SPIRAL INFLECTOR FOR CUSTOMS CYCLOTRON

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Abstract

Compact cyclotron for explosives detection by nuclear resonance absorption of γ-rays in nitrogen is under development [1]

Customs Cyclotron will be equipped with the external ion source. The injection system consists of a double-drift beam bunching system, a spiral inflector, beam analysis diagnostics, focusing and adjustment elements [2]. The spiral inflector for ion bending from axial to median plane is used.

Computer model of spiral inflector for the Customs cyclotron was developed. 3D electrostatic field calculations of the designed inflector were performed. Calculated electric and magnetic field maps were used for beam dynamic simulations. Numeric simulations were carried out for 500 particles using code for calculation of particle dynamics by integration of differential equations in Cartesian coordinate system written in MATLAB. Direct Coulomb particle-to-particle method was used to take into account space-charge effects.

SPIRAL INFLECTOR DESIGN

A spiral inflector consists of coaxial, spirally twisted electrostatic deflection plates placed in a magnetic field.

The chosen electric field of 24 kV/cm is restricted by breakdown limit. Height of the inflector is limited by cyclotron magnet center design and equal to 25 mm. Maximum ion energy for inflector with such characteristics is equal to 30 keV. The 10mm gap between electrodes was chosen to ensure bending of beam with emittance 100 ÷ 150 π mm mrad. The aspect ratio between the width and the spacing of the electrodes is taken equal 2 to avoid the fringe field effect and to tolerate shifts in beam trajectories inside the inflector. The main characteristics of spiral inflector are given in Table 1.

Table 1: Parameters of the inflector

Electric radius (height of the inflector) (mm)	25
Width of the electrodes (mm)	20
Voltage on the electrodes (kV)	±12
Gap (mm)	10

In a spiral inflector, the central beam trajectory derived analytically is generally used as the first-step in the design. The results of analytical approximation are given below.

Analytical approach.

The electric radius:

$$a = \frac{2W}{e\mathrm{E}} = 2.5\ \text{cm}.$$

Magnetic field:

$$B = 0.64\ \text{tesla}.$$

Ion characteristics:

$$A = 1,\ Z = 1,\ E_o = 938.279627\ \text{MeV}$$

Ion energy: $W_i = 0.03\ \text{MeV}$

$$\beta = \sqrt{1 - \frac{1}{\gamma^2}} = \sqrt{\frac{2W_i}{E_o}},\ v = \beta \cdot c,$$

$$v = 2.397 \times 10^6\ \text{m/s}, \beta = 7.9965 \times 10^{-3}$$

Magnetic radius**:**

$$\rho = m_i \cdot \frac{v}{Z \cdot e \cdot B},\ \rho = 0.039\ \text{m}.$$

K value:

$$k = \frac{a}{\rho},\ k = 0.64.$$

Central particle trajectory:

$$x(t) = \frac{a}{2}\left[\frac{2}{1-k^2} - \frac{\cos[(k+1)\cdot\theta(t)]}{k+1} - \frac{\cos[(k-1)\cdot\theta(t)]}{k-1}\right],$$

$$y(t) = -\frac{a}{2}\left[\frac{\sin[(k-1)\cdot\theta(t)]}{k-1} - \frac{\sin[(k+1)\cdot\theta(t)]}{k+1}\right],$$

$$z(t) = a \cdot (1 - \sin(\theta(t))),\ \theta(t) = v \cdot \frac{t}{a}.$$

Particle coordinates at the exit from the inflector:
x (t1) = 19.5 mm
y (t1) = -14.5 mm
z (t1) = 0 mm

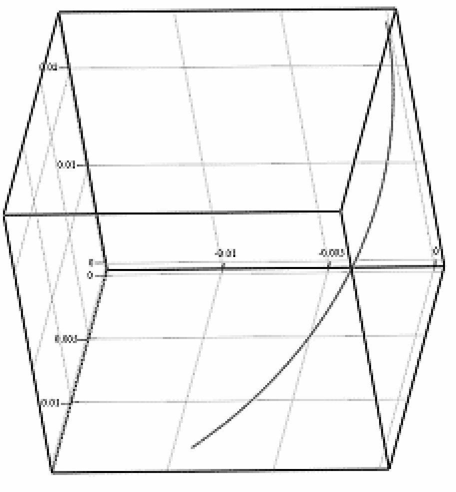

Figure 1: Central ray trajectory inside the inflector.

Numeric electric-field analysis

The next step in inflector design is numeric electric-field analysis of the inflector designed for analytical central ray and numeric simulation of central particle motion in the calculated electric and magnetic field (see Chapter 4). Fringe fields at the entrance to and the exit from the device have significant affects on the electric-field distribution and consequently, the trajectory of central particle within the inflector deviate considerably from one derived by analytical formulas. Inflector electrode voltage was fitted to assure that central ion would escape out from the inflector in the median plane with axial momentum equal zero. Afterwards the procedure was repeated once more around new central trajectory.

The spiral inflector view is presented in Figure 2, Figure 3 shows electric potential distribution inside the inflector.

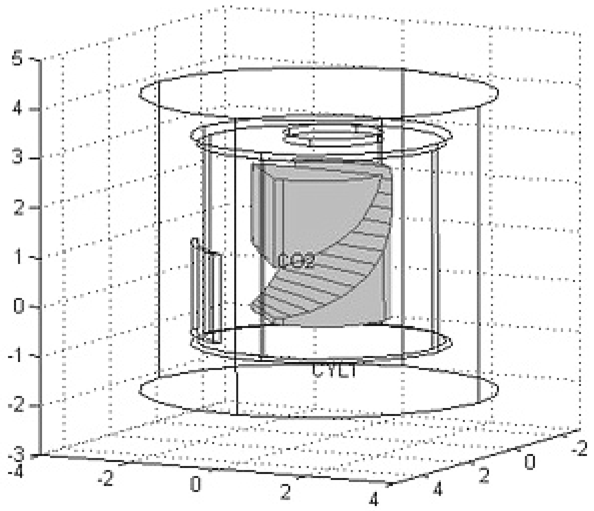

Figure 2: The spiral inflector.

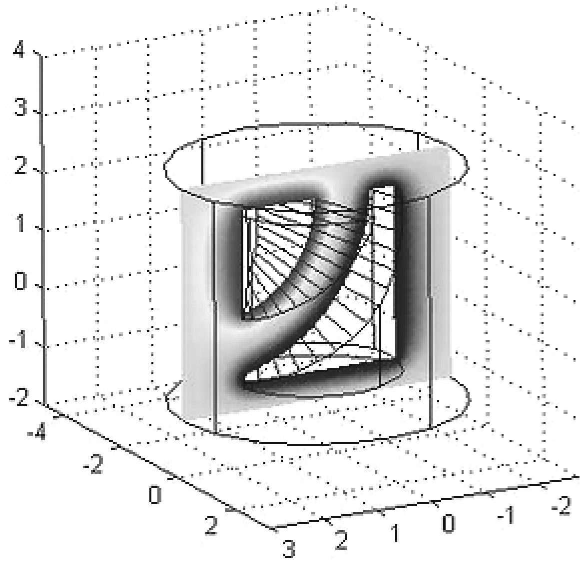

Figure 3: Electric potential distribution inside the inflector.

Beam dynamic computer simulations

The paths of ions in the inflector (computer dynamic modeling of 500 particles with initial transversal emittances equal to 2.5•40=100 π mm mrad, initial bunch phase extension of 60° RF, beam intensity I = 5 mA and energy 30 keV) are presented in Figure 4, where also inflector body is pointed.

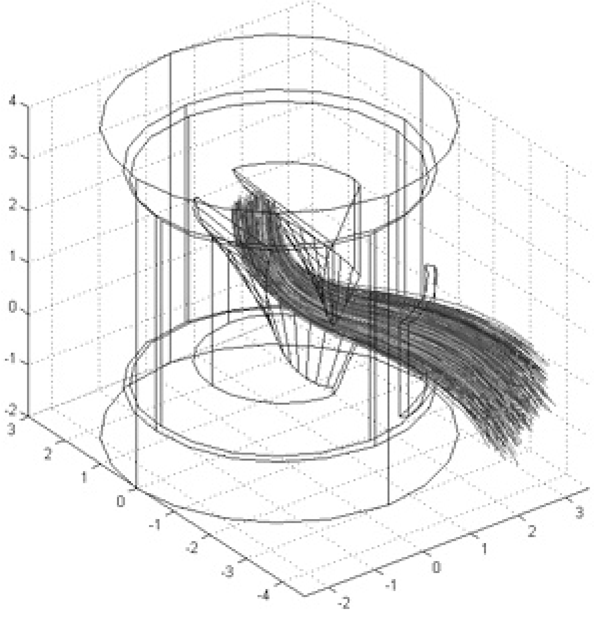

Figure 4: The paths of ions in the inflector, I = 5 mA.

Axial emittances at the exit from inflector for two beam intensities I = 0 mA and I = 5 mA are presented in Figure 5, Figure 6, correspondently. One can see major increase of axial divergence while increasing beam intensity from 0 to 5 mA, that is axial divergence is ±100 mrad for I = 0 mA and ±200 mrad for I = 5 mA.

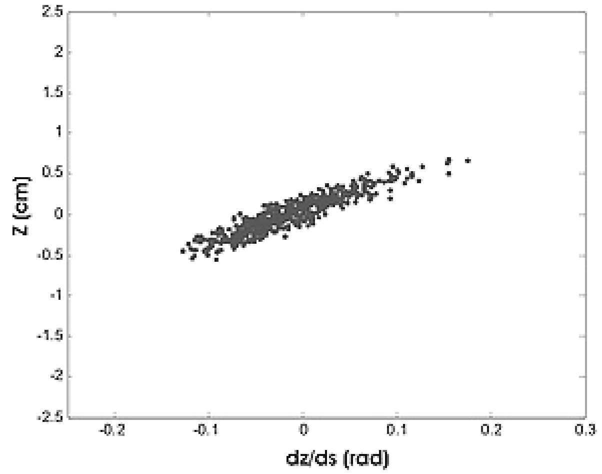

Figure 5: Axial emittance at the exit from inflector, I = 0 мA.

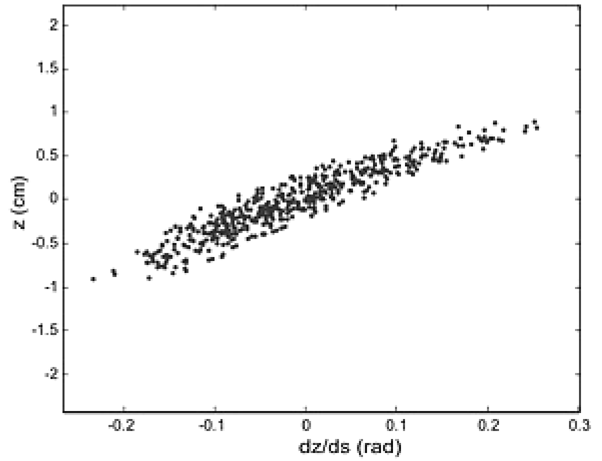

Figure 6: Axial emittance at the exit from inflector, I = 5 мA.

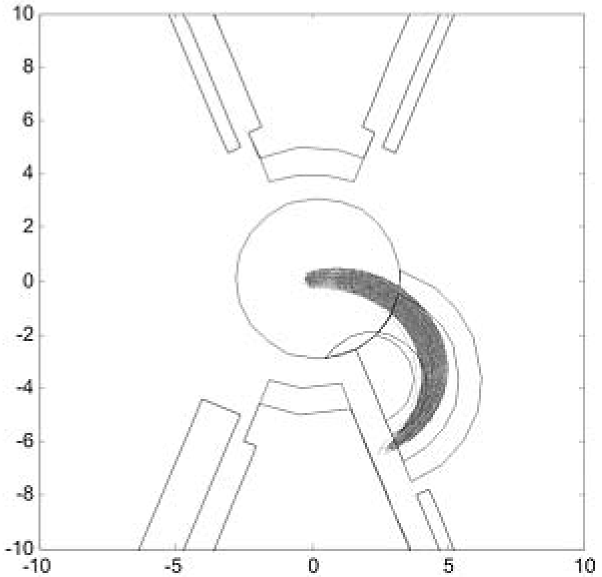

Figure 7: Particle trajectories from inflector to central region.

Attention was paid to fit particle trajectories from inflector to central region trajectories in radius, radial momentum and azimuth (see Figure 7), the inflector was turned 25° anticlockwise for this purpose.

CONCLUSION

Thus computer model of spiral inflector for the Customs cyclotron was developed. Numerical simulations of beam dynamics taking into account space charge effects in calculated electric field confirmed the possibility of ion bending with beam intensity 5 mA without losses but axial divergence of the beam can cause losses in the center of cyclotron.

1. Onischenko L.M. et al., this conference
2. Karamysheva G.A., Onischenko L.M.,Samsonov E.V., Injection system of customs cyclotron, this conference