

DEVELOPED NUMERICAL CODE BASED ON THE EFFECTS OF SPACE CHARGE IN CENTRAL REGION OF 10 MeV CYCLOTRON

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Abstract

To study of space charge effects in 10 MeV cyclotron of Amirkabir University of Technology the C++ code is developed. This cyclotron is designed to accelerate H- up to 10 MeV energy. The important components of cyclotron that effect on calculations of space charge include four sector magnets, 2 RF cavities with 71 MHz frequency and internal PIG ion source. Equations of motion and effects of charged particles in electromagnetic field of accelerator are integrated in C++ code. The conventional method, 4-order Runge-Kutta, is used to solve the equations. The results of calculations show space charge effects of beam particles on each other in accelerating process.

INTRODUCTION

The purpose of manufacturing 10 MeV Amirkabir University of Technology produced Fluor-18. The cyclotron contains some component to produce an electric field, magnetic field and injection particle. Component of central region shows in Fig. 1. Beam injection by an internal ion source PIG [1] was carried out. H- Beam with zero kinetic energy produced by the ion source, these particles by the puller that located at a certain distance from the ion source were pulled out due to potential difference between these two points. The primary particles begin to move and primary energy particles from this method will be provided [2]. Voltage of Dummy Dees and pullers are zero and 42 keV respectively, particles that accelerated in a first step and don't have any collection with a body of cyclotron now again accelerated. Continues acceleration of particles performed by a potential difference between the central part of the liner and central part of Dee's. Due to the beam dynamic depended to the early turns, set of electric and magnetic field geometry and initial condition of particle is very important. If the central region was not properly designed, couldn't be expected that particles extracted from cyclotron.

Numerical code was written in C++ program that used the conventional Rung-Kutta method and initial condition of particles and electric and magnetic distribution to calculate the trajectory of space charge effect of particles.

The method that used in this code is of effect of summing up the Coulomb's electric field of particles on one particle. That means effect of electric field of particles on the particle that located near them is considered.

THE METHOD OF CALCULATING OF THE BEAM TRAJECTORY SPACE CHARGE

A code for calculation of particle trajectory in the central region of cyclotron, written by using C ++ language. Electric and magnetic field calculated by OPERA-3D-TOSCA.

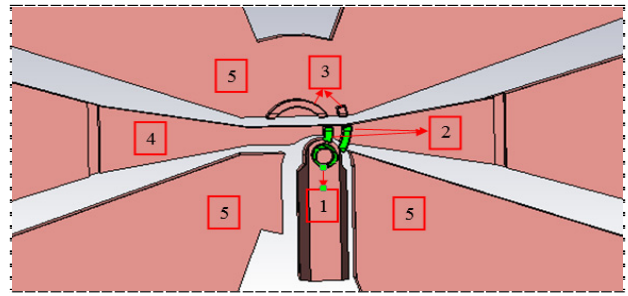


Figure 1: Geometry of electric field in central region 1) head of ion source 2) pullers 3) dummy Dee's 4) central part of Dee 5) central part of liner.

Results of TOSCA extracted and imported in to C++ code. C++ code calculated equation of motion according to the electric and magnetic field data's and initial condition that determined. Equation of motion that used in C++ code followed equation 1, 2, 3 [3].

$$\frac{d\vec{r}}{dt} = \frac{\vec{p}}{m\gamma} \quad (1)$$

$$\frac{d\vec{p}}{dt} = q(\vec{E} \cos \omega t + \frac{d\vec{r}}{dt} \times \vec{B}) \quad (2)$$

$$\frac{dW}{dt} = \vec{F} \cdot \vec{v} = \frac{d\vec{p}}{dt} \cdot \frac{d\vec{r}}{dt} \quad (3)$$

Above equations are used in Cartesian coordinate(x,y,z), where $B(B_x, B_y, B_z)$, $E(E_x, E_y, E_z)$ are magnetic and electric fields respectively. In this code magnetic field that created from beam current is not considered but electric field of that considered. So the electric field is as follows:

$$E_{(x,y,z)} = \epsilon_{(x,y,z)}^{RF} + \epsilon_{(x,y,z)}^{SC} \quad (4)$$

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where $\varepsilon_{(x,y,z)}^{RF}$ is electric field from cavity and $\varepsilon_{(x,y,z)}^{SC}$ is electric field from space charge between particles. Electric field of space charge in Cartesian coordinate are as follow:

$$\varepsilon(i)_x^{SC} = \sum_{n=1}^{n=N} \frac{q_n(x_i - x_n)}{4\pi\varepsilon_0[(x_i - x_n)^2 + (y_i - y_n)^2 + (z_i - z_n)^2]^{3/2}} \quad (5)$$

$$\varepsilon(i)_y^{SC} = \sum_{n=1}^{n=N} \frac{q_n(y_i - y_n)}{4\pi\varepsilon_0[(x_i - x_n)^2 + (y_i - y_n)^2 + (z_i - z_n)^2]^{3/2}} \quad (6)$$

$$\varepsilon(i)_z^{SC} = \sum_{n=1}^{n=N} \frac{q_n(z_i - z_n)}{4\pi\varepsilon_0[(x_i - x_n)^2 + (y_i - y_n)^2 + (z_i - z_n)^2]^{3/2}} \quad (7)$$

where i is characteristic of particle that electric field of other particle calculated on position of it ; n is number of other particle that effect on i particle; q is charge of particle; $\varepsilon_0 = 8.85 * 10^{-12} F/m$ [4]

Initial condition of beam motion in central region of cyclotron 10MeV and specification of cyclotron shown in Table 1.

Table 1: Initial Condition of Particle and Specification of Cyclotron

Parameter	Value
Initial energy of particle	0 keV
Dee width	40°
Number of sectors	4
RF frequency	71MHz
The magnetic field in the center of the cyclotron	1.18T

Electric and magnetic fields related to the position determined by the C++ code and entered into the calculations when the particle is in any position.

Figure 2 shows the geometry of the magnetic field and poles in the center of the cyclotron. This geometry imported to the TOSCA, after calculation and optimization of the geometry, extracted data's from it. Distribution of magnetic field in center of 10 MeV cyclotron shows in Fig. 3.

In Fig. 1 the geometry of electric field and effective component in electric field is shown. The effective components of the electric field in central region included head of ion source, pullers, dummy Dee's, central part of Dee and central part of liner. Potential of pullers and central part of Dee are 42 kV and potential of other components are zero. This geometry imported to the TOSCA and calculated electric potential with electro static solver of Opera3d.

Electric potential data imported to the C++ code and electric field calculated by it. Electric potential distribution of this geometry is shown in Fig. 4.

Electric and magnetic field and Primary condition of particle including phase, energy and position are determined. With frequent changes in the initial condition of the particle, tested numerical calculation by using C++ code. If we have not received to the appropriate beam

dynamic, geometry of electric field and distance of poles were changed. Finally, with optimized geometry and initial condition, horizontal and vertical beam trajectory are achieved.

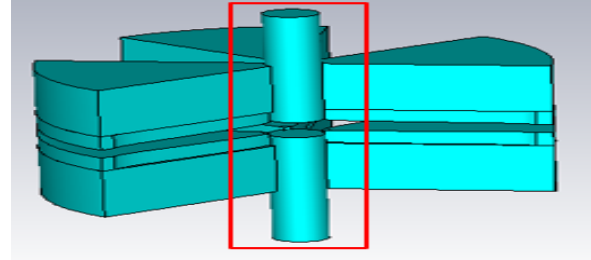


Figure 2: Geometry magnetic field in central region.

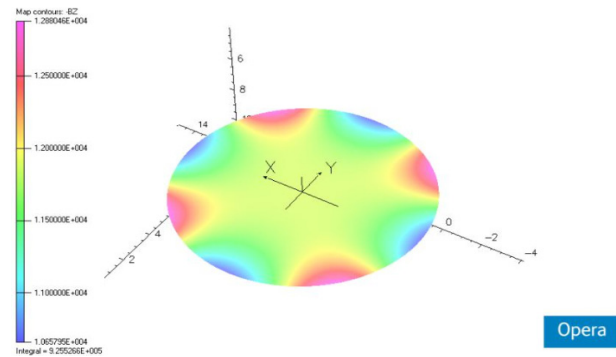


Figure 3: distribution of magnetic field in central region of cyclotron [5].

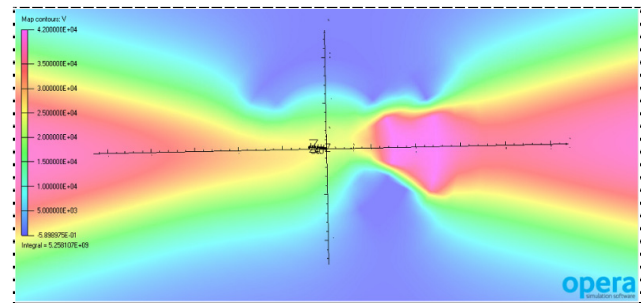


Figure 4: Distribution of electric field in central region.

RESULT OF SPACE CHARGE EFFECT (SCE)

Beam dynamic calculation carried out for 21 particle by ignoring and considering space charge effect. Figure 5 shows the horizontal motion of 21 particles without considering the space charge effect of particles in the central region. Figures 6 and 7 show horizontal motion of 21 particles without considering the space charge effect of particles in the central region. As seen in Figs. 5, 6 and 7 when ignore the space charge effect, particles approximately passes from the same path. But when space charge consider in calculation of equation of motion, seen particle repel each other. If our electric and magnetic field are not correct all of particles will be lost.

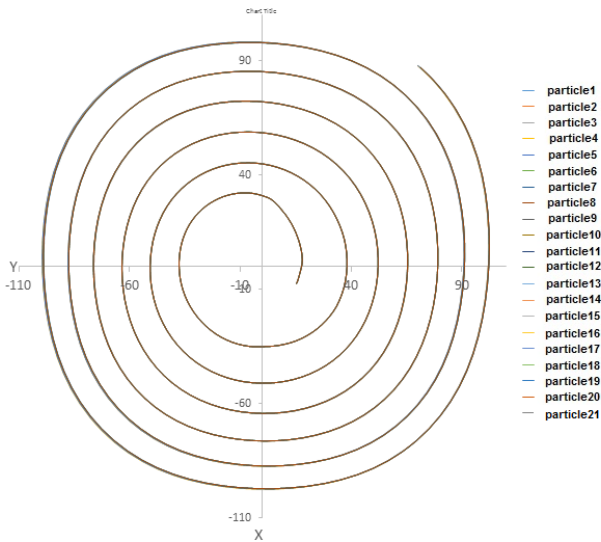


Figure 5: 21 particles Horizontal motion without space.

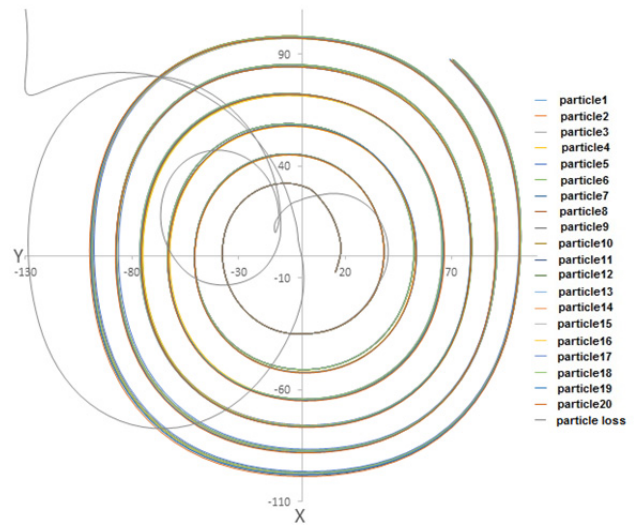


Figure 7: 21 particles Horizontal motion with space charge for the first 6 turns with phase 308° and illustrate beam losses.

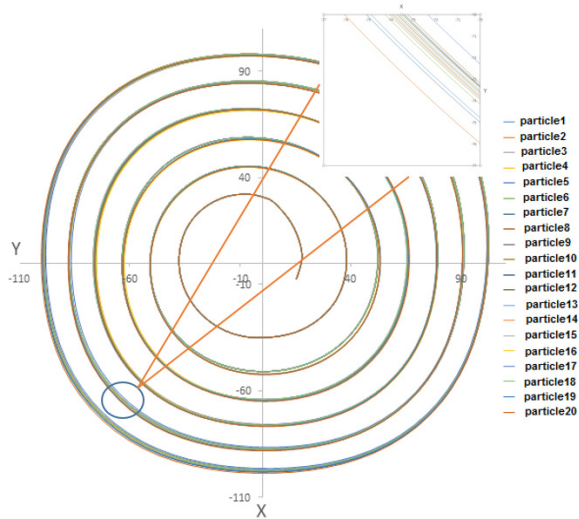


Figure 6: 21 particles Horizontal motion with space charge for the first 6 turns with phase 308° without illustrate beam losses.

Figures 8 and 9 show the vertical motion of particles with ignoring and considering space charge respectively

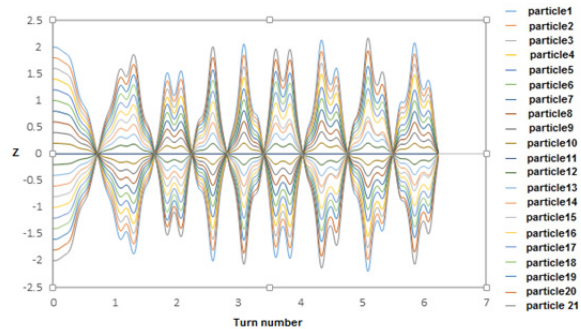


Figure 8: 21 particles vertical motion with space charge for the first 6 turns with phase 308° illustrate beam losses.

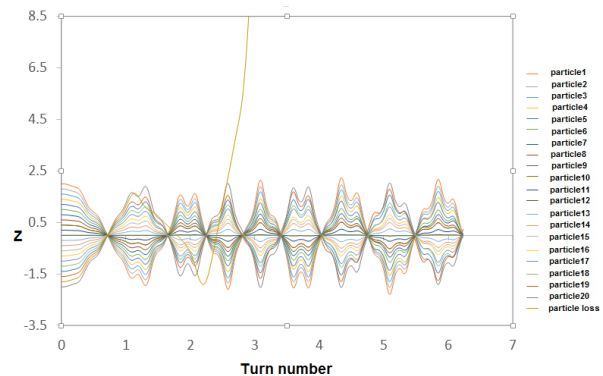


Figure 9: 21 particles vertical motion with space charge for the first 6 turns with phase 308° illustrate beam losses.

CONCLUSION

Previously, beam dynamic calculations carried out to find correct design geometry of central region and location of the tip of ion source [6]. In this paper, the beam dynamic calculation has been done with considering space charge effect of 21 particles by C++ code.

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