Studies on the Growth of Hot Gas Spots Produced by a Spark Dischage

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ABCTRACT

This paper discusses the growth of hot gas spots produced by a spark discharge and heat loss to electrodes. The hot gas spots in spark gaps were investigated by Mach-Zehnder interferometry, in which two methods of displacement fringe and density contour fringe were adopted.

This study indicates that heat loss to electrodes increases with the increasing of contact area-fraction of hot gas to electrodes, the growth of the spots are checked as the result of heat loss, and the energy possessed by the spots retains only about 20% of the total spark discharge even if in case of the biggest.

INTRODUCTION

The development of flame kernel, its decay, and flame movement in spark ignition engines have been investigated by several researchers. Regarding these problems, Witze et.al.(1) and Kerstein et.al.(2) discussed the flame kernel movement in their paper respectively, and Pischinger et.al.(3) treated the development of flame kernel and heat loss to electrodes. These papers gave many suggestions for this study. We have also attempted a numerical simulation regarding these problems in previous paper(4), in which the growth of hot gas spots produced by composite spark, its decay and the occurring of convection in the hot spots have been investigated. However, we noticed that there are many unknown facts to establish.

This study aims to investigate the relation between the growth of hot gas spots produced by a spark discharge and heat loss to electrodes. Spark test was mainly performed without gas flow at the atmospheric condition. In addition, the influence of pressure to hot spots has been investigated.

EXPERIMENT

Test apparatus is schematically shown in Fig.1 with the optical and electronic circuit. Electronic circuit is composed of power supply, pulse generator for spark, induction-coil and spark gaps. Pulse generator is acted first, and spark discharge is generated in spark gaps through the secondary coil.

The spark-discharged energy in all test is about 39mJ. Spark electrodes are made of iron, three kinds of electrode shapes are used as shown in Fig.2, and the spark gaps of 2.5mm has been fixed. The shapes of gaps are pointed ends and cylindrical ends having diameters of 1.6mm and 2.6mm.

He-Ne laser is used as a light source, the spark gaps is put in the light path of Mach-Zender interferometer as shown in Fig.1. The

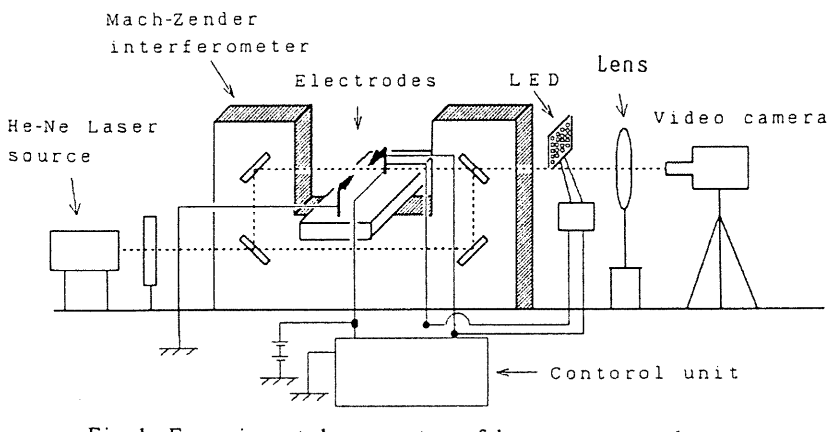

Fig.1 Experimental apparatus of hot gas spots-observation using a Mach-Zender interferometer

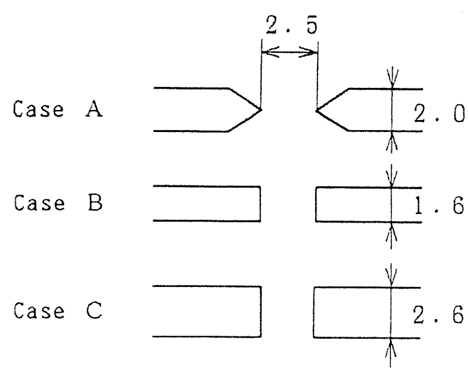

Fig.2 Shapes of electrode gaps

hot gas spots produced by spark discharge is visualized in the two methods which are displacement fringe and density contour fringe, taken with video camera of shatter speed 10^{-4}s and analyzed. The time from spark discharge is obtained from light-signals of luminous diodes in each frame.

RESULTS AND DISCUSSION

Development of hot gas spots

The growth of hot gas spots produced by spark discharge has been investigated by density contour fringe and displacement fringe.

First, spark test has been performed at atmosphere condition using three kinds of electrode shapes. Figure 3 shows photographs taken with density contour fringe. Each of these photographs represents different tests. Comparing the growth of hot gas spots of three kinds of electrodes in the early stage, there is almost no difference up to 0.4ms from spark onset about the outer fringe of the spots in the three cases. However, their differences are revealed after 2.0ms. As shown in Fig.3, a spherical hot spots develops largely in case of pointed ends, and the other hand the hot spots in case of cylindrical ends retains between electrode gaps. This indicates that the growth of the spots has been checked by heat loss to cold electrode gaps.

Second, figure 4 shows an example of photographs obtained by displacement fringe, the fringe-shift between electrode gaps are observed in the figure. The density change caused by the hot spots is obtained from the fringe-shift h and the length of light pass d as follows;

$$\rho_g = \rho_0 - \frac{\lambda h(x,y)}{kd} \quad (1)$$

$$T_g = T_o \frac{\rho_g}{\rho_0} \quad (2)$$

ρ_g = density of hot gas spots
ρ_0 = initial density
h = fringe shift
d = length of light pass
λ = wave length of laser
k = Gradstone-Dail number
T_0 = initial temperature
T_g = mean temperature of hot gas spots

Figure 5 shows the temperature-shift of hot gas obtained from density change. Where, the temperature is supposed to be uniform in the hot spots, and each curved line is obtained by a polynomial expression based on experimental values. As shown in the figure, the temperature is shifting in high level in case of pointed ends, and low levels in case of cylindrical ends. It is noticed that their temperature become the highest after 1.6ms to 2.4ms from spark onset in all cases.

Figure 6 shows the energy obtained from hot spot-volumes and their temperature. Affecting of the contact area of hot gas to electrodes, the energy is comparatively small in case of

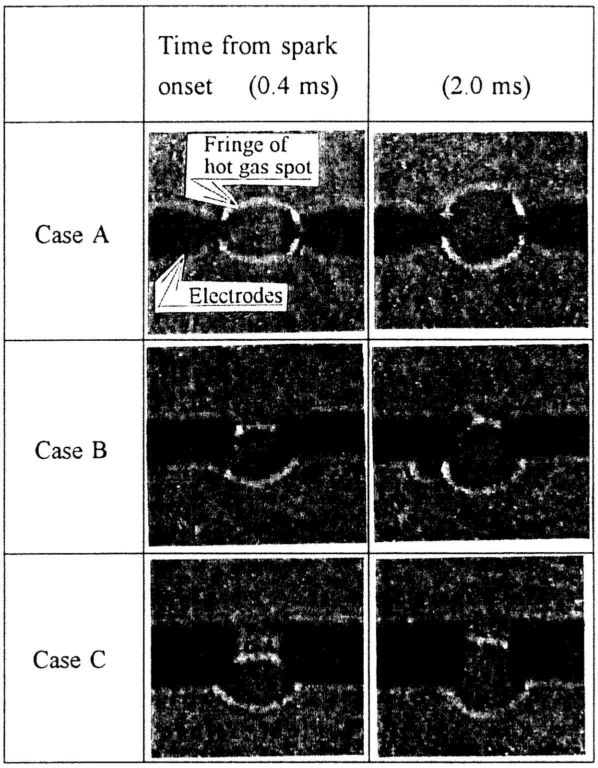

Fig.3 The growth of hot gas spots in three kinds of electrode gaps

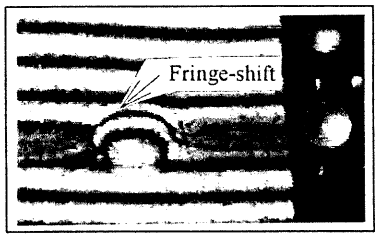

Fig.4 An example of photographs of the fringe-shift obtained by displacement fringe method

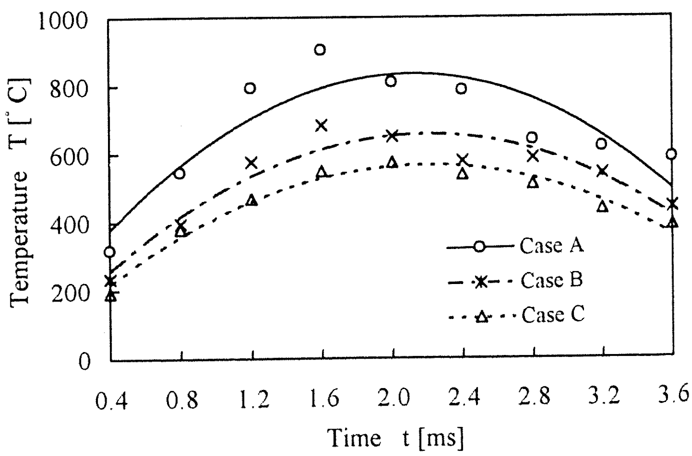

Fig.5 The temperature-shift of hot gas spots

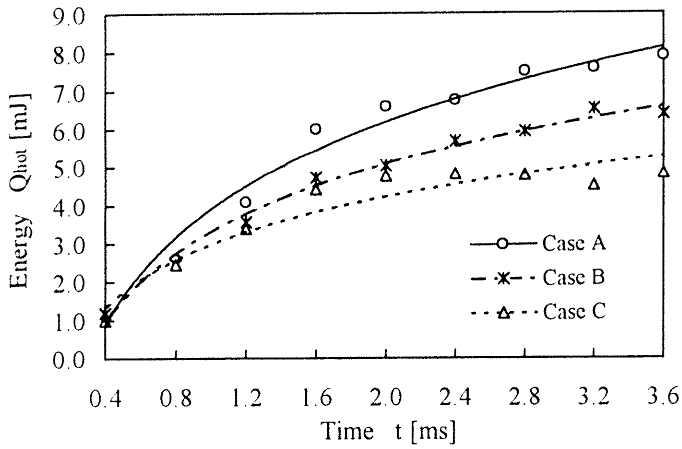

Fig.6 The energy of hot gas spots

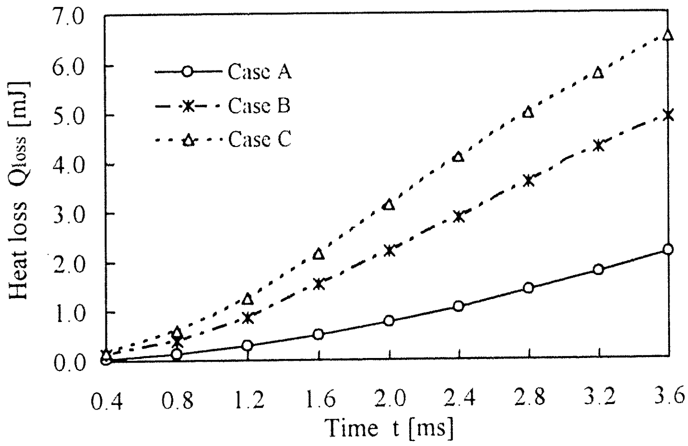

Fig.7 Heat loss to electrodes

Table.1 The energy percentage transferred from a spark discharge

Electrode shapes	Heat loss to electrodes	Energy of hot gas spots	Dissipated energy
Case A	4.9% (1.9mJ)	19.5% (7.6mJ)	75.6%
Case B	11.1% (4.3mJ)	15.7% (6.1mJ)	73.2%
Case C	14.9% (5.8mJ)	11.9% (4.6mJ)	73.2%

cylindrical ends, and large in case of pointed ends. However, even if it is the largest, the energy possessed retains only about 20% of the total spark discharge.

Heat loss to electrodes

Further, the heat loss to electrodes was evaluated by their temperature and contact area of hot gas to electrodes, using eq. (3). Where, the heat transfer coefficient means the average of heat flow rate from gas and plasma to electrodes. Coefficient h=1500 [J/m²Ks] which Pishinger et. al. were used in their study of the growth of flame kernel(3) was adopted.

$$Q_{loss} = hA_c(T_g - T_w) \qquad (3)$$

A_c = contact area of hot gas spots to electrodes
T_g = mean temperature of hot gas spots
T_w = temperature of electrodes

Figure 7 shows heat loss to electrodes obtained from the contact area and hot gas-temperature. Table 1 represents the energy percentage transferred from a spark discharge energy. From these values, it is noticed that energy of hot gas spots is about the same amount of heat loss to electrodes in case of cylindrical ends (Case B and C), and their losses are comparatively small for the total energy. It seems that much amount of energy is dissipated by means of radiation and pressure wave etc.

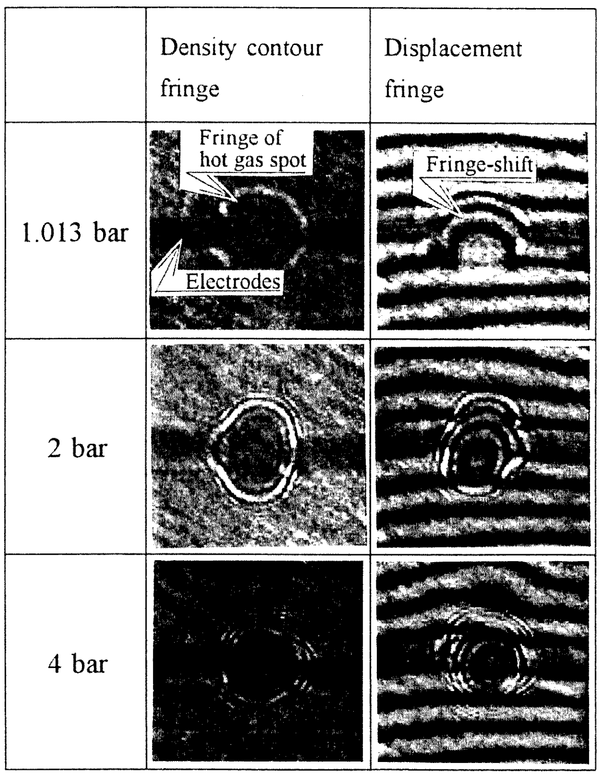

Fig.8 The fringes obtained by Mach-Zender interferometry of hot gas spots under various pressures (after 1.6ms from spark onset)

Effect of pressure

In order to investigate the initial pressure-effect to the growth of hot gas spots, an additional spark test was performed as same as mentioned before. A set of spark gaps in a high pressure vessel was put in the laser path penetrating windows of hard glass.

Figure 8 shows the fringes due to density change of hot gas spots under several pressures. As shown in the figure, the fringes produced by hot gas spots are piled up with pressure rise. The dual and triple fringes come out as the results of light path-difference owing to the steep density gradient at the outer of hot spots. The temperature-distribution in hot spots is not uniform, and shows the temperature-distribution focused in the center part of hot spots-bulk with pressure rise.

From above consideration, we can image schematic drawing of hot gas spots as shown in Fig.9. It is noticed that the uniformity of hot gas temperature is collapsed with pressure rise, there are the generation of hot spots having the high temperature regions focused in the center part.

Last, the mean temperature of hot spots shows in Fig.10, comparing that of two pressure levels. The mean temperature of hot spots under 2 bar is lower the that of the atmospheric condition, however, the reason is that the hot spots contain high temperature regions of the center part and the outer region of low temperature, the mean temperature decreases owing to the reason mentioned above, with the difference of heat capacity. We aboided to get the mean temperature of hot spots under 4 bar because of ambiguity of displacement fringe-shift. It is found that the temperature-structure of the hot spots is changed with pressure rises.

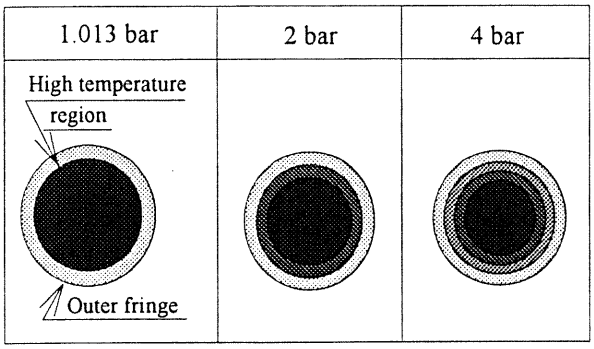

Fig.9 Schematic drawing of a hot gas spot-structure

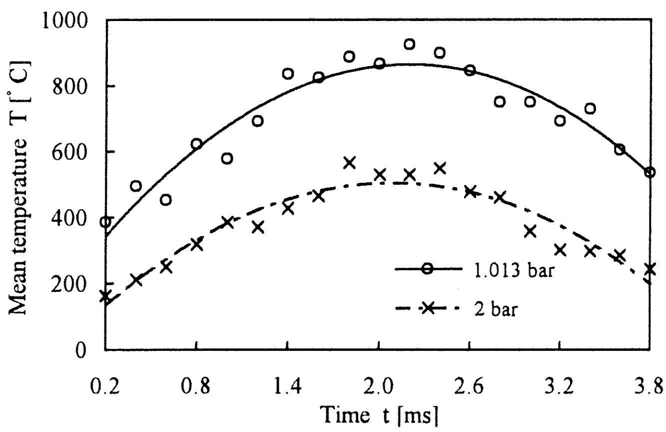

Fig.10 The temperature-shift of hot gas spots under the various pressures

CONCLUSIONS

The growth of hot gas spots produced by a spark discharge and heat loss to electrodes have been discussed, next facts are revealed.

(1) Heat loss to electrodes increases with the increasing of contact area-fraction of hot gas to electrodes.
(2) The growth of hot spots are checked as a results of heat loss.
(3) The energy possessed by the spots retains only about 20% of the total spark discharge.

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