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CENTRAL REGION OF 240 CM VARIABLE ENERGY CYCLOTRON

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The description of the central optics for 2.4 m isochronous cyclotron is given in this report. The main parameters of the cyclotron are reported in an other paper contributed to the conference [1]. This cyclotron will accelerate protons up to the maximum energy 100 MeV and other particles.

The aim of original orbits property studies is to obtain compact ion beam at possibly high time duration of current pulse. In addition to, the control flexibility requirement for the position of all central optics elements is taken into account, which is important for cyclotron with variable energy of particles.

A number of experiments were carried out on 685 mm sector cyclotron [1], which investigated the ion motion near the center.

1. Preliminary Study Basic Results of Initial Ion Motion.

Radial motion. Radial ion oscillation amplitude at the centre of cyclotron can be estimated as halfwidth of orbit center zone, if orbit centring requirement is carried out (that is, averaged orbit center coincides with magnetic field center). The blow up of orbit center zone depends considerably on the effective width of an accelerating slit. For different values of the parameter $\frac{\delta}{\lambda}=2\frac{\delta^2}{E_0}\cdot\frac{eH^2}{U_0}$ (δ - the effective halfwidth of the accelerating slit, U_0 - dee voltage amplitude, $E_0=m_0c^2$) and direct voltage value Ui (Ui - in units of U_0) at "constant injection", original orbit parameters were derived from the formulae of "homogeneous field".

Fig.1 shows the dependance of phase band width, accepted to further acceleration on δ/λ. The latter was derived according to original orbit calculation in 2.4 m cyclotron for several values of radial oscillation amplitude: 3 mm, 5 mm and 8 mm.

It is seen, that for the actual condition of this cyclotron (proton acceleration, when δ/λ =0,6) $\Delta\varphi$ =60°÷80°. Limit amplitude increase of radial oscillation above 5 mm is not effective from the point of view of time duration current pulse increase. It is also seen, that with the increase of δ/λ, positive phase ion fraction quickly drops.

The application of continious injection can considerably increase phase duration of beam pulse (by ~ 20° at Ui=0.1 and ~ 40° at Ui=0.5). The study of transversal beam blow up (in respect to the accelerating slit) shows that it is negligible in the system with an extracting electrode on dee (puller).

Vertical motion. Dee grids [2] or ion source displacement according to Smith method [3] are generally used to decrease vertical defocussing of ions with negative phases by dee accelerating field. In synchrocyclotron, where the accelerating voltage is not high, electrostatic focussing can be used [4]. The possibility of focussing improvement for 2.4 m cyclotron by decreasing accelerating slit aperture at the exit was considered (see fig.2). Fig.2 gives the calculation results of vertical oscillation effective frequency ν_{zef}^2 which are derived with the help of formulae similar to that cited in the paper [5] while using the experimental data of field modelling on electrolytic tank. Fig.2 shows the dependance of the value ν_{zef}^2 on the ion phase at R=10 cm for different optical systems: 1 - symmetrical accelerating slit (50 mm by 35 mm),
2 - 10° displaced source,
3 - grids with 3 mm slit width are set at the exit of accelerating slit,
4 - accelerating slit aperture is decreased at the exit from 50 mm to 25 mm. One can see that the most focussing effect can be achived when the dee is closed by grids. Slit aperture decrease at the exit is similar to 10° source displacement.

Orbit centering. In the cyclotron with variable energy of particles for maintaining the orbit centering, obtained for a single operation regime, it is necessary to correct the value of dee voltage ("constant orbit" regime) or the position of optics elements (the regime of accelerating voltage constancy). The advantage of the first regime is the absence of complicate mechanisms for the adjustement of the source position etc. It is convenient to use the displacement of the ion source or grid on the dees. However, when the ions are accelerated at frequencies, multiple the frequency of the ion revolution ("subharmonics"), the conditions of the phase motion

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can contradict the conditions of orbit constancy. As some studies have shown, the large radial expansion of the beam during acceleration at subharmonics may cause the losses of intensity while passing the central resonant region. During acceleration of multicharged ions with a large charge number high accelerating potential is desired in order to decrease the losses due to gas dissociation.

In case U_o = const one can expect increasing of pulse time duration by 15° - 20° due to decreasing of e/A parameter. The conditions of beam extraction for these regimes of the cyclotron operation are improved. The disadvantage is the practical difficuty of correction in a wide range of position of central optics individual elements. The most suitable method is probably that one, at which their position is corrected in the range of some tens of millimetres. Here we have a number of selected positions. If there is a slight deviation from the selected positions the correction is made by means of selection of the value of the accelerating voltage.

2. 2.4 m Cyclotron Central Region.

Fig.3 shows the head of the ion source (15 mm ×25 mm with flat part height of 40 mm, the heght of the extracting slit varies from 5 mm to 15 mm), the puller (13 mm from the source), the dummy dee and two collimators in the region free of electric field. The source is inserted into the chamber perpendicularly the dee edge, this is due to its construction. The accelerating dee voltage is 125 kv. The dummy dee of 360 mm length is rigidly connected with the source. The accelerating slit width in the central region is 35 mm with the aperture of 50 mm. The dee and dummy dee have special lugs of a refractory material. These lugs limit the slit aperture at the exit up to 25 mm (30 mm, 35 mm). The source and puller position is corrected in the range of ±50 mm from the original position (+40 mm from the chamber center). It is possible to correct the position of the source vertical axis relative to the magnetic field axis. All the displacements (including the collimator and their slit aperture) have the remote control.

3. Study of Ion Initial Motion in 685-mm Sector Cyclotron.

In the 685 mm sector cyclotron the slit source of hot type is installed. The dee (its aperture is 17 mm, potential - 5 kv ÷ 10 kv) has a puller with the slit height of 8mm. In the central region the dee and dummy dee aperture is decreased up to 10 mm. The collimator is placed behind the dummy dee. While accelerating deuterium ions to the energy of 4 MeV study of initial orbit properties was carried out. The determination of ion orbits, carried out with the help of a special probe with a narrow electrode and a collimator, showed good agreement (better than 1 mm) with the data of trajectory design in the case when the stepped approximation of accelerating field distribution obtained in the electrolytic tank is used. The design width of the phase band (-15° ÷ +27°) showed also good agreement with the subsequent measurements of phase motion [6] . Fig.4 shows the design distribution of the beam current on the first revolution and the orbit positions, found experimentally. It was possible to carry out the phase selection of the beam (Fig.5) and limiting of radial oscillation amplitude near the center up to ~ 1mm with the help of the collimator. The vertical height of the high energy beam was usually about 5 mm. While centering the orbits by means of the changing of the ion source position along the accelerating slit X_o the strong dependance of the amplitude of the radial oscillations on X_o was found (especially in the region of the finite radii of acceleration). It can be seen from Fig.6, which shows the dependance of amplitude of radial oscillations for different positions of the ion source on the acceleration radius. The value of the amplitude is determined brom the experiments on overshading of one probe by the other.

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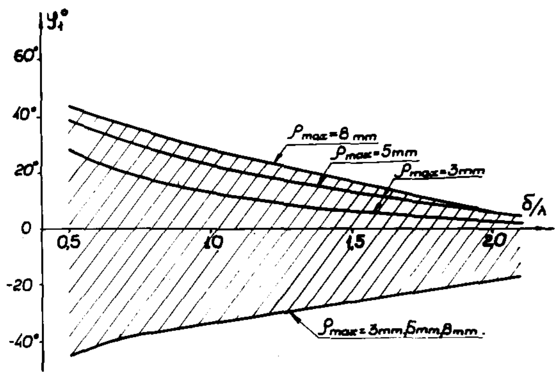

Fig. 1. Phase band width of ions, accepted to acceleration as a function of δ/λ parameter.

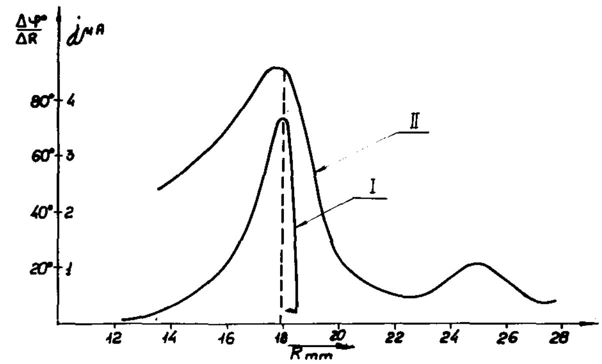

Fig. 4. Comparison of the experimentally found position of the first ion orbits with the design one.

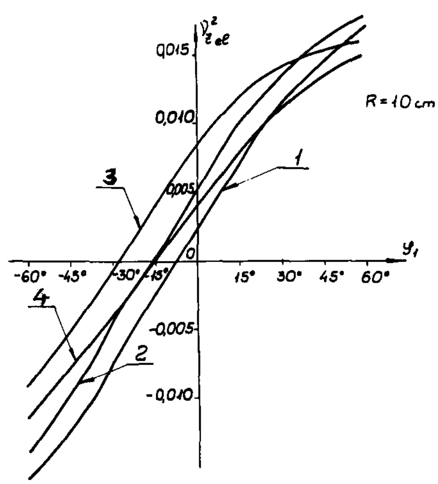

Fig. 2. Vertical focusing of ions by the electric field of the accelerating slit.

I - symmetric slit

II - ion source is displaced by 10°.

III - grid at dee entrance.

IV - slit output aperature half as input aperature.

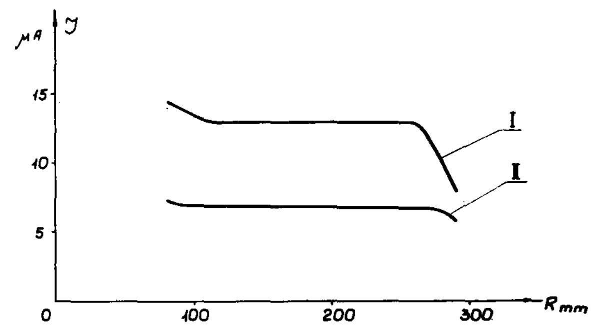

Fig. 5. The results (II) of beam phase selection. I - dependence of ion current when the collimator is removed.

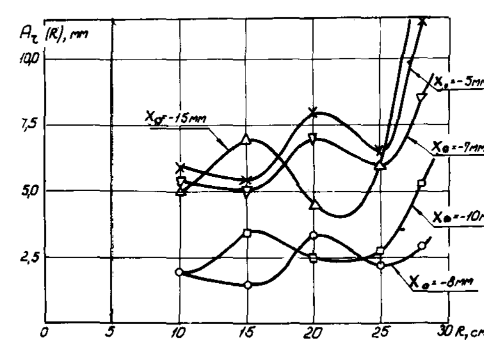

Fig. 6. Dependence of the amplitude of the radial oscillations on radius.
X_0 - is a coordinate of the source.

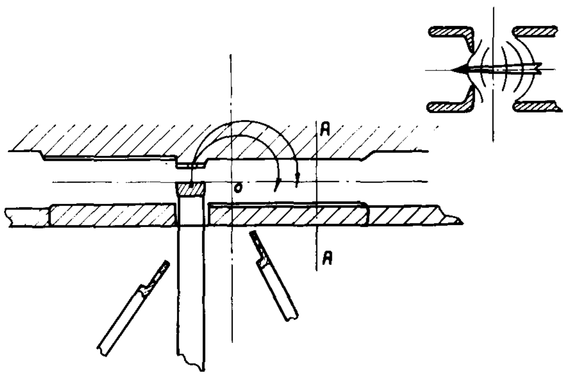

Fig. 3. Diagram of central region of the 2.4-m cyclotron.

DISCUSSION

BLOSSER: The phrase "centering optics" was used; does this refer to the movable source and puller?

VENIKOV: Yes. It is to the motion of the source and puller.

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