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SIMULATION OF THE BEAM EXTRACTION SYSTEM OF DC140 CYCLOTRON OF FLNR JINR

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Abstract

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research carries out the works under creating FLNR JINR Irradiation Facility based on the cyclotron DC140. The facility is intended for SEE testing of microchip, for production of track membranes and for solving of applied physics problems. The main systems of DC140 are based on the DC72 cyclotron ones that now are under reconstruction. The DC140 cyclotron is intended for acceleration of heavy ions with mass-to-charge ratio *A/Z* within interval from 5 to 5.5 up to two fixed energies 2.136 and 4.8 MeV per unit mass. The intensity of the accelerated ions will be about 1 pμA for light ions (*A*<86) and about 0.1 pμA for heavier ions (*A*>132). The beam extraction system consists of electrostatic deflector and two magnetic channels. The simulation of the extraction system of the cyclotron is presented in this report. The extracted beams characteristics outside the cyclotron, that will serve as initial conditions for the design of experimental beam lines of FLNR JINR IF are determined.

INTRODUCTION

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research carries out the works under the creating of Irradiation Facility based on the DC140 cyclotron. The DC140 will be a reconstruction of the DC72 cyclotron [1, 2]. Table 1 presents the main parameters of DC140 cyclotron.

Table 1: DC140 Cyclotron Main Parameters

Parameter	Value	
Pole (extraction) radius, m	1.3 (1.18)	
Magnetic field, T	1.415 - 1.546	
Number of sectors	4	
RF frequency, MHz	8.632	
Harmonic number	2	3
Energy, MeV/u	4.8	2.124
A/*Z* range	5.0 - 5.5	7.577 - 8.25
RF voltage, kV	60	
Number of Dees	2	
Ion extraction method	electrostatic deflector	
Deflector voltage, kV	70	

The irradiation facility will be used for Single Event Effect (SEE) testing of microchips by means of ion beams (^{16}O, ^{20}Ne, ^{40}Ar, ^{56}Fe, ^{84,86}Kr, ^{132}Xe, ^{197}Au and ^{209}Bi) with energy of 4.8 MeV per unit mass and having mass-to-charge ratio *A*/*Z* in the range from 5.0 to 5.5.

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Besides the research works on radiation physics, radiation resistance of materials and the production of track membranes will be carrying out by using the ion beams with energy of about 2.124 MeV per unit mass and *A/Z* ratio in the range from 7.577 to 8.25.

The working diagram of DC140 cyclotron is presented in report MOP019 at this conference [3]. The acceleration of ion beam in the cyclotron will be performed at constant frequency f = 8.632 MHz of the RF-accelerating system for two different harmonic numbers h. The harmonic number h = 2 corresponds to the ion beam energy W = 4.8 MeV/u and value h = 3 corresponds to W = 2.124 MeV/u. The intensity of the accelerated ions will be about 1 pμA for light ions (A ≤ 86) and about 0.1 pμA for heavier ions (*A* ≥ 132).

The extraction system of DC140 cyclotron differs from DC72 cyclotron one, based on extraction by stripping foil [4], and consists of electrostatic deflector and two magnetic channels. The first is the passive channel placed in the region of strong magnetic field of the cyclotron. The second is permanent magnet channel placed in the region of low level magnetic field.

This report presents the simulation of the ^{209}Bi^{38+} ion beam dynamic in the extraction beam line of DC140 cyclotron.

CYCLOTRON MAGNETIC FIELD

The magnetic field of DC140 cyclotron within the project range is formed by variation of the currents in the main and in ten correcting coils. Radial distribution of the magnetic fields for acceleration of ^{209}Bi^{38+} ions up to energy W = 4.8 MeV/u is shown in Fig. 1 [5].

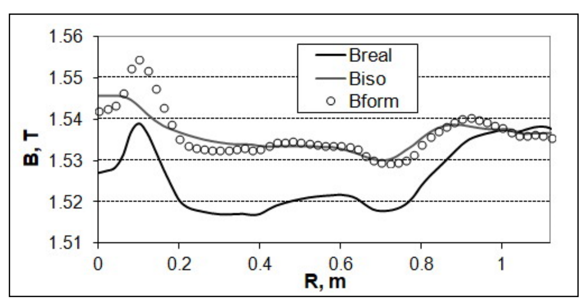

Figure 1: Magnetic fields for acceleration of ^{209}Bi^{38+} ions. Breal – magnetic field formed by main coils ; Biso – isocronous magnetic field ; Bform – magnetic field formed by main and correcting coils.

For the other kind of ions, the form of magnetic field is similar to the considering case.

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EXTRACTION BEAM LINE SCHEME

The scheme of the working region of DC140 cyclotron is shown in Fig. 2. The ion motion is considered in the polar coordinates system (R,Φ) having origin coincided with cyclotron center. The line $\Phi = 0$ (see Fig. 2) is the valley middle line. Ions move counterclockwise.

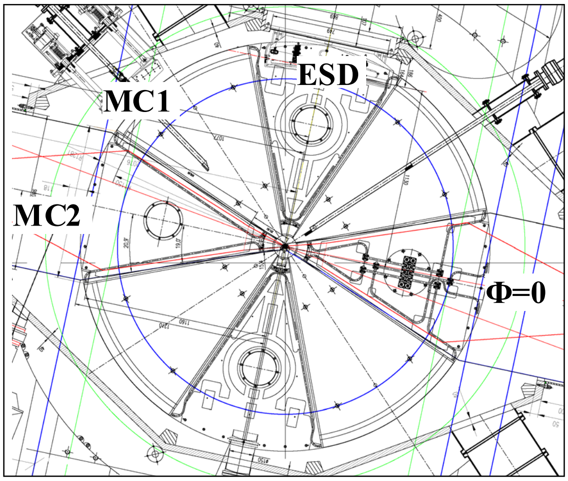

Figure 2: DC140 cyclotron working region. ESD – electrostatic deflector; MC1 – passive magnetic channel; MC2 – permanent magnet channel.

The closed orbit of the cyclotron corresponded to ion energy of 4.8 MeV/u and extraction orbit with final point at middle of special window in the wall of vacuum chamber (R = 197.1 mm, Φ = 194.60) are shown in Fig. 3. The length of extraction orbit is equal to 306.4 cm.

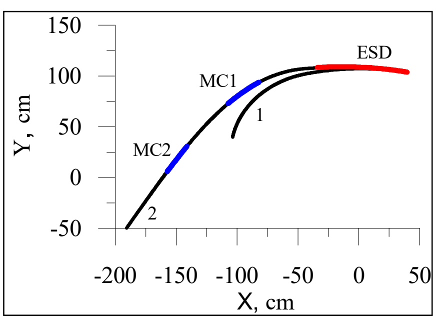

Figure 3: Closed (curve 1) and extraction (curve 2) orbits of DC140 cyclotron.

The cyclotron magnetic field B_z and its gradient along the direction of normal vector to the extraction orbit $\partial Bz/\partial x$ are shown in Fig. 4.

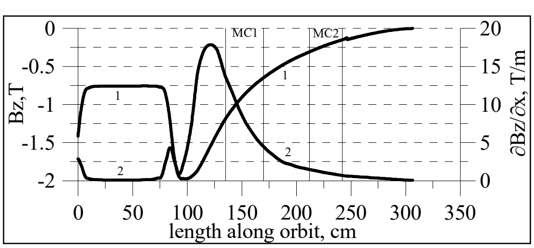

Figure 4: Cyclotron magnetic field B_z (curve 1) and its gradient (curve 2) distributions along the extraction orbit.

The entrance of electrostatic deflector ESD is placed at the common point of closed and extraction orbits having coordinates (R_{ex} = 111.20 cm, Φ_{ex} = 69.0°). The angular length of the deflector is equal to 42^0. The length along the extraction orbit equals 81.6 cm. The deflector gap is 0.9 cm. The deflector voltage U_{ESD} is equal to 70 kV (maximum) in the case of $^{209}Bi^{38+}$ ions extraction.

The passive magnetic channel MC1 is placed in the region of strong magnetic field B_z and its gradient (see Fig.4). The entrance of MC1 has coordinates (R = 126.16 cm, Φ = 135.64°). It length along the extraction orbit equals to 35.0 cm.

The permanent magnet channel MC2 is placed in the region of low level magnetic field B_z and its gradient (see Fig.4). The entrance of MC1 has coordinates (R = 144.61 cm, Φ = 167.65°). Its length along the extraction orbit is equal to 30.0 cm.

CLOSED ORBIT PARAMETRS

The betatron functions $\beta_{H,V}$ and horizontal dispersion function D_H for the closed orbit corresponding to beam energy W = 4.8 MeV/u are shown in Fig. 5.

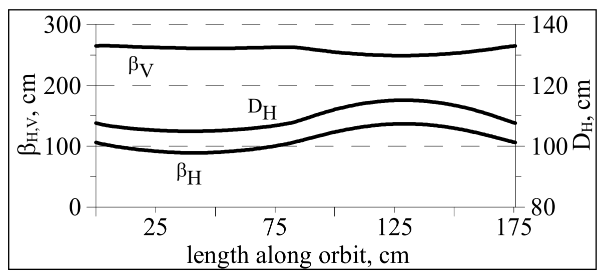

Figure 5: Horizontal β_H, vertical β_V betatron functions and horizontal dispersion function D_H. W = 4.8 MeV/u.

The frequencies of betatron oscillation at this orbit are equal to Q_H = 1.031, Q_V = 0.433.

These quantities give opportunity to evaluate one turn transfer matrix to compute of the extracted beam parameters.

ION DISTRIBUTION AT ESD ENTRANCE

The method of computation of ion distribution at electrostatic deflector ESD entrance is the same as being used in [6]. The radial shift ΔR of the orbit due to energy gain per turn ΔW = 0.031 MeV/u is evaluated as ΔR = 3.7 mm. The septum of the deflector is placed at radius $R_s = R_{ex} - \Delta R/2$. The radial (horizontal) beam size is evaluated as a_H = 8.6 mm and number of turns N_t needed for 100% beam extraction, is equal to 3.

The distribution of the ions at entrance of ESD was found by macro particle simulation. The coordinates of particle in five-dimensional phase was transformed by means of one turn transfer matrix for each N_t extracted turns. The particle having radius greater than R_s was accumulated and did not consider in the calculations of the next turns. The distributions of the ion $^{209}Bi^{38+}$ in the various phase space planes are shown in Figs. 6 and 7.

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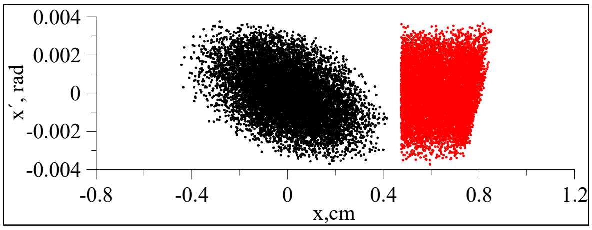

Figure 6: Horizontal plane (x,x′). Accelerated beam – left, beam at ESD entrance – right.

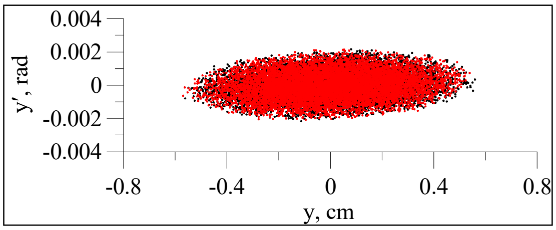

Figure 7: Vertical plane (y,y′). Accelerated beam – black dots, beam at ESD entrance – red dots.

The beam distribution in vertical plane (y,y′) (see Fig. 7) does not differ significantly from accelerated one.

ION DISTRIBUTION AT FINAL POINT

The fitting of magnetic field gradients in magnetic channels MC1, 2 gives the optimum values G_{MC1} = -12 T/m and G_{MC1} = -9 T/m.

The betatron functions $\beta_{H,V}$ and dispersion function D_H along the extraction orbit from are shown in Fig. 8.

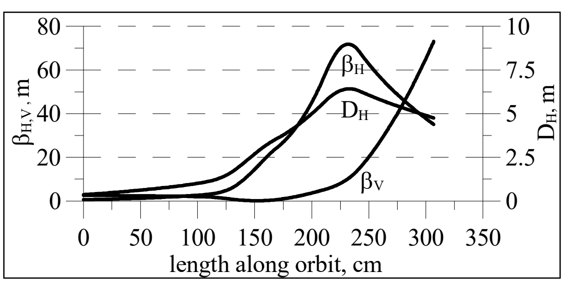

Figure 8: The betatron $\beta_{H,V}$ and dispersion D_H functions along the extraction orbit.

The changing of the beam envelopes (2σ) along the extraction orbit are given in Fig. 9.

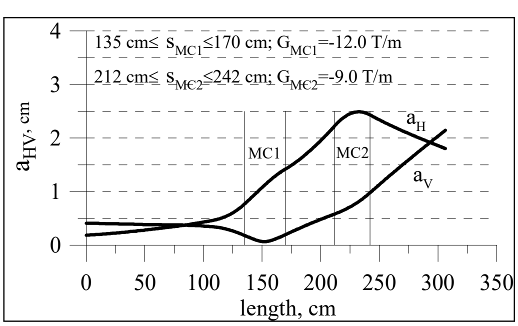

Figure 9: Horizontal (a_H) and vertical (a_V) $^{209}Bi^{38+}$ beam envelopes along the extraction orbit.

The ion distribution in the plane (x,y) at the final point of the extraction beam line is shown in Fig. 10.

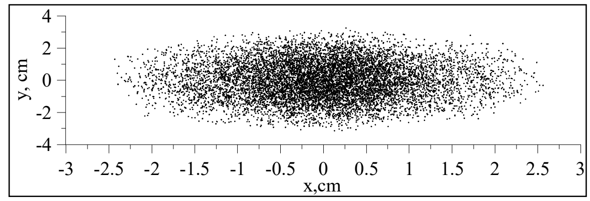

Figure 10: $^{209}Bi^{38+}$ ion distribution in plane (x,y) at final point of extraction beam line.

The ion distributions in horizontal (x,x′) and vertical (y,y′) planes at the final point of the extraction beam line are shown in Figs. 11 and 12.

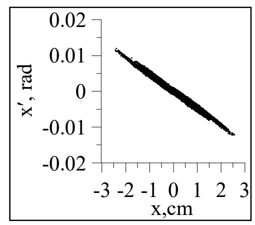

Figure 11: Plane (x,x′).

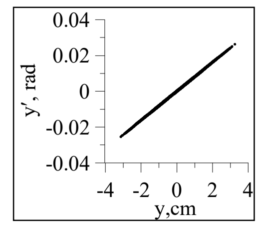

Figure 12: Plane (y,y′).

SUMMARY

The extraction system of DC140 cyclotron allows to extract all ion beams declared in the working diagram of FLNR JINR Irradiation Facility [3].

The parameters of the extraction system such as U_{ESD} and $G_{MC1,2}$ have reasonable values.

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