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HIGH-INTENSITY ELECTRIC DISCHARGE BETWEEN PARALLEL PLATES IN AIR*

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The present paper is a report on the investigation of electric pulse discharge in air at atmospheric pressure between two parallel wide metallic plates. Its properties indicate the possibility of using it as a source of compressed plasma.

ВЫСОКОИНТЕНСИВНЫЙ РАЗРЯД МЕЖДУ ПАРАЛЛЕЛЬНЫМИ ПЛАСТИНАМИ В ВОЗДУХЕ

В работе исследуется пульсный электрический разряд в воздухе при атмосферном давлении между двумя широкими параллельными металлическими пластинами. Свойства такого разряда указывают на возможность его использования в качестве источника сжатой плазмы.

I. INTRODUCTION

In recent years rather great attention has been paid to the investigation of dense plasma from both the theoretical and the experimental viewpoint. The laboratory preparation of such plasma requires sometimes exacting technical outfit-highpressure chambers for discharges at high pressures or vacuum chambers used for preparing erosive plasma. Not every laboratory intending to investigate dense plasma experimentally has the possibility to construct such an apparatus. Therefore it is advantageous to search for methods of obtaining dense plasma without a complicated apparatus and enabling also smaller laboratories to carry out research in this field. This paper refers to one of such methods discovered on experimenting with an pulse electric arc in air at atmospheric pressure.

II. EXPERIMENT

All experiments were carried out by a simple apparatus schematically shown in Fig. 1. HV 2500 V power supply, R_1 92 kΩ charge resistance, C capacitor battery of 238 μF, R_2 0.72 Ω discharge resistance, R_3 0.2 Ω coaxial shunt, G three-electrode spark gap, T trigger system, TC opening of the shutter of photographic camera, TO triggering of oscilloscope, TG triggering of sparg Gap, X discharge electrodes. The discharge through the electrodes X was initiated by a copper wire 0.09 mm in diameter. Its use enabled to ignite the discharge at a distance of electrodes higher than the breakdown distance and on spot previously selected.

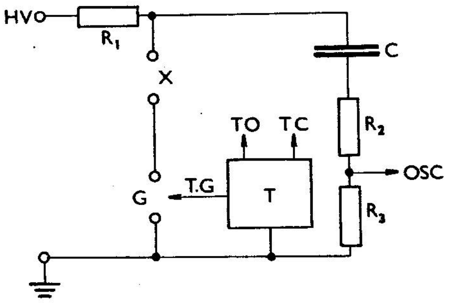

Fig. 1.

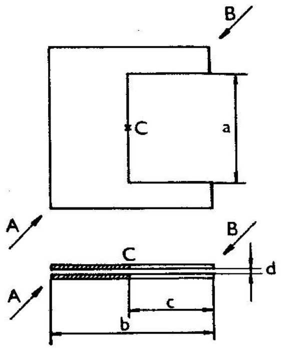

Fig. 2

In principle the experiment was based on a special shape and arrangement of the discharge electrodes X and at the spot of the discharge initiation. As discharge electrodes there were used parallel copper plates 1 mm thick, of the same shape and size, drawn in Fig. 2. This configuration of electrodes was designed on the basis of the effect discovered during the function test of the apparatus (Fig. 1). The initiating wire was placed on the margin of the plates in the centre of a large square (point C). The electrodes were connected to the discharge circuit at opposite corners of the large square in points A and B, so that the points A, B, C lay on its diagonal. In this way electrodynamic pressure on the discharge plasma is eliminated. The electrode dimensions were (Fig. 2): $a = 70$ mm, side length of the large square $b = 100$ mm, $c = 50$ mm, their distance $d = 1$ mm.

At the discharge of the capacitor battery C an integral photograph of the discharge plasma and the time behaviour or current were obtained. The discharge proceeded in an aperiodic regime. At first the current reched steeply, within a few microseconds, the maximum value of 2.6 kA, then it slowly decreased exponentially to zero during 1 ms. A characteristic appearance of such a discharge is shown in Fig. 3 (upper photo: view from above, lower photo: side view … as in Fig. 2. The

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discharge plasma does not spread inside between the electrodes from the spot of initiation; on the contrary, it flows away from the edge of the electrodes into the free space. In the following we shall try to elucidate this interesting phenomenon.

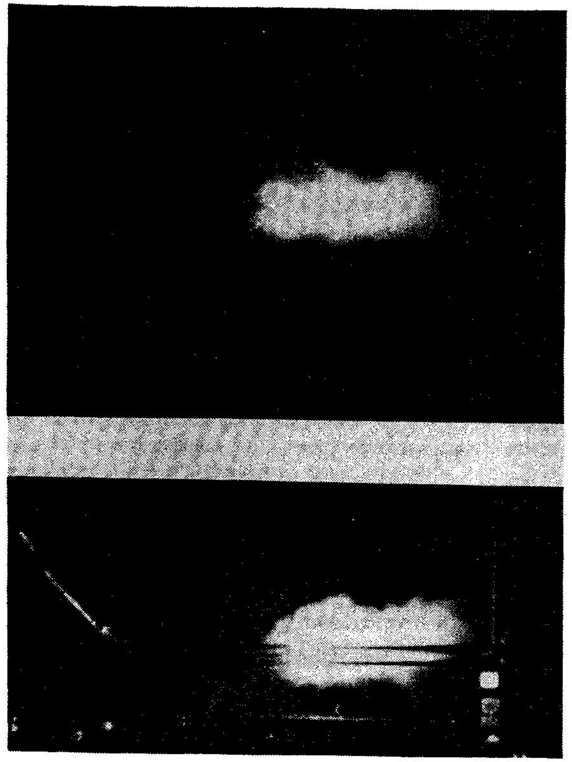

Fig. 3

III. ELUCIDATION OF PHENOMENON

It seems that the phenomenon, observed in the experiment, can be explained by the mechanism of decay of dense plasma, described in [1]. M. A. Cook and coworkers observed that upon the denotation of an explosive there appeared cohesive plasma of a high density, desintegrating into gas with a simultaneous rapid increase of presssure and expanding into a volume exceeding the original volume of plasma several times. The explanation of the observed phenomena is based on the presumption that the plasma exists in a metalliform quasilattice which holds the plasma together by cohesive forces. In this model, as long as the cohesion energy exceeds the thermal enegry, the plasma sholud hold together, but when the cohesion energy decreases below the thermal energy the cohesion should cease. By recombination of ions the cohesive forces disappear and the plasma becames a neutral gas expanding into a volume exceeding the original volume of the plasma several times.

In our case we can assume that by a high erosion of the electrodes a rather dense plasma of metal vapour is formed in the discharge space. The short distance of electrodes creates such a state in which the volume effect of plasma heating by the electric field is weaker than the surface effect of plasma cooling by the electrodes. The prevailing cooling causes recombination and expansive plasma decay between the plate electrodes. A gas flow into every direction from the spot of decay blows the plasma between the electrodes off. As the pressure affecting the plasma is caused by a recombination of ions of the dense plasma, it can be called "recombination" pressure [1]. This can be used for obtaining a plasma stream (Fig. 2) or for compressing the plasma inside between the electrodes.

IV. USE FOR PLASMA COMPRESSION

On the basis of the elucidation of the above phenomenon it can be anticipated that on initiating a discharge inside between the electrodes, not on the margin of the plates but in their centre, the plasma due to electrode cooling will recombine and decay on the entire surface. Thus, the recombination pressure, acting from all sides, should compress the plasma into the spot of initiation. Another experiment was carried out to prove this possibility. The plate electrodes in Fig. 2 were replaced by electrodes shown in Fig. 4. They are in the shape of equilateral triangles of a side length $e = 70$ mm, the distance between them can be changed from discharge to discharge. Now the plates are of molybdenum (0.45 mm thick), because the surface of copper plates is attacked by erosion in the discharge and the

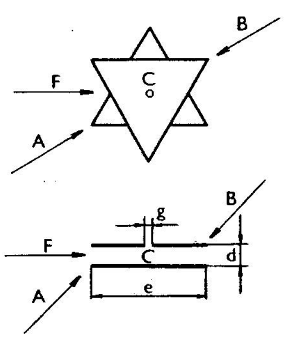

Fig. 4.

reproducibility of the discharge in a long series of shots is not secured. In the initiation spot C(Fig. 4), in the centre of the electrode surface, a hole of a diameter $g = 1.5$ mm was bored into one of the plates for determining the pressure between the electrodes. During the experiments the distance of the electrodes d was gradually shortened from 15.3 and 3.9 mm are shown in Fig. 5. The snaps were taken from the left (Fig. 4) as the arrowhead F indicates.

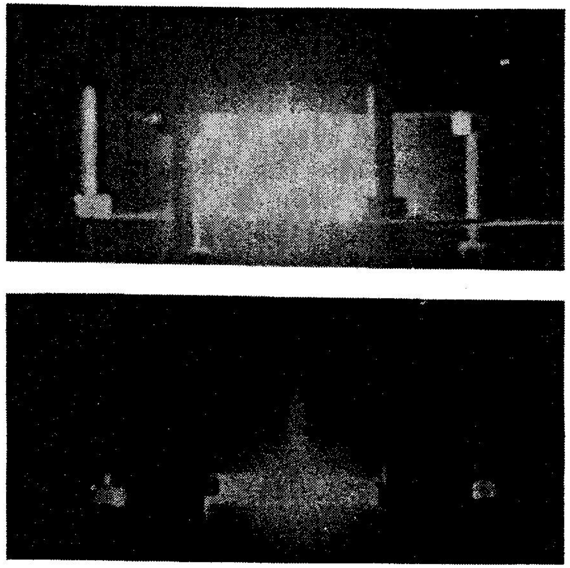

Fig. 5.

From the photographs in Fig. 5 it can be seen that with a high distance of electrodes the volume heating of the plasma by the electric field prevails over the surface cooling effect of the electrodes. The plasma occupies the entire volume of the discharge space and from the hole in the upper plate only a very weak plasma stream flows — thus, the plasma pressure exceeds the atmospheric pressure of air only slightly. On shortening the distance the cooling effect of the electrodes becomes more marked, the plasma has a smaller dimension in width and the stronger plasma column, flowing out of the hole in the plate, indicates that the plasma is under a higher pressure.

V. COMMENTS AND CONCLUSION

It can be seen from the above that a high-voltage electric discharge, initiated in the middle between wide plane-parallel plates at a close distance, can be a source of compressed plasma. From the experiments illustrated in Fig. 5 it follows that the plasma compression and its density increase with shortening the distance of the plane electrodes. This correlation is easily understood on bearing in mind that the short distance of the electrodes causes strong plasma cooling (intensive recombination) and a narrow gap between the electrodes hinders the dense gas from flowing into the ambient space which retains a high pressure level in the discharge centre.

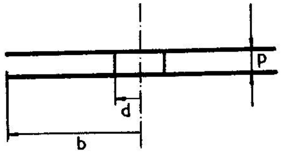

Fig. 6.

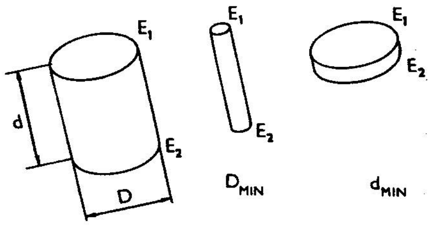

Fig. 7

Let us consider circular plates of diameter q, with a distance d, where plasma created a cylinder of radius p (Fig. 6). To reach the higher possible recombination pressure, it is necessary:

a) to maximize the density of the erosive plasma, i.e. the energy input into the metal of the electrodes. This can be achieved by maximizing the discharge current and minimizing the distance of the electrodes d;

b) to maximize the plasma decay, i. e. to realize the maximum intensity of cooling by the metal of the electrodes. It can be achieved by minimizing the d and maximizing the q of the electrodes;

c) to maximize the resistance of the electrode gap against gas flow, i.e. to make the equilibration of pressures more difficult. It is reached by minimizing d and maximizing q. In principle the equilibration of pressures can be prevented by closing the gap between the free edge of the electrodes by a dielectric. Such arrangement, however, represents a pressure chamber.

Summing up, to maximize the recombination pressure of plasma it is necessary: to maximize the discharge I, minimize the distance between the electrodes d and to maximize their diameter q.

It is interesting to compare this type of discharge with a capilary discharge. In a capillary discharge the dense plasma is formed by erosion of the dielectric walls of the discharge space, hindering simultaneously its expansion sideways. In our case the electrodes are subject to erosion and the plasma expansion sideways is hindered by the "recombination" pressure. Let us assume the discharge volume to be a cylinder (Fig. 7), the axis of which is parallel with the direction of the discharge current; thus the circular areas are the electrodes E_1, E_2. The characteristic dimensions are the length d and the diameter D. On minimzing the diameter D we obtain a capillary, minimization of the length d leeds to our discharge volume at a minimum distance of the electrodes..

REFERENCES

[1] Bauer, A., Cook, M. A., Keyes, R. T.: Proc. Roy. Soc. London, *A 259* (1960), 508.

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