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Sparking at Electrical Contacts on Closure

(Received 13, June, 1957)

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Abstract

The features of the sparks emitted by a heavy electric current at several metal contacts on closure have been determined, and the weight loss of the contact materials due to the electric current has been measured. They are;

The number of the spark trails and the loss of the contacts do not increase in proportion to the increase of the supplied energy at the contacts. The velocities of the pellets emitted from steel contacts in air, in O_2 gas and CO_2 gas were measured respectively with the rotating film. In O_2 gas the burst of the pellets is severe, while in CO_2 gas the burst is lax. Metals of lower melting points produce greater amount of loss by the closure.

I. Introduction

If a pair of electrical contact is closed abruptly and a heavy current starts to flow impulsively, the first point of contact is burned out by the rush of current, and it is seen usually that many spark trails are emitted from the touch point of the contacts. The main purpose of this report is to investigate the properties of these sparks and to measure the loss of the contact electrodes for various materials of the electrode. The luminosity of the spark trails radiates from the small metal pellets of about 10μ in diameter. These pellets are the molten fragments of the metal contacts; they receive the energy from the electric current, and then they are emitted into the suroundings, while heated by the oxidation. To prove these facts the observations of the spark trails in oxygen gas and in carbonic-acid gas were made respectively. Furthermore, the metal pellets were collected on soft papers and observed by microscope. The outside view of the spark trails is similar to that of the trails in the spark testing of metal with the grinder-wheel. But the metal which produces no trails in this testing (for example, such as aluminium and its alloys) produce luminous trails intensely at the closure of the electrical contacts.

II. Experimental Arrangement

The contacts of steel, nickel, copper, silver, aluminium and fuse were used in this experiment. Each contact consisted of a small rod about 0.5mm or 1mm in diameter and a plate electrode. The circuit is represent in Fig. 1. A variable capacity which has capacitances in the range from 0.5 to 100 micro-farads charged to a potential difference of 500 Volts were used as power supply of the contacts.

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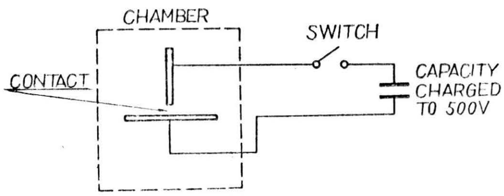


Fig. 1 Experimental Circuit

These contacts were operated by an electromagnet and the make - break actions were made remotely. Each duration of the closure was sufficiently long for the capacity to be completely discharged. The contacts were placed inside a chamber which could be filled with suitable gases and be kept dark in order to take photographs of the spark trails. Two apertures stand abreast on a wall of this chamber and each of them provides the camera. These two cameras could be arranged to take stereoscopic photographs of the trails. One of them could be provided with a rotating orbicular film when the velocity of the pellets was to be measured. Most of the observations of the spark trails were made by means of the photographs taken with these cameras and Super-XX film with Eastman D-76 developer containing Hydrum solution. Before the closure, the surfaces of the contacts were prepared by polishing with four sorts of emerypapers 1, 00, 0/2, 0/4 and pure benzene. To reduce the internal distortions of the material in polishing, the emery papers immersed in benzene were used. After a few closures of the contacts, the photographs of the trails were taken. All of the observations in this experiment were made as functions of energies imposed at the contacts.

III. Experimental Results

1. The number of the spark trails

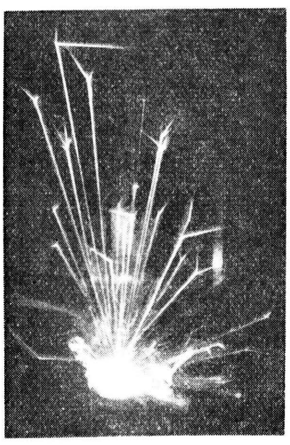


Photo. 1 Steel contacts in Air, C=8μf.

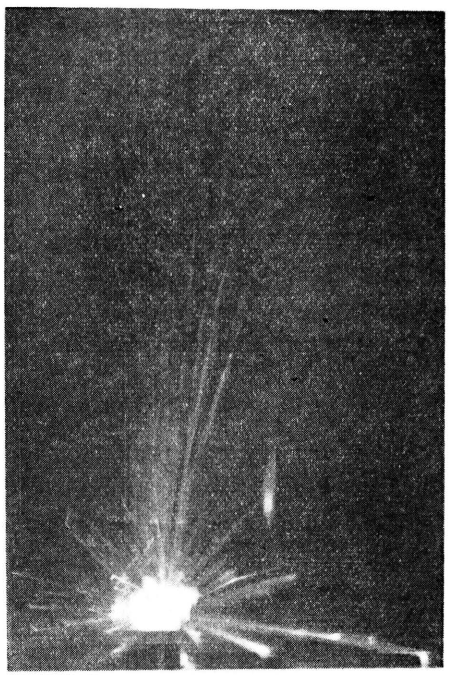


Photo. 2 Steel contacts in Air, C=50μf.

Photos. 1, 2 are of the trails in the air for the contacts of a rod of steel 0.5mm in diameter and a steel plate. The carbon contents of the former is about 0.2% and the latter about 0.3%. From the photographs taken with the lens with small iris, the numbers of the spark trails in the pattern of the photographs were counted for the above electrode. In the next place the chamber was filled with O_2 gas and CO_2 gas respectively, and the numbers of trails were counted for both cases. When the polarity of the contacts is reversed, the observed numbers of trails changed slightly. Fig. 2 shows the results, in which the capacitance lies in the range from 8μf to 90μf. The ordinate represents the number of the trails and the abscissa the capacitance. As seen in this figure the trails in CO_2 gas are less than that in air and in O_2 gas, the luminosity of the sparks is distinct, while in CO_2 gas dim and weak trails were observed. Photos. 3~6 represent the trails in these cases.

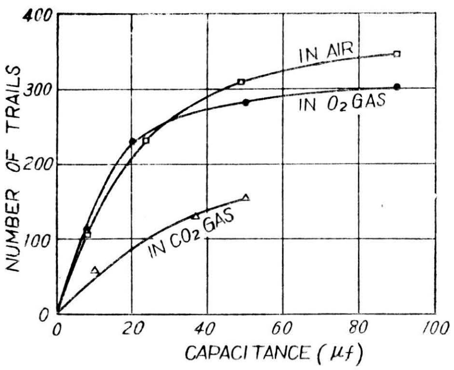


Fig. 2 **The number of the Spark Trails in Air, O_2 gas, and CO_2 gas.**

The trails emitted from steel, copper, silver, and carbon electrode were also photographed, and the numbers of the

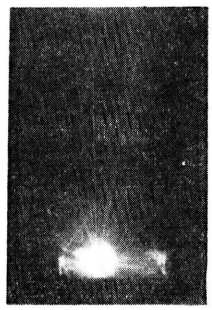


Photo. 3 Steel contacts in CO_2 gas. $C=8\mu f$,

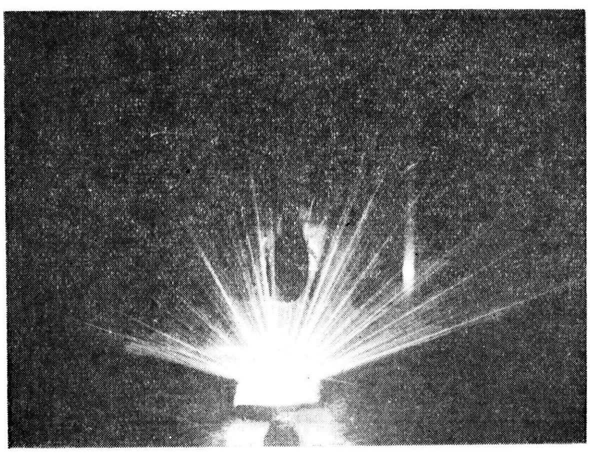


Photo. 4 Steel contacts in CO_2 gas, $C=50\mu f$.

trails were also counted. Fig. 3 shows the results, and photos. 7 ~ 11 represent their experiments. The shapes of the trails differ with the elecrtrode materials. These features are shown in Fig. 4. Silver, copper, and carbon have straight trails, steel has ruptured trails, nickel has spear heads at the ends of trails, while aluminium has turned trails at the ends. As seen in photos. 3~6 the trails of steel do not rupture in CO_2 gas, but in air and in O_2 gas they rupture severely. From these facts, it is clear that the ruptures of the steel trails need oxygen gas.

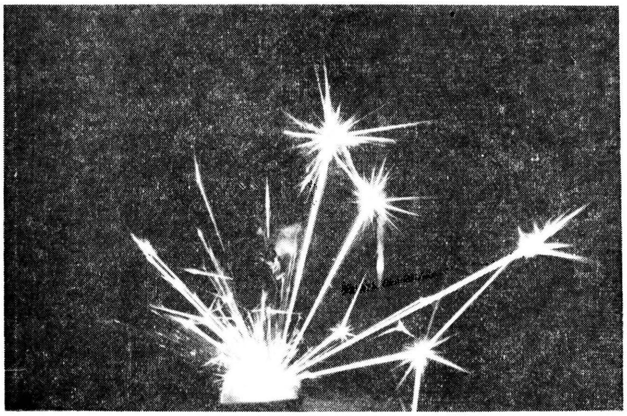


Photo. 5 Steel contacts in O_2 gas, $C=8\mu f$.

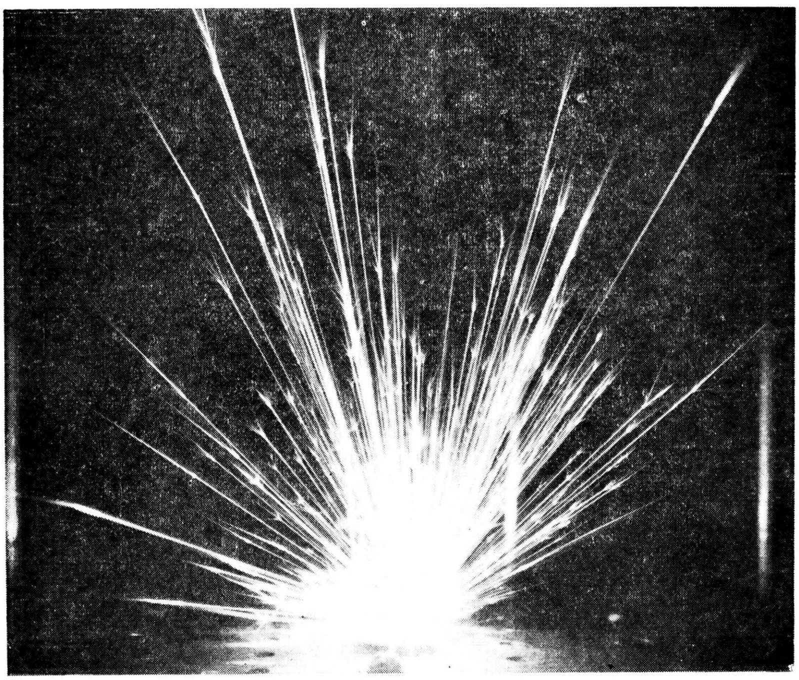


Photo. 6 Steel contacts in O_2 gas, $C=50\mu f$.

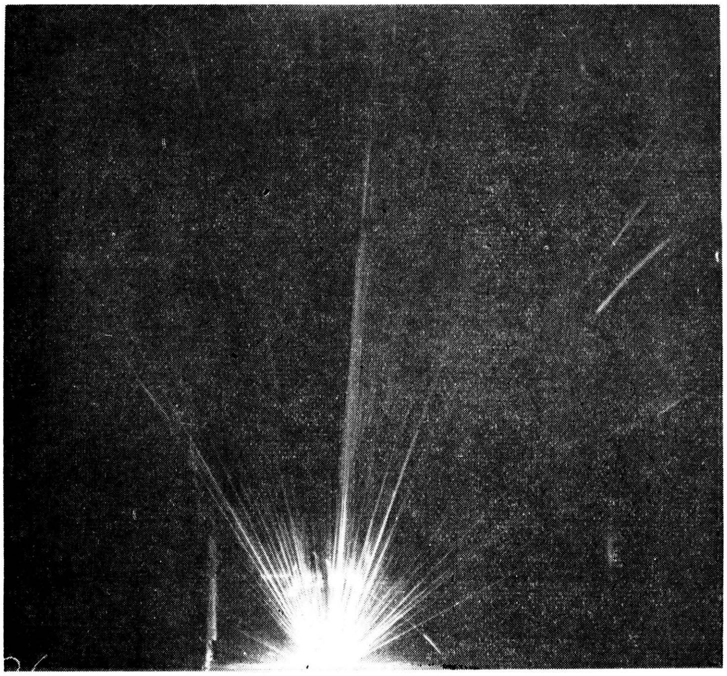


Photo. 7 Nickel contacts in Air, C=40μf.

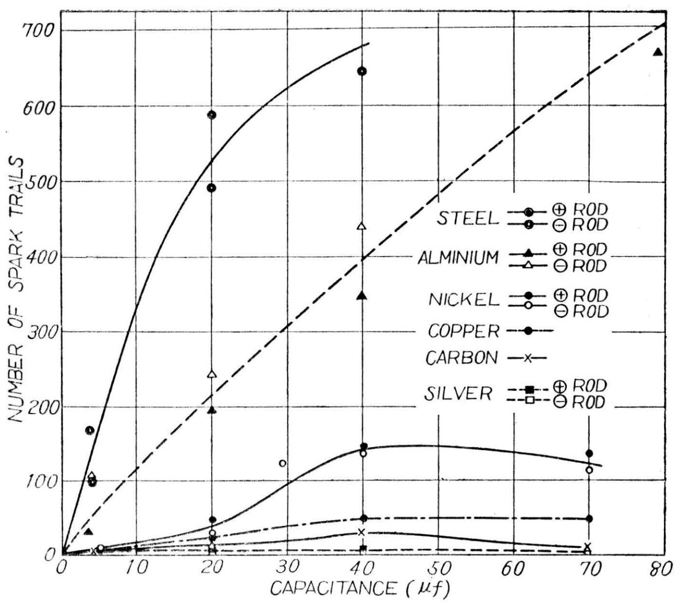


Fig. 3 The number of the spark trails emitted from the contacts.

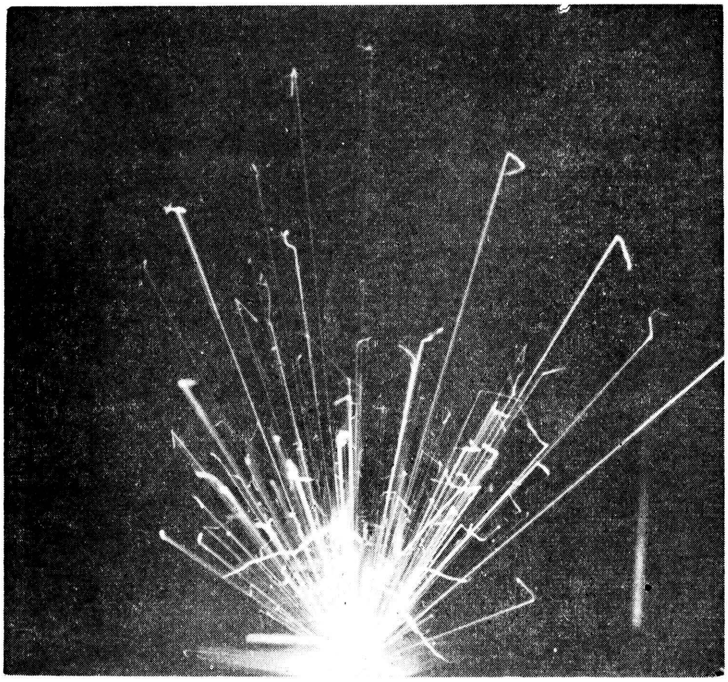


Photo. 8 Aluminium Contacts in Air, C=40μf.

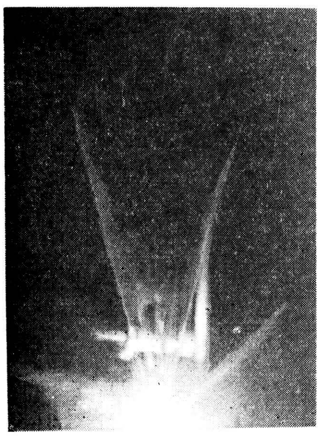


Photo. 9 Copper Contacts in Air, C=40μf.

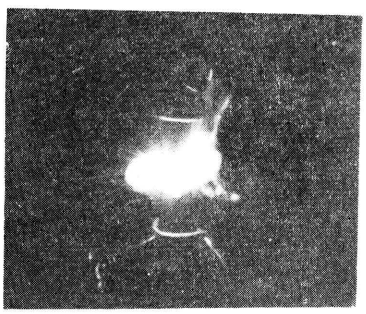


Photo. 10 Carbon Contacts in Air, C=40μf

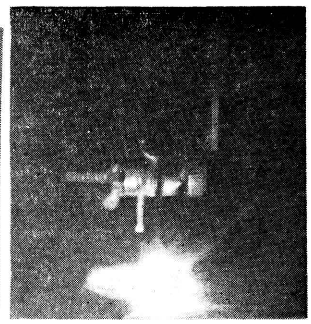


Photo. 11 Silver Contacts in Air, C=40μf.

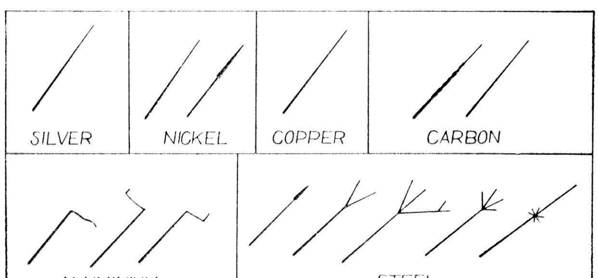
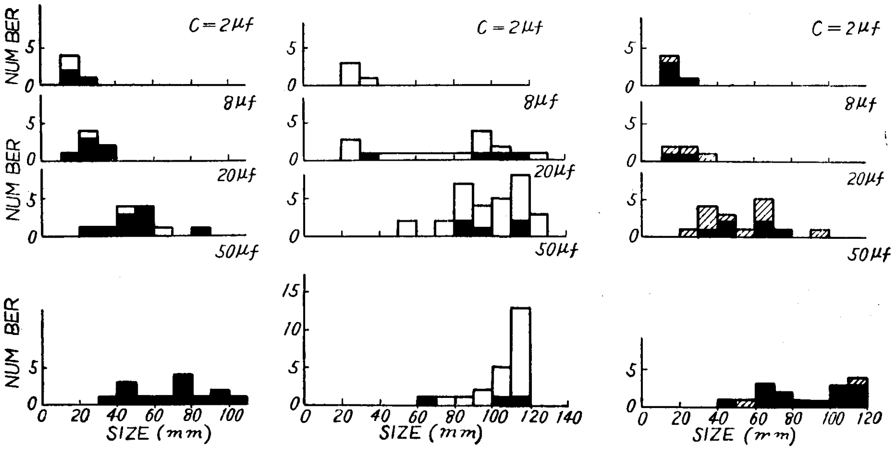


Fig. 4 Typical Shapes of Spark Trails of Various Electrodes.

2. The length of the spark trails

From the photographs taken with a lens whose depth of focus is slight, the length of the trails was measured. This is made possible because the lens is focused at the contacts and the images in the film in focus is directly proportional to the length of the spark trails. Fig. 6 is the distribution of the trails emitted from a



(A) In air. (B) In carbonic acid gas. (C) In oxygen gas.

Fig. 6 The distributions of the length of the spark trails emitted from steel contacts.

point of contact in air, in O_2 gas and in CO_2 gas. As seen from the histogram, in O_2 gas the length of the trails is shorter than in CO_2 gas. In the same gas, larger capacitance gives larger values to the length, since the center of the distributions shifts to the righthand as capacitance increases. In Fig. 6, the black square represents the numbers of the ruptured trails, and the hatched square the numbers of the spear head trails. As seen in the photographs of the spark trails in oxygen gas, the trails ruptured remarkably. In this case the ratios between the length of the trails measured from the original contact point to the ruptured and the total length of the trails were encounted. (See Fig. 5) The mean values of the ratio are of the order of 0.8. In air when the same process is made, and the ratio is found to be 0.9. In Table 1 these results are shown.

Capacitance (in μf)	Mean value of ratio $\frac{a}{a+b}$ (in O_2 gas)
2	0.8
8	0.8
50	0.8
90	0.8
	(in air)
2	0.9
8	0.9
50	0,9
90	0.9

Table. 1

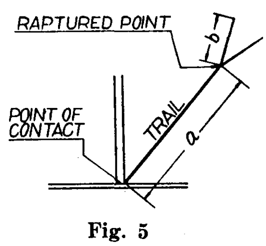


Fig. 5

3. The weight loss of the contacts

The weight loss of the rod electrode due to the erosion was measured for copper, silver, nickel, steel and fuse. Since the weight loss of the materials for one closure is very small, after fifty closures, the rod electrode was weighed and the mass loss of electrode were computed for one closure. In this case the rod electrode was connected to the positive terminal of the condenser. When the polarity is reversed, the loss of the rod electrode changes appreciably, but the definite tendency for this effect was undetermined. Fig.7 shows the results, in which the

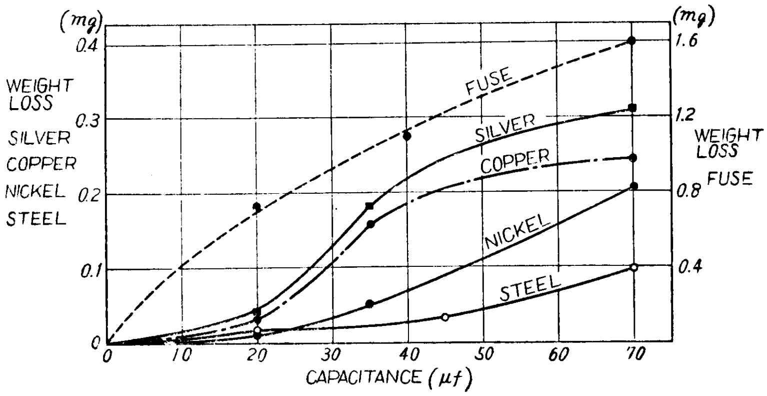


Fig. 7 Weight loss of Rod Electrode.

ordinate indicates the loss of the rod electrode and the abscissa the capacitance of the condenser. As seen in this figure, the metal of lower melting point produces greater amount of loss, i. e. the order of the loss is equal to the inverse order of the melting point of the metal. Above 20μf, the loss of the electrode increases sharply.

4. Pellet

If screen of paper is set vertically in the vicinity of the contact, small pellets are caught on the surface of the paper. These pellets have various sizes. Fig. 8 shows the distribution of the size of the pellets, in which the sizes were plotted as the geometrical mean values of the maximum and minimum diameters for non-sphere pellets. Greater portion of the pellets produced in air and O_2 gas have spherical shapes, and in CO_2 gas are bright, it is seen that the metal pellets were heated by oxidation during flight, while their shapes became spherical.

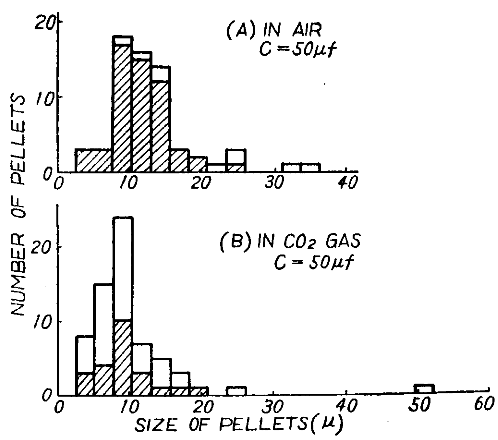


Fig. 8 Distribution of the Size of the Pellets for Steel Contacts.
Hatched square represents spherical pellets and black square represents non-spherical pellets.

5. The velocities of the pellets.

From the photographs taken with the rotating orbicular film, and the common photographs taken at the same time, the velocities of the bursting pellets were calculated. The orbicular film was 10 cm in diameter and the center of the film was mounted vertically on the rotating shaft of a small commutatormotor. The revolution numbers of the motor were between 600 to 800 r.p.m. In front of this film, the camera lens (f=2.0 D=50mm) was set to project exactly in focus on the film the images of the spark trails which lie perpendicular to the optical axis of the lens.

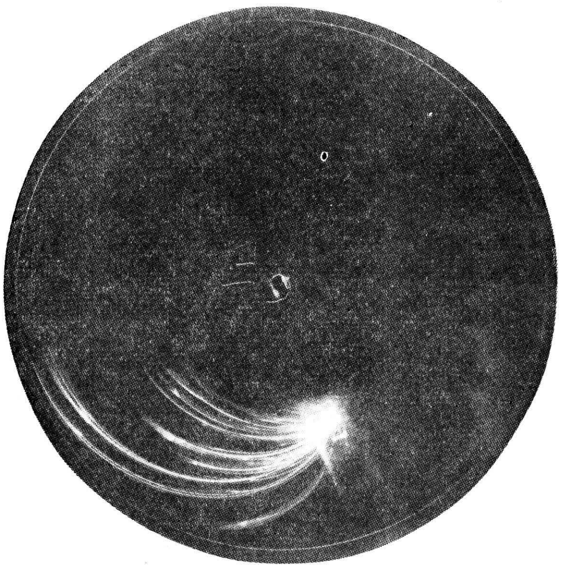


Photo. 10 Photograph of the Spark trails of Steel Contacts taken with the Rotating Film. (14.7Rev/sec.) C=8μf.

Photo. 10 is the image of the trails taken with the rotating film. The trails of the sharp images on the film were used to calculate the velocity of the pellets. This was tried in air, in CO_2 gas and in O_2 gas. Figs. 9 (A), (B), (C) show the velocity of the pellets.

The data are plotted in the graph of the velocity of the pellets against the distance from the contact point. As seen in the results, higher capacitance gives higher velocity to the pellets. The drag coefficients of pellets are in the same order, because the gradients of the curves of Fig. 9 are in the same order. In CO_2 gas the velocity of the pellets is smaller than in air and in O_2 gas. The ruptures of the

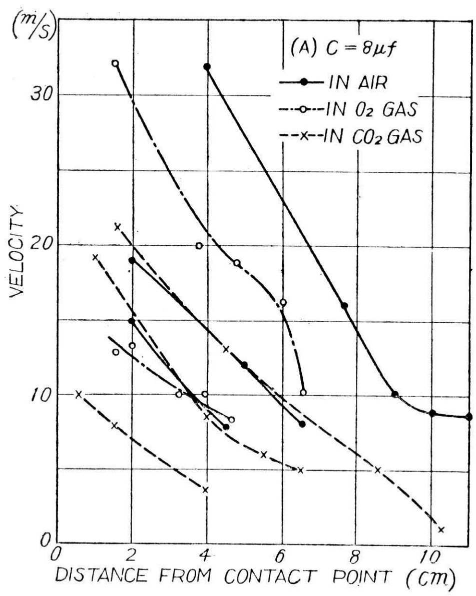


Fig. 9 (A) Velocity of Steel Pellets.

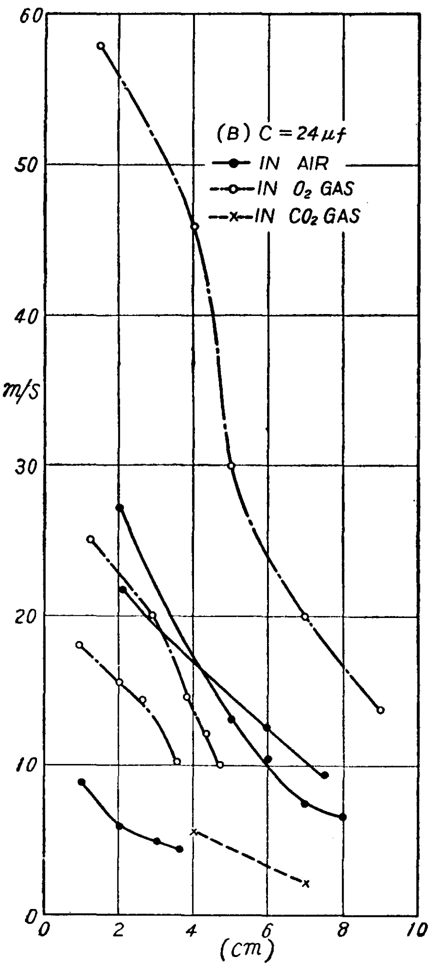


Fig. 9 (B)

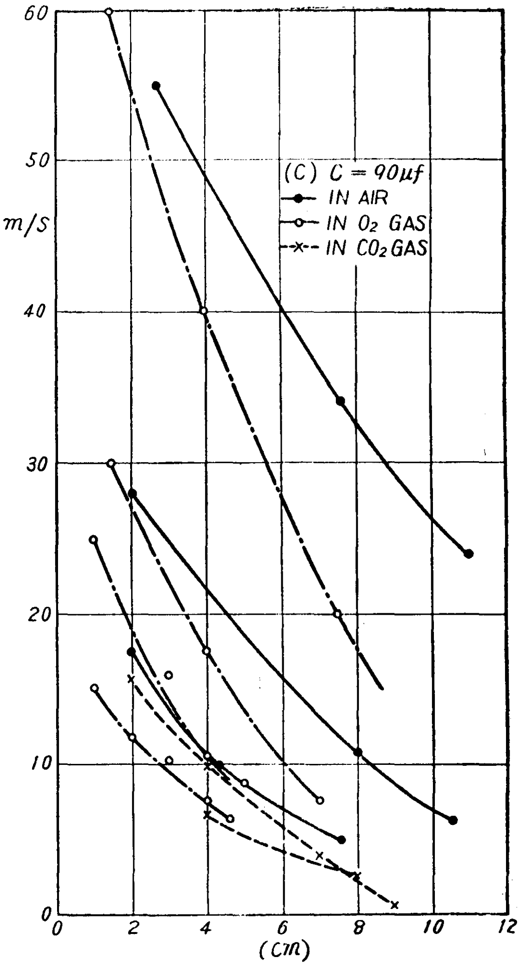


Fig. 9 (C)

pellets in air and CO_2 gas both occured at the velocity of about 10m/sec.

IV. Conclusions

Silver, copper, and carbon electrodes emit few trails, while nickel, aluminium and steel emit bright and many trails. Most of the steel pellets in air and O_2 gas have spherical shape, while in CO_2 gas good many of them are distorted. In O_2 gas, most of the trails of steel are ruptured, bright and their length is shorter than in air, while in CO_2 gas the trails are rarely ruptured, and their length is longer and the luminosity dim, From these results it is seen that the pellets are oxidated in air, and the temperature of the pellet increase by the heat of the oxidation. Higher energies produce more numbers of spark trails, longer trails, and greater loss, but these three quantities do not increase in proportion to the increase of the energy.

As a result, the violence of the burst at the contacts by electric current is not directly proportional to the supplied energy in the energy range of this experiment. The velocity of the pellets in CO_2 gas is slightly lower than those in O_2 gas and in air. The reason for this discrepancy is undetermind.

Acknowlegement

The author wishes to express his heartfelt thanks to professor M. Mashima of Keio University for his guidance and helpful instructions, to Lecture M. Sakata for his kind advices.