
MOP020

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

N. Kazarinov†, G. Gulbekian, I. Ivanenko
JINR, Dubna, Moscow region, 141980, Russia
† nyk@jinr.ru

## 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 (see Fig.1) [1,2]. Table 1 presents the main parameters of DC140 cyclotron

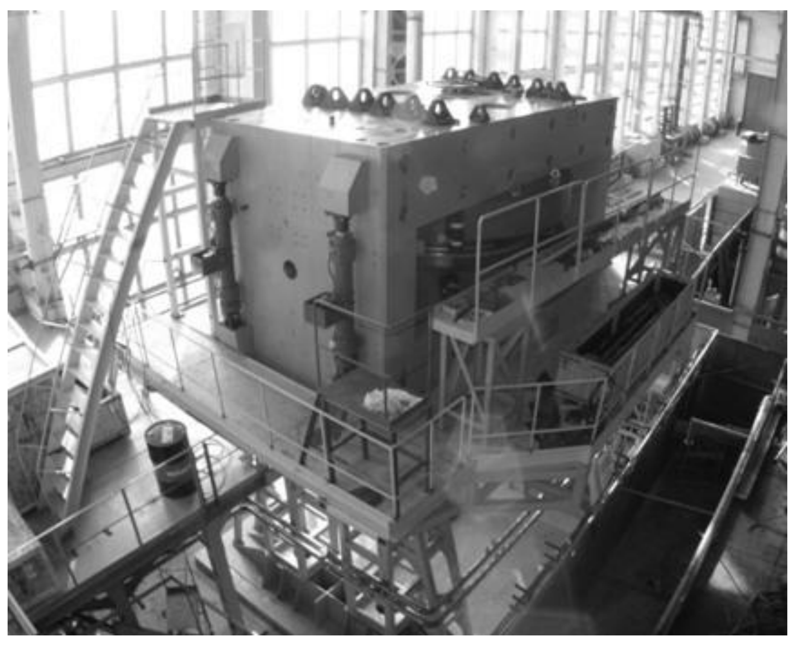

Figure 1: DC140 cyclotron at test bench

Table1:Main parameters of DC140 cyclotron

| | | |
|---|---|---|
| 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.

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 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 ($A \le 86$) and about 0.1 pμA for heavier ions ($A \ge 132$).

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.2 [5].

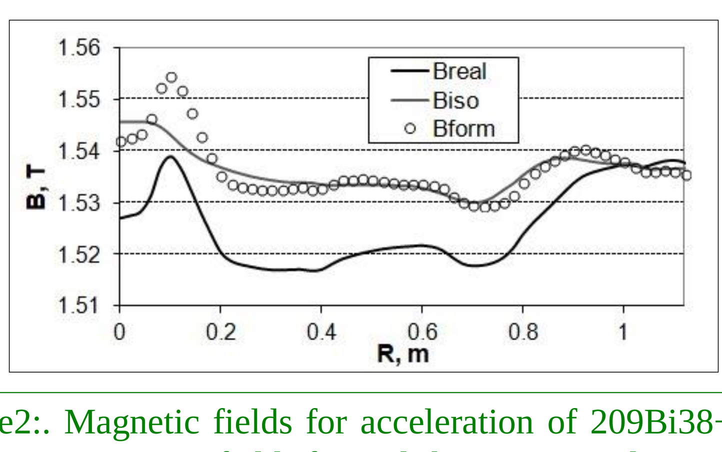


Figure2:. Magnetic fields for acceleration of 209Bi38+ ions. Breal – magnetic field formed by main coils ; Biso – isocronous magnetic field ; Bform – magnetic field formed by main and correcting coils

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

## 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 Φ = 0 (seeFig.2) is the valley middle line. Ions move counterclockwise.

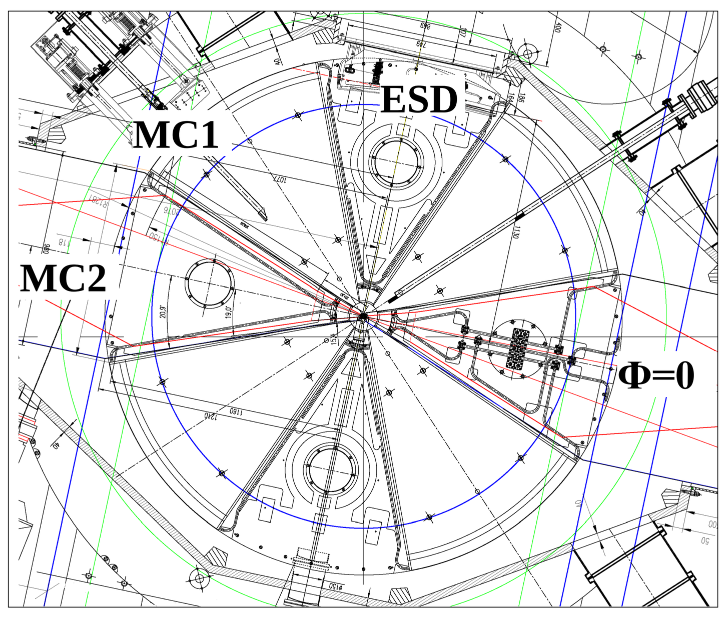


Figure 3: DC140 cyclotron working region. ESD – electrostatic deflector; MC1 – passive magnetic channel; MC2 – permanent magnet channel

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.4. The length of extraction orbit is equal to 306.4 cm.

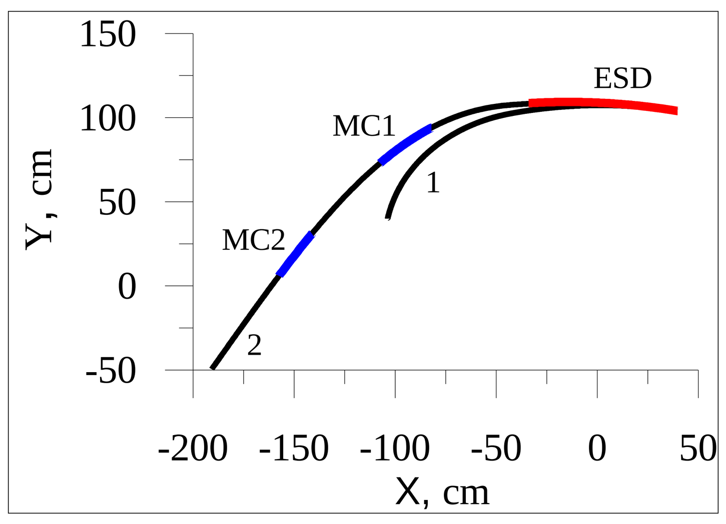


Figure 4:Closed (curve 1) and extraction (curve 2) orbits of DC140 cyclotron

The cyclotron magnetic field Bz and its gradient along the direction of normal vector to the extraction orbit ∂Bz/∂x are shown in Fig.5.

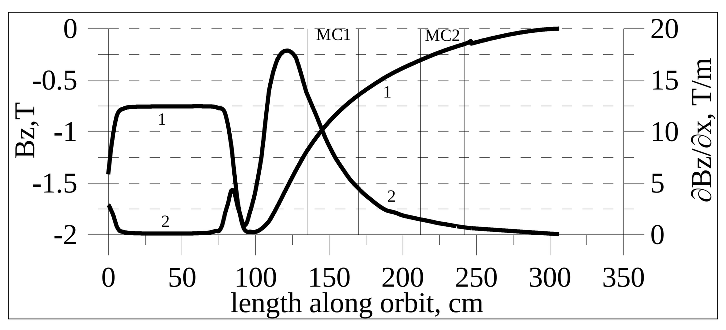


Figure 5:Cyclotron magnetic field Bz (curve 1) and its gradient (curve 2) distributions along the extraction orbit

The entrance of electrostatic deflector ESD is placed at the common point of closed and extraction orbits having coordinates (Rex = 111.2 cm, Φex = 69.0$^0$). The angular length of the deflector is equal to 42$^0$. The length along the extraction orbit equals to 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 Bz and its gradient (see Fig.4). The entrance of MC1 has coordinates (R=126.16 cm, Φ = 135.64$^0$). 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 Bz and its gradient (see Fig.5). The entrance of MC1 has coordinates (R=144.61 cm, Φ = 167.65$^0$). It 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.6. The frequencies of betatron oscillation at this orbit are equal to $Q_H$ = 1.031, $Q_V$ = 0.433.

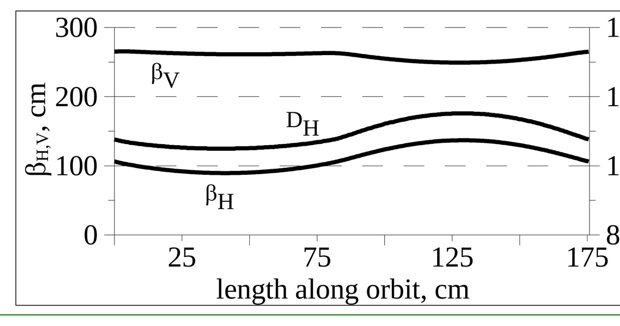


Figure 6: Horizontal $\beta_H$, vertical $\beta_V$ betatron functions and horizontal dispersion function $D_H$. W = 4.8 MeV/u

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 Rs = Rex - ΔR/2. The radial (horizontal) beam size is evaluated as $a_H$ = 8.6 mm and number of turn Nt 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 Nt extracted turns. The particle having radius greater than Rs was accumulated and did not consider in the calculations of the next turns. The distributions of the ion $^{209}Bi^{38+}$ in planes (x,x′) and (y,y′) are shown in Figs. 7,8.

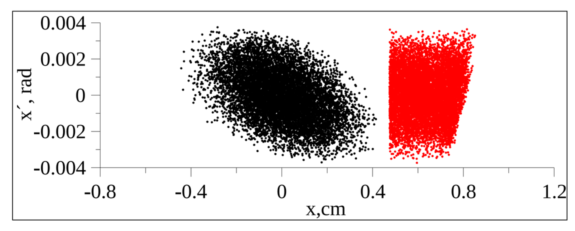


Figure 7: Plane (x,x′). Accelerated beam – left, ESD entrance – right.

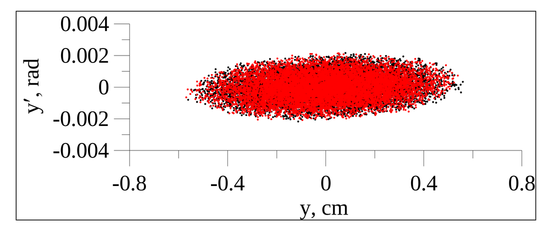


Figure 8: Plane (y,y′). Accelerated beam – black dots, ESD entrance – red dots.

## 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.9.

The changing of the $^{209}Bi^{38+}$ ion beam envelopes (2σ) along the extraction orbit are given in Fig.10.

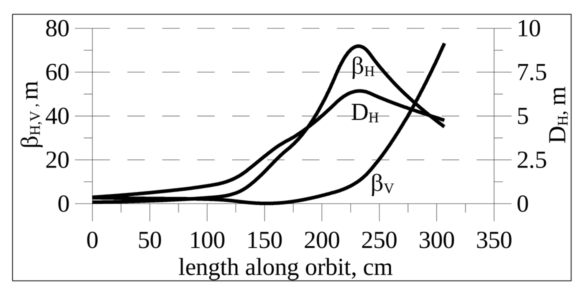


Figure 9: The betatron $\beta_{H,V}$ and dispersion $D_H$ functions along the extraction orbit

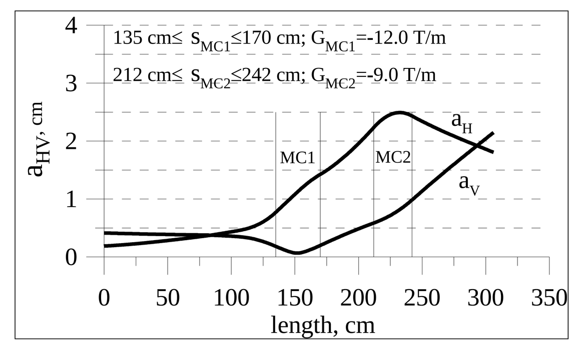


Figure 10: Horizontal ($a_H$) and vertical ($a_V$) beam envelopes along the extraction orbit

The $^{209}Bi^{38+}$ ion distribution in the plane (x,y) at the final point of the extraction beam line is shown in Fig.11. The distributions in horizontal (x,x′) and vertical (y,y′) planes at the final point of the extraction beam line are shown in Fig.12,13

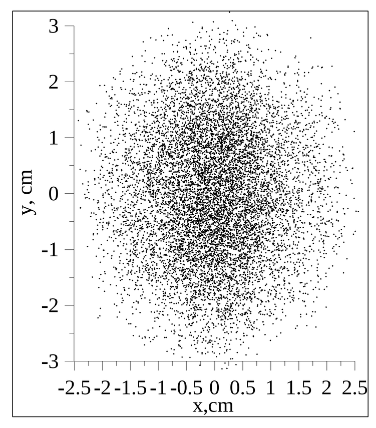


Figure 11: Plane (x,y)

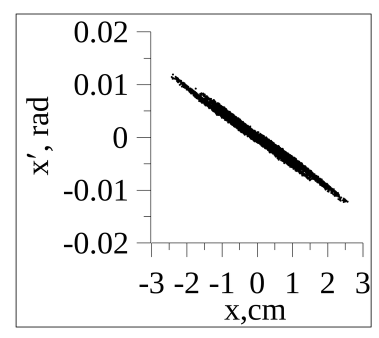


Figure 12: Plane (x,x′)

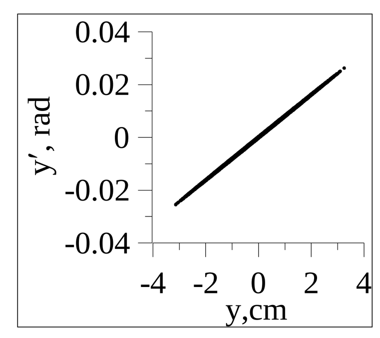


Figure 13: Plane (y,y′)

## 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 a reasonable values.

## REFERENCES

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