MEASUREMENT OF THE SPATIAL—TEMPORAL CURRENT DENSITY DISTRIBUTION OF HIGH-CURRENT ELECTRON BEAMS WITH THE HELP OF A pin-DIODE MATRIX

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New applications of the methods of diagnostics of the parameters of high-current electron beams (HEB), based on the use of x-ray bremsstrahlung, are increasingly being developed. The problems solved with the help of x-ray procedures include monitoring of the form of a current pulse and measurement of the energy spectrum of electrons and the spatial characteristics of HEB.

At the present time electrooptical converters combined with a scintillator or a pin-hole camera [1], a sectioned Faraday cylinder [2], and pin-diode matrices [3, 4] are used for measuring the spatial characteristics. Electrooptical converters make it possible to obtain an insignificant number of time points within one shot, and their use entails well-known technical difficulties. The use of a sectioned Faraday cylinder is ineffective, since its position in the vacuum chamber practically eliminates the possibility of efficient operation with this apparatus. In addition, the collector plasma formed shunts the receiving strips of the cylinder, which becomes especially apparent in microsecond beams. These disadvantages can be eliminated by using collimated pin-diodes as bremsstrahlung detectors. In [3] the angular distribution of x-ray radiation on the collector was measured with the help of a pin-diode matrix, and in [4] the distribution of the current density on the target at several points along the radius was determined as a function of time.

In this paper we describe a procedure for measuring the space—time parameters of an electron beam with the help of a pin-diode matrix. The radial distribution of the current density of a hollow beam as a function of time is obtained.

The matrix setup includes a framework, in which collimators with pin-diodes are placed. The standard collimation scheme is shown in Fig. 1, where 1 is a detector, 2 is a collimator, and 3 is a collector. The collimated detector detects radiation from a small section of the target. The magnitude of the signal is proportional to the electron current density on a given section of the target. The collimators are placed coaxially with the vacuum chamber. The dimensions of the collimators and of the receiving target make it possible to use up to ten detectors in the matrix. Several modifications of matrix frameworks, in which the pin diodes are arranged either along the diameter of the collector for measuring the radial structure of the beam or along the circumference for studying the azimuthal nonuniformities of the HEB, have been developed. The construction of the matrix makes it possible to make linear displacements of the matrix as a whole along the surface of the collector, and also to rotate the matrix relative to its axis. Due to the indicated displacements and the high repeatability of the results from one pulse to another, it was possible to obtain a large number of experimental points. The spread in the measurements of the form of the voltage, current, and γ signal pulses with the same charging voltage of the pulsed voltage generator does not exceed 2%. To raise the efficiency with which the measurements of the radial structure of the beam are performed, the dimensions of the beam on the collector can be varied by introducing an imbalance in the values of the matrix fields in the region of formation of the beam and in the transport channel.

The fundamental difficulty which usually arises in performing the measurements consists of obtaining a good ratio of the useful signal in the pin diodes to the noise level while providing high spatial resolution of the collimator. The optimal parameters of the collimators, for which the magnitude of the signal equalled 0.5-2.0 V with a noise level of ~0.03 V, were determined by experimental testing of the procedure. The spatial resolution equalled 3 mm. Pin-diodes of the DKT type with the following characteristics were used in the experiment: the working voltage equalled 10-200 V; the thickness of the sensitive region, ~120 μm; the sensitive surface area, 12 mm in diameter; and the temporal resolution, 5 nsec.

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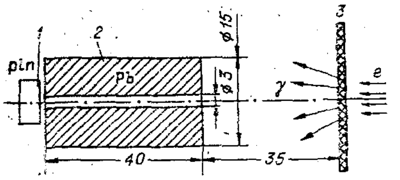

Fig. 1

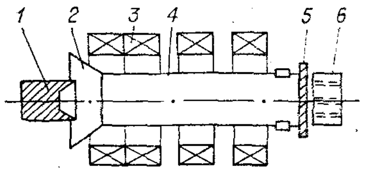

Fig. 2

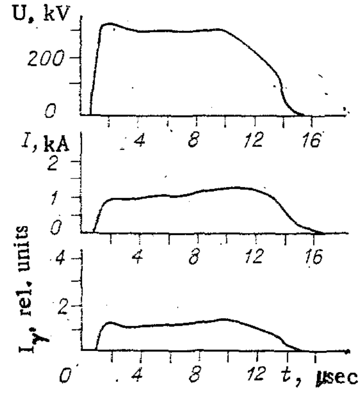

Fig. 3

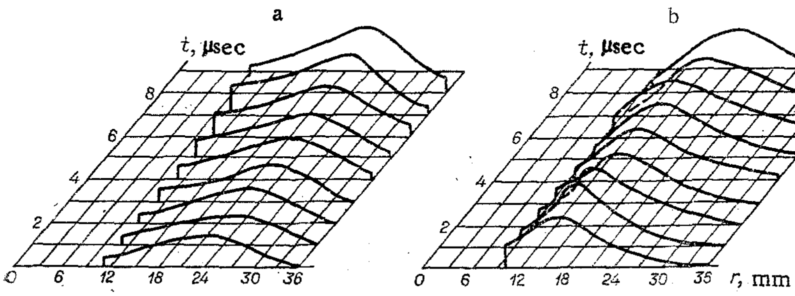

Fig. 4

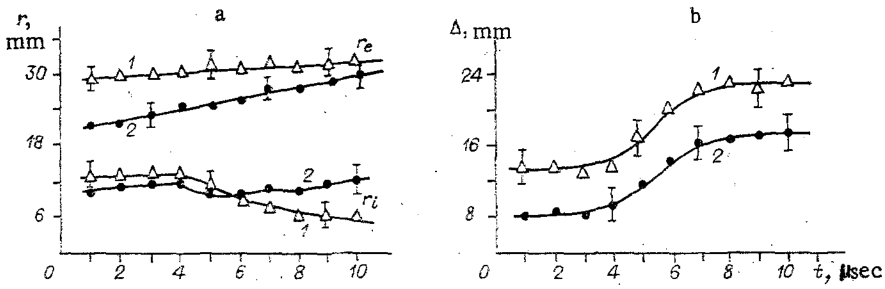

Fig. 5

The experimental testing of the proposed procedure and measurement of the space–time characteristics of HEB were performed on a setup with the following beam parameters: electron energy 200-350 keV; beam current 0.6-1.2 kA; pulse duration 10-12 μsec. The layout of the setup is shown in Fig. 2: 1 is the cathode; 2, anode; 3, coil of the magnetic system; 4, liner; 5, collector; 6, diode matrix. The beam is formed in a vacuum channel 1 m long with the help of an explosion-emission diode with magnetic insulation. The liner is 70 mm in diameter, and the guiding magnetic field is equal to 0.3-1.5T. The cathode consists of a stainless-steel tube 66 mm in diameter. The experimental results presented below refer to the variant of beam injection into a magnetic plug, when the cathode is located at a distance of 70 mm from the anode cone and its degree of magnetization is equal to 0.32 [5]. The voltage pulse U, current pulse I, and bremsstrahlung pulse I_γ are shown in Fig. 3.

The purpose of the experiments was to measure the radial distribution of the current density as a function of time. These measurements were performed for a magnetic field of B = 0.3 and 1.0T, with a constant voltage on the diode equal to 300 kV. The beam current was equal to 1.0 kA. To measure the current density, the signals from the γ detectors were normalized to the magnitude of the voltage at each time point. The distribution of the current density in the beam tube is shown in Fig. 4a, b for B = 0.3 and 1.0T, respectively (the current densities are given in relative units).

Figure 5 (B = 0.3 for curve 1 and 1.0T for curve 2) shows the inner radius r_i, outer radius r_e, and also the thickness Δ of the beam tube as a function of time (the values of these parameters were calculated at one-half the maximum of the current density distribution).

Experimental results showed that there exists a quite intense beam halo on the collector. Previously it was presumed (based on measurements with the help of a pin-hole camera) that a hollow beam is thin and has sharp boundaries. The measurements showed that, under the conditions of beam injection into a magnetic plug with a cathode far away, the form of the radial distribution of the beam profile remains virtually constant as a function of time. The structure of the beam is maintained practically constant for 10 μsec. The changes in the radial distribution are associated with the increased density of the halo part of the beam and are caused by the motion of the cathode plasma across the magnetic field. According to our estimates, the transverse velocity of the cathode plasma does not exceed 10^5 cm/sec. From the curve shown in Fig. 5b it is evident that the main broadening of the beam occurs at 4-6 μsec. This is most likely attributable to the fact that it is precisely at this moment that the plasma cathode flame enters the anode cone. The sharp change in the mutual orientation of the magnetic and electric field vectors at the emitting boundary causes the dimensions of the beam to increase.

The measurements performed do not exhaust all possible applications of a pin-diode matrix. Future applications of this method will depend on the improvement of the spatial resolution of the collector measurements. Aside from measurements of the radial structure of the beam, it is necessary to study the azimuthal distribution of the current density. Such experiments make it possible to study the instability of the beam, and the nonuniformity of emission at the cathode. An important problem is the measurement of signals on pin-diodes with high time resolution. To solve this problem it is necessary to improve the frequency characteristics of the circuit for switching on the pin-diodes and to use a fast recording apparatus with high sensitivity. Because of the structural complexity of the radial distribution of the current density as a function of time according to the oscillogram, the data processing should be automated.

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