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OBSERVATION OF SECOND COMPRESSION IN THE FINAL STAGE OF A DISCHARGE OF THE "PLASMA FOCUS" TYPE

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1. The increased recent interest in thermonuclear installations with superdense plasma of the plasma-focus, θ-pinch, laser-plasma type and similar ones is due to the unprecedented large figures obtained with these installations after the Lawson criterion is reached. "Plasma-focus" discharges have produced in addition, unprecidented neutron yields [1, 2] with a considerable fraction of neutrons of thermal origin [2, 3] and high electron and ion temperatures.

Numerous investigations of the cumulative stage of this discharge (henceforth denoted PF) have made it possible to study experimentally and to adequately describe theoretically [4, 5] the initial phase of PF development, the so-called "first compression," which is characterized by a relatively small neutron yield, a flash of soft x-radiation, a density reaching 10^{20} cm^{-3}, and a temperature $T_e \sim T_i \sim 2 - 5$ keV, as well as by a typical outflow of a considerable part of the mass along the z axis from the focal region, resulting in the high temperature. On the other hand, the data on the final phase of development of the PF are quite skimpy and are limited in practice to investigations of the neutron emission and of the hard x-rays.

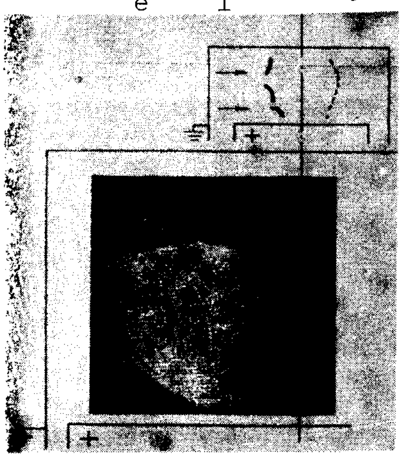

Fig. 1. PF interference pattern obtained during the time of rupture of a current sheath, coinciding with the start of a pulse of hard x-rays. A schematic diagram of the interference pattern is shown on top. The arrows show the locations of the ruptures in the current sheath.

We present here the results of a high-speed interferometry study of this final PF stage, performed with a setup described in [1]. The investigation procedure is similar to that previously employed to study laser plasma [6].

2. It was established earlier that short-wave instabilities of zeroth order develop on the PF surface during the stage intermediate between the first and second compressions [4, 7]. Our investigations have shown that the current sheath subsequently experiences discontinuities, but not in the "neck" of the bridge, as predicted in [8] (Fig. 1). The plasma begins to flow out of the compression region through the produced discontinuities, thereby decreasing further the number of

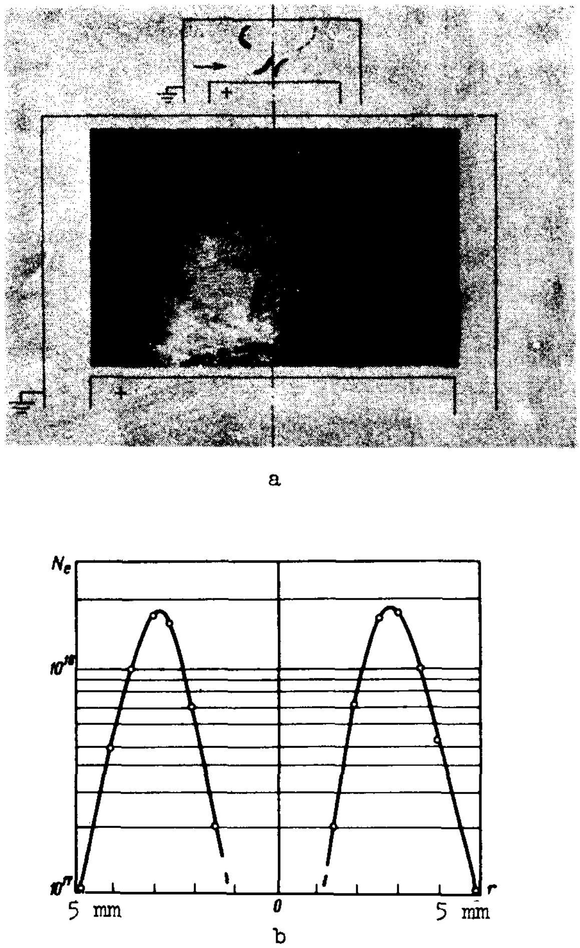

Fig. 2. Interference pattern of the second compression (a) and its reduction (b) pertaining to the instant of time prior to the final additional compression, total development of the turbulence, and maximum of the neutron pulse approximately after 20 nsec. The arrow on the diagram shows the region of the second compression. The data reduction shows that the pinch structure is tubular during that instant of time.

particles in the PF. The undisturbed parts of the current sheath continue to converge to the axis. The instant of rupture onset coincides with the maximum of a pulse of hard x radiation (the leading front of which was in our case of the order of the photomultiplier resolving time), and by with a weak peak of neutron radiation. These results point to a more complicated mechanism of formation of hard x-radiation, compared with that proposed in the theoretical papers [8, 9].

3. A typical interference pattern pertaining to the second compression, i.e., to an instant of time close to the maximum of the main neutron pulse, taken with an exposure of ∿1 nsec, is shown together with the result of its processing in Figs. 2a and 2b, respectively. It is seen from the figure that the length and radius of the PF have decreased considerably by the instant of the second compression, and its axis is curved and inclined to the system axis. This confirms the hypothesis advanced in [4] that the randomly varying short tracks on the obscurograms obtained with soft x-rays pertain to the second compression.

An investigation of a large number of interference patterns has shown that such a secondary "additional compression" of the current sheath can occur in different places, and even immediately in several places on the same PF at time intervals on the order of several dozen nsec. In the regions below such additional compressions, a very strong smearing of the interference fringes takes place at the instant of the maximum of the neutron pulse, accompanied by random breaks and bendings, which apparently indicate that the plasma is turbulent in this part of the PF.

It is seen from Fig. 2b that the gradient of the electron density on the PF boundary decreases sharply at this instant of time. This indicates a much deeper penetration of the magnetic field into the plasma compared with the instant of time corresponding to the first compression, and confirms qualitatively the theoretical calculation in [4].

4. At the center of the compressed plasma, and particularly on the boundary of the "additional compressions" and turbulent regions, one can see formations that are elongated along the z axis and contain sharp gradients, with completely smeared-out interference fringes, and with transverse dimensions exceeding the dimension of the resolved element. This is evidence of the important role played in plasma heating, during the second compression, by the mechanism connected with the turbulence produced by the two-stream instability [10]. This turbulence is excited by electrons accelerated in the electric fields produced when the current sheath is ruptured.

Estimates of the neutron yields, made for the region of the second compression at parameters $T_i \sim 20$ keV [3], $\tau \sim 10$ nsec, and $N_e \sim 10^{18}$ cm^{-3} turns out to be in good agreement with experiment ($\sim 10^{10}$ neutrons). On the other hand, estimates of the neutron yield for the region of rupture of the current sheath during the same time and at the same temperature, but at a density $N_e \sim 10^{17}$ cm^{-3} (which exists here prior to the turbulence development), give a value smaller by two orders of magnitude. The plasma volumes used in these estimates were taken from the interference patterns.

The results thus demonstrate that the PF current sheath becomes ruptured at the instant of maximum of the hard x-ray pulse, that the remaining parts of the sheath are additionally compressed, and turbulence develops at the rupture place. The results also establish an additional mechanism whereby the plasma flows out of the sheath. This mechanism explains the hitherto unexplained insufficiently large neutron yield of the PF at the assumed temperature $\sim$20 keV, and point to an appreciable penetration of the magnetic field into the discharge plasma at that instant of time. A detailed discussion of the results will be presented in a separate article.

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