Table 2: Magnetic system parameters

Magnet sizes	3.7×2×1.65 m^3
Pole diameter	1.6 m
Pole gap: hill valley	 40 mm 100 mm
Average magnetic field	1.48 T
First harmonic	<0.0003 T
Magnet weight	83 t
Power consumption	25 kW

The dependencies on radius of the average magnetic field and of the focusing harmonics B4, B8, B12 and B16 are presented in Fig. 3.

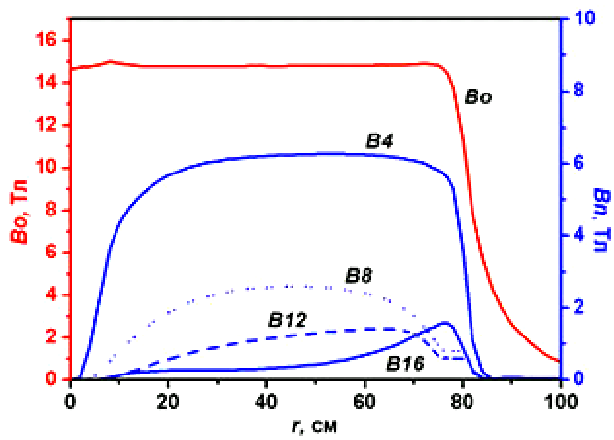

Figure 3: Cyclotron magnetic field

AXIAL INJECTION LINE

Axial line between the ion source and the median plane of the cyclotron consists of the diagnostics block, buncher, two quadrupoles and the spiral inflector. Injection energy is equal 3 keV/A, beam intensity from the ion source is near 3 μA. In the diagnostic box the Faraday cup, profilometer, defining slit and buncher are placed. The measured beam profile is shown in Fig. 4.

The quadrupoles are mounted inside the hole in the upper yoke and pole. The spiral inflector is placed in the centre of the magnet, between its poles. The inflector height is equal 2.5 cm, electrostatic voltage on its plates is near ±7.5 kV. The inflector can be turned around axial axe by the angle ±8° to optimize the horizontal injection angle for the first orbit. Usual efficiency injection with spiral inflector is near 30%.

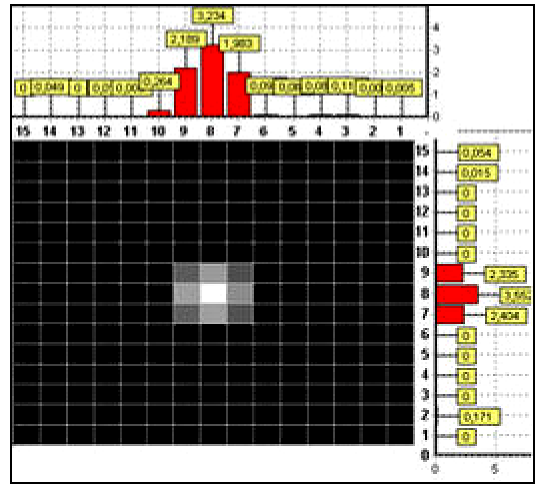

Figure 4: Beam profile in injection line

ACCELERATING SYSTEM

RF system consists of two λ/4 resonator ended by accelerating dee. Resonators are tuned with trimmers on fixed frequency in the range 18.2÷18.6 MHz. The dees with the azimuthal angle 45° each are placed in the opposite valleys of magnet. The dee axial aperture is equal 24 mm. Main parameters of accelerating system are given in the table 3.

Table 3: Main RF system parameters

Number of dees	2
Dee azimuth angle	45°
Resonance frequency	18.26 MHz
Harmonic number	4
Dee voltage	40÷50 kV
Dissipated resonator + (the dee) RF power	8.5 kW
Resonator quality	3500

Each resonator is feeded by the separate 15 kW RF amplifier with one general driver for both amplifiers. Amplifiers were developed and constructed by TIRA firm from St-Petersburg under leadership of E.A. Petrov.

EXTRACTION SYSTEM

General view of the extraction system is shown in Fig. 2. Extraction system includes two electrostatic deflectors with azimuthal extension 21° (ESD1) and 28° (ESD2), three current probes (at the ESD1 entrance, between deflectors and at the ESD2 exit) and the passive magnetic channel FD with the azimuth extension 17° for the beam horizontal focusing in the magnet fringe field. The deflector horizontal aperture is equal 7.5 mm (can be regulated); the nominal deflector voltage is equal 53 kV (can be regulated up to 60 kV).

THE EXTRACTED TRANSPORTATION LINE AND THE IRRADIATION INSTALLATION

The extracted beam is guided by the vacuum transportation beam line to the irradiation installation (Fig. 5 and Fig. 6). Beam line consists of the bending magnet (SM on Fig. 2), two quadrupoles for focusing the beam in horizontal and vertical planes, the vertical magnet corrector and the magnet scanner to scan the beam along the moving foil width. The beam line includes also some beam probes (after bending magnet and before the irradiated foil) to measure the beam position and the beam distribution.

The irradiation installation is the two boxes vacuum chamber which provides the vertical moving the foil tape inside the vacuum with the constant velocity in the range 2÷80 cm/s.

Figure 5: Extracted beam transportation line. From left side is cyclotron, from right side is irradiation installation

Figure 6: View of the irradiation installation

BEAM DINAMICS

Computer simulation of the beam dynamics in the central region as well as in the main acceleration region and at extraction was done. [2]

Configuration of the central region electrodes has the determining influence on the transverse oscillations.

During the analysis of particle dynamics in the central region of CYTRACK a three-dimensional electric field, obtained as a result of numerical simulation was used.

In order to get the optimum configuration of the central region the axial and radial sizes of the diaphragms (see Fig. 7), dimensions of window at the spiral inflector exit, and also a width of first and second accelerating gaps were varied. The aim of this procedure was obtaining the smallest possible amplitudes of radial oscillations after the first five revolutions of beam with acceptable level of axial losses. Axial losses arise due to axial divergence of the beam just after the inflector exit. Code CENMOT was used for a particle tracking inside this region. After ten changes of the central region geometry the required geometry was chosen. Ion losses on dees and diaphragms for this geometry are not larger than 40% of injected beam with 20°RF length. Computation shows that the maximal amplitude of the free radial oscillations after five turns is not greater than 5 mm. The dynamic calculation in the main acceleration region of the 587 ions with the axial amplitudes not greater than 8 mm was performed during 60 ÷ 70 revolutions, until ions reached the entrance of extraction system. The radial amplitudes spread increases under action of the 1-st harmonic of the magnetic field, however, for 98% of ions the amplitude do not exceed 6 mm. This is acceptable for a high extraction efficiency.

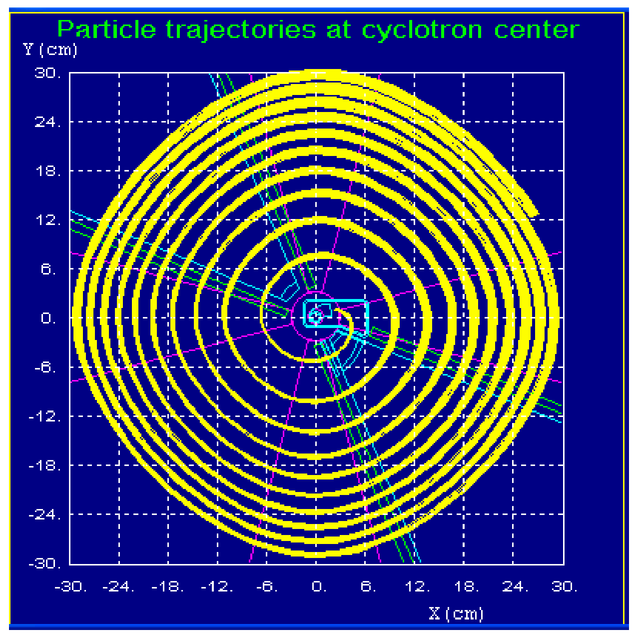

Figure 7: Ion trajectories in the central region

High extraction efficiency imposes the following requirements to the magnetic and accelerating systems. Fist harmonic of the magnetic field amplitude has to be less than 3G, the amplitude and phase misalignment of dees voltage (50kV) should be in limits ±0.5kV and ±5° RF, respectively.

With these conditions final beam energy spread will be inside ±1%, transverse emittances – 15 π mm·mrad and the beam intensity losses inside the extraction system when it occupies optimal position are not exceed 15% of the circulating beam.

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REFERENCES

[1] Yu.G. Alenitsky, L.M. Onischenko et al., Magnetic system of the heavy ion cyclotron for track membrane production, Nucleonika, 2003; 48 (Suppl.2); S55-S57.

[2] L.M Onischenko, E.V. Samsonov, Dynamics of heavy ions in the isochronous cyclotron for production of nuclear membranes, Problems of atomic science and technology, №2 (2004), Series: Nuclear Physics Investigations (43), p. 129., Kharkov, Ukraine.