V. P. Sarantsev, *Acceleration of Ions in Electron Storage Rings*. The collective heavy-ion accelerator at the Joint Institute for Nuclear Research is based on the traditional scheme of ion acceleration in an electron ring proposed by V. I. Veksler *et al.* The prototype accelerator consists of two main elements, namely, the electron-beam injector and the compressor, i.e., the system used to shape and accelerate the electron rings.

The injector is the SILUND linear accelerator.[1] The parameters of the electron beam injected into the compressor chamber are as follows:

- electron energy 2–2.4 MeV
- current pulse length 20 nsec
- electron energy spread in the pulse 1–3%
- beam diameter at the point of injection 40 mm
- beam emittance less than 30 mrad/cm
- maximum injection current 600 A.

The main experiments were performed at injection currents of 300 A.

The compressor, or the adiabatic generator of charged toroids (the ADGEZATOR), consists of a vacuum chamber, a magnetic system, and systems for the injection and correction of the beam trajectory. The vacuum chamber of the ADGEZATOR is a welded stainless-steel configuration with wall thickness of 0.5 mm and spherical side walls approaching the axis of the system. The chamber walls can act as elements reducing the azimuthal component of the electric field of the beam in case azimuthal instability develops. This enables us to increase the maximum stable ring current.[2]

In the prototype accelerator, a magnetic method of compressing and accelerating the rings is used. The magnetic system of the ADGEZATOR (Fig. 1) consists of four pairs of coils in the compression stages and an extraction solenoid supplied with pulsed current. The magnetic system operates in two modes, namely, the compression mode and the extraction mode. In the compression mode, the ADGEZATOR operates as a ring accelerator with weak focusing and the betatron condition unsatisfied.[3]

In the extraction mode, the magnetic well holding the ring is shifted away from the median plane and is made flat in the direction of extraction by shunting one of the coils in stage *IV* and turning on the solenoid. The electron ring moves together with the well and, when the well is completely removed, the ring begins to accelerate in the field of the solenoid which falls off linearly along the axis.

Experiments on the capture of the ring into a closed orbit have shown that the capture efficiency is about 50–70%. The captured current is 200–300 A, i.e., $10^{13}-1.5\times10^{13}$ particles. The lifetime of the ring is comparable with the time of operation of stage *I*, i.e., 5 msec.

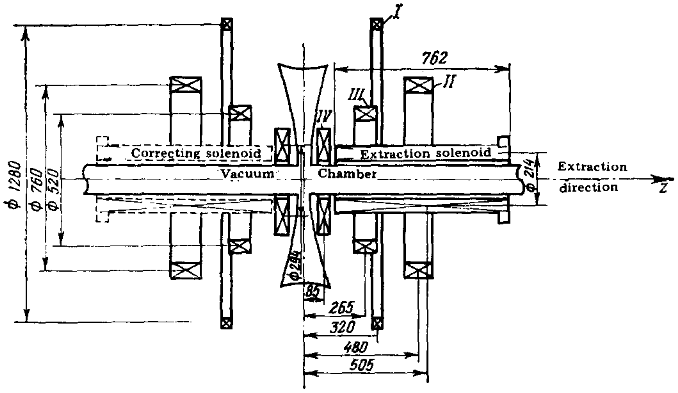

FIG. 1. Magnetic system of the ADGEZATOR.

By removing azimuthal magnetic field inhomogeneities and by correcting the parameters of the magnetic system, it has been possible to produce an electron ring with a maximum radius of 3 cm and transverse half-size $a_z \sim a_r \approx 1.5$–2 mm (Fig. 2) which ensures an electric field of 50 MV/m in the ring.

After optimization of the extraction conditions, the electron ring was extracted through the port of the ADGEZATOR chamber. The measured half-size of the ring in the z direction in the extraction region (2 cm $\leqslant z \leqslant$ 6 cm) was 4–5 mm.

When the region from which the magnetic well was removed was traversed by the ring at 5–7 cm from the median plane, we found a radial displacement of the ring as a whole. The maximum displacement was 15 mm. Additional experiments showed that the presence of 0.1% of the first harmonic of the field of stage *IV*, which appeared due to overlapping of turns in the coil windings in making the transitions from layer to layer, could produce a drift of the ring during passage through the in-

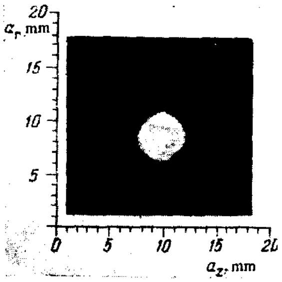

FIG. 2. Photograph of the electron ring cross section recorded in synchrotron radiation at a radius of 3 cm.

tegral resonance with $\nu_r = 1$ in the region from which the well was removed, where $n \to 0$. Measures taken to compensate the first harmonic of the field of stage *IV* (by varying the mutual azimuthal disposition of the coils of this stage and introducing field correcting elements) have ensured that the shift does not exceed 1.5mm. However, the shift appeared again when the operational conditions of the magnetic system were altered.

Analysis of the equations describing oscillations near resonance[4] has shown that the maximum displacement of the ring in the presence of the first harmonic is given by

$$X_{\max} = R\frac{H_{1z}}{H_z}\sqrt{\frac{2\pi\omega_0}{\dot{\nu}}}$$

where R is the ring radius, H_z is the field at the orbit, H_{1z} is the first harmonic of the field, ω_0 is the orbital frequency of the electrons, and $\dot{\nu}_r$ is the speed of passage through resonance. Hence, it follows that the ring displacement can be reduced by increasing this speed of passage. To verify this, a system of additional turns with radii smaller than the radius of the electron ring, and capable of producing an additional magnetic well with increased rate of removal, was introduced into the region from which the magnetic well is removed. Experiments then showed that the introduction of this system resulted in a considerable reduction in the influence of the resonance and reduced the displacement to 1–2 mm.

When the displacement of the ring was eliminated, the electron ring was taken to the end of the acceleration sector. The radius of the electron ring during the acceleration process was found to vary from 3.7 to 4.5 cm. This suggested that the solenoid field gradient was close to the calculated value (70 Oe/cm). The velocity of the electron ring at the end of the acceleration sector was 0.45 sec ± 0.05 sec.

Attempts were made in the course of these experiments to record accelerated nitrogen ions by using tracks left in plastic detectors. The number of fast ions (~30 MeV) in the ring was not more than 10,000, which corresponded to the absence of self-focusing in the ring.

These experiments have shown that, in contrast to the work done at Berkeley, the electron ring does not decay as a result of overcompensation in the presence of nearby conducting walls. Near the ion compensation point, the reduction in the containing Coulomb forces results in the escape of the ions from the ring and the formation of an ion cloud. However, the stability of the electron ring itself is completely retained.

Experimental work is at present in progress at the accelerator to determine the efficiency of self-focusing of the electron-ion ring under high ion loads.

[1] N. I. Beznoshchenko *et al.*, in the book Trudy IV Vsesoyuznogo soveshchaniya po uskoritelyam zaryazhennykh chastits (in: Proc. Fourth All-Union Conf. on Charged-Particle Accelerators), Nauka, M., 1975.

[2] L. S. Barabash *et al.*, Preprint No. P9-7697, Joint Institute for Nuclear Research, Dubna, 1974.

[3] V. S. Aleksandrov *et al.*, Preprint No. P9-9215, Joint Institute for Nuclear Research, Dubna, 1975.

[4] K. R. Symon, in: Symposium on ERA, LBL, UCRL-18103, Berkeley, California, 1968, p. 304.

[5] V. P. Sarantsev, in the book Trudy II Mezhdunarodnogo simpoziuma po kollektivnym metodam uskoreniya (in: Proc. II Intern. Symposium on Collective Methods of Acceleration), Dubna, 1977, p. 13.

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