Experiment on trapping a strong-current stream of relativistic electrons in a closed orbit

A.N. Didenko, A.V. Petrov, A.I. Ryabchikov, V.A. Tuzov, and Yu.P. Usov

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The beam of the "Tonus" accelerator was trapped in a closed orbit without using external electric and magnetic fields, via the repelling action of a trough-shaped copper screen. The lifetime of the shaped electron ring was 250 nsec at an injection pulse duration 50 nsec.

Electron clusters of high density, in the form of rings made up of revolving relativistic electrons, are of great interest for plasma research, for collective acceleration of charged particles, and for other important applications. Such rings are produced in the Astron[1] or Adhesator[2] facilities or by compressing a hollow beam from a strong-current electron accelerator by an external magnetic field.[3]

The ability of strong-current relativistic electron beams to propagate over considerable distances in a neutral or partly-ionized gas[4] and to be reflected from a conducting surface[5] make it possible to obtain a closed electron ring as a result of the repelling action of a metallic screen—"mirror capture".[6] We do not know, however, of any experimental data confirming this possibility. Our earlier measurements have shown that a high-energy beam remains unchanged after reflection from a conducting surface, does not experience an appreciable loss of electrons,[7] and is transported under gas-focusing conditions over a distance up to 3 meters.[8]

Mirror capture of the electron beam from the "Tonus" accelerator[9] in a closed orbit was realized with the aid of a reflecting screen constructed in the form of a conducting trough. Figure 1 shows a diagram of the experiment. The reflecting copper screen 1 was placed in a volume made up of a copper cylinder 2 and two dielectric covers—bakelite and Plexiglas; the beam was photographed through the latter with an RFK-5 camera. The electron beam 3 was injected through a tangential stub 4. The beam of the "Tonus" accelerator was extracted from the electron gun through a titanium foil 50 μ thick and transported under gas-focusing conditions through a drift tube that coupled the tangent stub 4 to the anode flange of the accelerator.

Figure 2 shows a photograph of the electron ring, obtained under the following conditions: air pressure in the chamber 2.0 mm Hg, injected current 40 kA, maximum electron energy 1 MeV, pulse duration (injection time) 50 nsec, rise time of electron-current pulse 15 nsec. It should be noted that the pressure at which the conditions for focusing and containment of the beam in the ring are best satisfied is much higher than the pressure at which gas focusing is carried out for a straight-line beam). The structure details at the center of the ring, which can be seen on the photograph of Fig. 2, ensure mechanical strength of the chamber, and the illuminated section on the side of the ring is due to the glow

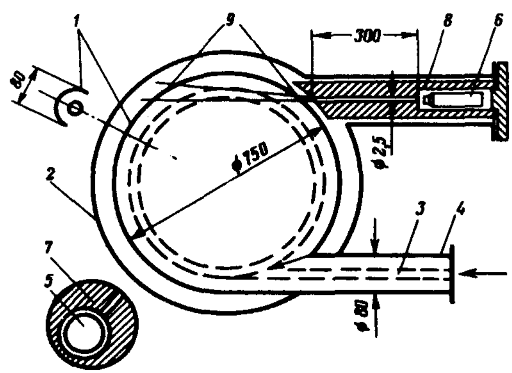

FIG. 1.

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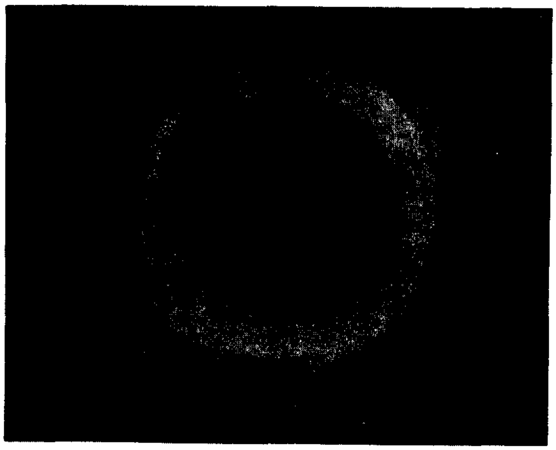

FIG. 2.

of the beam through the reference aperture in the tangential stub. A change in the chamber pressure produces large scale instabilities, in which the beam begins to move along the chords and then leaves the trough.

The lifetime of the electron ring was measured with the two x-ray pickups shown in Fig. 1, namely an electron-beam multiplier 5 of the ÉLU-19 type, with an x-ray registration threshold $E_{min} = 300$ keV, and a scintillation counter 6 (FÉU-87 photomultiplier in plastic scintillator) with $E \sim 80$ keV. Pickups 5 and 6 were placed in lead collimators 7 and 8.

The pickup 5 was placed 50 cm away from the chamber and registered the overall γ-radiation background. Pickup 6 registered the γ radiation due to the scattering of the ring electrons by the residual gas. To exclude the γ radiation connected with the scattering of the electrons from the surface of the reflecting screen, the holes 9 were drilled through the latter.

The oscillograms of the x-ray pulses from the electron ring, obtained with the aid of pickups 5 and 6, are shown in Fig. 3. The pulse durations were 190 and 250 nsec, respectively, which greatly exceeds the injection time.

Comparison of the obtained data with the results of experiments on the formation of the E layer[10] indicates that under the conditions of our experiments the observed lifetime of the ring is determined not by the scattering of the electrons by the gas, but the time during which the reflecting screen exerts a repelling action.

Photometry of the image of the electron ring and of the direct electron beam, at equal pressure, indicates that the current circulating in the ring greatly exceeds the injection current. However, to estimate the coefficients of capture and accumulation of the current it is necessary to have additional experimental data. We are making preparations for measurements of the parameters of an electron ring with an image converter of nanosecond resolution, and we are calibrating the x-ray pickups. Direct measurements of the current of fast electrons circulating under gas-focusing conditions in a closed reflecting screen are made difficult by the presence of a plasma countercurrent and by the open geometry of the reflecting screen, which on the other hand is convenient for further utilization of the shaped electron ring.

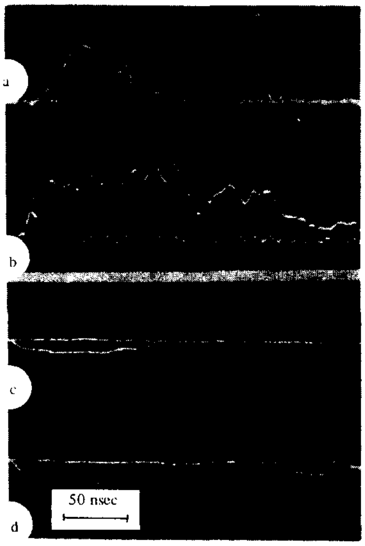

FIG. 3. Oscillograms of x-ray pulses obtained with the aid of the ÉLU-19 multiplier (a, b) and a scintillation pickup (c, d); a, c—no capture, b, d—a ring was produced. The frequency of the timing wave is 100 MHz.

[1] N. S. Christofilos, Plasma Physics and Controlled Nuclear Fusion, Pergamon Press, London, 1, 576 (1959).
[2] V. P. Sarantsev, Proceedings of 7th International Conference on Charged-Particle Accelerators, Erevan, 1970.
[3] M. Reiser, IEEE Trans. on Nucl. Sci., No. S-20, 1, 310 (1973).
[4] A. V. Agafonov, Atomnaya tekhnika za rubezhom **10**, 31 (1973).
[5] W. Link, IEEE Trans. on Nucl. Sci. No. S-14, 3, 777 (1967).
[6] K. V. Khodataev, Atomnaya Énergiya **32**, 379 (1972).
[7] I. Z. Gleĭzer, A. N. Didenko, *et al.*, Atomnaya Énergiya **36**, 379 (1974).
[8] A. S. Smith, Jr., C. E. Swannack, H. H. Fleischmann, and D. A. Phels, L. P. S. **139**, Cornell University, December, 1973.