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SIMULATION OF THE AXIAL INJECTION BEAM LINE 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 of 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 2.124 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 injection into cyclotron will be realized from the external room temperature 18 GHz ECR ion source. The simulation of the axial injection system of the cyclotron is presented in this report.

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

Pole (Extraction) Radius, m	**1.3 (1.18)**	
Magnetic field, T	1.415 to 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 to 5.5	7.577 to 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 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 shown in Fig. 1. 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 ($A \leq 86$) and about 0.1 pμA for heavier ions ($A \geq 132$).

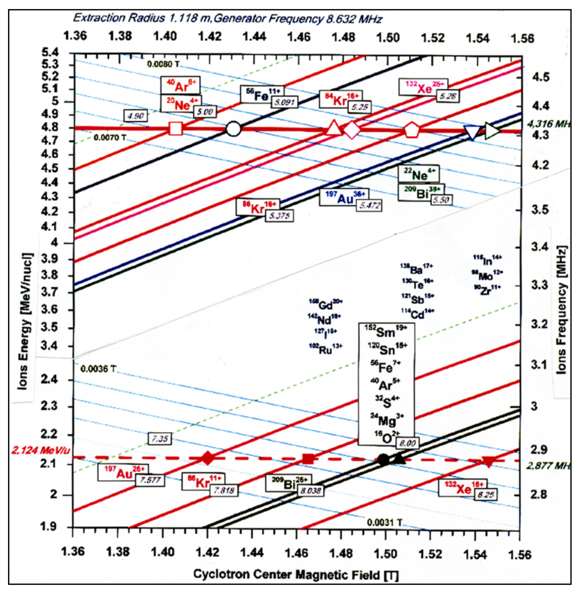

Figure 1: Working diagram of DC140 cyclotron.

The axial injection system of DC140 cyclotron will be adapted from the existing DC72 cyclotron one [3].

This report presents the simulation of the beam dynamic in the axial injection beam line of DC140 cyclotron. The simulation was carried out by means of MCIB04 program code [4].

ECR ION SOURCE

The ion beams are produced in superconducting ECR ion source DECRIS-SC designed in Flerov Lab of JINR [5]. The working frequency DECRIS-SC is equal to 18 GHz. It is able to produce the beams of ion from ^{22}Ne to ^{209}Bi. The ion beam currents at the source exit sufficient for the facility operation are contained in Table 2.

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Table 2: Ion Beam Current Extracted from DECRIS-SC

Ion	Current, pmcA	Ion	Current, pmcA
$^{22}Ne^{4+}$	~ 50	$^{132}Xe^{23+}$	~ 4
$^{40}Ar^{7+}$	~ 30	$^{132}Xe^{24+}$	~ 4
$^{56}Fe^{10+}$	~ 4	$^{197}Au^{34+}$	~ 0.3
$^{84}Kr^{15+}$	~ 8	$^{209}Bi^{37+}$	~ 0.2

The charge state distribution of argon beam current used in simulation is shown in Fig. 2.

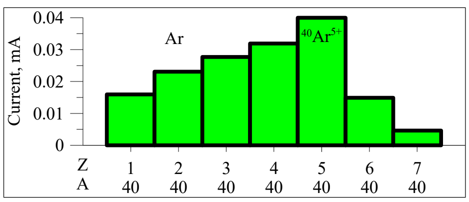

Figure 2: Ar beam current distribution.

The parameters of the ion beams at the extraction hole of ECR ion source are contained in Table 3.

Table 3: Parameters of Ion Beam Used in Simulation

Injected ions	$^{209}Bi^{38+}$	$^{132}Xe^{16+}$
A/Z	5.5	8.25
Extraction voltage U_{inj}, kV	17.26	14.31
Beam current [μA]	10	10
Beam diameter, [mm]	8	8
Emittance, π·mm·mrad	225	200

BEAM LINE SCHEME

The scheme of the beam line is shown in Fig. 3.

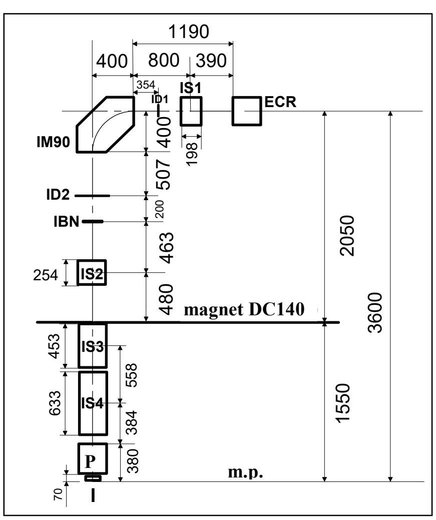

Figure 3: Scheme of the axial injection beam line.

The length of the beam line is equal to 5.018 m. The 90-degree analysing magnet IM90 separates the injected beam. The solenoidal lenses IS1-4 focus and match beam with the acceptance of the spiral inflector I for all level of the cyclotron magnetic field. The sinusoidal buncher IBN increases the beam capture into acceleration. Two movable diaphragms ID1,2 are used for analysis of the beams spectra.

ANALYZING MAGNET IM90

The analysing magnet IM90 has a bending radius R_M equal to 0.4 m, gap 80 mm and maximum magnetic field 0.2 T. This magnet was used in U400M cyclotron axial injection beam line before it upgrading.

SOLENOIDS IS1-IS4

The solenoids IS1-IS4 are the part of existing DC72 cyclotron axial injection beam line [3]. Its on-axis magnetic fields are shown in Fig. 4.

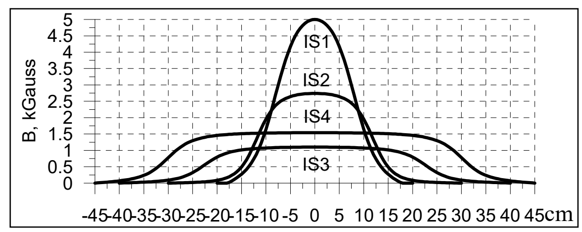

Figure 4: On-axis magnetic field of solenoids.

MAGNETIC PLUG

The parameters of the magnetic plug (P in Fig. 3) of the DC72 cyclotron were used in the calculation. The channel aperture in plug is shown in Fig. 5.

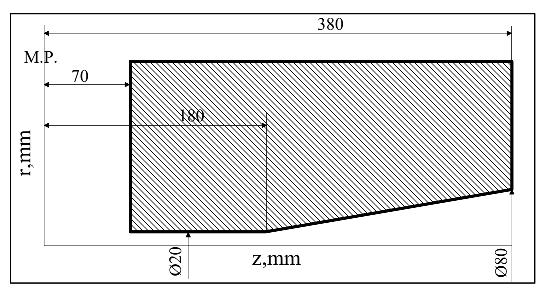

Figure 5: Magnetic plug scheme.

SINUSOIDAL BUNCHER IBN

To improve the efficiency of beam capture into the acceleration a sinusoidal (one harmonic) buncher IBN, located outside the yoke of the magnet at a distance of 2.493 m from the median plane of the cyclotron, is used. The maximum applied voltage at the grids of buncher is 423.4 V for the injecting ions having A/Z = 5.5($^{209}Bi^{38+}$). The efficiency of bunching is approximately equal to 2 (see Fig. 6).

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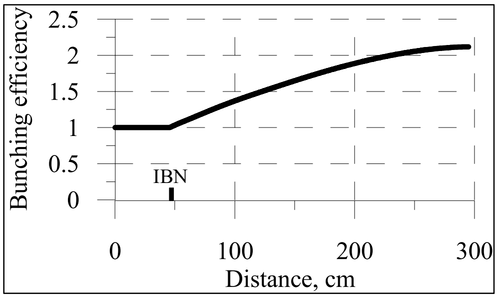

Figure 6: Bunching efficiency.

SPIRAL INFLECTOR I

The spiral inflector I rotates the beam onto the median plane of the cyclotron. In the case of harmonic number h = 2, the inflector of DC72 cyclotron with magnetic radius ρ_M of 28.7 mm is used. The ECR extraction voltage U_{inj} varies from 15.69 kV to 17.27 kV for ions having A/Z in the range 5.0 ($^{40}Ar^{8+}$) to 5.5 ($^{209}Bi^{38+}$).

In the case h = 3 the new inflector with magnetic radius ρ_M = 32.0 mm is used. Then the voltage U_{inj} varies from 13.14 kV to 14.31 kV in the case of injection of ions having A/Z in the range from 7.577 ($^{197}Au^{26+}$) to 8.25 ($^{132}Xe^{16+}$).

SIMULATION RESULTS

The calculations of ion injection with the parameters specified in Table 3 were carried out. In all cases, the transfer efficiency is equal to 100%.

A/Z=5.5, B0=1.546 T, ρ_M=28.7 mm, h=2

Transport of $^{209}Bi^{38+}$ ion beam was considered. In this case the magnetic field at the center of the cyclotron B_0 = 1.546 T is maximal. The horizontal (H) and vertical (V) envelopes of $^{209}Bi^{38+}$ ions in the beam line is shown in Fig. 7.

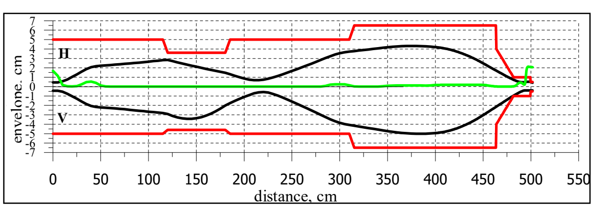

Figure 7: Horizontal (H) and vertical (V) $^{209}Bi^{38+}$ beam envelopes, aperture (red line) and longitudinal magnetic field (green line).

A/Z=8.25, B0=1.546 T, ρ_M =32.0 mm, h=3

Transport of $^{132}Xe^{16+}$ ion beam was considered. In this case the magnetic field at the center of the cyclotron B_0 = 1.546 T. The horizontal (H) and vertical (V) envelopes of $^{132}Xe^{16+}$ ions in the beam line is shown in Fig. 8.

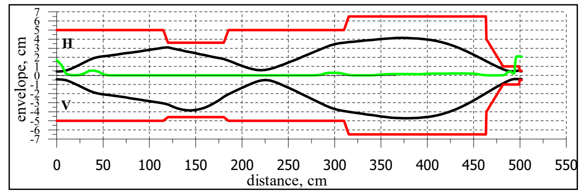

Figure 8: Horizontal (H) and vertical (V) $^{132}Xe^{16+}$ beam envelopes, aperture (red line) and longitudinal magnetic field (green line).

Beam Spectrum Analysis

Two movable diaphragms ID1,2 are used in the beam spectrum analysis. The first diaphragm ID1, has the form of a square with a side of 10 mm and shown in Fig. 9, is located at a distance of 354 mm in front of the IM90 magnet.

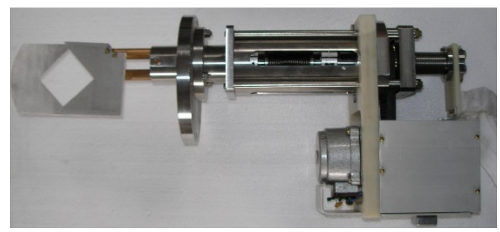

Figure 9: Diaphragm ID1.

The second one ID2 is a slit with a width of 5 mm < d < 10 mm, located at distance of 507 mm after IM90 magnet. The distance between diaphragm ID2 and Faraday cap is equal to 100 mm.

The beam emittance is decreased at diaphragm ID1 in 16 times that give opportunity to separate two neighbour charges in the beam spectrum by means of diaphragm ID2.

The distribution of ions $^{209}Bi^{37+,38+,39+}$ in front of the diaphragm ID2 is shown in Fig. 10.

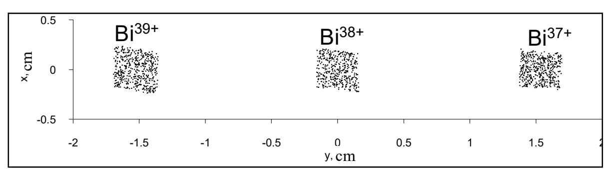

Figure 10: Bi ions distribution.

SUMMARY

The axial injection system of DC140 cyclotron allows transporting with of 100% efficiency all ion beams declared in the working diagram of FLNR JINR Irradiation Facility (Fig. 1).

The proposed system of beam spectrum analysis allows to separate ion charge up to value Z=38.

In the calculation the parameters of the existing solenoids IS1-4 of the axial injection channel of the DC-72 cyclotron have been used. The magnitudes of their magnetic fields are in the design range.

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