PRESENT PERFORMANCE OF COLLECTIVE ION ACCELERATION IN JINR

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Thoughout the last few years all the laboratories investigating and studying collective ion acceleration method paid a great attention to theoretical as well as experimental possibilities of the accelerator. However, to come to final conclusion a progress towards greater densities of electrons in the ring and specified experimental studies of the main effects accompanying by the electron ring formation and electron-ion acceleration are necessary. If the results of the last year studies are summarized it appears that one can avoid the known limitation for heavy ion accelerator using a specified scheme of the ring formation. It allowed us to start investigations of the scheme individual elements so that to create a prototype of heavy ion accelerator and a possibility of studying the behaviour of dense electron ring with ions under different conditions.

I. Accessible Estimations of Heavy Ion Accelerator Parameters.

For multi-charged ion collective accelerator the following two parameters are the most determinative:
1. Energy storage per nucleon per the unity of the length

$$U = k \cdot \frac{N_e}{\pi r_0 (a_r + a_z)} \cdot Z^*/A \quad \left(\frac{\mathrm{Mev}}{\mathrm{cm}}\right) \qquad (1)$$

where Ne - electron number in the ring, r_0 - major radius, $a_{r,z}$ - radial and axial sizes of the ring cross section, Z^* - ion charge, k - the ratio of acceleration to its limit value. 2) Accelerated ion number - Ni.

If our task is obtaining energy ~7 MeV per nucleon at the number of accelerated ions $\sim 10^{11}$ per pulse then inserting in (1) the ring parameters which seem to be real nowadays $a_{r,z} \sim 1;2$ mm, $r_0 \sim 4$ cm and choosing $(Z^*/A) \simeq 1/10$ and $K \sim 1/4-1/5$ (there's no ion loss during acceleration at such K) we'll realize that the required electron number in the ring should be about $5.10^{13} \div 10^{14}$. During adiabatic compression of such intense beams in ADHEZATOR and their acceleration it is too difficult to provide their stability. Azimuthal instabilities are presented as the most dangerous ones. The threshold particle number Ne for such instabilities is proportional to electron energy spread in the ring and inversely proportional to the so-called ring impedance in the chamber Z_c.

The growth of the energy spread is unreasonable since it leads to the growth of a_r and in accordance with (1) to U decrease. So Ne increasing is provided by impedance decrease. Since Z_c value characterizes the ratio of azimuthal electric fields to created currents the decrease of Z_c might be attainable by locating metallic screens close to the ring. On the screens and close to them the electric fields are significantly small than in free space. The location of the screens close to the ring while being compressed has undesirable consequences. Firstly, the metallic compressor chamber screens the external magnetic fields which compress the ring that limits the admittable external field frequency (for the chosen chamber the admittable frequency is now $f \lesssim 1000$ cps). Secondly, the chamber side-wall closer to the ring location deteriorates the condition of the single-particle stability because of the field image in the walls which are necessary to be compensated by the appropriate choice of the external field geometry.

At the final stage of the ring compression and its acceleration there appears a danger of resonance instabilities on the chamber self-modes and wave resonances. For suppression of the instabilities a metallic tube is expected to be used with radius less than r_0 and the quality-factor at resonance modes is supposed to be decreased to the value $Q \sim 40$.

Among electron-ion instabilities the hosing one is the most dangerous. The accelerated heavy ion number that is defined by theoretical threshold condition of sinuous instability at typical electron ring parameters is about 10^{11}. A more strong restriction on ion number is connected with magnetic method of ring acceleration. In order no to change the ring sizes significantly $(Ni/Ne) \lesssim 10^{-3}$ is required. The similar estimations are based on the choice of the arrangement parameters.

II. Present Performance of Heavy Ion Accelerator.

Heavy ion accelerator based on collective method consists in fact of the two large arrangements. The high-current induction linear accelerator of electrons is an injector for collective accelerator. Adiabatic charged toroid generator - - ADHEZATOR is intended for electron ring formation, their ion loading and initial ring acceleration. The acceleration of the ring to the final energy is produced by solenoid with the decreasing magnetic field. Magnetic system of ADHEZATOR accelerator allows the formation of the rings with the electron number $Ne \sim 10^{13} - 5.10^{13}$ and electron density $n_e \sim (0.5-2.5) \cdot 10^{13}$ 1/cm. The other expected accelerator parameters are defined by the figures.

I. Injector - High-Current Pulsed Linear Accelerator of Electrons - SILUND.

Electron pulsed accelerator used as

an injector was constructed due to the requirements of providing the following parameters of the accelerated beam.
Particle energy in the beam - E=3.0 MeV
Peak current in pulse - I=1000 a
Pulse length τ =10 ÷ 15 nsec.
Pulse repetition frequency f=10 Hz
Energy electron spread at E=3MeV ($\Delta E/E$)=3%
Emittance at E=3.0 MeV
$\varepsilon = \pi a \theta \leq 0.1$ cm·rad.

Accelerator consists of 5 accelerating sections containing 18 accelerating element-inductors each and fed by nanosecond pulse generators (fig.1). A more detailed description of the linear accelerator system was reviewed earlier /4/. The most complicated stage in the adjustment of electron accelerator appeared to be a reasonable configuration of the source - autoemissive cathode operating at high pressure with the accelerating system of accelerator. In the initial experiments there was pressure gradient along the whole accelerating system so that to provide the conditions of focusing. Under such routines of accelerator operation current to 1.5 ka was registrated at the output of the system. However, the studies of the current showed that the main part of it contained electrons - 200--300 kev. Taking into consideration the analysis of the obtained data one can draw the conclusions:
the acceleration occurs in the last section and the source is ionized electrons produced in the result of collisions with gas atoms. Further experiments were carried out under normal vacuum conditions along the whole acceleration (operating pressure - 10^{-5} torr.). Normal electron source operation was provided by higher pressure in the first section. Cathode was associated with the first accelerating section (fig.2). Operating pressure in cathode region was 10^{-2} torr. and it decreased towards anode at the first section output to 10^{-5}torr. The studies of the electron beam behind anode showed that the whole potential of the first section at the pulse moment applied to charge region near cathode and electron energy correlated with the applied voltage. The choice of magnetic field parameters and operating pressure allowed to monitor the value of electron current from 300 a to 1.5 ka. Thus the first accelerating section was used as an electron source. The source operation is clearly seen in the plots of the current and voltage given in figure 3.

The investigations of loading features of pulsed accelerating system (fig.4) witnessed that loading influence did not change the magnitude of accelerating voltage for the chosen formation system significantly at the currents of loading to 1000 a. The calculated energy dependence of the accelerated beam on the current (without a glance at the energy of injection is shown in figure 5. It is clear that the change of the beam current of an order $\Delta I/I = \pm 10\%$ will lead to energy variation not greater than ± 2%. The studies of the beam current passing along the accelerator gave quite satisfactory results. Under optimal conditions current passing contains 90%. After three acceleration sections current (600-700 a) with the energy correlating with the summarized pulse voltage (fig.6) is registrated*. Presently the operations of the studies of the probe characteristics of the electron beam and its injection into chamber are being carried out. One more accelerating section is expected to be installed for increasing electron beam energy and its intensity. Operations on the beam trapping and injection will be carried out with the mentioned above parameters until an additional section is installed.

System of the Ring Bunch Formation - - ADHEZATOR.

The design of the chamber and magnetic field system were chosen due to conditions to provide electron ring stability in the process of its formation.

Metallic chamber of ADHEZATOR represents the welded construction made of stainless steel with thickness of 0.5 mm (fig.7). The side-wall surfaces of the chamber are spherical. In the rim there is a number of snouts intended for the input of the electron ring from SILUND, placing the measurement devices and the electron path corrector, vacuum chamber pumping out.

In the center of side-walls two snouts are placed (7 and 8). They are intended due to injection of a flow of neutral atoms into the electron ring and for output of the accelerated electron-ion ring from the chamber.

The forces produced onto the chamber surface by the atmosphere pressure and interaction of inducted eddy currents in the metal of chamber with the external magnetic fields are transmitted through the ring crested expanders 3 made of 0.8 mm stainless steel onto two glass-textolite rings 9 mounted on the support II and rigidly connected with each other.

On the support table (II and IO) made of textolite besides the chamber a rigid framework made of glass-textolite is placed. In the rigid framework the windings forming dc and ac fields are mounted. The design of the chamber, support and framework includes the device for adjustment and rigid fixation of the median plane of the chamber and the windings in respect to based axes of heavy ion accelerator. At the previous test runs vacuum 5.10^{-8} torr. was obtained. A general scheme of the chamber is shown in fig.8. The magnetic field system consists of dc field coils, three-stage compression coils forming ac magnetic fields and the solenoid

* The beam current along the acceleration was measured by Rogovsky coils installed between accelerating sections and movable Faraday cup.

which is intended for output end acceleration. Their locations and currents were selected due to magnetic fields by means of metal walls of the chamber. For passing the dangerous resonance regions of n-path of the ring correcting loops are expected to be used.

The magnetic field sources are multi-turn coils poured by epoxy compound. The main perameters of the coils are given in the table (variant A).

Coils	Mean Radius (cm)	Distance from the median plane of the chamber	Winding Number	Section Sizes (cm)	
dc field	67	31	2 x 80	10,5	10,5
I stage	38	48	2 x 28	8	4
II stage	26	24-29	2 x 48	8	6
III stage	14,3	8-10	2 x 71	6	12

In figure 10 the measured curvature H(R) is given for the magnetic field coils shown in Table I. In the process of magnetic field formation a significant influence of the broken three stage coil on n-path was found. The influence is shown in figure 2 which indicates the chosen geometry does not provide the required parameters. The alteration of the third stage geometry of pulsed field resulted in the significant alterations in n-path (fig.12).

The final R-path of the ring is given in figure 13. In figure 14 one of the n-paths of the electron ring for two stages of the magnetic field is shown.

At the present time the operations on electron injection into ADHEZATOR system have been begun. Preliminary test runs with various injector types have been carried out (with magnetic screening, electric pulsed, magnetic pulsed). These test runs indicated that the best conditions for trapping and the most small value of distortions can be obtained with the magnetic-screening injection system.

Present Performance on KOLTSETRON.

The first cryogen start up was in December 1972. During the start up one cavity of KOLTSETRON with Nb-Ti coating and copper stark as well as one gradient superconducting solenoid (with length of 40 cm, diameter 17 cm, 16 sections) were operative. The stable cooling regime of KOLTSETRON cavity was not obtained. Gradient solenoid was cooled and its probe test runs were performed. The start up indicated that in a number of cryogenic systems of KOLTSETRON there are significant warm flows coming from the environment. By the present time the warm flows have been decreased. The part of the warm flows with nytrogenic screening of Helium pipelines contains only 0,2 v/m.

Operations on sample cylindrical cavities on E-wave with frequency $1{,}3 \cdot 10^9$ Hz with Nb-Ti coating showed that the improvement of the stark design made the hopes of obtaining quality-factor in operating cavities of KOLTSETRON true.

In June 1973 the detailed investigations of gradient solenoid at independent current test runs of 16 coils were carried out. Well operative stabilization of power supplies provided the required current stability and allowed to avoid the expected difficulties.

By the present time the design of the main external solenoid of KOLTSETRON (with length of 2,4 m) has been finished. Helium test runs of the solenoid in KOLTSETRON under operative conditions are being prepared.

REFERENCES :

1. I.N. Ivanov et al. Preprint JINR Dubna 1970 P9-5335.
2. Yu.I. Aleksahin et al. Preprint JINR P9-7065, P9-7066 Dubna 1973.
3. Yu.I. Aleksahin , V.P. Sarantsev Preprint JINR P9-7357 Dubna 1973.
4. L.J. Laslett IEEE Vol. NS-20, NO 3, p.271
5. V.P. Sarantsev VIII International Conference on Accelerators CERN 1971.

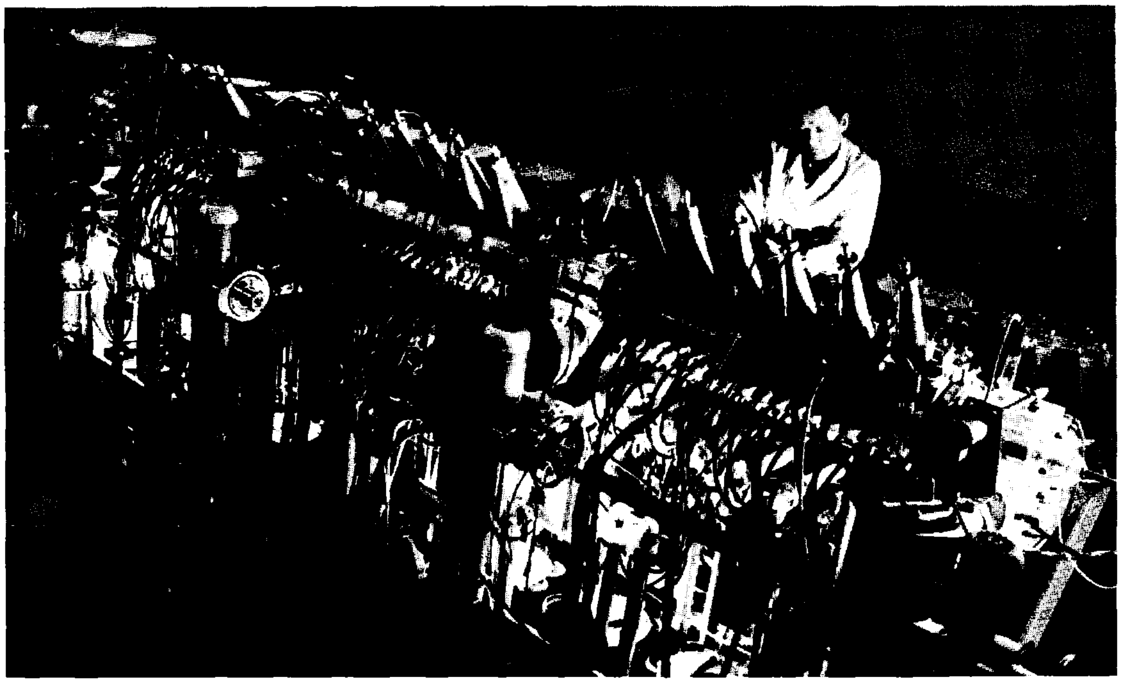

Fig.1 General scheme of electron accelerator - SILUND.

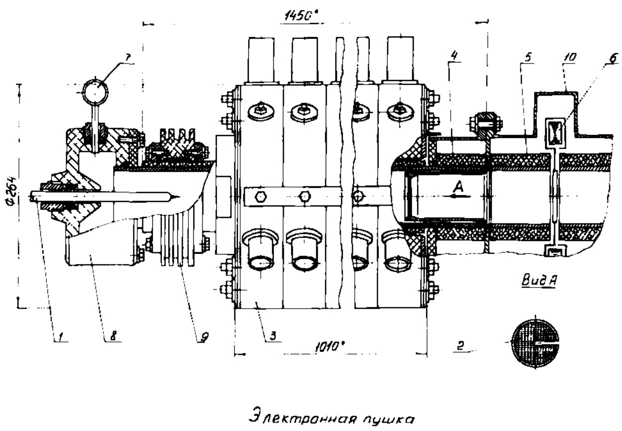

Fig.2 Electron gun of the accelerator.

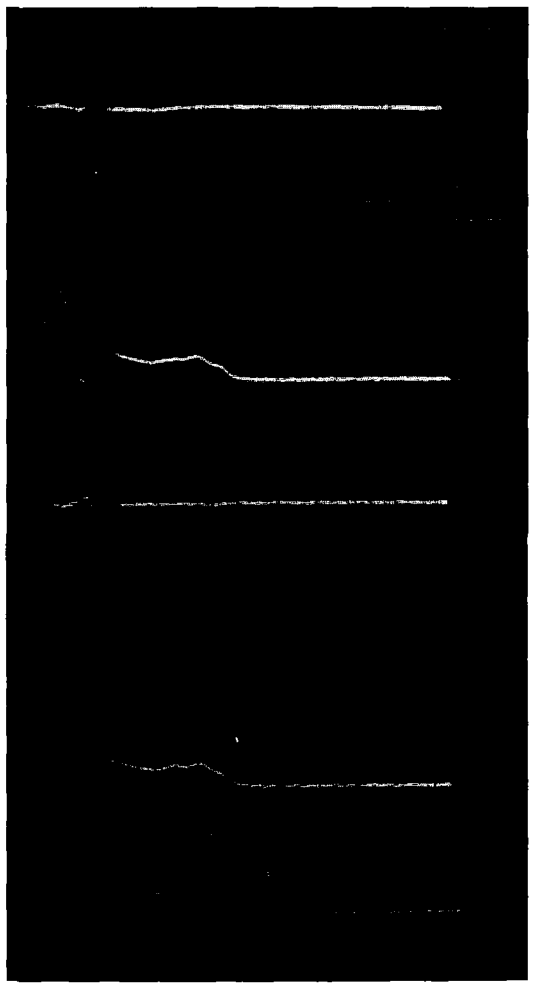

Fig.3 Oscillograms of operative electron source.
a) Voltage pulse on cathode.
b) Charge current of cathode.
c) The pulse of accelerating voltage on the inductors of the first section.
d) Charge current of cathode at the presence of voltage pulse on the inductor.
e) Electron current at the output of the first section.
Rate - 200 nsec/fission.

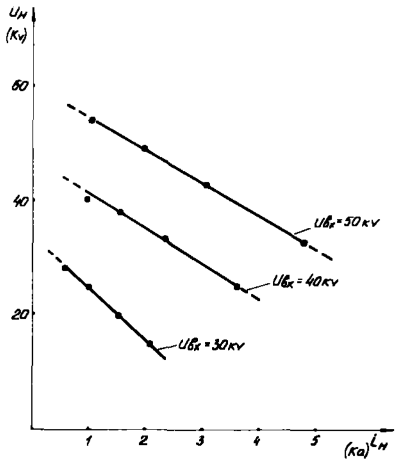

Fig.4 Loading characteristics of the inductor.

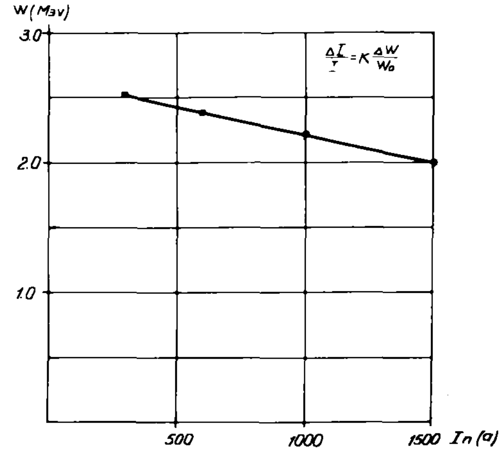

Fig.5 The dependence of electron accelerator energy on accelerated current.

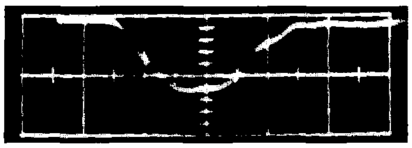

Fig.6 The shape of accelerated current of electrons.
(Rate - 20 nsec/fission)
Vertical Scale - 800 a/fission.

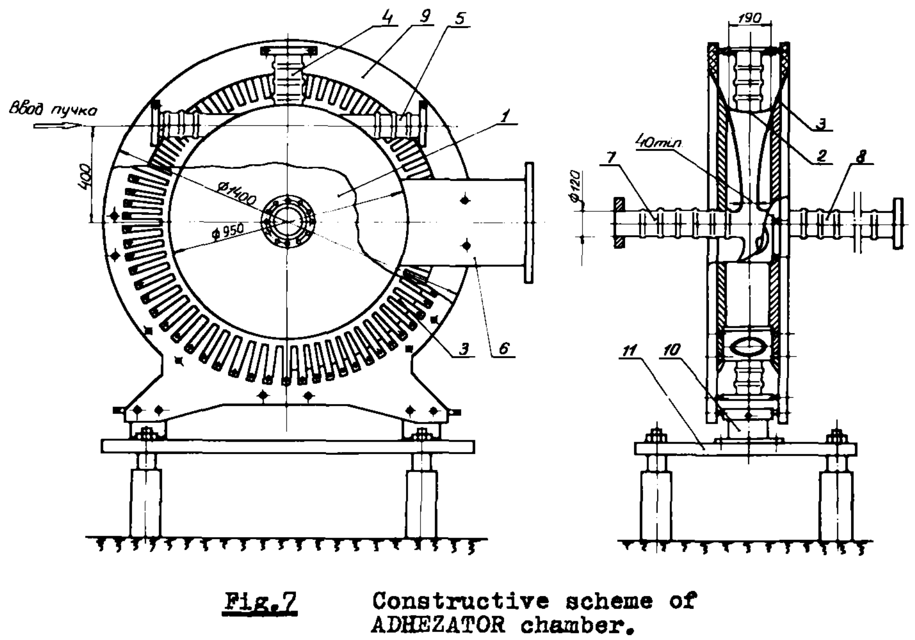

Fig.7 Constructive scheme of ADHEZATOR chamber.

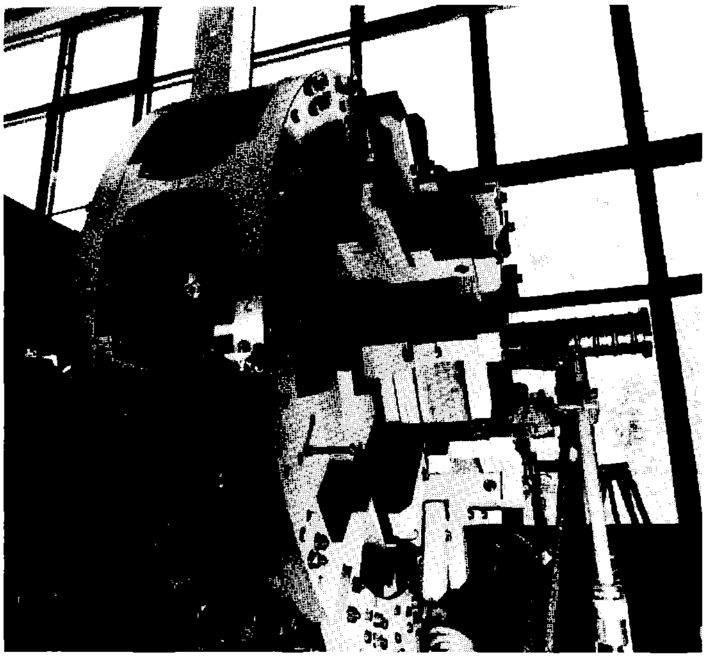

Fig.8 General scheme of ADHEZATOR.

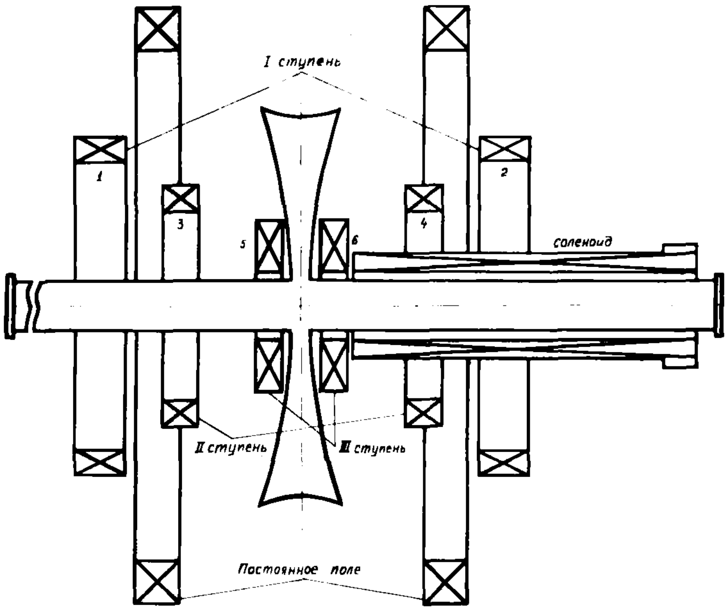

Fig.9 Scheme of winding location of magnetic field.

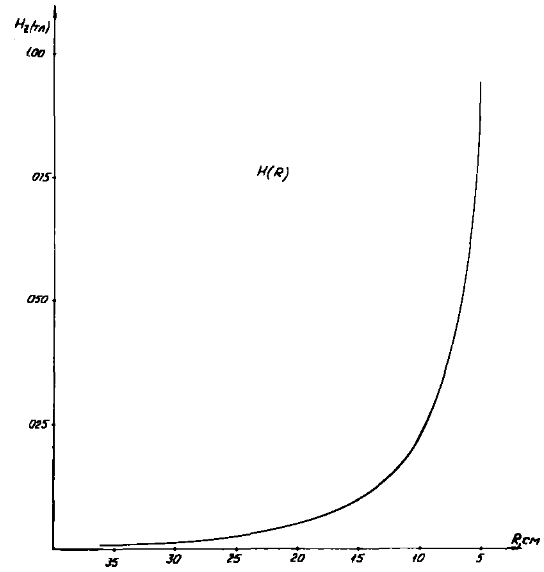

Fig.10 Magnetic field values at different radii of ADHEZATOR H(R).

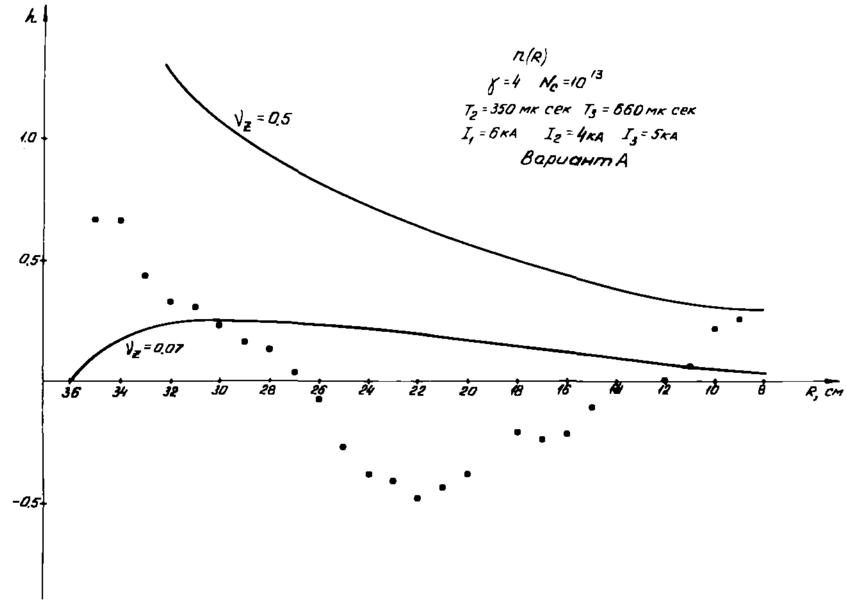

Fig. 11

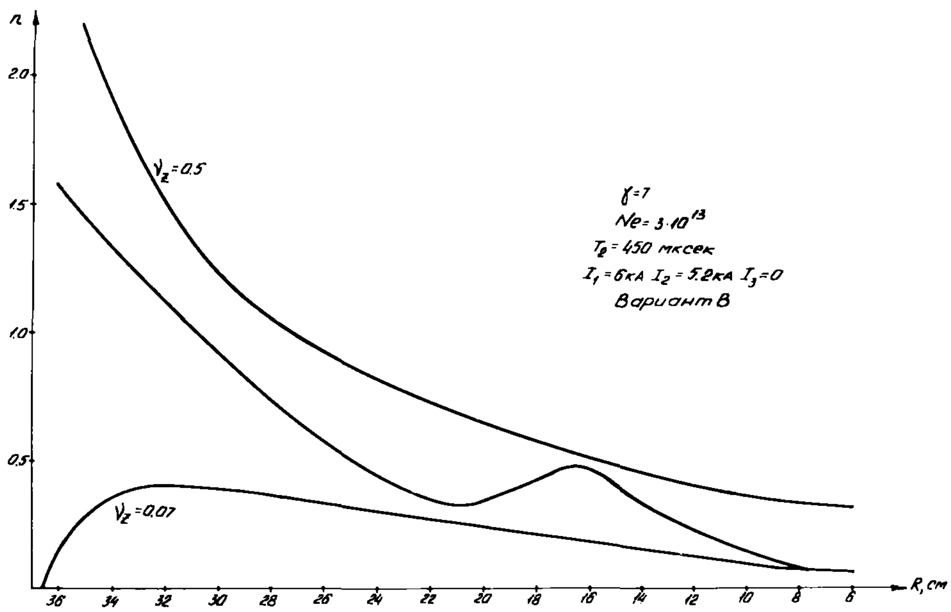

Fig. 12

Fig. 11, 12 The influence of different broken coils of the third stage on n-path of the magnetic field. (Variant A and Variant B).

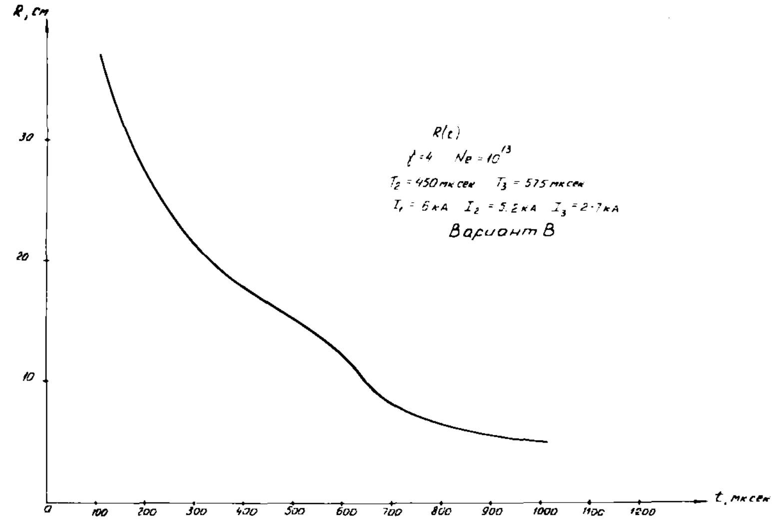

Fig. 13 Radius change of the electron ring in time.

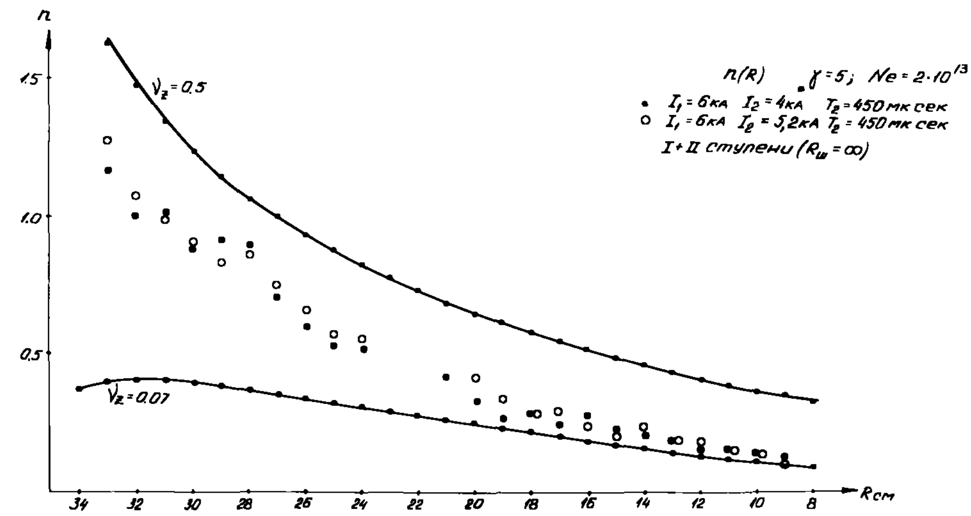

Fig. 14 The change of the external magnetic field index in ADHEZATOR.