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DESIGN AND SIMULATION OF THE EXTRACTION SYSTEM OF DC140 CYCLOTRON

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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 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 pmcA for light ions (A<86) and about 0.1 pmcA for heavier ions (A>132). The system based on three main elements - electrostatic deflector, focusing magnetic channel, Permanent Magnet Quadrupole lens is used in the DC140 cyclotron for extraction of the accelerated beam. The design and simulation of the beam extraction system from the DC140 cyclotron are presented in this report.

INTRODUCTION

The DC140 is a sector cyclotron is intended for acceleration of heavy ions with variation of the magnetic field level at range B_o=1.415÷1.546 T [1]. The main parameters of DC140 cyclotron are given in Table 1.

The DC140 will be a reconstruction of the DC72 cyclotron [2, 3].

In DC72 beam was extracted by stripping method. In DC140 the extraction will be carried out using an electrostatic deflector.

Table 1: DC140 Cyclotron Main Parameters

Parameter	Value	
Pole (extraction) radius [m]	1.3(1.18)	
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	

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For beams extraction from the cyclotron is used the electrostatic deflector. The extraction system of the DC140 cyclotron consist a next elements (see Fig. 1):

1. Electrostatic deflector (ESD);
2. Focusing magnetic channel (MC);
3. Permanent Magnet Quadrupole lens (PMQ).

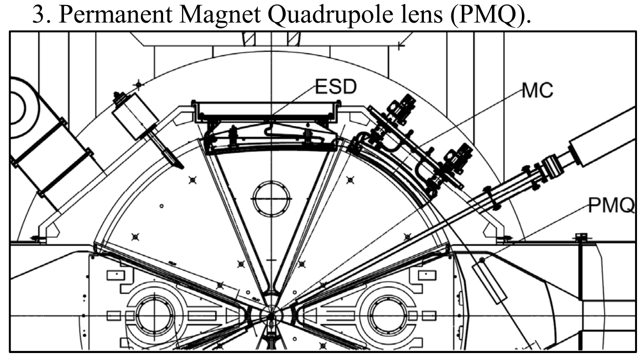

Figure 1: Layout of the elements of extraction system

OPTIMIZATION OF THE CURVATURE RADIUS OF THE ELECTROSTATIC DEFLECTOR

Azimuthal position of the electrostatic deflector - 70÷110 degrees (40 degrees).

The main parameters of the electrostatic deflector are given in Table 2.

Table 2: Parameters of the Electrostatic Deflector

Parameter	Value
Azimuthal position [deg]	70÷110
Max. Voltage [kV]	73.5
Thickness of the “septum” plate [mm]	0.3÷1.0
Gap between plates [mm]	9
Displace of the deflector edges [mm]	± 10

The task of the optimization comes down to minimizing the sum of differences of radius of curvature of the deflector R_d centered at a point (X_0; Y_0) and distances from this point to the point of the extraction orbit as shown in Eq. (1).

$$\frac{1}{n}\sum_{i=1}^{n}(R_\mathrm{d}-R_i)^2 = \min \qquad (1)$$

R_d – radius of curvature of deflector, cm;

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R_i is the minimal distance from the centre of curvature of the deflector (X_0; Y_0) to the i point of extraction orbit of ion beam (Table 3)

$$R_i = \sqrt{(r_i \cdot \cos(\varphi_i) - X_0)^2 + (r_i \cdot \sin(\varphi_i) - Y_0)^2} ;$$

φ_i is the angle of i point of extraction orbit of ion beam, [deg].

Table 3: Coordinates for the Centre of Curvature and Radius of Curvature

Ion	$^{40}Ar^{8+}$	$^{209}Bi^{38+}$	$^{197}Au^{26+}$	$^{132}Xe^{16+}$
W [MeV]	4.8	4.8	2.124	2.124
$B\rho$ [T×m]	1.58	1.74	1.59	1.73
X_0 [cm]	20.87	19.01	20.6	19.16
Y_0 [cm]	-200.26	-176.31	-198.67	-177.33
R_d [cm]	309.28	285.68	307.68	286.71
d_{max} [cm]	0.011	0.011	0.01	0.008

The y-axis of the local coordinate system (x, y) is turned up to 3.71 degree angle (for all the considered ions) from Y-axis of the global one (X, Y) with origin in the centre of the cyclotron (see Fig. 2). Figure 3 shows the extraction orbits of beams and the medium position of septum of electrostatic deflector.

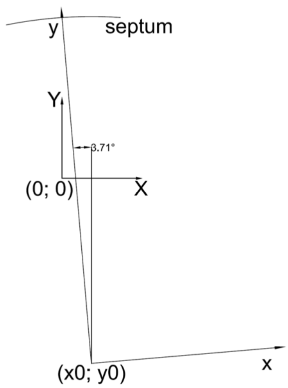

Figure 2: The septum of deflector in the local coordinate system.

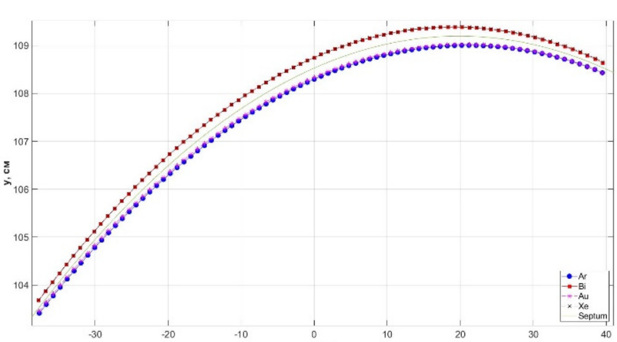

Figure 3: The graph of extraction orbits of ion beams and medium position of septum of electrostatic deflector.

On the basis of the calculation of the optimization, the deflector radius is R = 2947 mm, L = 775 mm.

NUMERICAL SIMULATION OF THE BEAM EXTRACTION

For numerical simulation the test ion in accordance with working diagram are used [See Fig. 4-6]. The parameters of this ion are given in Table 4.

Table 4: Parameters of the Test Ions

Ion	$^{209}Bi^{38+}$
A/Z	5.5
B_o [T]	1.5458
B(R) [T]	1.5540
E(R)	4.80
F_{ion} [MHz]	4.316
Harmonic	2
R_{mag} [cm]	3
U_{inj} [kV]	18.86

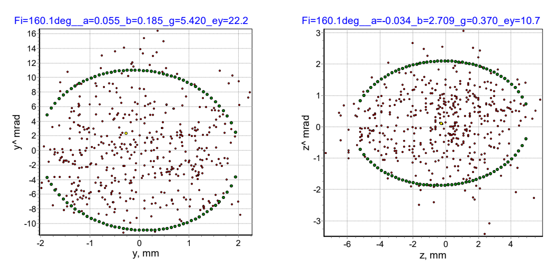

Figure 4: The horizontal and vertical beam emittances at the deflector entrance (A/Z=5.5, Bo=1.55 T).

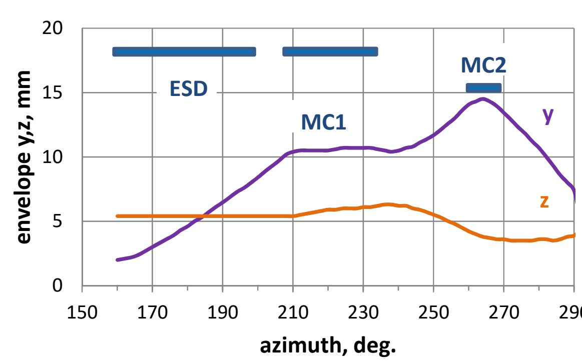

Figure 5: The horizontal and vertical beam envelopes.

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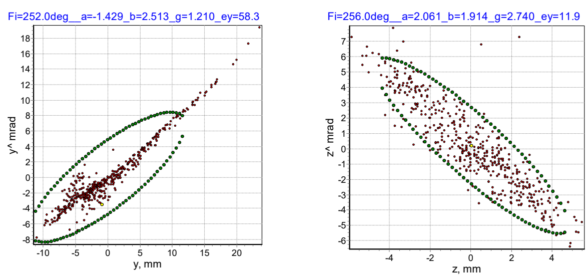

Figure 6: The horizontal and vertical beam emittances at the PMQ entrance (A/Z=5.5, Bo=1.55 T).

FOCUSING MAGNETIC CHANNEL

The calculation of the magnet field carried out by using OPERA 3D program code [4]. The main parameters of the magnetic channel are given in Table 5. The magnetic channel is shown in Fig. 7.

Table 5: Parameters of Magnetic Channel

Parameter	Value
Azimuthal position [deg]	36÷64
Horizontal aperture [mm]	32
Vertical aperture [mm]	20
Displace of the edges [mm]	± 15
Focusing gradient of the magnetic field [T/m]	13.5

Figure 7: Computer model of the magnetic channel.

PERMANENT MAGNET QUADRUPOLE LENS

The main parameters of the permanent magnet quadrupole lens are given in Table 6.

Table 6: Parameters of PMQ

Parameter	Value
Horizontal aperture [mm]	64
Vertical aperture [mm]	25
Effective length [cm]	29.9
Focusing gradient of the magnetic field [T/m]	8.1

The working area takes into account the horizontal spread of orbits ± 4 mm.

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