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DC140 CYCLOTRON, TRAJECTORY ANALYSIS OF BEAM ACCELERATION AND EXTRACTION

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Abstract

At the present time, the activities on creation of the new heavy-ion isochronous cyclotron DC140 are carried out at Joint Institute for Nuclear Research. DC140 facility is intended for SEE testing of microchip, for production of track membranes and for solving of applied physics problems. Cyclotron will produce accelerated beams of ions A/Z= 5 – 5.5 and 7. 5 – 8.25 with a fixed beam energy 4.8 MeV/n and 2.124 MeV/n respectively. The variation of operation modes is provided by changing of magnetic field in the range 1.4T – 1.55T with fixed generator frequency 8.632MHz. In this report, the results of design and simulation of the beam acceleration and extraction are presented.

INTRODUCTION

DC140 cyclotron will accelerate the beams from O till Bi in two main operational modes, (see Fig. 1). First mode - for SEE testing of microchips, based on ions with A/Z =5.0 – 5.5 and fixed extraction energy 4.8 MeV/nucl. Second mode - for research works on radiation physics and production of track membranes, based on ions with A/Z= 7.5 – 8.0 and fixed extraction energy 2.1 MeV/nucl. [1].

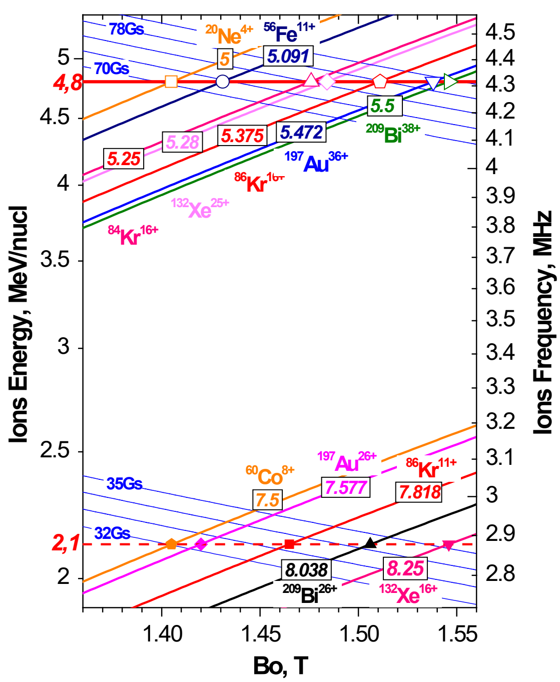

Figure 1: DC140 operational modes diagram.

DC140 cyclotron will be created as a deep reconstruction of DC72 cyclotron. The main parameters of new DC140 cyclotron are presented at Table 1. DC72 main magnet cover the new cyclotron magnetic field range 1.4T – 1.55T and stays without changing. Two 42-degree dees are placed at opposite valleys and provides acceleration voltage up to 60kV. DC140 RF generator works at fixed frequency 8.632 MHz. Acceleration modes operates at 2 and 3 RF harmonics, 4.316 MHz, and 2.877 MHz respectively. The usage of fixed frequency gives the extremely decreases of the time for switching between operation modes that very important in applied physics tasks, especially for SEE testing method.

Table 1: Main Parameters of DC140 Cyclotron

Magnet size, m	5,6x2,7x3,1
Diameter of the pole, m	1.6
Number of sector pairs	4
Number of radial trim coils	10
Number of azimuthal trim coils	4
Magnetic field range, T	1.4 – 1.55
Number of dees	2
RF voltage, kV	60
RF frequency, MHz	8.632
RF harmonic	2 – 3
Ion injection method	axial
Ion source	ECR
Ion extraction method	electrostatic
Deflector voltage, kV	75

CYCLOTRON MAGNETIC FIELD

DC140 is a compact type isochronous cyclotron based on DC72 magnet [2]. Main magnet has H-shape form with 1.6 meter pole diameter.

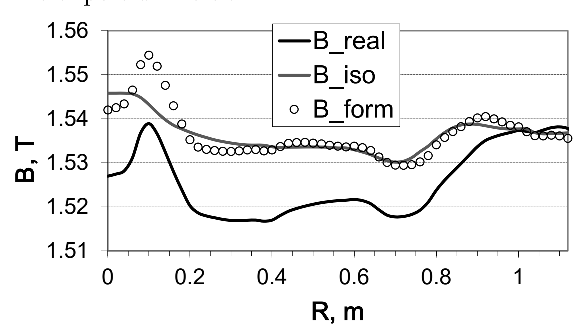

Figure 2: Operational formation of the magnetic field for 209Bi38+ acceleration mode.

Figure 2 demonstrates the usage of 10 radial trim coils for operational formation of isochronous magnetic field for 209Bi38+ acceleration mode. B_real presents base magnetic field, without trim coils. B_iso presents calculated isochronous field for 209Bi38+ acceleration mode. B_form presents final magnetic field, operationally formed with radial trim coils. Formed magnetic field keeps betatron frequencies in the ranges 1.005<Qr<1.05 and

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0.2<Qz<0.45, excluded central region, there beam crosses resonance Qr=1, (see Fig. 3). At the first orbits the beam has a high tempo of radius growth and cross Qr=1 resonance area very quickly.

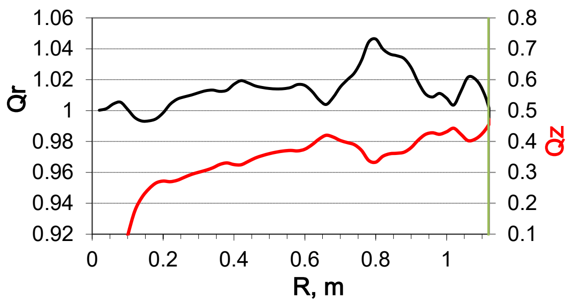

Figure 3: Radial and vertical betatron oscillation frequencies for 209Bi38+ acceleration mode.

INFLECTOR AND CENTRE REGION

Electrostatic spiral inflector with magnetic radius R_{mag}=30mm and electric radius A_e=35mm is used to turn the injected beams onto acceleration region. Because magnetic radius is constant for all operational modes, the injection voltage varies in the ranges 16kV – 20kV for the first main operational mode and 11kV – 13kV for the second.

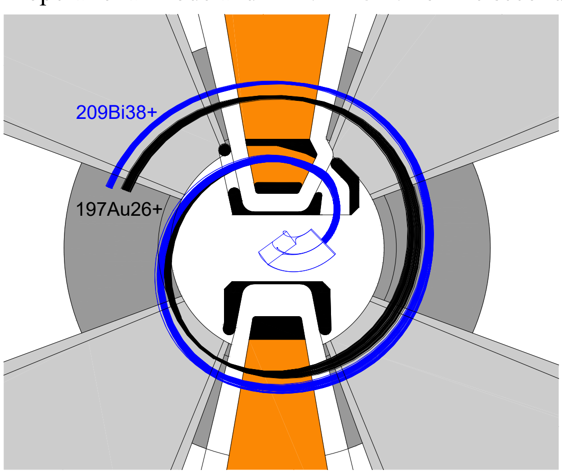

Figure 4: DC140 central region.

Figure 4 demonstrates DC140 central region with calculated first orbits of 197Au26+ (A/Z=7.577) and 209Bi38+ (A/Z=5.5) ions beams. First acceleration gap is placed at angular position 28° from the dee central axis as a compromise between operation modes at 2 and 3 RF harmonics. Figure 5 demonstrates R-R' position of 209Bi38+ beam after inflector and before first acceleration gap. Red line represents the variation of beam R-R' position in depends on inflector angulare rotation. At the start position of calculations, at the inflector entrance, the beam with momentum deviation dp/p=0.01 and phase range ±10° of RF was taken. After crossing the accelerating gaps at the first orbit, the deviation of 209Bi38+ ions energy in the beam become dW/W≈0.07, (see Fig. 6). Phase range increases in about 2 times because different paths of ions during the crossing of first accelerating gap.

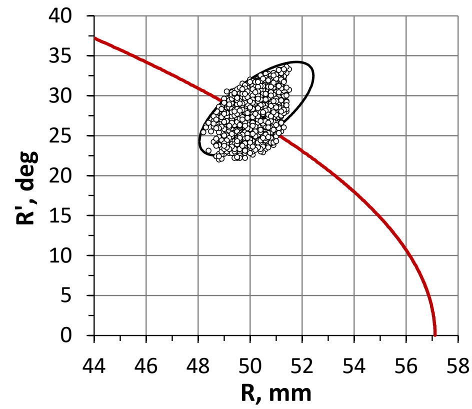

Figure 5: Radial position of 209Bi38+ beam at the entrance of puller (first acceleration gap).

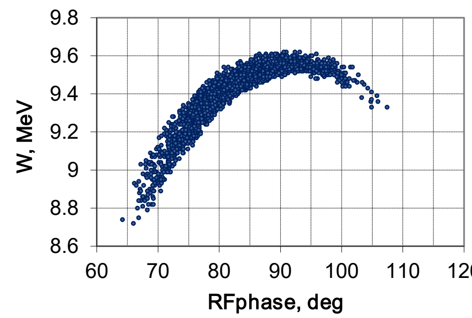

Figure 6: The distribution of ions energy in 209Bi38+ beam at first orbit after injection.

Coefficient of the beam transmission through the cyclotron center is about 16% for total phase range without usage buncher, and about 90% for chosen start phases ±10°.

BEAM ACCELERATION

In DC140 cyclotron the beams pass about 170 orbits up to extraction radius R_{ext}=1.12m. Figure 7 demonstrates the phases of ions in 209Bi38+ beam during acceleration. The criteria of chosen of magnetic field level is a zero phase shifting of the reference ion at the extraction radius, red line at Figure 7.

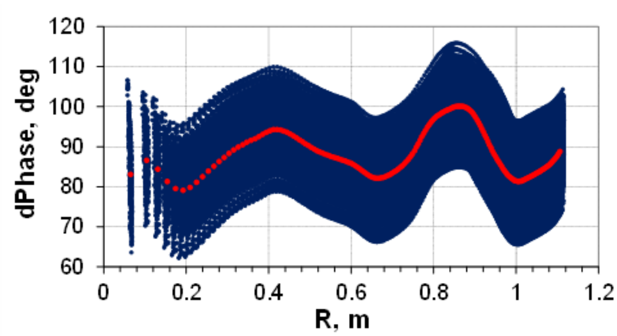

Figure 7: The phases of ions in 209Bi38+ beam during acceleration from cyclotron center to extraction radius.

Figure 8 demonstrates the radial coherent oscillations of ions in 209Bi38+ beam during acceleration from cyclotron center to extraction radius. Red line represents behavior of radial oscillations of reference ion. The main reason of the

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increasing of this oscillations at the central radiuses up to value Ar ≈ 0.03m is the compromise angle position of puller accelerating gap for 2 and 3 RF harmonics, (see Fig. 4). Figure 9 demonstrates the vertical behavior of ions in 209Bi38+ beam when it is accelerated from cyclotron center to extraction radius. The coefficient of the beam transmission through acceleration region is about 91%.

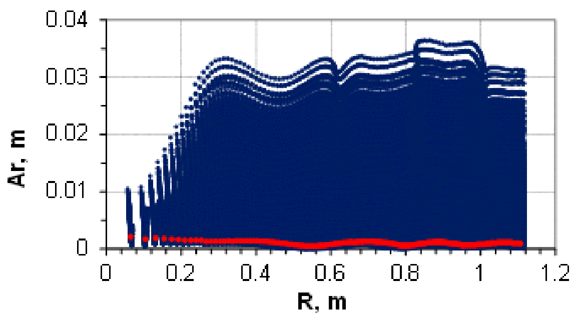

Figure 8: Radial coherent oscillations of ions in 209Bi38+ beam from cyclotron center to extraction radius.

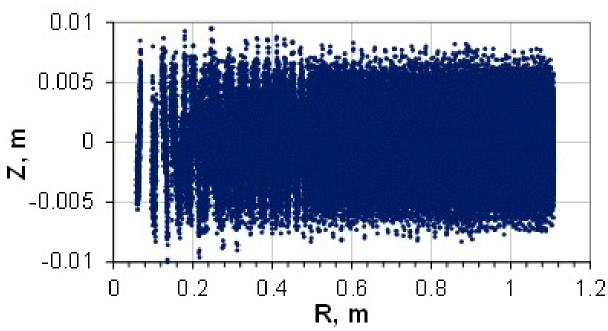

Figure 9: Vertical dimension of 209Bi38+ beam during acceleration from cyclotron center to extraction radius

BEAM EXTRACTION

DC140 beam extraction system consists of electrostatic deflector with maximal extraction voltage 75kV and two correctors (see Fig. 10).

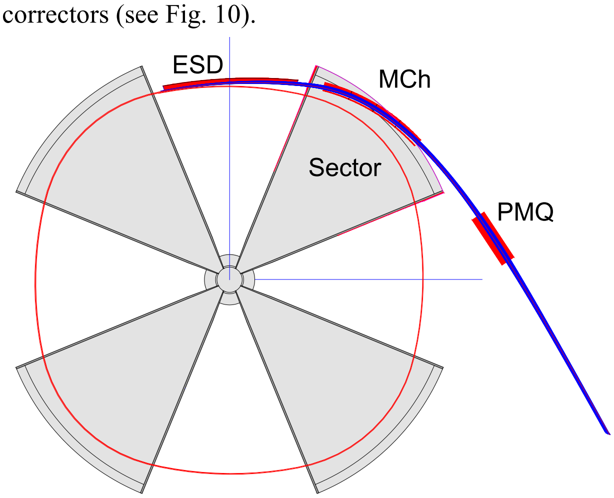

Figure 10: Last orbits and extraction trajectory of 209Bi38+ ion beam.

First corrector, passive magnetic channel MCh, is plased exactly after deflector and compensate the gradient of magnetic field at the sector edge. Second corrector, quadrupole lens PMQ, based on permanent magnets, produce an additional beam focusing in the area of low magnetic field. The distance between neighbor orbits before extraction ≈3.5mm. Because radial coherent oscillations is about 30mm, more then 4 – 5 orbits are accepted at the septum of deflector, as it is shown at the Figure 11. Whereis the deviation of 209Bi38+ ions energy in the extracted beam become dW/W≈0.03.

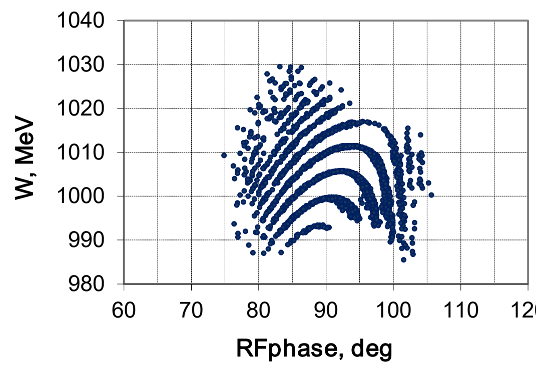

Figure 11: The distribution of ions energy in 209Bi38+ beam at the septum of deflector.

Figure 12 represents radial and vertical envelopes of 209Bi38+ beam when it is passes electrostatic deflector ESD, passive magnetic channel MCh and quadrupole lens PMQ. The efficiency of beam transmission through DC140 extraction system is about 80%.

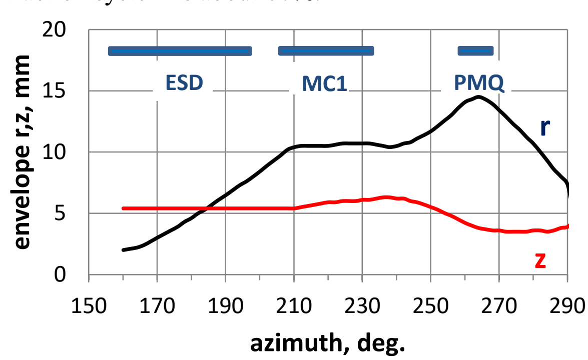

Figure 12: The radial and vertical envelopes of 209Bi38+ extracted beam.

CONCLUSION

DC140 cyclotron will be created as a deep reconstruction of DC72 cyclotron. New cyclotron will produce accelerated beams of ions A/Z= 5 – 5.5 and 7. 5 – 8.25 with a fixed beam energy 4.8 MeV/n and 2.124 MeV/n respectively. Based on results of DC72 magnetic field measurements, the trajectory analysis for DC140 beams was carry out. The results of analysis have shown a good transmission efficiency of injection (≈16% without buncher), acceleration (≈91%) and extraction (≈80%) systems of new cyclotron.

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