POSSIBLE MECHANISM OF BREAKING THE CURRENT SHEATH IN A NONCYLINDRICAL Z-PINCH

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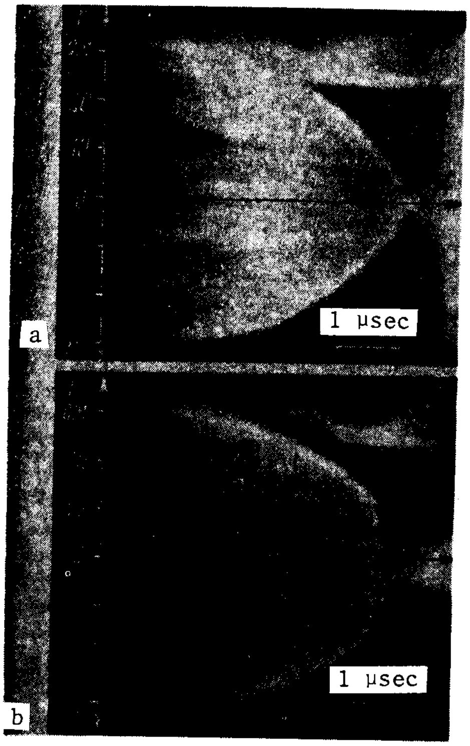
In a number of experiments devoted to the "plasma focus" in the "MG" apparatus [1] it was observed that when working with a mixture of detuerium with a heavy gas (e.g., 0.3 – 1% Xe), the current sheath is disrupted ("breaks") in the anode region as it moves towards the axis of the chamber. The current sheath breaks at relatively large distances (8 – 15 cm) from the axis, commensurate with the anode diameter. The deuterium pressure in these experiments is 0.3 – 1 Torr, the discharge current at the instant of the break is $\sim$ 1 mA, and the capacitor-bank voltage is 16 – 18 kV.

The figure shows scans of the discharges in pure deuterium (a) and with Xe admixture (b), obtained through a slit perpendicular to the camera axis. The instant of the break of the current front, corresponding to a sharp rise in the radial velocity (up to $\sim 10^8$ cm/sec) is clearly seen in case (b). The "snow-plough" mechanism ceases to operate after that instant, and the current is compressed towards the axis without the increase in the plasma density in the focal zone (this increase is typical of case (a)). Conditions are then produced for the formation of a strong electron beam, generated at the expense of the magnetic-field energy stored in the chamber. Such discharges (without a dense pitch registered with a pinpoint camera in soft x-radiation) are usually accompanied by a fragmentation damage to the central part of the anode and by intense x-rays [1].



Scans of discharge, taken through a horizontal slit at a distance 1.5 cm above the anode surface: a) discharge in pure deuterium, b) discharge in mixture of deuterium and xenon.

It has been noted that the breaking phenomenon depends on the thermophysical properties of the anode material and is easier to observe if duraluminum is used in place of copper. In the present paper, we explain the break of the current sheath as being due to a deterioration of the conductivity in the near-anode region, due to the appearance of dense neutral vapor of the anode material at the point of contact between the plasma and the electrode.

The heat flux to the surface of the anode as a result of the electronic thermal conductivity of the plasma is

$$P \approx \frac{nT_e^{3/2}}{3\sqrt{2m}},$$

where n is the plasma electron density, T_e is the electron temperature, and m is its mass. (The influence of the ionic thermal conductivity and of radiation on the heating of the anode surface only enhances the effect.) At $T_e \sim$ 100 eV and $n \sim 5\times10^{16}$ cm^{-3} we have $P \simeq 4\times10^7$ W/cm^2. For such heat fluxes, the surface temperature still depends on the thermal conductivity of the anode material and increases with time like

$$T_{an}(K^\circ) \simeq \frac{P\sqrt{t}}{\sqrt{\lambda C}},$$

where t is the characteristic time, λ the coefficient of thermal conductivity of the anode material, and C the specific heat. The heating time needed to reach the boiling temperature T_b (in °K) of the anode material is $\tau_1 = 18mT_c^2\lambda C/n^2T_e^3$. The surface evaporation, and with it the destruction of a current sheath of thickness Δ, is possible if $\tau < \Delta/v_r$, where v_r is the radial velocity of the sheath. It follows from a large number of experiments that in discharges in mixtures with Xe the value of Δ changes insignificantly, and the sheath radial velocity before the instant of the break is much lower than at the same radius in discharges in purex deuterium. In this case the condition $\tau_1 < \Delta/r$ is satisfied earlier. The influence of the anode material is manifest in the fact that $\tau_1 \propto T_b^2/\lambda C$. The neutral vapor density produced at the anode surface is $n_{vap} \simeq nT_e^{3/2}/3\sqrt{2m}qv_T$, where v_T is the thermal velocity of the evaporated anode atoms and q is the work function. According to [2], the frequency of the collisions between the plasma electrons and the vapor atoms (ν_{vap}) can be regarded as independent of the electron velocity. For $T_e \sim 100$ eV the plasma conductivity is the $\sigma \simeq ne^2/m\nu_{vap} \sim 10^{15}(n/n_{vap})$. Within a time on the order of the time of flight the vapor can rise above the anode to a distance much larger than the mean free path of the current electrons, so that we can speak of a "diffusion" of the magnetic field through the vapor zone, i.e., into the base of the current sheath. An estimate of the diffusion time τ_{dif} yields a value on the order of 10^{-7} sec, which is comparable with Δ/v_r. The disruption (break) of the current sheath starts at that instant, since the condition for the conservation of the discharge current calls for a redistribution of the current density with the concentration of the latter in the front of the sheath, without a corresponding redistribution in the particle density. As a result, the current electron velocity in the front increases simultaneously, the ponderomotive force increases, and the mass of the anode part (layer) of accelerated current sheath decreases. The upward development of this phenomenon along the current layer causes a change in the shape of the entire plasma sheath that converges to the axis and is the cause of a sharp increase in the radial velocity of a section of the sheath several centimeters in height.

It was noted above that under such operating conditions of the apparatus, in contrast to the case (a), no dense plasma focus is registered with pinpoint cameras on the chamber axis. On the other hand, the observed neutron emission can be attributed, in accord with [3], to the appreciable radial velocity of the current-layer deuterons converging to the axis, exceeding 10^8 cm/sec.

[1] V. I. Agafonov, Plasma Phys. and Contr. Nuclear Fusion Research IAEA, 2, 1969.
[2] E. W. McDaniel, Collision Phenomena in Ionized Gases, Wiley, 1964.
[3] J. H. Lee et al., Phys. Fluids 14, 2217 (1971).