HIGH EFFICIENCY STRIPPING EXTRACTION ON 80 MEV H-MINUS ISOCHRONOUS CYCLOTRON IN PNPI

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Abstract

H-minus cyclotron has the advantage that high intensity internal beam can be extracted from the acceleration chamber with practically 100% efficiency by transformation H-minus ions into H-plus ion by using thin foil. The extraction system is consists from the probe with stripping foil, extraction window in the vacuum chamber and two allaying magnets to match the extracted beam with beam transport line. The beam optics calculations in the measured magnetic field make it possible to find optimal relative position of the extraction system elements as well the parameters of the extracted beam with energy 40 - 80 MeV. At present time the beam is extracted from the chamber with efficiency about 100 % and there is good agreement with the optic calculations.

INTRODUCTION

The start up of a new high intensity isochronous cyclotron with the design beam energy from 40 up to 80 MeV and beam current of 100 microamperes was announced in November of 2016. The cyclotron is intended for production of high quality medicine isotopes, organization of eye melanoma treatment facility, treatment of surface forms of cancer and radiation resistance tests of the electronics for the aviation and space [1].

The external view of the cyclotron and the first part of the beam transport line is presented in Figure1.

Figure 1: The external view of the C-80 cyclotron and beginning part of the transport line.

Basic parameters of the cyclotron are summarized in the Table1.

Table 1: Parameters of C-80 Cyclotron

MAGNET	
Pole diameter	2.05 m
Valley gap	386 mm
Hill gap (min.)	163 mm
Number of sectors	4
Spiral angle (max.)	65°
Magnetic field in centre	1.352 Tl.
Flatter (max.)	0.025
Extraction radius	0.65-0.90 m
EXTRACTED BEAMS	
Energy	40 - 80 MeV
Method	stripping

Advantage of H – minus cyclotron is that high intensity internal beam can be extracted from the acceleration chamber with practically 100% efficiency by stripping H^- ions to H^+ ions using thin foils.

The 3D sketch of the cyclotron and extraction system is presented in Figure 2.

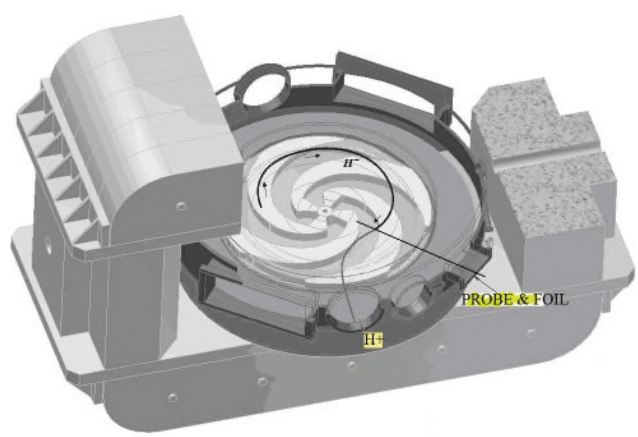

Figure 2: 3D sketch of C-80 cyclotron and the extraction system.

The extraction system consists of the probe with stripping foil, extraction window in the vacuum chamber and two correction magnets to divert the extracted beams of different energy into the transport line.

Schematic view of the extraction system is presented in Figure 3.

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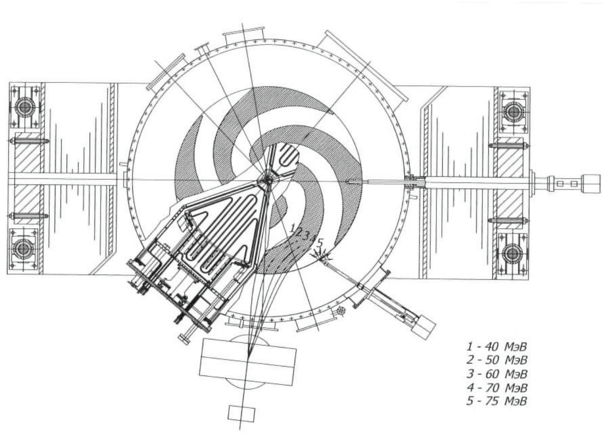

Figure 3: Schematic view of the extraction system of C-80 cyclotron.

MAGNETIC FIELD

To design the extraction system it is necessary to now magnetic field as in the acceleration region as on the edges. For that reason the residual magnetic field was measured up to a radius of 230 cm.

The C-80 cyclotron has some specific features in the magnetic structure. As can be seen from Table 1 the magnetic structure with very low flatter and very high spiral angle (up to 65 degrees) is used in the cyclotron. Such a structure makes it possible to decrease the magnetic field in the hill region to avoid beam losses due to electro-dissociation of H-minus ions. As a result it permits acceleration of H–minus ions up to an energy of 80 MeV using a magnet with the pole diameter of 2 meters and keeping the beam losses below 3 %. Detailed description of the magnetic structure can be found in RUPAC-2014 report [2]. The final magnetic field of C-80 cyclotron is presented in Figure 4.

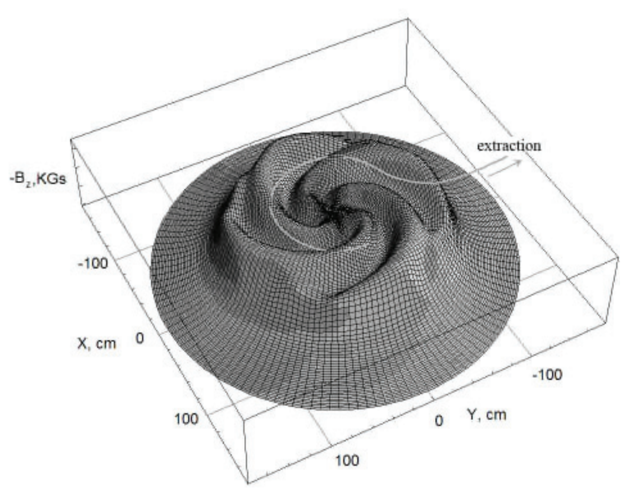

Figure 4: Magnetic field of C-80cyclotron.

REFERENCE TRAJECTORIES

One of the problems in design of the extraction system is to determine the relative positions of the extraction window in the vacuum chamber and the extraction foil. As a first approximation positions of the window and foil were estimated based on simulated closed orbits in the calculated magnetic field. The particle trajectories were started from the closed orbit. It is necessary to provide that participles of different energies pass throw the extraction window and enter the entrance of the allaying magnet. It can be achieved by varying the stripper position along the radius and azimuth. The trajectories of the extracted particles are shown in Figure 5.

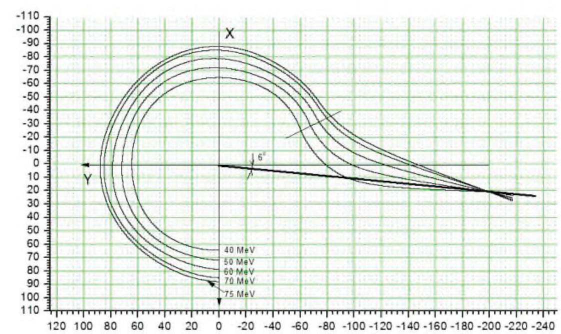

Figure 5: Trajectories of the extracted particles.

As result of these calculations it was established that the full energy in a range from 40 up to 80 MeV can be obtained when stripper foil is moved along the nearly the straight line (line equation $Y=0,88857\ X - 36,27$) in the coordinate system shown in Fig.5. The maximal deviation from the straight line should not exceed a few centimeters.

Original stripper probe with tree stripper foil was designed for C-80 cyclotron. The probe can be moved along the straight line and in addition each foil can move along the azimuth by 5 cm. As a result it permits to obtain the whole energy range by moving the probe along the straight line. The reference trajectory calculations make possible to estimate the main parameters of the extraction system: position of the extraction window in the vacuum chamber, position and movement ranges of the stripper foil, arrival points of particles with the different energies at the allaying magnet entrance, direction of the extracted beam and at last the necessary angles range for the allaying magnet. The direction of the extracted beam is at 6 degrees with respect to longitudinal axis of the cyclotron magnet as it is shown in Fig.5. Deviation angle in the allaying magnet is varied from 15 up to - 4 degrees.

BEAM OPTICS CALCULATION

Besides the reference trajectory it was necessary to determine the size and divergence of the beam near the reference trajectory to design the beam transport line.

The computer simulation [3] can be used to calculate both the reference trajectory and beam optics. In the linear approximation the movements in the vertical and horizontal planes are independent and the beam behavior can be described by two independed phase ellipses. The starting ellipse size on the stripper in the vertical plane

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was defined assuming that the maximum beam size in cyclotron is about 6 mm and divergence corresponds to divergence of matched with magnetic structure ellipse on the stripper position. The beam spot on the stripper is supposed to be 3 mm in horizontal plane and divergence should correspond to divergence of matched ellipse. Example of evolution of the phase ellipses in the extraction process for 70 MeV beam is shown in Figure 6.

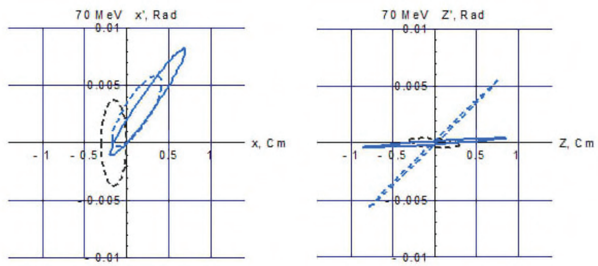

Figure 6: Phase ellipses for 70 MeV beam in the extraction process (the black dotted line corresponds to stripper position; the blue dotted line corresponds to entrance of the allaying magnet and a blue line corresponds to exit of the magnet).

Figure 7 shows evolution of the beam envelopes from stripper up to the exit from the allaying magnet for 70 MeV beam. After stripper the beam is exposed to the defocusing forces in the horizontal and vertical planes.

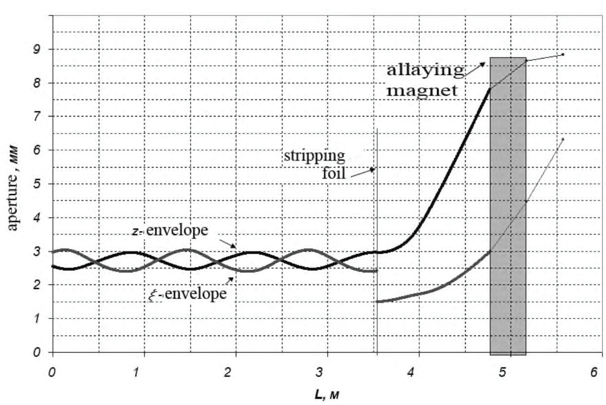

Figure7: Transformation of the beam envelopes in the extraction process.

The calculated parameters of the beam ellipses at the allaying magnet are presented in Table 2.

TRAJECTORY CALCULATIONS IN THE EXPERIMENTALLY MEASURED MAGNETIC FIELD

At the final stage it was calculated 500 particle trajectories with random start condition in the experimentally measured magnetic field map from inflector exit up to entrance of the allaying magnet. This calculation to a great extent confirmed the previous results for the extraction window and stripper position, direction of the extracted beam and the beam parameters. In addition it was found that beam spot in horizontal plane on the stripper is 3mm, as it was assumed in previous calculations. The energy uncertainty is about 1%. Furthermore it was found that internal beam quality strongly depends on the cyclotron tuning, in particular on central optic tuning, the first and third harmonics in the magnetic field. It is interesting to note that the second and fifth harmonics have no effect on the beam emittance.

Table 2: Beam Ellipse Parameters at the Allaying Magnet Entrance

T, MeV	40		70	
	ξ	z	ξ	z
α	*-1.793*	*-5.079*	-3.562	-3.123
β, mm/mrad	*5.801*	*5.010*	3.559	62.220
γ, mrad/mm	*0.727*	*5.348*	3.845	0.173
ε, mm·mrad	*5.4*	*3.8*	5.6	1.2
D, cm	105		51	
D^1 , rad.	1.03		0.52	

EXPERIMENT

The physical start up of C-80 cyclotron was in summer of 2016. Design beam parameters were achieved in November. To avoid irradiation of cyclotron elements and personal it was operated in the pulse regime. The extracted beam has been obtained in the energy range from 40 up to78 MeV. Extraction efficiency estimated as a ratio of the current on the first in beam line Faraday cap and current on the internal probe is 80-100%. The beam is directed into the beam line, which position was defined from computer simulations. The energy range was obtained by moving the stripper probe along the calculated line. Results of computer simulations have been confirmed by experiment.

Optimization of the beam line and the tuning of the cyclotron regime are planned for the near future.

ACKNOWLEDGMENT

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