Proceedings of the International Conference on Isochronous Cyclotrons, Gatlinburg, Tennessee, 1966

EXPERIMENTS ON ION ACCELERATION AT 685-mm SECTOR CYCLOTRON

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The sector cyclotron with pole diameter of 685 mm, the basic parameters of which are given in the status report [1], is a working model of the 2,4m isochronous cyclotron with the variable energy of particles. It is intended for research works with the proton and deuterium beam. At present the 685 mm cyclotron allows to accelerate the protons in isochronous regime up to 2 MeV, deuterons up to 4 MeV, 3 MeV and 0.5 MeV.

Cyclotron Construction. Fig.1 shows some of the important machine components: accelerating chamber, dee, ion source, three measuring probes and two-sectional electrostatic deflector. The input accelerating voltage (up to 15 kv) is applied to the dee through the insulator. The coupling of the output tube with the resonance system is a capacitive one and operation regime of r.f. generator is a continuous one. The region of ion acceleration is separated from the forevacuum chambers by the thin lids. In the forevacuum chambers trim and harmonic coils are placed. The trim coils are mounted at 3 cm, 5.2 cm, 7.5 cm, 12 cm, 16.5 cm, 18.5 cm, 24.5 cm and 28.5 cm radii. The coils maximum current is 1500 a. The harmonic coils have three sections along the radius and allow to compensate field disturbance of the first harmonic type up to 25 gauss.

Magnetic Field Characteristics.

The measurements of magnetic field were made with the help of Hall magnetometer, developed at our Institute. The measurement accuracy was up to 2.10^{-4}. These measurements were made at three levels of magnet induction, corresponding to acceleration regimes of the protons up to 2 MeV (H_0=7 kG) and of the deuterium ions up to 3 MeV and 4 MeV. (H_0=12 kG 14 kG). Fig.2 shows dependences of the mean magnetic field for the given field values in the center ona radius. They are shown by the solid lines. The dashed curves present "isochronous" dependences of the mean field. For the radii, larger than 15 cm, the flutter value f is 0.4

$$\left(f^2 = 2\frac{\langle H^2 \rangle - \bar{H}^2}{\bar{H}^2} \right)$$

The "spirality" angle for region of the finite radii is $\sim 20^\circ$. The magnetic fields of all trim coils were measured at the magnetic field pointed levels. These magnetic fields are considered to be a linear function of the current flowing through them with a good degree of approximation. The measurement accuracy of the trim coils fields is 2.10^{-2}. Fig.3 shows the distribution functions of the mean fields of the trim coils along the radius with H_0=14 kG. The calculation of trim coils currents was made on an electronic computer. The experimental checking of the results of forming the isochronous dependence of the mean magnetic field verified the design data. For all operating modes of the cyclotron the differences of actual distribution of the magnetic field from its isochronous dependence did not exceed $\pm$10 gauss. For the measurement of lower harmonics of magnetic field azimuthal inhomogeneities two inductive coils, connected in opposite directions, spread per element of magnetic structure periodicity (120°) were used[2]. The measurement accuracy is $\pm$0.5 gauss. The value of measured amplitude of the first harmonic did not exceed 10 gauss.

Experiments on Ion Acceleration.

The proton acceleration in the large cyclotron, where r.f. voltage amplitude is 125 kv, was modeled according to phase motion by the acceleration of the deuterium ions up to 4 MeV at voltage amplitude on the dee of 5 kv. The current dependence of the accelerated ions on the radius for U_0=5 kv is shown in. Fig.4. The dependence nature indicates on the absence of beam intensity losses, cased by the phase shifts. When the dependences shown in Fig.4 were measured the beam current because of radiation safety was limited up to 10 μA. However it was possible to obtain the currents of 4 MeV deuterons up to 50 μA. This figure shows also the dependences of the beam current on the radius, obtained during the acceleration of the protons up to 2 MeV and deuterium ions up to 3 MeV and 0.5 MeV. In the latter case the acceleration on the third harmonic of revolution frequency was used.

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The phase motion during the acceleration of the deuterons up to 4 MeV was studied. The picture of the beam phase behavior i.e. the dependence sin φ (R), is obtained by the analysis of series of resonant curves I(H) for the different values of radius of the probe position. Preliminary we found the current dependences of the beam on the radius for different values of the magnetic field shifts.

The position of the phase band can be also found from the curves I(R) for the different values of trim coil current. The width of the phase band Δ sin φ =0.75÷0.8, determined experimentally is in a good agreement with design data of the initial ion motion (-15°÷+27°).

The position of the initial orbits of the ions was found with the help of a special probe, having a narrow (0.5 mm) vertical electrode. The results of these experiments showed a good agreement with the design results of the initial trajectories. When these trajectories were designed, the map of electric field of the accelerating slit, obtained on the electrolytic tank, was used.

The phase selection of the beam can be carried out with the collimator, placed near the chamber center. In this case the beam losses were practically not observed in the radii range from R=100 mm up to the finite accelerating raduis - 290 mm.

The effect of the ion source position with respect to the chamber center on the amplitude of radial oscillations was studied in detail. The amplitude of the radial oscillations was determined from the experiments shading one probe by the other, which is shifted at 120°.

When the source was displaced from its optimum position (y_0 = -8 mm) by some millimeters the low energy "spurious beam" was observed. When the source is installed in the center of the accelerating chamber, the beam vanishes completely, not reaching the energy of 0.5 MeV (these experiments were carried out during deuterium acceleration up to 4 MeV). The results of these experiments verify the data of study of the ion acceleration through the central resonant region ($\nu_z \approx 1$), obtained with the electronic computer. Fig.5 shows the dependence of the amplitude of the radial oscillations on the value of the source displacement with respect to the chamber center. The curves are given for 100 mm and 280 mm radii. It is seen that the radial oscillations can be reduced up to 2 mm÷3 mm by thorough changing the source position.

It was possible to reduce the oscillation amplitude up to 1-2 millimeters by the beam collimation during its first revolutions. Near the finite radius the efficiency of the beam collimation is slightly less, although at the first revolutions (over 30 revolutions) the distinct separation of the orbits was observed (Fig.6). The oscillation amplitude in this region is 1 mm÷2 mm. Under these conditions, but without the collimator the orbits "coincide" after several revolutions. It is caused by instability of the magnetic field level, amplitude and frequency of accelerating voltage, and by the difference in energy gain per revolution for the particles with different starting phases. The improvement of the initial separation of the orbits, when the collimator is installed, is obtained by narrowing the phase band. In both cases, however, instabilities of the magnetic field and accelerating voltage cause the "mixing" of the orbits on the mean and large radii.

Frequency measurement of the vertical oscillations was made during the acceleration of the deuterium ions. Found frequency of oscillations (ν_z =0.3) agreed with accuracy of 10% with the design data by formulae [3].

All described experiments were carried out with the internal ion beam. At present the mounting of the beam extraction system is completed. This system represents two-sectional electrostatic deflector (40° and 30° with 10° free gap). The deflector potential is 30 kv, its aperture -4mm÷5 mm. The beam extraction is assumed to be accomplished from the decreasing field, where ν_z=0.8. The design efficiency of the extraction is about 30%, energy spread in the beam is ±1%. For focusing the external beam the quadrupole lenses with the aperture of 60 mm and gradient of 400 gauss/cm are installed.

The beam analysis will be made by 90° magnet with n=0.5.

References:

1. Alexeev A.G. et al "240cm and 68.5 cm Isochronous Cyclotrons with Variable Energy of Particles". Status Report at the Present Conference.
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3. Basargin Ju.G. and Belov V.P. "Electrophysical Apparatus" issue 3., 3, Atomisdat 1965.

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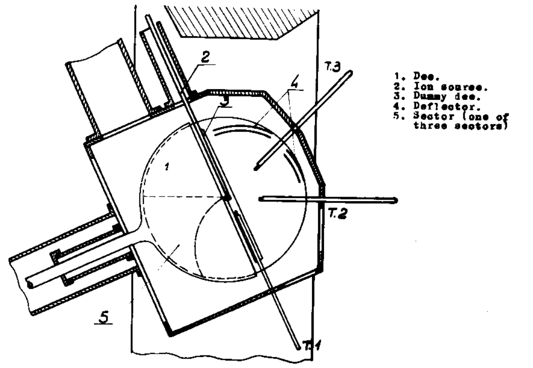

Fig. 1. Accelerating chamber of the 685 mm cyclotron.

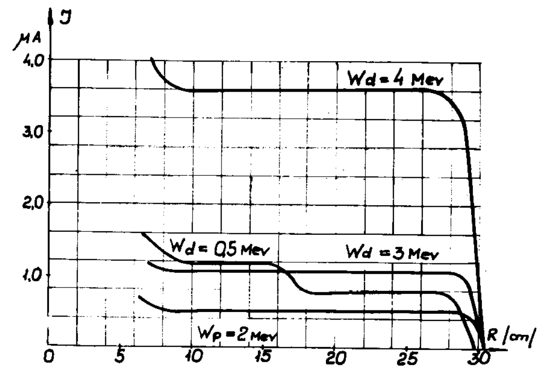

Fig. 4. Current dependences of the accelerated ions on a radius.

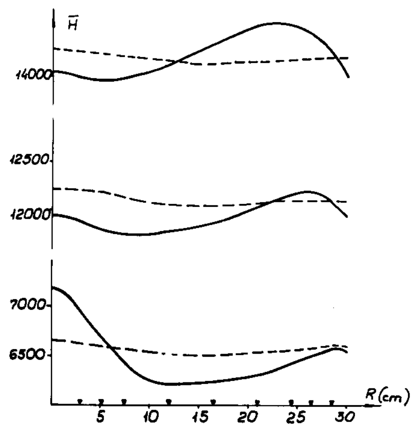

Fig. 2. Mean magnetic field dependence on a radius for three values of the field in the center.

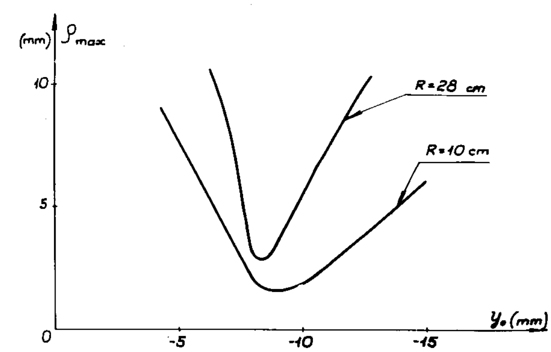

Fig. 5. Effect of ion source displacement on the amplitude value of the radial oscillations ρ_{max}.

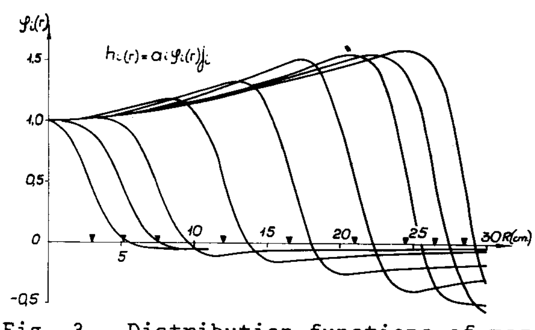

Fig. 3. Distribution functions of magnetic fields of the trim coils for H_o = 14000 gauss.

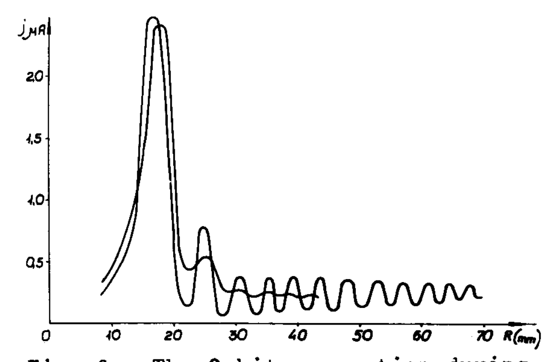

Fig. 6. The Orbit separation during collimating the ion beam.

DISCUSSION

HUDSON: Did I understand the 68.5-cm machine was put in a 240-cm magnet?

STEPANOV: No. The 68.5-cm cyclotron is a 1 to 3.5 scale model of the larger machine.

REISER: What is the voltage on the dee? What is the spacing between ion source and dee?

STEPANOV: Under 15 kV on the model, but 125 kV will be used on the 240-cm machine. The distance between the ion source and the dee is 3 or 4 mm in the model.

REISER: How was the phase width of the beam measured?

STEPANOV: By the Smith-Garren Method, that is, following the changes in beam intensity with radius while varying the field of the concentric coils.

