DISCRETENESS OF PULSED PLASMA JETS

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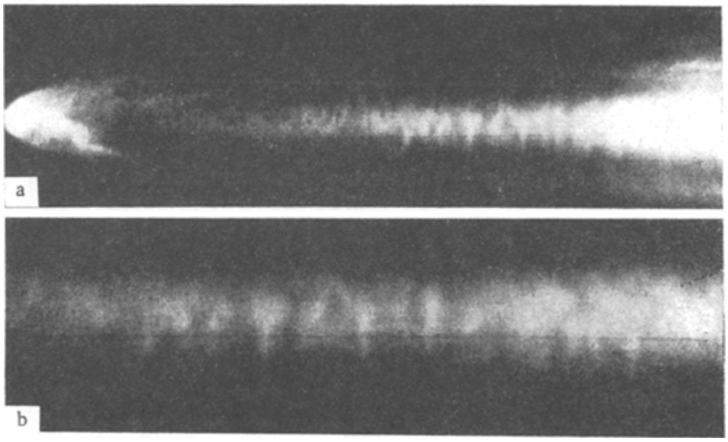
The discrete structure of pulsed supersonic plasma jets, whose source may be explosive processes at the electrodes, and the propagation of waves of a disturbance in the structure of the jet are examined. The waves of a disturbance are propagated with the speed of sound in different directions and are recorded on photoscans in the form of successive bands of different intensities. The appearance of disturbances is observed when a shock wave collides with an obstacle. The velocity of the sound waves is determined from the experimental data, and the temperature of the jet is calculated.

The discrete structure of pulsed plasma jets is detected in an ordinary high-energy pulsed discharge, in pulsed plasma jets, in electrode discharge shock tubes, and in pulsed plasma accelerators [1]. It is assumed that the discreteness is connected with the presence of individual high-temperature microclusters of plasma ("plasmoids") moving within the overall flow. However, in individual cases, for example when one electrode is removed from the capillary or an electrode is recessed in the body of the discharger, periodic disturbances in the discharge are not observed at all.

The plasma microclusters formed during explosive evaporation represent regions of increased temperature and density localized in space (on photoscans they are bent disks of increased brightness). As they move within the medium they should be smeared out, but this is not observed on the photographs; for certain discharges, their motion opposite to the moving stream is recorded.

This indicates the complexity of the processes during the formation of a discrete structure in a supersonic plasma jet. Obviously, the question of the nature of the disturbances in such a discharge cannot be solved uniquely for all pulsed jets and must be considered separately for each specific case.

It is shown in [2] that with a powerful discharge in the interelectrode space a shock-compressed plasma region develops which undergoes periodic oscillations propagating in the volume of the resonator and bounded by slanting compression discontinuities.



τ, μsec

Fig. 1

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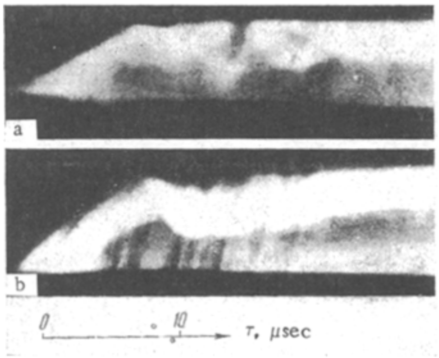

Fig. 2

In the present work a study is made of discrete plasma formations for pulsed plasmotrons, analogous to [3], using high-speed photography of the jet discharge with fourfold enlargement. The structures of flares and jets were studied for Pb, Sn, Al, Cu, Fe, Mo, W, and C over the entire distance from the base of the jet to the direct compression discontinuity at energies above 500 J. Jets have the clearest discrete structure for electrodes prepared from W and C. Clearness and spatial separation of individual discrete structures do not occur on the photoscans for low-melting metals.

It is seen from time photoscans of the jet structure in the direction perpendicular to the jet axis (Fig. 1) that the individual discrete structures have dimensions comparable with the transverse cross section of the jet. They are curved, i.e., they consist of thin disks. Periodic compressions (zones of increased brightness), located at the sites of slanted discontinuities of the jet, are observed on both sides of the central brightest part of the jet. They are seen on an enlarged photograph of a section of the jet (Fig. 1b). Their frequency of appearance coincides with the discrete disturbances in the jet.

The discontinuous structure of the jet is not observed for 6-8 msec in the initial stage of the discharge. then diffuse discontinuous formations appear (9-12 msec), after which the jet assumes the form of a pronounced discrete structure (Fig. 1a).

This discharge is a complex formation in which there are, along with plasma microclusters. waves of compression and rarefaction which propagate with the speed of sound within the closed volume of the jet [4, 5]. Such waves also create disturbances in the jet which are recorded in the form of periodic bands of increased brightness (compression waves) separated by dark bands (rarefaction waves) (Fig. 1).

Explosive processes of evaporation at the electrodes may serve as the source of the waves of compression and rarefaction. The waves propagate in the volume bounded by the straight and slanted compression discontinuities. Propagating within the volume. the waves of compression and rarefaction arrive at the compression discontinuities and are reflected; regions of increased brightness are formed at the sites of reflection of compression waves.

The absence of such disturbances at the initial moment of discharge (~10 msec) is evidently connected with the processes of heating of the air and the formation of the wave structure of the supersonic plasma jet. It should be observed that the recording of sound waves from an extraneous source propagating within the plasma volume is made from the zones of emission. just like the recording of the passage of waves from a spark discharge through an arc discharge.

Similar discrete disturbances (waves of rarefaction and compression) are observed when a jet encounters a barrier. These disturbances appear especially clearly on high-speed photoscans in the initial stage of the action of the jet on the barrier (Fig. 2). Sound waves form when the wave front hits the barrier. According to the concepts of hydrodynamics, a compression wave reaching to the boundary of the volume should replace it at the barrier. During the approach of the rarefaction wave to the shock layer of the plasma it leaves the barrier (Fig. 2). Because of the quenching of the oscillations and screening by the peripheral zones of the jet, no more than two such displacements of the shock layer can be observed on the photoscans.

Usually the velocity of the discharge has been determined by the photoscan method from the slope of the individual jets. assuming that the flow velocity is equal to the velocity of these discrete disturbances. Variation in the velocity is clearly seen on the photoscans. The velocities V_1 and V_2 of the propagation of disturbances in the direct and reverse directions with respect to the jet movement are not the same. From the difference between these velocities one can calculate the speed of sound (C) in the medium and the true velocity of flow (U) and determine the temperature T of the jet by solving jointly the velocity equation and the Saha equation. with allowance for ionization [2].

The results of the measurements for a discharge energy of 600 J are presented below.

The velocity when the directions of the moving stream and the wave of disturbance are the same is $V_1 = 11 \pm 1$ (km/sec), and when they are the opposite it is $V_2 = 5.9 \pm 0.5$ (km/sec). From this we find $C = 2.9 \pm 0.3$ (km/sec). $U = 8 \pm 0.9$ (km/sec), and $T \approx 15{,}500$°K. The plasma temperature determined by spectroscopic methods agrees with the temperature obtained within the measurement errors.

An examination of the heterogeneous structure of pulsed plasma jets showed the complexity of the physical processes in the formation of these disturbances. Together with the conventional viewpoint that the discontinuity of the jet is caused by the discrete entry of electrode material during explosive evaporation, one must consider the disturbances not only as plasma microclusters but also as the appearance of waves of rarefaction and compression propagating with the speed of sound in the closed plasma volume, which forms the very structure of the jet at a high enough discharge energy.

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