Direct detection of flux of epithermal electrons from micropinch plasma

A. A. Gorbunov, M. A. Gulin, A. N. Dolgov, O. V. Nikolaev, and A. S. Savelov
Moscow Engineering-Physics Institute

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The energy distribution of the epithermal electrons emitted from the plasma of a micropinch discharge has been detected directly by means of a magnetic analyzer. The kinetic energy of the flux of epithermal electrons is comparable in magnitude to the thermal energy of the micropinch plasma.

The model of radiative contraction for the micropinch phenomenon in z-pinch discharges is currently regarded as the most systematic model and that which is supported best by experimental results.[1] The formation of a micropinch—a local region which is an intense source of soft x radiation[2]—is interpreted as a result of the contraction of the plasma channel of the discharge due to a flow of plasma out of the channel and a radiative loss of energy. The formation of fluxes of epithermal particles is not part of this model.

On the other hand, there is evidence for the presence of epithermal electrons in the plasma of a micropinch.[3] In the opinion of several investigators, the development of acceleration processes can play an important, of not decisive, role in the mechanism for the formation of a micropinch region.[4,5] The appearance of this region is interpreted as a result of the production, focusing, and relaxation of a relativistic electron beam in a limited volume of the plasma of the pinch.

In the present letter we are reporting the direct detection of a flux of epithermal electrons from a micropinch plasma. For these measurements we used a compact analyzer with directional focusing, with a 180° turning of the beam, and an emulsion particle detector.

The experiments were carried out in an apparatus which produces a low-inductance vacuum spark (Fig. 1). The working medium of the discharge is made up of the erosion products of the (iron) anode. The current source is a bank of high-voltage, low-inductance capacitors. The analyzer is positioned directly in the vacuum chamber (the vacuum is no worse than 10^{-4} torr) of the discharge apparatus, near the end of the outer electrode. The analyzer is calibrated with the help of a collimated monoenergetic electron beam with a given set of discrete energies and with an adjustable current in an ÉG-100M electron chronograph.

The working conditions are monitored by means of an x-ray pinhole camera, which records the structure of the emitting plasma in the regions $\lambda < 18$ and $\lambda < 3$ Å in each pulse. The current and the total charge of the emitted electrons are monitored by replacing the magnetic analyzer by a Faraday cup.

The flux of fast electrons is detected in the micropinch regime during the second

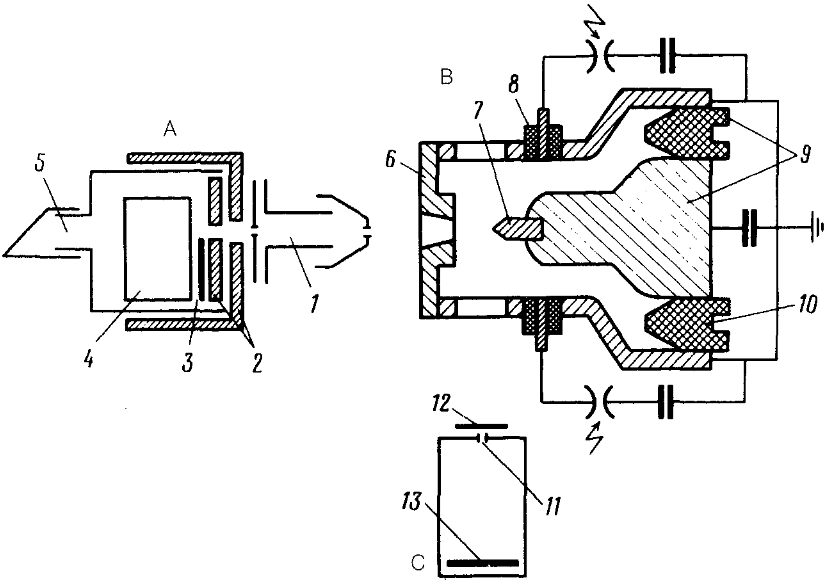

FIG. 1. Experimental layout. A: Magnetic analyzer. B: Discharge apparatus. C: Pinhole camera. 1—Collimation system; 2—magnetic screens; 3—detector; 4—permanent magnets made of a rare-earth alloy; 5—adjustable window; 6—cathode; 7—anode; 8—triggers; 9—coaxial leads; 10—separation insulator; 11—objective of pinhole camera; 12—beryllium filter; 13—x-ray film.

half-period of the discharge current, with an appropriate selection of electrical parameters, such that the polarity of the electrodes is inverted, and the flux of accelerated electrons is directed toward the outer electrode.

At discharge currents <50 kA, at which a micropinch does not form, the energy

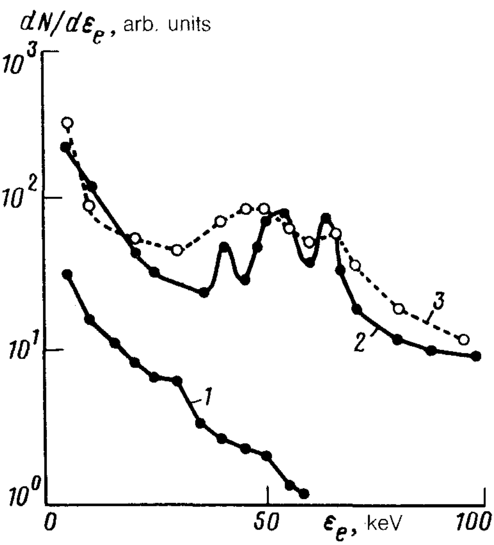

FIG. 2. Measured energy distribution of electrons emitted from the plasma of a micropinch discharge. 1—$U=5$ kV, $I=45$ kA; 2—$U=25$ kV, $I=150$ kA; 3—$U=10$ kA, $I=90$ kA (U is the voltage to which the capacitor bank is charged, and I is the maximum discharge current).

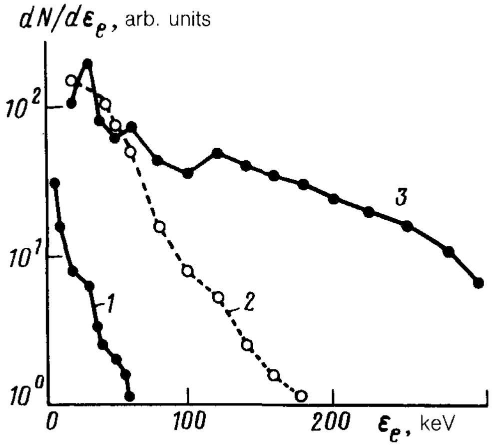

FIG. 3. Electron distributions recorded for various lengths (l) of the separation insulator. 1—$U = 5$ kV, $I = 45$ kA, $l = 8$ cm; 2—$UU = 17$ kV, $I = 150$ kA, $l = 3$ cm; 3—$U = 17$ kV, $I = 150$ kA, $i = 8$ cm.

distribution detected is distinguished by its high reproducibility, in terms of both the shape of the distribution and its absolute values. At currents above 50 kA (the micropinch regime), the shape of the distribution varies from one series of experiments to another. We frequently observe a distribution which is not smooth; at the same time, the number of detected particles increases significantly (Fig. 2).

In several series of experiments, electron distributions were recorded at various lengths of the separation insulator. This length determines the dielectric strength of the gap between the electrodes. An increase in the length of this insulator results in an intensification of the high-energy part of the distribution.

The mechanism responsible for the production of a flux of fast electrons in a micropinch may be an acceleration of particles in the electric field which arises because of the onset of an anomalous resistance of the pinch plasma.[6] Another mechanism, which operates in the stage preceding the appearance of the anomalous resistance, is the conservation of the adiabatic invariant $\varepsilon_\perp / B = \text{const}$ and of the angular momentum $rv_\varphi = \text{const}$ under collisionless conditions in the course of the pinch.[7]

An estimate of the total energy of the epithermal electrons from the results of the direct detection of these electrons yields a value on the order of 0.5 J. This figure corresponds to the result found from measurements of the absolute yield of hard x radiation by means of a scintillation dosimeter.[8]

Our estimates show that the kinetic energy of the epithermal electrons is comparable in magnitude to the thermal energy of the pinch plasma, so the development of acceleration processes is capable of having an important effect on the plasma dynamics during the micropinch process. This point must be kept in mind in the construction of theoretical models for the physical phenomenon.

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