PROPAGATION OF A STEADY ELECTRON BEAM IN AIR

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Investigations of the propagation of electron beams in a gas are interesting, both for development of physical description of multiple scattering phenomena, and for practical applications, e.g., nonvacuum electron beam technology.

This paper presents results of measurement of current density of a beam of electrons propagating in the magnetic field of a solenoid and in field-free space, and gives data on measured beam dimensions after rotation by a transverse magnetic field.

The main elements of the experimental equipment are shown in Fig. 1. The beam of electrons from accelerator 1, injected into the atmosphere by means of the exit device 2, passes through the solenoid 7 (Fig. 1a), and falls on the target 9. The dosimeter device 8 inserts into the beam a film of material sensitive to the radiation, and determines the radiation exposure necessary to give the beam "print." Photometric measurement of the print is recalculated into the radial distribution of current density.

For measurement at large distance (because of the limited space below the exit device), the beam is rotated by the magnet 4 (Fig. 1b) and falls on target 6. The radial current density distribution is measured by means of the graphite collector 5, which moves radially or axially relative to the beam.

The beam is observed by means of the television camera 3.

The direct action type ELV-4 electron accelerator [1] gives a steady beam of maximum energy 1.5 ± 3% MeV at a current of up to 30 mA. The exit device [2, 3], which operates on the principle of differential pumping of the accelerator-atmosphere channel, forms a beam in such a way that the entry point into the atmosphere coincides with its crossover. The radius of the exit aperture is 0.12 cm. The beam emittance at energy 1.4 MeV is on the order of $3 \cdot 10^{-8}$ cm•deg. The solenoid consists of six coils of internal diameter 280 nm and height 55 mm, separated by gaps of 15 mm width. The faces of the solenoid are closed with iron end-pieces with apertures for beam entry and exit. The solenoid current fluctuations do not exceed ±7%. Depending on the end-piece configuration, one obtains a uniform field of induction B = 0.21 T in a length of 40 cm, or a linearly increasing field from induction B = 0.1 to B = 0.5 T in a length of 24 cm. The dosimeter device is inserted in the gap between the solenoid coils, and exposes the beam by means of a moving slit. Depending on the beam radius and current, the slit width ranges from 0.3 to 1.2 mm, and its speed from 0.35 to 200 cm/sec.

The turning magnet, with a field of 0.11 T and a sector angle of $\pi/4$, is used to measure the beam dimensions in the transverse field. For measurement at large distance from the exit device the sector angle is chosen so that the beam is axisymmetric at the exit.

The parameters of the beam, such as the energy E and the current I, are monitored by measuring instruments included in the accelerometer. The radial distribution of beam current density at entrance to the atmosphere is found from the measured dependence of the current passing through the aperture in the diaphragm as a function of the changing radius of this aperture at a fixed value of total beam current, and the emittance is calculated from measurements of beam bending inside the vacuum channel of the exit device. The radiation-sensitive films used were Du Pont cellophane type MS-300 and astrolon. The images on the cellophane were photometered by means of a type DFE-10 microdensitometer with a collimator of diameter 1 mm, and the astrolon was measured with a type MF-4 microphotometer. The radial distribution of beam current density j(r) was computed from the optical density on the astrolon by the method of [4], and for the cellophane a prior calibration was used. In computing the j(r) curve from the current oscillograms of the graphite collector, we accounted for the variation

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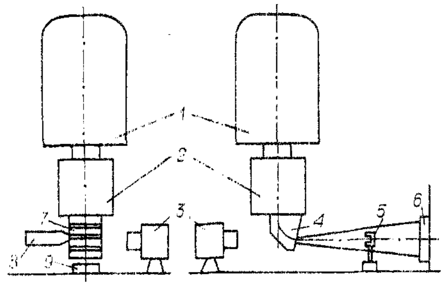

Fig. 1

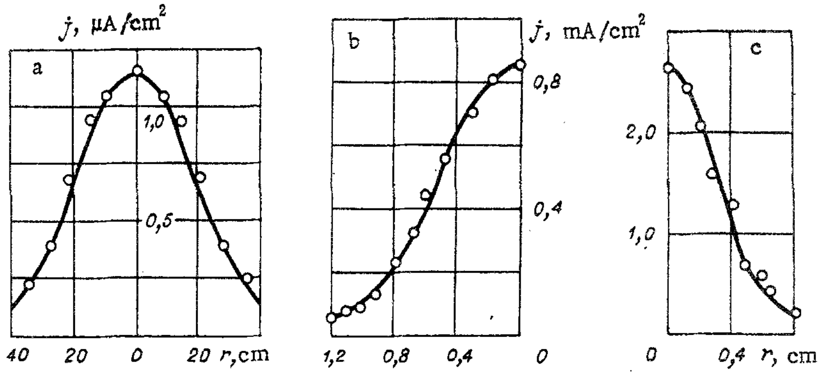

Fig. 2

of the effective area of the collector due to the change in the angle of incidence of electrons at large r.

The points on Fig. 2 show the measured radial distribution of beam current density typical for experiments on the distribution j(r) (*a* refers to the graphite collector, b to astrolon, and c to cellophane), while the solid curve is a Gaussian curve corresponding to the measured beam current. For the great majority of the measurements the deviation of the experimental points from this curve did not exceed ±10% for $r \leqslant 1.5\sqrt{\langle r^2 \rangle}$. With this justification the results of all the experiments to measure j(r) are shown in terms of the average radius $r_0 = \sqrt{\langle r^2 \rangle}$ of the Gaussian distribution as a function of z, I, and B.

The solid line in Fig. 3 corresponds to a computation for air at normal conditions of the distribution of current density for a beam of energy E = 1.2 MeV according to the results of [5], and the points are measured values (1: I = 2.5 mA; 2: 10 mA; 3: 20 mA). Estimates show that the original beam parameters have little influence on the results of the experiment. The agreement between calculated and measured values of j(r) indicates the weak influence of effects such as heating of the air and large-angle scattering, on the nature of beam propagation in field-free space with a current of up to 20 mA.

Figure 4 shows the distribution of beam current density in the solenoid field with I = 1.5 mA, E = 1.4 MeV (the equipment layout is shown in Fig. 1a). The points in Fig. 4 correspond to measured values of rms beam radius with no magnetic field (curve 1), in the uniform solenoid field (curve 2), and in the linearly increasing solenoid field (curve 3). Lines 1 and 2 correspond to computation according to [5], and 3 corresponds to a numerical computation for the appropriate magnetic fields (I is the measured cellophane results, II the astrolon). According to estimates, the contribution to the value of r_0 of the original beam parameters does not exceed 3% at z = 10 cm and falls rapidly as this increases, i.e., the measured j(r) is determined mainly by the scattering process. Figure 5 shows a photograph of the beam inside the upper part of the solenoid, taken from the television screen (*a* — with no magnetic field, b — in the linearly increasing field).

Table 1 shows the measured values of rms beam radius in the increasing solenoid field at z = 24 cm, E = 1.4 MeV, I = 1.5; 8; 12; at 16 and 20 mA, from which one can see that as the beam current increases by approximately a factor of 13 (from 1.5 to 20 mA), the average beam radius decreases by almost a factor of 3, and here the axial current density increases

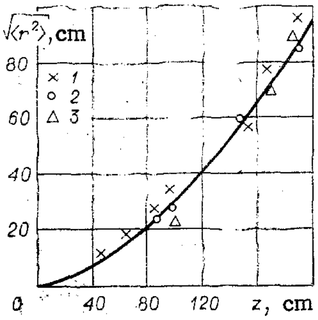

Fig. 3

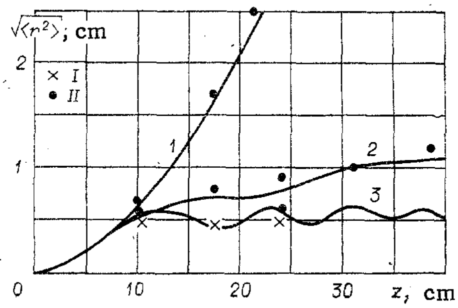

Fig. 4

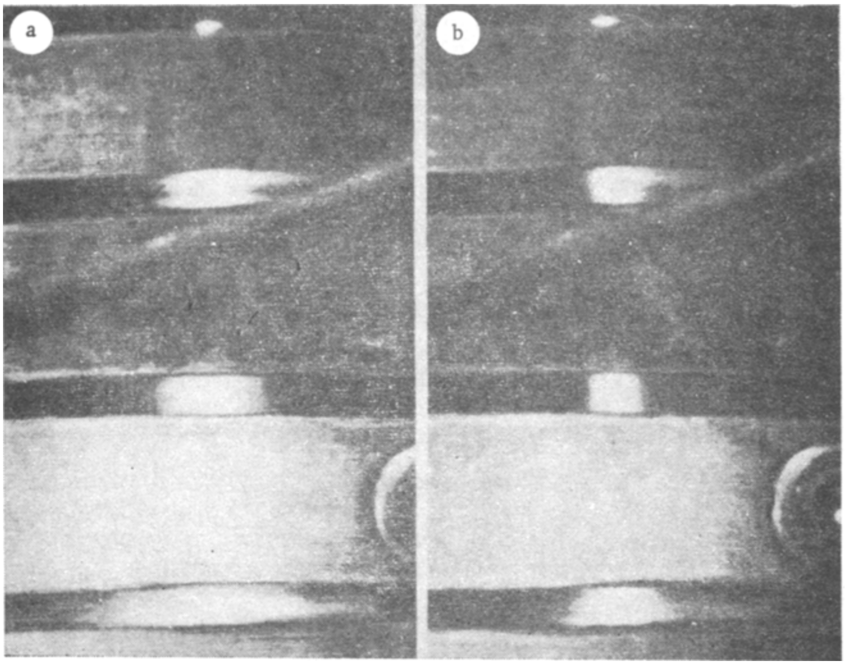

Fig. 5

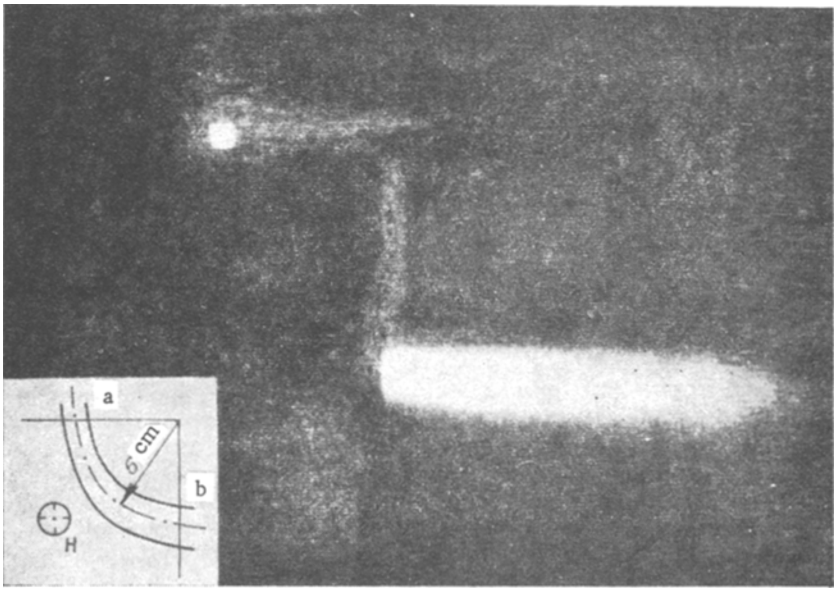

Fig. 6

TABLE 1

I, mA	r_0, cm
1,5	0,6
8	0,45
12	0,315
16	0,25
20	0,22

by a factor of 100 (from 1.3 to 130 mA/cm^2). This effect is associated with reduced scattering of electrons due to lowering of the gas density in the propagation region because of heat release. The average air temperature in the propagation region of a beam with current 20 mA is estimated to exceed 1000°C. Thus, at a current of more than 5 mA in a longitudinal magnetic field the nature of the propagation of an electron beam with r_0 = 0.5 cm differs markedly from that calculated using the theory of multiple scattering and with no allowance for heat release.

Figure 6 shows a photograph of a beam (E = 1.4 MeV, I = 3 mA, turning radius 6 cm) at the exit and the entrance of the turning magnet, taken from the television screen. An elliptical aperture of dimension 2.8 cm along the field, and 1.5 cm across the field, was fused in a stainless foil of thickness 0.3 mm located at the point of exit of the beam from the magnet.

These experiments illustrate the high efficiency of using a magnetic field to reduce the expansion of an electron beam due to scattering in air, and a transverse field to turn and deflect the beam. For beam currents of tens of milliamps the efficiency of a longitudinal magnetic field increases due to heating of the air.

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