High-time-resolution focusing of an intense relativistic electron beam

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The instantaneous current density of the diode of an intense-beam relativistic electron accelerator has been measured. The measured current density reaches 80 MA/cm^2, or an order of magnitude higher than the value averaged over the pulse length. The power density reaches 6×10^{13} W/cm^2.

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Babykin *et al.*[1] have reported a focusing of relativistic electron beams in the diodes of intense-beam electron accelerators. The diameter of the focus was determined from its hard-x-ray image recorded with a pinhole camera over the entire duration of the pulse. It is important to know the temporal characteristics of the electron beam for studying the beam dynamics in the diode and for correctly interpreting the heating of the anode foil, in particular, the role played by the anomalous deceleration of electrons due to their magnetization. In this letter we are reporting a study of the dynamics of a focused relativistic electron beam. The most important result is the detection of a power density $\sim 6\times 10^{13}$ W/cm^2 at current densities up to 80 MA/cm^2. The results were found by time-resolved photography of the focus in hard x rays. An electron-optical image converter of the direct-image-transfer design was used. The cathode of the converter was a microchannel plate sensitive to x rays with energies of tens or hundreds of kiloelectron volts. An x-ray image of the focus was constructed with the help of a pinhole camera on this plate. The plate doubled as an intensifier.

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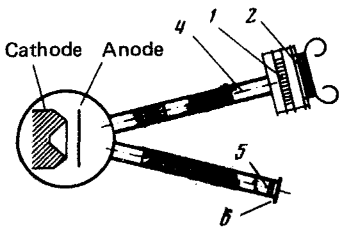

FIG. 1. Experimental arrangement. 1—Microchannel plate; 2—screen; 3—pinhole camera; 4—Kovar window of image converter; 5—x-ray filter; 6—RM-5-1 x-ray film.

For the experiments we used the Mirazh device[2,3] with a cathode similar to that described in Ref. 1. At a voltage of 800 kV across the diode, the current reached 200 kA under focusing conditions with a total pulse length of 90 ns. The experimental arrangement is shown in Fig. 1. The exposure time for an x-ray frame, ≅5 ns, was set by the effective length of the voltage pulse applied between the microchannel plate and the image-converter screen. The spatial resolution of the system, 400 μm referred to the object, was set by the effective aperture and the collimation angle of the lead pinhole camera.

Time-integrated measurements of the beam current density were carried out with a pinhole camera using RM-5-1 x-ray film. The spectral transmission characteristic of the detection systems allowed detection of x rays with energies ⩾(40–60) keV.

Figure 2 shows time-integrated (a) and instantaneous (b, c) x-ray photographs of the focus of the electron beam at various times, along with corresponding curves of the x-ray

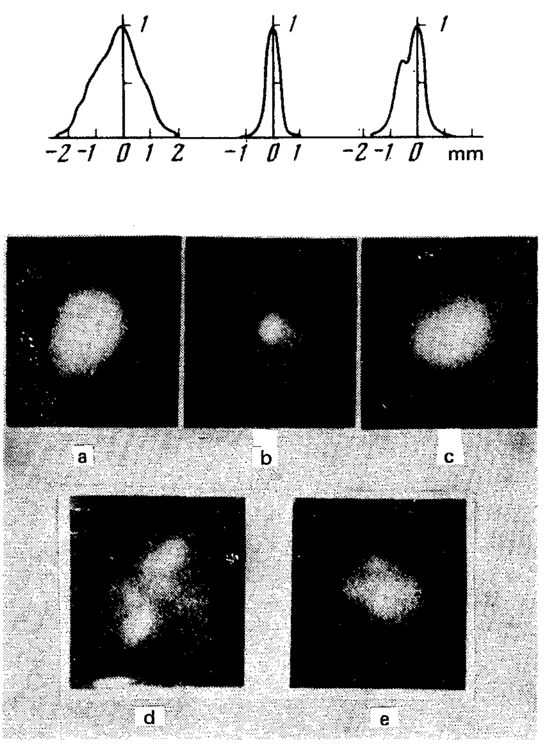

FIG. 2. X-ray photograph of the focus of the electron beam and its intensity distribution. a—Time-integrated photograph; b—photograph taken 45 ns after the beginning of the current flow; c—70 ns after the beginning of the current flow; d, e—break-up of the current into filaments.

TABLE I.

	j_{max} [MA/cm^2]		
τ (ns)	5–10	50–55	70–75
a	63	80	6.3
b	6.7	5.3	5.0

a—Diode current densities at various times.
b—Time-averaged current density in the corresponding experiments.

intensity distribution. The half-width of the intensity curve corresponding to the time-integrated photograph is seen to be sharply different from that on a photograph recorded in 5 ns. If we assume that the x-ray emission spectrum is uniform over the size of the focus and that the current in the diode is carried primarily by electrons, we can estimate the electron-beam current density in the focus. The instantaneous current density is determined from the value of the current at the measurement time, while the integrated current density is determined from the maximum value of this current. As the area of the focus we used the area corresponding to half the maximum intensity. Some representative current densities are listed in Table I, from which it follows that the instantaneous current density exceeds the current density measured by the time-integrated method by more than an order of magnitude up to a certain time. The instantaneous current density reaches 80 MA/cm^2. The instantaneous power density is 6×10^{13} V/cm^2, which is approaching the power density currently being achieved in laser-fusion experiments. In some of the experiments, however, we observed a complex structure for the focus (Figs. 2d and 2e), indicating that the diode current is breaking up into several filaments (this was also asserted in Ref. 1).

This sharp focusing into one or several filaments was observed only up to a point 50–60 ns after the beginning of the current flow. The instantaneous photographs at later times indicate a lowering of the current density to a level on the order of the values measured by the time-integrated method. It may be suggested that the defocusing of the beam results from the occurrence of a strong instability of the diode current at this time.

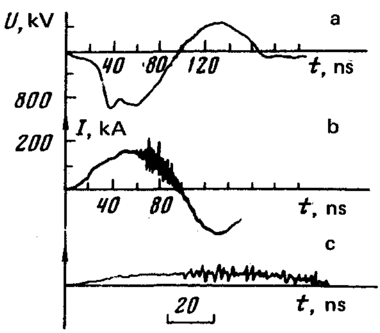

FIG. 3. Typical oscilloscope traces of the voltage across the diode (a) and of the accelerator current (b and c). For trace c, the diode current was measured with a higher time resolution.

It can be seen from the oscilloscope traces of the current (Fig. 3) that the rf oscillations in the current grow sharply during the last third of the pulse. The characteristic period of these oscillations is a few nanoseconds. Comparison of the x-ray intensity distribution in the focus found with the image converter with that measured by the time-integrated method suggests that during its existence the well-formed beam changes position on the anode, tracing out a "hatching" over the area identified by the time-integrated measurements. In the course of these events, small parts of the foil are rapidly heated. After the beam leaves, a hot part of the foil cools off by expansion over a time comparable to the heating time. The temperature averaged over the surface of the integrated focus is thus lower than in the case of heating throughout the pulse. This point was drawn to our attention by L. I. Rudakov, whom we thank.

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