Investigation of flame measurement characteristics on multiple ion-probes

Hiroshima Institute of Technology　Naoya MIURA

■ Introduction

Ion probes are used in detonation measurement and flame measurement in engines as a method of measuring the presence or absence of the arrival of a flame. The multiple-ion probes method enables temporal and spatial resolution of the flame behavior near the wall of the combustion chamber. Furthermore, a design that takes thermal and mechanical strength into consideration is possible. In this study, we used a 120-ch probes, By using the 120ch ion probes, we aimed to improve the time and space resolution within the measurement range and measure the propagation flame more precisely. The fuel used in the experiment was a stoichiometric mixture of CH_4 and O_2, and was diluted with N_2 according to the experimental conditions.

■ Measurement principle of ion probe

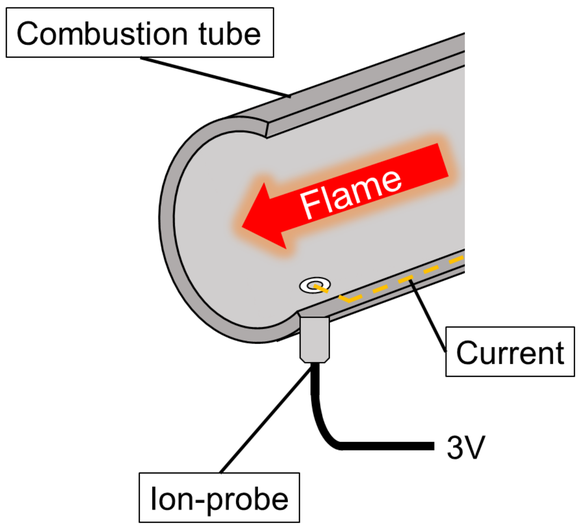

Figure 1. Measurement principle of ion probe.

The ion probe measures the flame using the weak electrical conductivity of the flame.3V is added in advance to the tip of the ion probe, and when the flame passes, the combustion tube becomes ground and an output voltage is generated. Although the output voltage is used as a flame detection signal, since the signal is weak as it is, the signal amplification circuit amplifies the signal.

■ Experimental apparatus and conditions

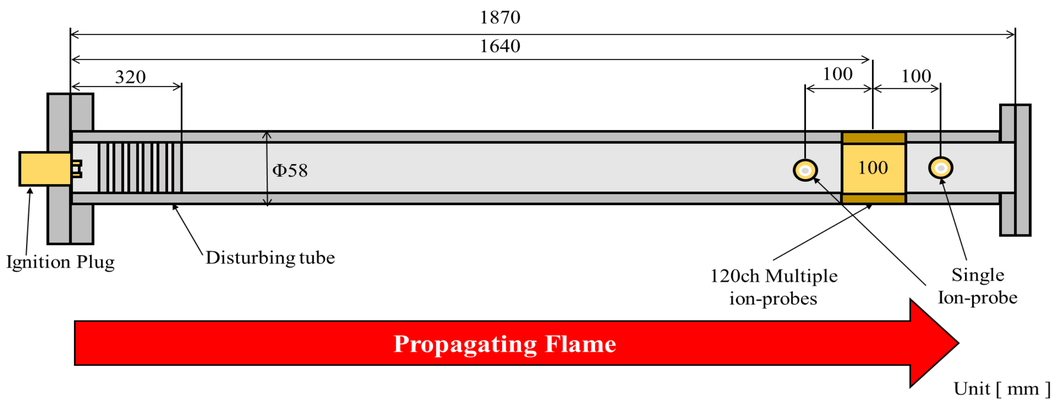

Figure 2.　Appearance of experimental equipment.

The propagating flame propagates from left to right in the combustion tube shown in Fig.2. Multiple-ion probes are placed at a position 1640 mm from the spark plug, and the flame transitioning to detonation is measured by a disturbing tube. In order to calculate the average propagation velocity of the flame, independent ion probes are attached at 100 mm on both ends of the multi-ion probe.

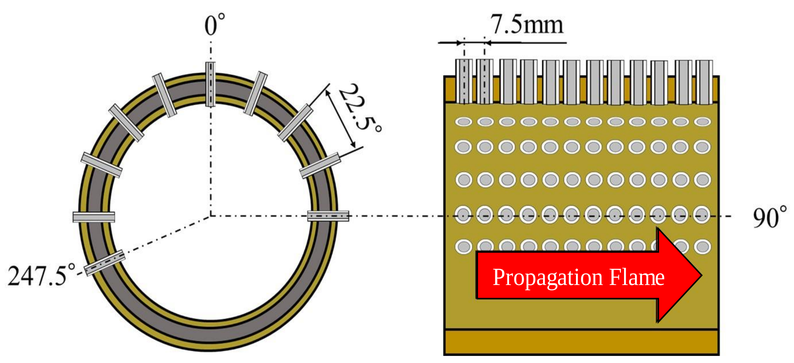

Figure 3. Multiple-ion probes.

Fig. 3 shows the layout of the 120ch multiple-ion probes. The ion probes are arranged in ten rows of 22.5 ° in the circumferential direction. Twelve are arranged at intervals of 7.5 mm in the tube axis direction. There are a total of 120 installed in 10 rows in the circumferential direction and 12 in the tube axis direction.

Table.1 Experimental conditions

Nitrogen Mole Fraction(NMF)		NMF=0	NMF=0.45	NMF=0.71
Mixing ratio	CH_4	1		
	O_2	2		
	N_2	0	2.5	7.5
C-J Velocity[m/s]		2394	1977	1806
Initial pressure[atm]		1		
Initial temperature[K]		293		

Table 1 shows the experimental conditions. The stoichiometric mixture of CH_4 and O_2 was diluted with N_2. NMF means nitrogen mole fraction, NMF = 0 corresponds to no dilution, NMF = 0.45 corresponds to a dilution limit at the transition to detonation, and NMF = 0.71 corresponds to a stoichiometric mixture gas with air.

■ Experimental results

Fig.4 to Fig.7 visualize the results under each experimental condition. In Fig. 4, between each ion probe It can be seen that the propagation velocity repeats acceleration and deceleration. Fig.5 to Fig.7 are contours showing the flame surface shape with time. The color of the contour represents the detection time, which means that the detection time is delayed as it changes from red to blue.

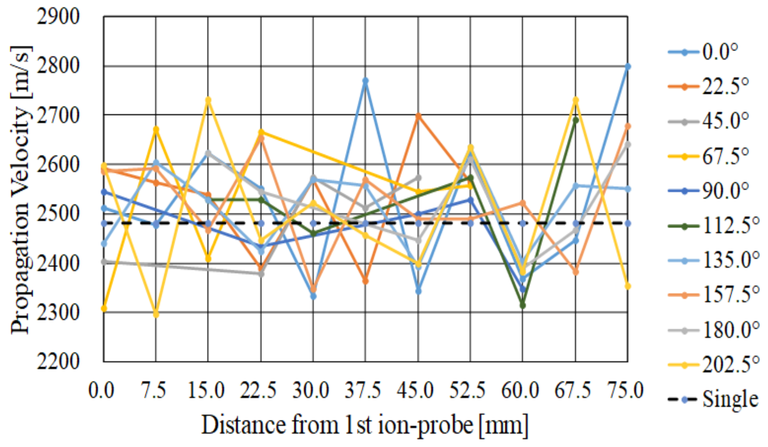

Fig.4 Flame propagation velocity NMF=0

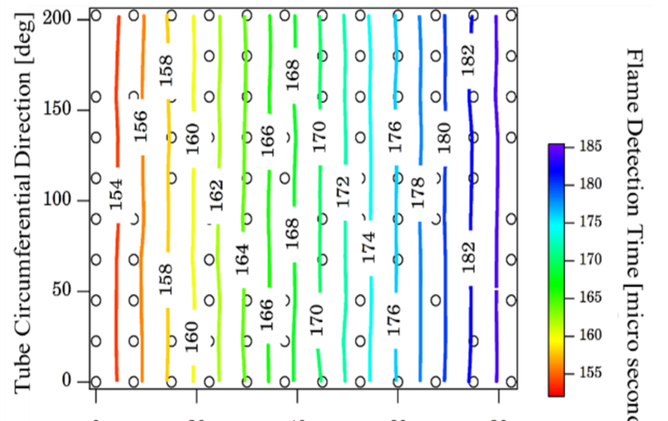

Fig.5 Propagation flame at NMF=0

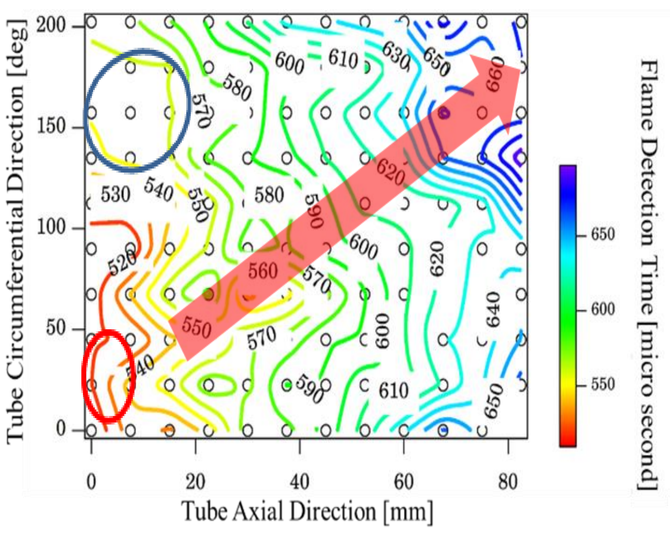

Fig.6 Propagation flame at NMF=0.45

The red circle in Fig. 6 has a slow propagation velocity, and the blue circle has a fast area. Also, the flame is propagating in the direction of the red arrow.
The upper figure in Fig. 7 shows the flame front shape after detection time 10.4 ms. The figure below shows the shape of the flame front before 10.4 ms. The flame average propagation velocity was 119.5 m / s.

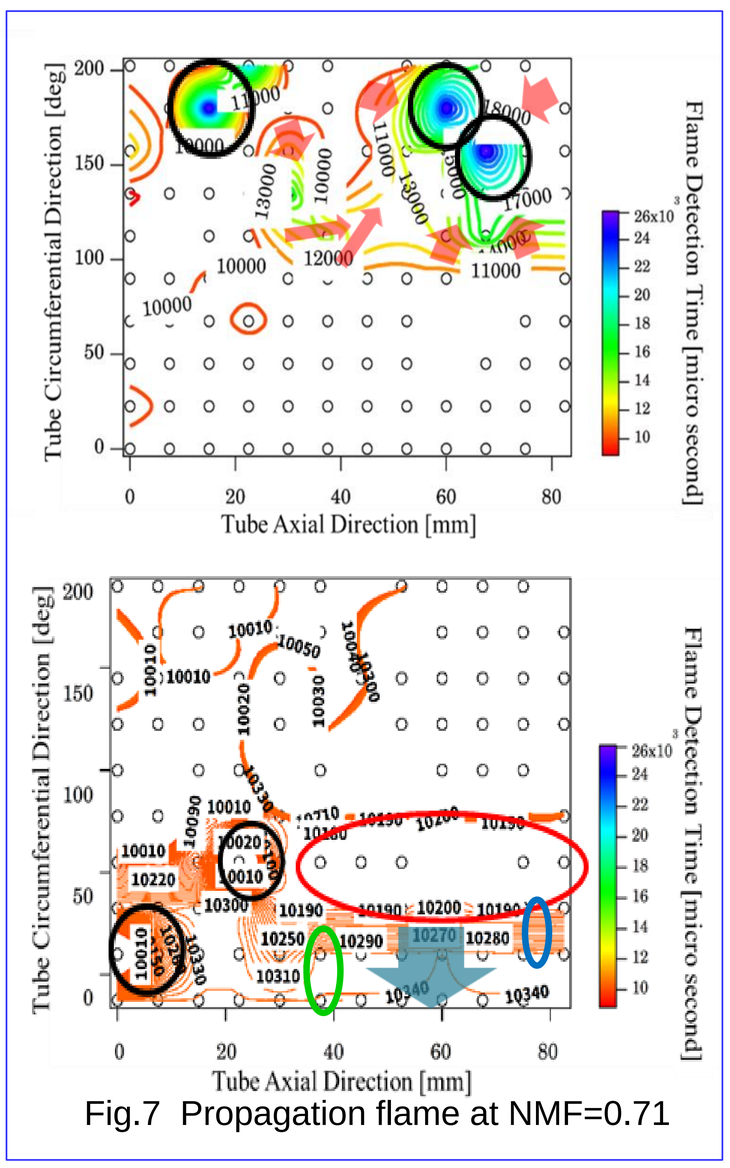

Fig.7 Propagation flame at NMF=0.71

In the upper figure of Fig. 7, the region with extremely slow propagation velocity indicated by the black circle was detected. This is considered to be detection of the stagnation and unburned area of the flame by unburned gas. Under the condition of NMF = 0.71, the flame does not transition to detonation, and the pressure and temperature are low, so that the conditions for combustion are severe. Therefore, this unburned area is considered to be the extinction of the local flame.

The lower figure of Fig. 7 shows the part where the detection time is less than 10.4 ms. After the flame contacts the red circle in the figure, the flame propagates in the direction of the blue arrow. Since the area of blue circles has a propagation velocity of 62.5 m / s and the area of green circles has 250 m / s, the flame propagation velocity is accelerating or decelerating. Also, a new unburned area in the black circle area was also detected.

■ Conclusions

Detailed measurement experiments of flames were conducted using multiple ion probes. Under the condition of NMF = 0, we were able to capture micro-explosions of the detonation wave front and two-dimensional flame propagation. Under the condition of NMF = 0.45, it was possible to measure the acceleration and deceleration of the propagation flame, and under the condition of NMF = 0.71, it was possible to measure the appearance of the flame propagating in the unburned region and the tube circumferential direction.

■ References

[1] Tomoaki Yatsufusa, Keigo Kii, Kentaro Takatani, Shinsuke Miyata, “Detailed measurement on propagating flame of methane-oxygen mixture by densely installed multiple ion-probes”COMODIA2017（2017）

[2] Keigo Kii, Naoya Miura, Hiroki Yamamoto, Tomoaki Yatsufusa, “Detailed measurement of propagating flame by multiple ion-probes” JSME Yamaguchi (2019)