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GASDYNAMIC SELF-STRUCTURE UNDER UNSTABLE EVAPORATION OF CATHODES IN A PULSED UNIPOLAR DISCHARGE

V. G. Zhogol', V. F. Reznichenko,
S. V. Selishchev, and A. A. Uglov

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The action of concentration energy fluxes (pulsed discharge, laser radiation, electron beam, etc.) on a material is accompanied by instability of the erosion plasma-outflow [1-3]. The pulsations of the ionized gas near the target surface affect the thermophysical and gasdynamic processes, the nature of mass transfer and, hence, the physicomechanical properties of the action zone. In the general form there are erosion-plasma pulsations with two types of space-time structures: in the form of bundles [1, 3], i.e., intermittent plasma fluxes whose initial diameter is equal to that of the concentrated energy flux and jet pulsations [1, 2], i.e., individual plasma fluxes which arise at random and in different zones where the concentrated energy flux acts.

In this study we show that one more type of space-time structure of the erosion plasma, a helical structure, is observed when a pulsed unipolar discharge in a gaseous medium acts on cathodes made of different materials. We have found the conditions under which different types of erosion-flare structures are transformed into each other. We have demonstrated that the space-time evaporation structure depends on the pulse energy and length and on the form of the cathode material.

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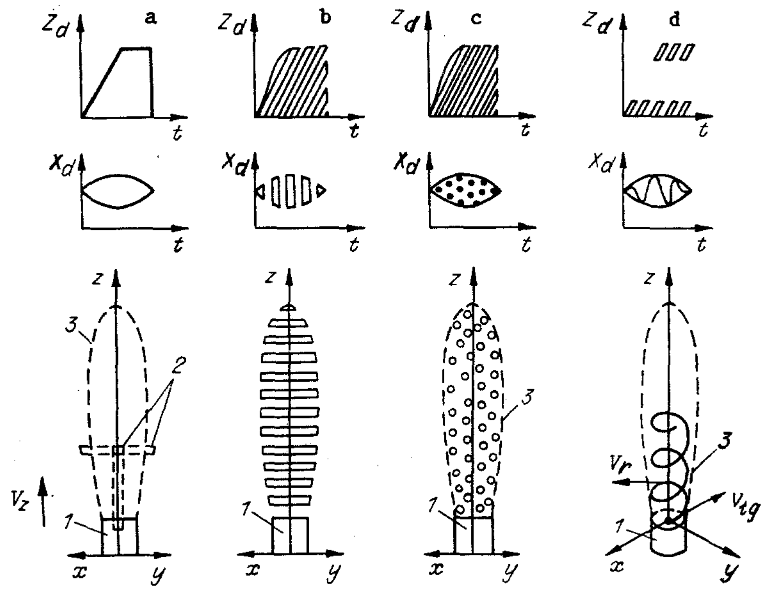

Fig. 1

Experimental Procedure. The jet of the erosion plasma (flare), propagating from the cathode, was photographed by the slit-scan method using an FÉR-7 photoelectronic recorder. A discharge was excited between the ends of a cylindrical cathode and the edge of a plate anode, placed perpendicular to the cathode axis. A protective gas (anode) was fed into the discharge zone. We used 2-mm-diameter rods of W, Mo, Ti, Ni, and Cr for the cathode and a tungsten rod for the anode. The electric pulses had the following parameters: pulse energy W_p = 4.8-10.8 J, pulse length τ_p = 1.2-1.6 and 0.12-0.14 msec. (The experimental setup and the electrical parameters of the pulse are described in greater detail in [4].) Photographic records of the flare were made in two directions: longitudinal (slit diaphragm of the photoelectronic recorder with a 50-μm slit parallel to the flare axis) and transverse (slit diaphragm perpendicular to the flare axis). When recording in the transverse direction we studied two zones of the flare, at a distance of 50-100 μm and 15-20 mm from the ends of the cathode. To simplify the interpretation of the moving-image photographs we consider the schemes of some idealized motions of an erosion-plasma jet.

Figure 1 shows flares during the continuous evaporation of cathode 1 with no internal structure (a), with a space-time structure in the form of bundles (b), with jet filamentation (c), and with a helical instability (d) and the corresponding longitudinal and transverse moving-image photographs [the graphs of $Z_d(t) = Z_d$ and $X_d(t) = X_d$, where Z_d and X_d are the coordinates in slit diaphragm 2, arranged parallel to one coordinate axis).

Moving-image photographs with no internal structure (a) have a uniform exposure background, whose boundary corrsponds to the flare front 3. The velocity of the front in the direction of the z axis was $V_f = dZ_d(t)/dt$. The velocity V_f in the direction of the x axis is determined in a similar manner.

A flare with a space-time structure in the form of bundles (b) is represented on a longitudinal moving-image photograph as an alternation of a series of continuous bright and dark bands, inclined to the time axis. No such inclination to the time axis is present in the transverse moving-image photograph. The bands are the result of a discrete structure and the band width, equal to X_d, corresponds to the transverse dimension of the bundle. We see that the velocity of an individual element of the structure is not equal to the velocity of the flare front. The width of the dark band characterizes the pause between the pulsations. The width of the white band in the longitudinal moving-image photograph corresponds to the length (period) of a unit element of the structure.

The image of a flare with a jet filamentation (c) in the longitudinal moving-image photograph is also a series of bands, inclined to the time axis. Instead of bands, however, the transverse moving-image photograph shows point or small spots. The velocity of individual elements of the structure is determined by the slope of the band. The band splitting (formation of forks) corresponds to the formation of a stationary shock wave [3].

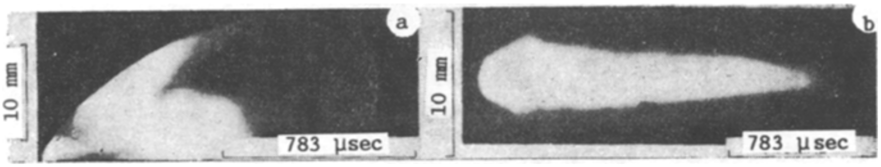

Fig. 2

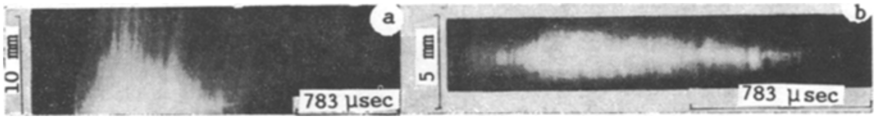

Fig. 3

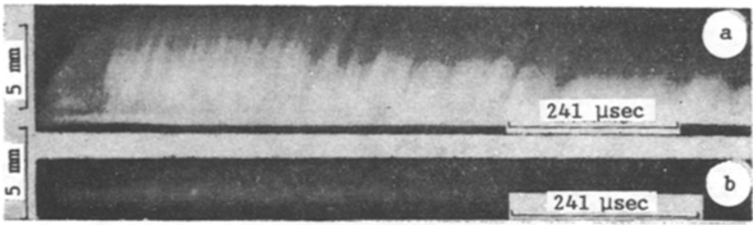

Fig. 4

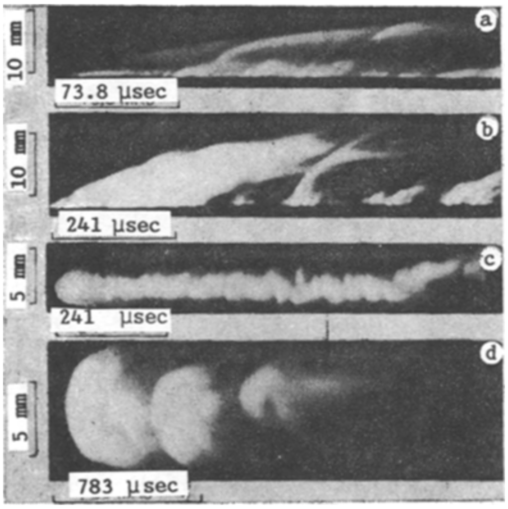

Fig. 5

A helix is a more complex space-time structure of a flare. A helical structure can exist under different motions of the erosion plasma: 1) the vapor source rotates along the periphery of the cathode with velocity V_r and the jet moves rectilinearly with velocity V_z; 2) the vapor source is stationary and the jet moves along a helix with velocity V_{tg}; 3) when $V_r > 0$ the velocities $V_z > 0$ and $V_{tg} > 0$. In the first case the longitudinal moving-image photograph will have the form of bands inclined to the time axis and the transverse photograph will have the form of the projection of a helix onto a plane, i.e., a sinusoid. The distance between bands is equal to half the period of vapor-source rotation. In the second case bands which are parallel to the time axis and whose origins are shifted relative to each other should be observed in the longitudinal moving-image photograph. They should also be observed in the transverse moving-image photograph. The longitudinal and transverse moving-image photographs for the latter case are shown in Fig. 1d. In the longitudinal moving-image photograph we will observe discrete bands, parallel to the time axis; the first band will necessarily be discrete while the second need not necessarily be discrete (depending on the relation between V_{tg} and V_z). The dark interval between the bands is due to the plasma jet leaving the zone of visibility of the slit diaphragm. The time between departure from the zone of visibility and the return to it is equal to the time of a half-turn about the z axis or half the period of rotation. In this case the transverse moving-image photograph is also sinusoidal.

Experimental Results and Discussion. The flares from W and Ti cathodes at τ_p = 1.2-1.6 msec evaporate virtually without pulsations (Fig. 2). With shorter scans a small segment with pulsations can be noticed, in the case of the W cathode, in the form of bundles which rapidly cease. The velocity of the flare front decreases nonuniformly, and is constant in one segment. At τ_p = 0.12-0.14 msec pulsations are observed throughout the pulse.

The structure of the pulsations of a Cr cathode depends on W_p. Bundles are observed during the entire pulse at W_p > 8 J and τ_p = 1.2-1.6 msec (Fig. 3) and filamentation of the jet occurs at lower values (Fig. 4). The velocity of individual elements of the structure vary little during a pulse and is close to the initial velocity of the front. The erosion flares of Mo and Ni cathodes undergo a helical instability at τ_p = 1.2-1.6 msec, which periodically changes to pulsations in the form of bundles. Figure 5a shows the longitudinal moving-image photograph of an erosion flare of a Ni cathode. It clearly shows two discrete bands parallel to the time axis, with a dark space between them. This is an indication that the plasma jet forms a helical structure; at some times such a structure is formed because of the rotation of the vapor source (separate bright bands penetrate the dark space) while at the other times it is formed because of the conditions $V_r > 0$, $V_z > 0$, and $V_{tg} > 0$. The transverse moving-image photograph resembles Fig. 5c. The frequencies of the plasma rotation about the z and y axes of the vapor source on the periphery of the cathode are $5 \cdot 10^3$ and $3 \cdot 10^4$ Hz, respectively.

Figure 5b, c shows the longitudinal and transverse moving-image photographs of the flare of a Mo cathode at τ_p = 1.2-1.4 msec. As in the first case, we observe two types of helical space-time flare structure. The transverse moving-image photograph clearly shows a sinusoid, which alternates with discrete bands in places. The sinusoid corresponds to the helical space-time structure and the bands, to bundles. In the longitudinal moving-image photograph the lowest discrete band has short elements in which the slope to the time axis is constant. This indicates that they were not retarded on the visible part of the path. The elements vanish from the zone of visibility without loss of velocity, which can occur only if the jet moves along a helix. The frequency of the vapor source rotation along the periphery of the cathode is very nonuniform in the case of a Mo cathode and can range from $3.5 \cdot 10^3$ to $2.7 \cdot 10^4$ Hz. The jet rotates about the z axis with a frequency of $5 \cdot 10^3$ Hz.

A splitting band extending to the flare front is clearly visible in the middle part of the moving-image photograph. The characteristic fork attests to the existence of a standing shock wave. Moreover, at that time a "sinusoid" and, hence, a band, formed in the transverse moving-image photograph because of the formation of the vapor source.

In the transverse moving-image photograph of the remote part of the flare of Mo and Ni cathodes (at a distance of 15-20 mm) we observe several luminous formations of relatively large size (Fig. 5d). Such formations arise because of the compression of the helical flux of the erosion flare. We should point out that in the second part of the current pulse the erosion flare of Mo and Ni cathodes has a helical instability only when $V_r > 0$, $V_z > 0$, and $V_{tg} > 0$, and in this case the rotation frequency decreases to $1.7 \cdot 10^3$ Hz by the end of the pulse.

The space-time structure of the erosion flare depends on the material of the cathode and the pulse energy and length. The effect of the pulse energy and length, however, is indeterminate for the cathode materials studied. At τ_p = const, e.g., only Cr is sensitive to variation of W_p while a decrease in τ_p has the most pronounced effect on W and Ti. When the pulse is shortened the power density of the energy flux at the cathode increases, causing instability of the evaporation of W and Ti cathodes. A slight increase in the power density at a Cr cathode (increase in the pulse energy) results in a change from one type of space-time structure to the other. Moreover, as the power density increases filamentation of the jet goes over into a bundle-like space-time structure. For the cathodes mentioned above, therefore, the power denisty and its distribution determine the space-time structure of the flare.

A helical space-time structure can be formed by two mechanisms: rotation of the vapor source as the result of the effect that the crossed electromagnetic self-fields have on the jet and purely gasdynamic spontaneous twisting [5]. The importance of electromagnetic fields in the formation of the helical instability is confirmed by the fact that the cathode spots rotate in external magnetic fields [6] and by the decrease in the rotation frequency by the end of the pulse, which can be attributed to a decrease in the strength of the self-field.

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ELECTRICAL BREAKDOWN IN AMMONIUM PERCHLORATE

Yu. N. Sukhushin and I. G. Khaneft

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The study of electrical breakdown of thermodynamically labile materials (that is, materials which decompose under external stimuli with an exothermal effect) is of great interest, since in such materials charge carriers may enter into a chemical reaction which leads to decomposition of the material, passing through a stage of conversion of electrical energy into heat [1, 2]. Nor can it be excluded that as a result of chemical conversions initiated by charge carriers additional electrons or holes will be formed, which support conductivity during the breakdown process or in prebreakdown stages. It was shown previously in studies of electrical initiation in heavy metal azides [3-6] that depending on the macroscopic parameters (density ρ interelectron distance L) three processes which differ in their electrophysical nature may exist: discharge between grains of polycrystalline material, microdischarges in pores, and indirect electrical breakdown with an exothermal decomposition reaction. Ammonium perchlorate (APC) is a well-known representative of the class of thermodynamically labile solids [7], which differs significantly from azides in the nature of its conductivity and decomposition reaction [8]. The goal of the present study is to study the phenomenology of electrical strength loss in single-crystals and polycrystalline pressed specimens of APC to the point of distinguishing macroscopic stages of the process.

1. Polycrystalline APC powder, chemically pure grade, with granulometric composition characterized by a maximum in the size distribution at 30 μm was used in the study. The polycrystalline specimens were prepared by pressing the powder on the polished surface of a quenched roller (ShKh-15 steel) into a polymethyl methacrylate shell. A 1/4-sphere electrode of the same material was pressed to the free surface of the tablet at constant pressure, with no deformation of the specimen. Preliminary experiments showed that introduction of a protective medium between the tablet surface and the 1/4-sphere electrode had no effect on the value of the breakdown voltage or its dependence on interelectrode dis-

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