DYNAMICS OF HEAVY IONS IN THE ISOCHRONOUS CYCLOTRON FOR PRODUCTION OF NUCLEAR MEMBRANES

L.M. Onischenko, E.V. Samsonov
Joint Institute for Nuclear Research 141980, str.Joliot-Curie, 6, Dubna, Russia
E-mail: sams@nusun.jinr.ru

Isochronous cyclotron CYTRECK intended for a production of nuclear membranes was put into operation in 2002 year in Dubna. The ions with the relation A/Z=5 are accelerated to the energy ~2.4 MeV/nucleon and extracted at the intensity ~2·10^{11} ions per second. The calculations of the ions dynamics beginning from the exit of an inflector to their extraction from the cyclotron chamber are examined in the report.

PACS: 29.20.Hm, 29.27.Bd, 83.10.Rs

1. MAIN PARAMETERS OF THE CYCLOTRON

CYTRECK is 4-sector compact isochronous cyclotron equipped by 14GHz ECR ion source as an injector. Cyclotron has axial injection line, spiral inflector, two accelerating dees and electrostatic extraction system. Some cyclotron parameters are shown in Table and its layout in Fig.1.

Main parameters of the CYTRECK

Type of accelerated ion A/Z	5
Injection energy (keV/nucl)	3.0
Extraction energy (MeV/nucl)	2.4
Average magnetic field (T)	1.48
Betatron frequencies: ν_r ; ν_z	1.015; 0.3
Radius of injection (cm)	~3.0
Radius of extraction (cm)	73.0
Emittances on injection (π mm·mrad)	~150
Emittances on extraction (π mm·mrad)	~15
Phase width of the bunch (°RF)	~20
Orbital frequency (MHz)	4.626
Harmonic number	4
Number of dees	2
Angular width of dees (°)	40
Accelerating voltage (kV)	50

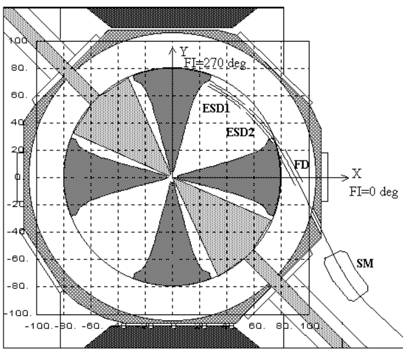

Fig.1. Layout of the cyclotron vacuum chamber with 4 sectors and 2 dees. ESD1, ESD2 – electrostatic extraction system, FD – ferromagnetic focusing channel, SM – steering magnet

2. CENTRAL REGION

Configuration of the central region electrodes has the determining effect on the transverse oscillations of ions. During the analysis of particle dynamics in the central region of CYTRECK a three-dimensional electric field, obtained as a result of numerical simulation was used. In order to get the optimum configuration of center the axial and radial size of the diaphragms (see Fig.2), dimensions of window in the inflector case, and also a width of first and second accelerating gaps were varied. The aim of optimization was obtaining the smallest possible amplitudes of radial oscillations after the first five revolutions of beam on acceptable level of the axial losses. Axial losses arise due to axial divergence of the beam just after the inflector exit. Code CENMOT [1] was used for a particle tracking inside this region.

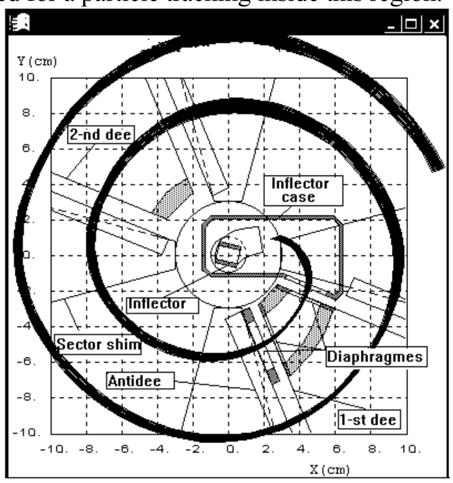

Fig.2. Layout of the cyclotron central region

After ten changes of the central region geometry the required configuration was chosen. In Fig.3 one can see axial trajectories during 1-st turn. Ion losses on dees and diaphragms are not larger than 40% of injected beam with 20°RF length. Computations show that the maximal amplitude of free radial oscillations after 5 turns is not greater than 5 mm.

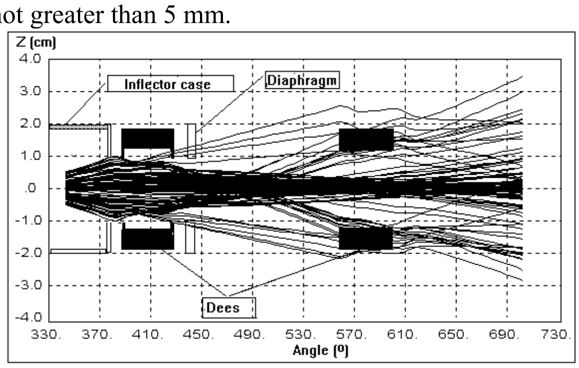

Fig.3. Axial trajectories of 100 ions for 1-st turn. The ion losses on the dees and diaphragms are neglected

3. MAIN ACCELERATION REGION

For calculating of beam dynamics in the basic acceleration region were undertaken 587 ions, having the amplitude of axial oscillations not more than 8 mm in the center of cyclotron. Calculation was carried out during 60-70 revolutions, until all ions reached the entrance of the extraction system. In the calculations the analytical description [2] of electric field of dees was used. Magnetic field parameters are given in figs. 4,5.

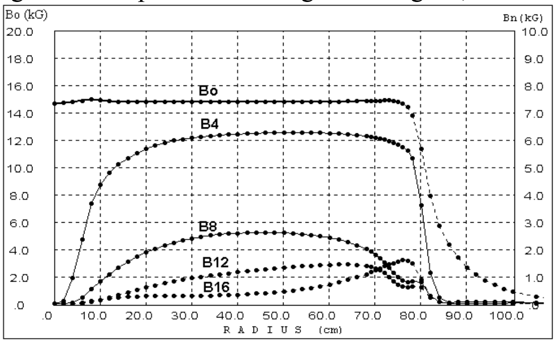

Fig.4. Average value B_{av} and amplitudes of multiple harmonics $B_4 - B_{16}$ of the cyclotron magnetic field

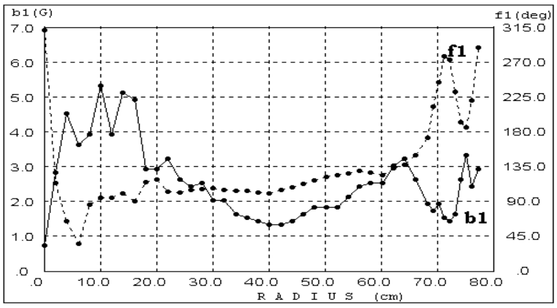

Fig. 5. Amplitude b1 and phase f1 of the 1-st harmonic of azimuthal imperfection

Fig.6 shows the amplitudes of the free radial oscillations of ions in the dependence on the mean radius of accelerated orbit. It is evident that the amplitude spread increases from 4 to 9 mm (reason – action of the 1-st harmonic of magnetic field). However, for 98% of ions toward the end of the acceleration the amplitude of radial oscillations do not exceed 6 mm, that, as it will be shown below, gives good beam parameters at the entrance of the extraction system.

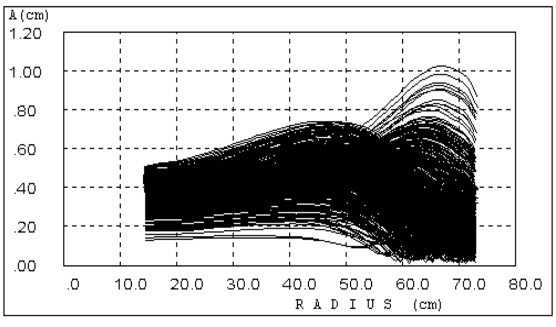

Fig. 6. Amplitudes of free radial oscillations versus radius

The results of simulation of the differential probe signal are shown in Fig.7. This probe is located on azimuth 90° and has lamella width of 1 mm. One sees that the first 9 turns are completely separated, and up 50 turns can be identified in the signal amplitudes.

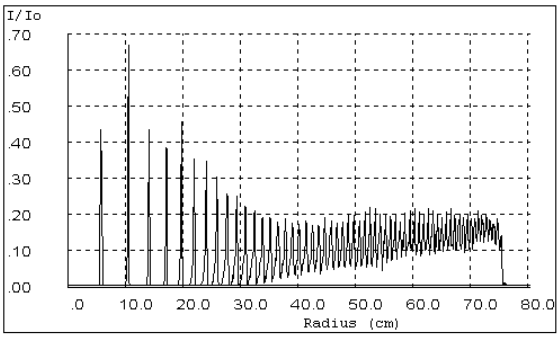

Fig. 7. Signal of differential probe versus radius

Frequencies of betatron oscillations are shown in Fig.8. Inside main acceleration region their values comprise $Q_r \approx 1.015$, $Q_z \approx 0.33$. Only at extraction radius 73.0 cm radial frequency crosses resonance value $Q_r = 1$ and axial one approaches to $Q_z = 0.5$. But due to large radial gain (~0.7 cm), deterioration of the beam parameters do not occur in this region.

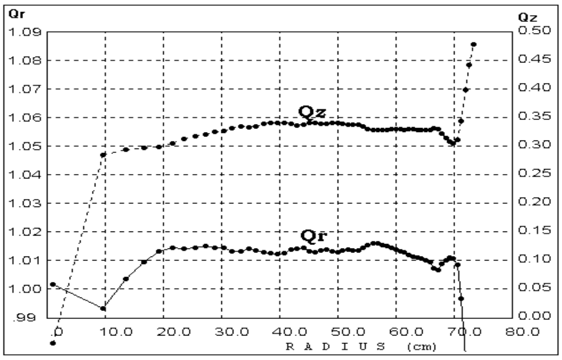

Fig. 8. Frequencies of free oscillations versus radius

Fig.9 represents phase motion of ions in the main acceleration region. These results show that average magnetic field is formed with high accuracy without using of correction coils.

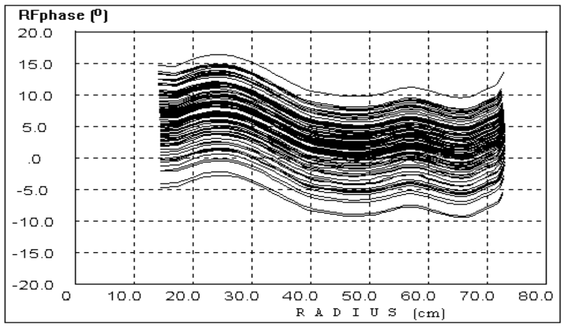

Fig.9. Phase motion of ions versus radius beginning from 2-nd turn

4. EXTRACTION SYSTEM

Fig.10 depicts in the coordinates (azimuth - radius) the position of the extraction system relative to the boundary of the circulating beam, shims and magnet pole. Here is shown position of probes, intended for measuring the throw of beam to the entrance of the system and its parameters after both electrostatic elements.

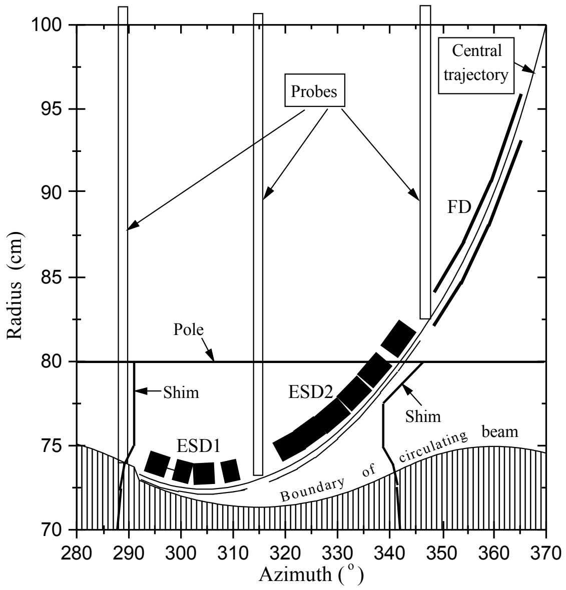

Fig.10. Sketch view of extraction system

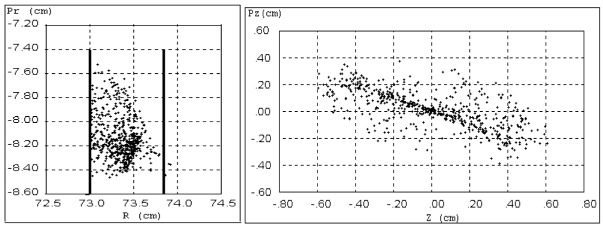

Fig.11.Beam parameters on phase planes (R, P_r) and (Z, P_z) at the entrance of extraction system

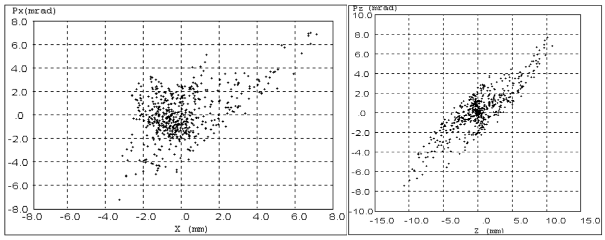

Fig.12.Beam parameters on phase planes (X, P_x) and (Z, P_z) at the entrance of steering magnet SM

Extraction system consists of three elements: electrostatic deflectors ESD1 and ESD2, and passive ferromagnetic device FD. Deflectors represent itself the segments of the cylindrical capacitors, whose internal plate (septum) is under zero potential, and external under the negative potential by value approximately 50 kV. Ferromagnetic device consists of three steel plates magnetized by the magnetic field of cyclotron. The throw of beam to the entrance of the system is ensured due to radial gain ~7 mm provided by acceleration.

ESD1 provides primary radial deviation of the extracted beam on ~12 mm from the boundary of circulating one. Inside this element there is no need of creating the focusing gradient of electric field, since beam does not achieve here a dropped fringing field.

ESD2 makes additional deviation of beam outside, (on the exit of this element the beam is located already at a distance of about 70 mm from circulating one), and also provides the compensation for the action of the radially defocusing gradient of fringe magnetic field.

Basic purpose of FD is the radial beam focusing and additional its deviation outside the vacuum chamber.

Figs.11,12 show phase beam portraits at entrance of ESD1 and steering magnet SM, accordingly. Final beam average energy W=2.4 MeV/A, energy spread $\Delta W/W=\pm$ 1%, transverse emittances $\varepsilon_r \approx \varepsilon_z \approx 15\ \pi$mm·mrad. Ion losses inside the extraction system when it occupies optimal position do not exceed 15% of the circulating beam. High extraction efficiency imposes the following requirements to the magnetic and accelerating systems. First harmonic of the magnetic field imperfections must be less than 3 G, the amplitude and phase misalignment of dees should be in limits ±0.5 kV and ±5° RF, respectively.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to N.G.Shakun for the computation of electric field in the central region of the cyclotron.

REFERENCES

1. E.V.Samsonov // *Proceedings of Workshop on the magnetic field and ion beam dynamics of the VINCY cyclotron*, Dubna. 1996, p.156.
2. N.Hazewindus et al. // *Nuclear Instruments and Methods*. 1974, v.118, p.125.

ДИНАМИКА ТЯЖЕЛЫХ ИОНОВ В ИЗОХРОННОМ ЦИКЛОТРОНЕ ДЛЯ ПРОИЗВОДСТВА ЯДЕРНЫХ МЕМБРАН

Л.М. Онищенко, Е.В. Самсонов

Изохронный циклотрон ЦИТРЕК, предназначенный для производства ядерных мембран работает в Дубне с 2002 г. Ионы с отношением A/Z=5 ускоряются до энергии ~2.4 МэВ/нуклон при интенсивности ~2·10^{11} ионов в секунду. В статье приводится расчет динамики ионов, начиная от выхода из инфлектора до их вывода из камеры ускорителя.

ДИНАМІКА ВАЖКИХ ІОНІВ В ІЗОХРОННОМУ ЦИКЛОТРОНІ ДЛЯ ВИРОБНИЦТВА ЯДЕРНИХ МЕМБРАН

Л.М. Онищенко, Є.В. Самсонов

Ізохронний циклотрон ЦИТРЕК, призначений для виробництва ядерних мембран працює в Дубні з 2002 р. Іони з відношенням A/Z=5 прискорюються до енергії ~2.4 МеВ/нукл при інтенсивності ~2·10^{11} іонів у секунду. У статті приводиться розрахунок динаміки іонів, починаючи від виходу з інфлектора до їхнього виходу з камери прискорювача.