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DESIGN AND 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 8.25 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 design and simulation of the axial injection system of the DC140 cyclotron is presented in this report.

INTRODUCTION

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research continues the works under the creating of Irradiation Facility based on the DC140 cyclotron [1]. The DC140 will be a reconstruction of the DC72 cyclotron [2, 3]. Table 1 presents the main parameters of DC140 cyclotron.

Table 1: 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	7.57÷8.25
RF voltage, kV	60	
Number of Dees	2	
Ion extraction method	electrostatic deflector	
Deflector voltage, kV	73.5	

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≤86) and about 0.1 pμA for heavier ions (A≥132).

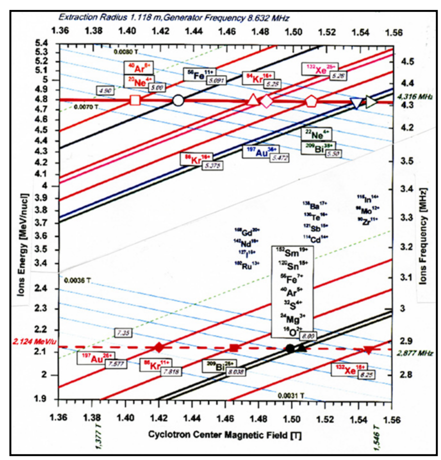

Figure 1: Working diagram of DC140 cyclotron.

The axial injection system of DC140 cyclotron will be adapted from the existing DC72 cyclotron one [4].

This report presents the design and 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 [5].

ECR ION SOURCE

The ion beams are produced in room temperature ECR ion source DECRIS-5 designed in Flerov Lab of JINR [6]. The working frequency DECRIS-5 is equal to 18 GHz. It is able to produce the beams of ion from ^{22}Ne to ^{209}Bi.

The parameters of the ion beams at the extraction hole of ECR ion source are contained in Table 2.

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Table 2: Parameters of Ion Beam Used in Simulation

Ions/harmonic number	$^{209}Bi^{38+}/2$	$^{197}Au^{26+}/3$
A/Z	5.5	7.58
Extraction voltage U_{inj}, kV	18.86	11.55
Beam current, μA	1.25	6
Beam diameter, mm	8	
Emittance, π mm × mrad	220	237

BEAM LINE SCHEME

The scheme of the beam line is shown in Fig. 2.

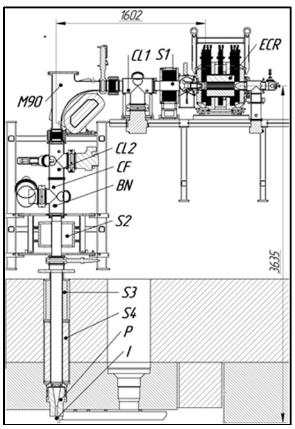

Figure 2: Scheme of the axial injection beam line.

The length of the beam line is equal to 5.065 m. The 90-degree analyzing magnet **M90** separates the injected beam. The solenoidal lenses **S1-4** focus and match beam with the acceptance of the spiral inflector **I** for all level of the cyclotron magnetic field. The two-harmonic buncher **BN** increases the beam capture into acceleration. Two movable diaphragms **CL1, 2** are used for analysis of the beam spectra.

ANALYZING MAGNET M90

The analyzing magnet **M90** has a bending radius R_M equal to 0.4 m, gap 80 mm and maximum magnetic field 0.2 T.

SOLENOIDS S1-4

The solenoids **S1-4** are the part of existing DC72 cyclotron axial injection beam line [4]. Its on-axis magnetic fields are shown in Fig. 3.

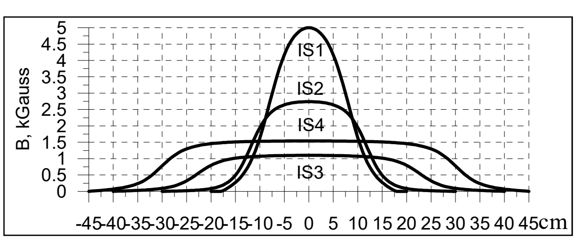

Figure 3: On-axis magnetic field of solenoids.

MAGNETIC PLUG

The channel apertures in the magnetic plug **P** are shown in Fig. 4.

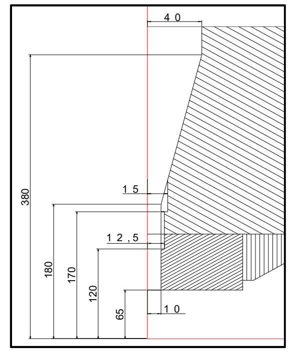

Figure 4: Magnetic plug scheme.

TWO-HARMONIC BUNCHER BN

To improve the efficiency of beam capture into the acceleration the two-harmonic buncher **BN**, located outside the yoke of the magnet at a distance of 2.341 m from the median plane of the cyclotron, is used. The maximum applied voltage at the grids of buncher is 500 V for the injecting ions having A/Z = 5.5 ($^{209}Bi^{38+}$). The efficiency of bunching is approximately equal to 2.75 (see Fig. 5).

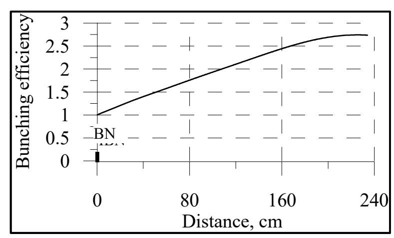

Figure 5: Bunching efficiency.

SPIRAL INFLECTOR I

To simplify the operation of the cyclotron only one inflector with a magnetic radius of 30 mm is used. In the case of accelerating with harmonic number of h = 2, the injection voltage U_{inj} changes from 17.15 kV to 18.86 kV for the injected ions with A/Z in the range from 5.0 ($^{40}Ar^{8+}$) to 5.5 ($^{209}Bi^{38+}$). In the case of h = 3, the voltage U_{inj} changes from 11.55 kV to 12.58 kV for the injected ions with 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 2 were carried out. In all cases, the transfer efficiency is equal to 100%.

A/Z=5.5, B_0=1.546 T, ρ_M=30.0 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

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(V) envelopes of $^{209}Bi^{38+}$ ions in the beam line is shown in Fig. 6.

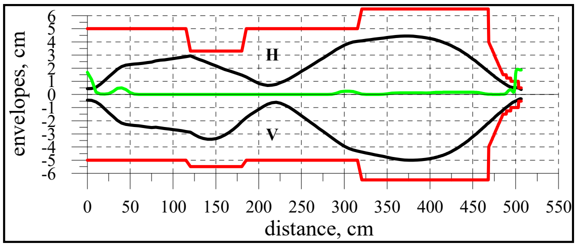

Figure 6: Horizontal (H) and vertical (V) $^{209}Bi^{38+}$ beam envelopes, aperture (red line) and longitudinal magnetic field (green line).

A/Z=7.58, B₀=1.420 T, ρ_M=30.0 mm, h=3

Transport of $^{197}Au^{26+}$ ion beam was considered. In this case the magnetic field at the center of the cyclotron $B_0 = 1.420$ T. The horizontal (H) and vertical (V) envelopes of $^{197}Au^{26+}$ ions in the beam line is shown in Fig. 7.

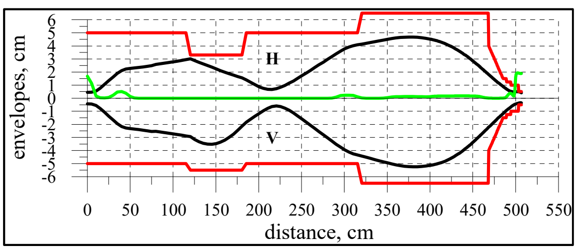

Figure 7: Horizontal (H) and vertical (V) $^{197}Au^{26+}$ beam envelopes, aperture (red line) and longitudinal magnetic field (green line).

BEAM SPECTRUM ANALYSIS

Two movable diaphragms **CL1**, **2** are used in the beam spectrum analysis. The first diaphragm **CL1** has the form of a square with a side of 10 mm and shown in Fig. 8, is located at a distance of 373 mm in front of the **M90** magnet.

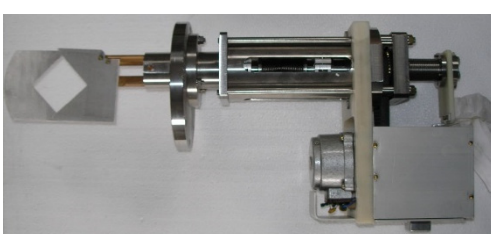

Figure 8: Diaphragm CL1.

The second one **CL2** is a slit with a width of 5 mm<d<10 mm, located at distance of 510 mm after exit of **M90** magnet. The distance between diaphragm **CL2** and Faraday cap **CF** is equal to 100 mm.

The beam emittance is decreased at diaphragm **CL1** in 16 times that give opportunity to separate two neighbor charges in the beam spectrum by means of diaphragm **CL2**. The $^{209}Bi^{38+}$ ion beam envelopes are shown in Fig. 9.

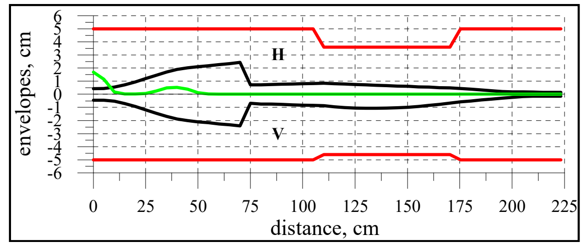

Figure 9: $^{209}Bi^{38+}$ ion beam envelopes.

The distribution of ions $^{209}Bi^{37+,38+,39+}$ and $^{16}O^{3+}$ in front of the diaphragm **CL2** is shown in Fig. 10.

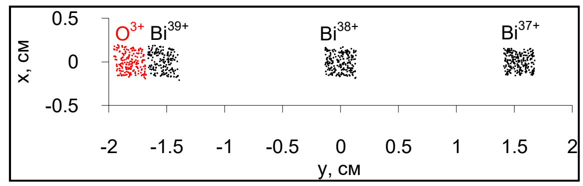

Figure 10: Bi and O ions distribution at slit CL2.

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 (see Fig. 1).

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

REFERENCES

[1] S. V. Mitrofanov *et.al.*, “FLNR JINR Accelerator Complex for Applied Physics Researches: State-of-Art and Future”, in *Proc. of 22nd Conf. on Cycl. and their Appl.*, Cape Town, South Africa, Sep. 2019, pp. 358-360. doi:10.18429/JACoW-CYCLOTRONS2019-FRB02

[2] B. N. Gikal, “Dubna Cyclotrons – Status and Plans”, in *Proc. 17th Int. Conf. on Cyclotrons and Their Applications (Cyclotrons'04)*, Tokyo, Japan, Oct. 2004, paper 20A1, pp. 100-104.

[3] G. Gulbekyan, I. Ivanenko, J. Franko, and J. Keniz, “DC-72 Cyclotron Magnetic Field Formation”, in *Proc. of 19th Russian Part. Acc. Conf (RuPAC’04)*, Dubna, Russia, Oct. 2004, paper WENO12, pp. 147-49.

[4] G. G. Gulbekyan, S. L. Bogomolov, V. V. Bekhterev, I. V. Kalagin, N. Yu. Kazarinov, and M. V. Khabarov, “Axial Injection Channel of the DC-72 Cyclotron”, in *Proc. 19th Russian Particle Accelerator Conf. (RuPAC'04)*, Dubna, Russia, Oct. 2004, paper WENO11, pp. 144-146.

[5] V. Aleksandrov, N. Kazarinov, and V. Shevtsov, “Multi component ion beam code-MCIB04”, in *Proc. of 19th Russian Part. Acc. Conf (RuPAC’04)*, Dubna, Russia, Oct. 2004, paper THBP09, pp. 201-203.

[6] S. L. Bogomolov *et al.*, “Recent Development in ECR Ion Sources at FLNR JINR”, in *Proc. 23rd Russian Particle Accelerator Conf. (RuPAC'12)*, Saint Petersburg, Russia, Sep. 2012, paper FRYOR01, pp. 203-207.