure sensor is high enough for high-intensity combustion.

1.2 Multiple ion-probe method in reciprocating engines

Ion-probe method is to detect the flame contact and the activity of flame chemical reaction by measuring the electric current flows on ionized intermediate products in flame. Because this simple principle to detect makes this method inexpensive and physically strong, this method is often used in measurement of explosive combustion in experimental field.

However, ion-probe method can only detect the information of activity of chemical reaction at a certain contact point to flame, and cannot detect the spatial information.

The new technic developed by our group adopts the multiple ion-probes that densely installed on the combustion chamber wall [12]. These densely installed ion-probes detect the flame one by one as flame propagating. If the density and the number of the multiple ion-probes are large enough, dynamic and spatial behavior along the chamber wall can be reproduced by recorded ion-current signals detected by each ion-probe.

In the previous studies, this newly developed multiple ion-probe method was applied to the measurement of propagating flame of LPG-oxygen-nitrogen mixture in confined tube. A few types of multiple ion-probes were tested and the characteristics of measurement were investigated. From the series of experiment, both the minimum and maximum propagation velocity, that is from a few meters

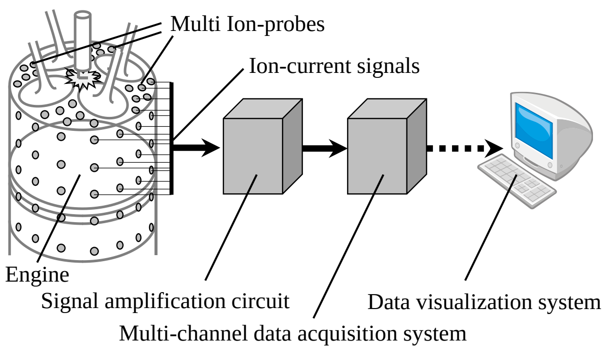

Figure 1. Schematic of engine combustion measurement system by multi ion-probes.

per second to about 2300m/s were measured successfully. This range covers most type of combustions utilized in the industrial field.

2 Details of multiple ion-probe system and experimental setup

Figure 1 shows the schematic of engine combustion measurement system by multi ion-probes. The ion-current signals were amplified by a signal amplification circuit. Amplified signals from the multiple ion-probes were recorded by multi-channel data acquisition system. In the previous studies, the confined combustion tube instead of the engine and the originally developed 64ch data acquisition system were used. In the present study, measurement target was 2-storoke gasoline engine, and the high-speed data logger was used for data acquisition because longer recording duration were required.

As a first step of combustion measurement, 2-stroke gasoline engine was chosen, because hemispheric and air-cooled cylinder head of 2-stroke gasoline engine is ideal for installation of ion-probes. Figure 2 shows the aspect of tested 2-stroke gasoline engine on chainsaw ECHO CS-370. Table 1 shows the details of the CS-370. From the reason of safety, chain-bar that has chain rail and cuts trees was removed. During the measuring test, engine operation was executed without any load.

Figure 2. Aspect of tested 2-stroke gasoline engine on chainsaw CS-370.

Table 1. Details of tested 2-stroke gasoline engine.

Product	ECHO CS-370
Displacement	36.3 cc
Bore	38 mm
Stroke	32 mm
Number of cylinder	1
Cooling type	Air cooling
Engine type	2-stroke gasoline engine

Figure 3 shows the schematic diagram of installation of ion-probes on cylinder head of 2-stroke gasoline engine. Three ion-probes were installed with the interval of 33 degree from the summit of the cylinder hemisphere to the opposite direction of the ignition plug. Diameter of the ion-probes were 0.8mm, and were insulated electrically from the aluminum cylinder head by ceramic tube. One additional ion-probe was placed (not installed) nearby the ignition plug to pick the ignition spark noise up to determine the ignition timing. Therefore, four signals including three ion-signals and one ignition signal were recorded.

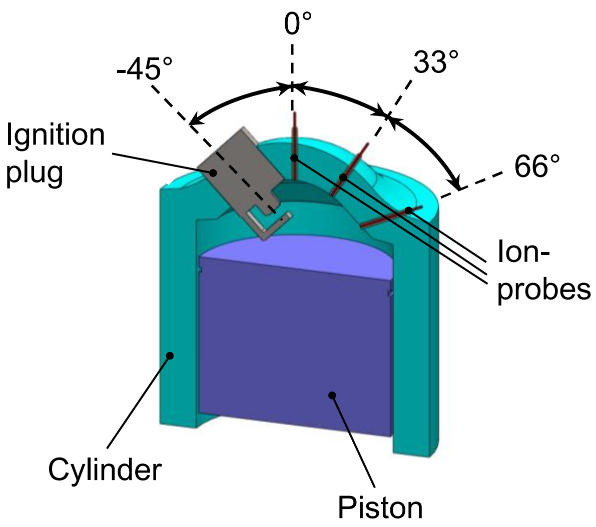

Figure 3. Schematic diagram of installation of 3 ion-probes.

3 Experimental results

Figure 4 shows the recorded ion-signals in one second under idle operating condition. 42 times of ignition signal were detected in the recorded duration, and calculated engine speed was 2,520 rpm. The recorded signal includes firing and misfiring cycles. Misfire is the characteristic feature of 2-stroke gasoline engine in idle operating condition. There were several firing cycles in numerous number of misfiring cycles at 0.25sec, 0.41sec, 0.55sec, 0.70sec and 0.87sec, where much denser signals were observed.

In the next, the details of firing and misfiring cycle were compared each other. Figure 5 shows the detailed recorded signal from 0.30 to 0.35sec in Figure 4, which is thought to be misfiring cycle. There was less signal rising behind the first ignition signal rising around 0.31sec. This must mean that no ignition occurred in this cycle. On the other hand, there were some signal risings on ion-probe of 0 degree and 66 degree behind the second ignition signal rising around 0.337. It is uncertain that these signals were caused by flame or some noise. In addition, the engine speed calculated by the time difference between first and second ignition signal rising was 2,143rpm, that is lower than average speed of 2,520rpm in one second recorded duration. This means that the engine speed was decelerated in this cycle, and there is no contradiction that misfiring tends to decelerate engine speed.

Figure 6 shows the enlarged recorded signal from 0.54 to 0.59sec in Figure 4 that is thought to be firing cycle. In fig. 6, three signal risings caused by ignition signal were detected. The engine speed calculated from the average time interval from these ignition signal was 2,941rpm, which was higher than average speed of 2,520rpm. This is the result of acceleration by firing cycle. Signal risings behind the ignition signal seem to be the detected flame signals. Although the expected order of the signal rising on each ion-probe was 0deg. - 33deg. - 66deg, actual order of signal rising did not follow the expected order.

Figure 7 shows the recorded ion-signals in the period of 0.05 second under wide open throttle (WOT) conditions. The displayed period in this figure is same as fig. 5 and fig. 6. 10 times of ignition signal was recorded in that period, and the engine speed calculated from these ignition signals was 12,371rpm. Ion-signals from all of tree ion-probes were detected. Although, the expected signal rising was in order of 0deg. - 33deg. - 66deg, actual signal riging were randomize and irregular. This recorded signal does not seem that the ion-probes did not detect the accurate flame arrival time.

Figure 8 shows the detailed signals from 0.040 to 0.052sec in fig. 7. Three ignition signals are shown in fig. 8, that means two engine cycles are included in this figure. In a 2-stroke gasoline engine, latter half period of the cycle occupies scavenging and compression

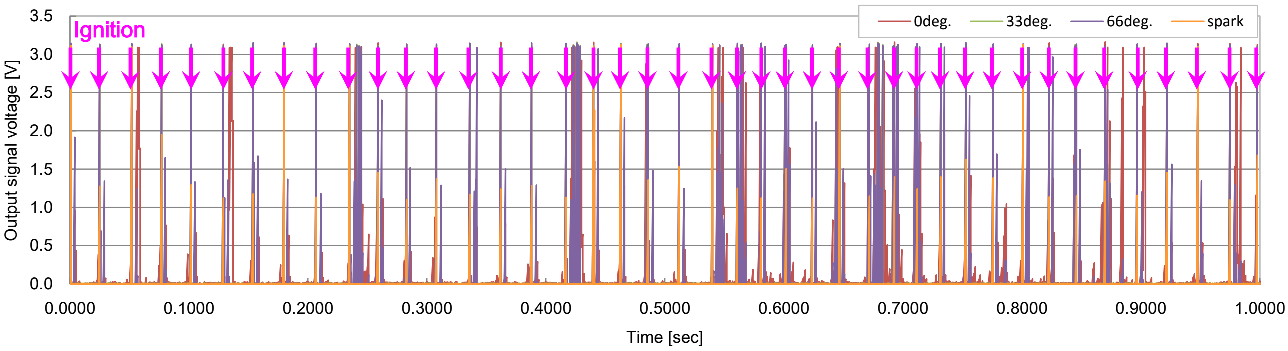

Figure 4 Output ion-current signal in idle operating condition

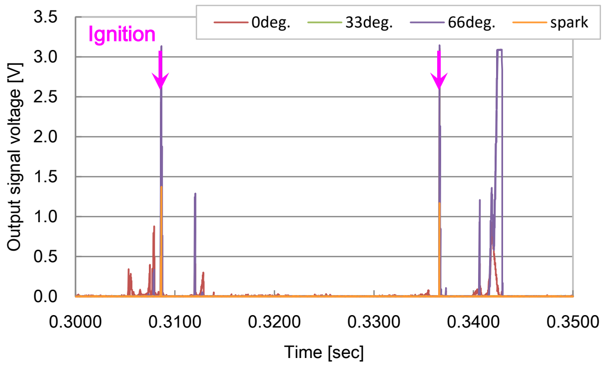

Figure 5 Output ion-current signal at misfiring cycle in idle operating condition

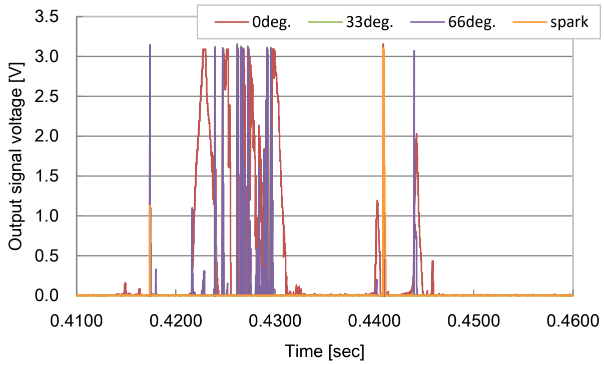

Figure 6 Output ion-current signal at firing cycle in idle operating condition

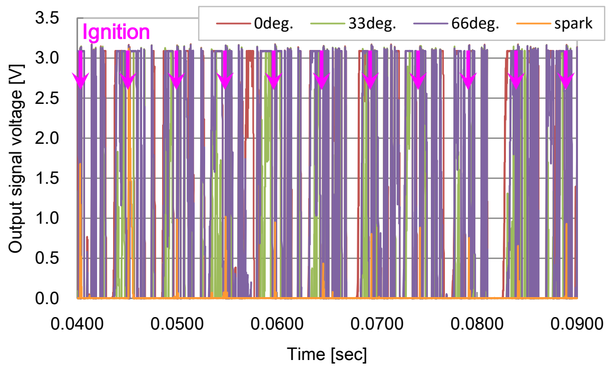

Figure 7 Output ion-current signal of 10 cycles in WOT operating condition

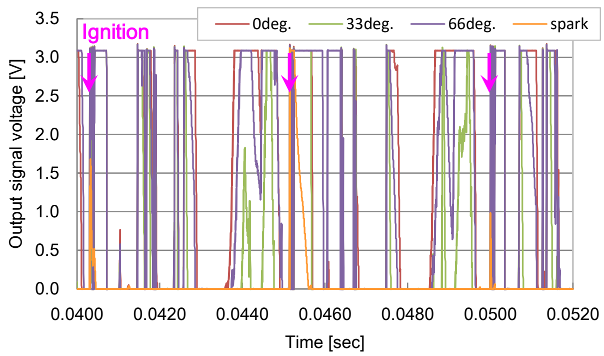

Figure 8 Output ion-current signal of 2 cycles in WOT operating condition

process. Therefore, no combustion reaction occurs in the latter half period and nothing should be detected by ion-probes. However, signal risings in all ion-probes appeared just prior to the ignition signals, where scavenging and compression process occurred. This means that the recorded rising signals in latter half of engine cycle were fake.

There are some possibilities that cause these fake signals. One is that ignition spark noise affects the amplification circuit to result malfunction. The second possibility is combustion products. Combustion products including water and solid hydrocarbons have small electric conductivity, which breaks the insulation between ion-probe and ground. This situation allows flowing small electric current between ion-probe and ground. This results the same reaction, which electric current flows when flame contact with ion-probe. To solve these problems, our group will continue to find the proper ways to reduce effect of noise and combustion product.

4 Conclusion

Measurement of flame propagation in 2-stroke gasoline engine by multi ion-probes was conducted. The following results were obtained.

- In the idle operating condition, firing cycle and misfiring cycle were able to be distinguished by ion-signals. This means that the multi ion-probe system can respond to the flame in 2-stroke gasoline engine.
- In the wide open throttle conditions, the fake signals were detected even in the scavenging and compression process occurred. This may be resulted by the effect of ignition spark noise on amplification circuit and breaking of electric insulation by combustion products.

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