Formation of a plasma precursor due to the collapse of multiwire liners

I. K. Aĭvazov, V. D. Vikharev, G. S. Volkov, L. B. Nikandrov, V. P. Smirnov, and V. Ya. Tsarfin

(Submitted 17 November 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **45**, No. 1, 23–25 (10 January 1987)

A study of the initial stage of the collapse of multiwire liners is reported. The dynamics of the formation of a plasma precursor has been studied. The velocity of radial streams has been measured [$(2–3)\times 10^7$ cm/s]. It has been established that the acceleration of these streams is of an electrodynamic nature. A numerical simulation of the process has been carried out.

Of particular interest in research on liner collapse[1–7] is the regime of the contraction of a compact shell,[2] in which the shell effectively peaks the power of the generator. On the other hand, certain pieces of experimental evidence[3,4,6] imply that a current-carrying plasma appears at the axis before the bulk of the liner arrives at the center. This current-carrying plasma detracts from the compactness of the compression.

Our purpose in the present study was to obtain experimental data on the dynamics of liner compression in the initial stage. In the experiments we used a liner consisting of 4–24 copper or aluminum wires with a mass per unit length $M = 15–30\ \mu$g/cm. The wires are arranged on a cylindrical surface, parallel to the axis of the cylinder, with a radius $R = 1.5–0.75$ cm. The amplitude of the current through each wire reaches 500 kA.

Analysis of the results shows that a flash of soft x radiation is observed some 15–40 ns before the collapse of the bulk of the mass; the actual time depends on the amplitude of the current through the liner and on the value of the parameter MR^2. Framing photographs taken with an x-ray image converter provide evidence that a cylindrical plasma channel forms at the liner axis at this time. This channel is the primary source of the soft x radiation. The image-converter photograph in Fig. 1 was recorded by the x-ray image converter 40 ns before the arrival of the bulk of the wires at the axis. We see that at this time the wires have moved as a whole toward the liner axis, over a distance of 2.5 mm from their initial radius of 7.5 mm. Images of "hot spots" on two wires moving in directions perpendicular to the observation direction are stretched out radially so we can estimate the velocity of the wires (allowing for the exposure time). This velocity turns out to be $(1–2)\times 10^7$ cm/s. The size of the axial foreplasma is about 1 mm. To study the dynamics of its formation, we recorded framing pinhole photographs in the soft x radiation. As in Ref. 4, but in the present case in the soft x radiation, we can see plasma streams which are accelerated from distinct, immobile wires toward the liner axis. Figure 2 is a fragment of a corresponding image-converter framing photograph. The velocity of the streams in Fig. 2 is 2×10^7 cm/s. The ratio of the radial velocity to the transverse velocity is close to 10,

 0021-3640/87/010028-04$01.00

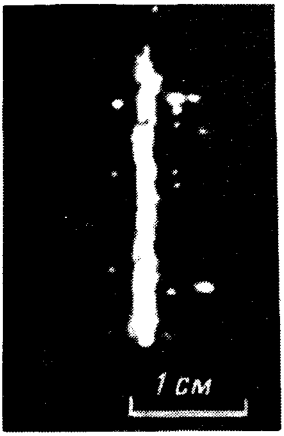

FIG. 1. Framing x-ray image of a liner recorded 40 ns before the collapse. The exposure time is 5 ns.

providing evidence that the acceleration of the plasma occurs by an electrodynamic mechanism.

Analysis of the experimental data shows that the dynamics of the initial stage of the collapse of the multiwire system can be interpreted in the following way. As a current on the order of a few hundred kiloamperes flows through one wire, the wire explodes, and the plasma channel that forms expands at a velocity of[4] $(2–5)\times 10^6$ cm/s. By the time the plasma of the exploded wires begins to move toward the axis, it has acquired transverse dimensions $\rho \sim 0.1$ cm. Because of the radial variation of the density of the plasma channel of an individual wire, the acceleration of the plasma toward the wire axis will depend strongly on its distance from the axis of an individual plasma channel, even if the current is distributed uniformly along the cross section of an individual exploded wire. As a result of the electrodynamic acceleration of the low-density plasma closer to the liner axis, some converging, supersonic, radial plasma

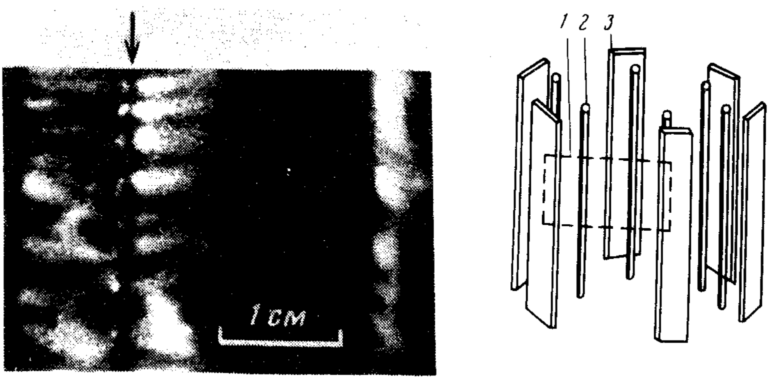

FIG. 2. Fragment of a framing x-ray image of the initial stage of the collapse of a liner; diagram illustrating the geometry of the recording and the positions of the wires and the return conductors. The exposure time is 15 ns. 1—Return conductor; 2—wires of liner; 3—field of view of the image converter.

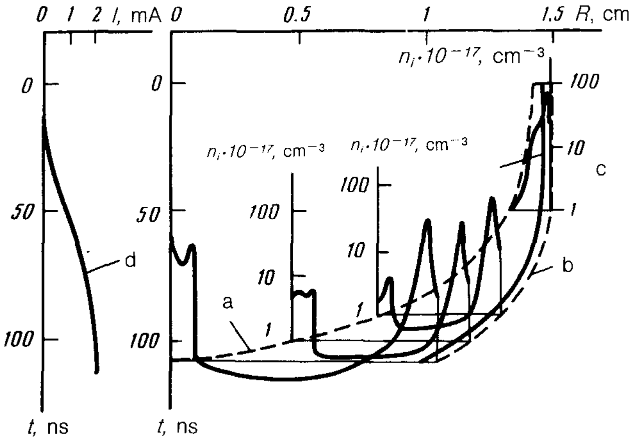

FIG. 3. Time evolution of the profile of the density of n_i. a,b—Positions of the inner and outer boundaries of the liner; c,b—curves bracketing half the mass of the liner; d—current flowing through the liner. The mass per unit length of the liner is 65 μg/cm.

streams form with a transverse dimension on the order of ρ (Fig. 2). We can thus use the one-dimensional MHD model for the acceleration of liners without discontinuities[8] for a numerical and analytic study of the appearance of the precursor. Figure 3 shows the results of one version of the numerical calculations on the liner motion. Shown here are radial profiles of the plasma density n_i at times 50, 90, 100, and 108 ns after the current begins to flow. We see that by 90 ns a clearly defined plasma precursor has formed. The liner has essentially stratified into two shells. After this time ($t \simeq 100$ ns), there may be a finer radial structure in the plasma density. After the plasma appears at the axis ($t \simeq 110$ ns), the collapse process is, for 20–30 ns, a sequential acceleration of the inner plasma layers against the background of a motion of the entire mass as a whole toward the center. The approximation used by us, which ignores the topology of the magnetic field of the multiwire liner, shortens the collapse process.

It follows from the calculations that the appearance of a precursor does not substantially change the amount of kinetic energy that is transferred to a shell of optimum mass,[8] but it does prevent a significant peaking of the power. A study of the formation of the plasma precursor at currents in the range 150–500 kA through the wire thus clearly demonstrates the need for allowing for this phenomenon in an analysis of the thermalization of the energy of electrodynamically accelerated shells.

[1]V. N. Mokhov *et al.*, Dokl. Akad. Nauk SSSR **247**, 83 (1979) [Sov. Phys. Dokl. **24**, 557 (1979)].
[2]S. G. Alikhanov *et al.*, Pis'ma Zh. Tekh. Fiz. **5**, 1395 (1979) [Sov. Tech. Phys. Lett. **5**, 587 (1979)].
[3]R. F. Benjamin *et al.*, Appl. Phys. Lett. **39**, 848 (1981).
[4]L. A. Dorokhin *et al.*, Preprint No. 3814/7, I. V. Kurchatov Institute of Atomic Energy, Moscow, 1983, p. 21.
[5]Yu. D. Bakulin *et al.*, Zh. Prikl. Mekh. Tekh. Fiz. No. 6, 7 (1980).
[6]R. B. Baksht *et al.*, Fiz. Plazmy **9**, 1224 (1983) [Sov. J. Plasma Phys. **9**, 706 (1983)].

[7]S. L. Bogolyubskiĭ *et al.*, Pis'ma Zh. Tekh. Fiz. **11**, 1271 (1985) [Sov. Tech. Phys. Lett. **11**, 525 (1985)].
[8]I. K. Konkashbaev *et al.*, Doklady 3-eĭ Vses. konf. po inkh probl. termoyad. reaktorov (Proceedings of the Third All-Union Conference on Engineering Problems of Fusion Reactors), Vol. 1, TsNII atominform, 1984, p. 252.

Translated by Dave Parsons