BEAM TRACKING SIMULATION FOR A 9 MeV CYCLOTRON

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Abstract

Recently, the development of a 9 MeV cyclotron for production of radioisotope has been carried out. It has four sector magnet and RF cavity which resonance frequency is 83.209 MHz. The internal ion source was adopted and the central region was designed to accommodate the starting beam. In this paper, the design of the central region to optimize the initial circumstances for H^- beam and the study of extraction were described. The electric and magnetic field distribution were designed by electrostatic and magnetic solver in OPERA-3D TOSCA. A numerical code was developed to simulate the particle tracking and used to evaluate the performance during the acceleration in the designed EM field. The beam characteristics including the beam orbit, motion of the center of orbit, energy gain was investigated for central region and the entire acceleration characteristic until extraction was discussed.

INTRODUCTION

A 9 MeV cyclotron for the production of short-lived radioisotope has been developed. The cyclotron has four sector magnet having deep-valley structure for higher vertical focusing effect and RF cavity of which resonant frequency is 83.209 MHz. It adopted internal Penning Ion Gauge (PIG) ion source to produce H^- beam [1,2]. According to the use of internal ion source, the central region has been designed by iterative process considering the initial condition of the beam [3,4]. The optimal condition of the starting particle was determined to accommodate the beam at the first acceleration gap. The beam characteristic during the acceleration process was investigated to estimate the efficiency loss and minimize the beam loss caused by inappropriate central region design. It can decrease the beam current at the aimed energy level or damage the component inside the cyclotron. The thin carbon foil was used for extraction due to its high efficiency of stripping and the lower cost [5]. In this paper, the performance of the single particle beam starting from the central region of the cyclotron until it is extracted by carbon foil was described.

CENTRAL REGION

The electric and magnetic field distribution was designed by OPERA-3D TOSCA. The geometry of the electrode to accelerate the early beam was configured and initial parameters of the particle were investigated by including the ion source in the geometry. Then the beam properties in central region were evaluated with particle tracking calculation.

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Electric Field Distribution

The three dimensional modelling was carried before the electrostatic field was analysed in OPERA-3D TOSCA. In order to correlate the acceleration gap angle in cavity, the overall shape of the centre dee was determined based on the four gaps placed on the lines of ±15° from the x axis of cyclotron. The electric field generated by the model was evaluated with the single particle tracking simulation. Then, the position of the gap was gradually corrected based on the information of the particle passing through it and improved after few steps of iteration.

Figure 1 shows the optimized electric potential distribution. The electrode tip was included right after the chimney of ion source to effectively pull the particles by higher electric field. For more realistic analyse, the horizontally inserted PIG ion source was included in the simulation as shown in Fig. 2.

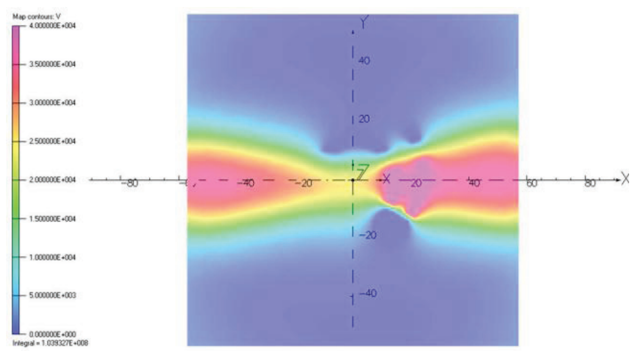

Figure 1: Electric potential distribution in central region.

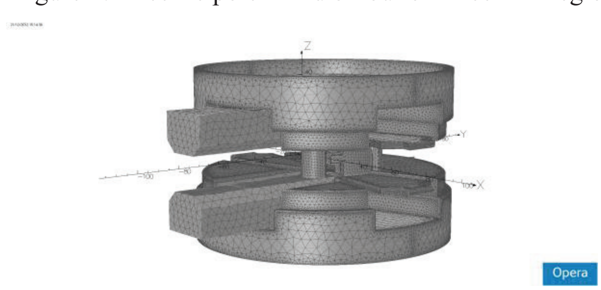

Figure 2: Electric field analysis in TOSCA.

Magnetic Field Distribution

The magnetic flux in central region was generated by a pair of centre pole which radius is 57mm and controlled by changing the current density of the electromagnetic coil.

For the control of vertical focusing, the bump of magnetic flux in central region was intentionally created. In order to minimize the beam loss which occurred when the particle hits the upper and lower center dee, the

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amplitude of the bump was determined while it satisfied the isochronism of entire magnet. The final value of the amplitude was 200 Gauss in radius at zero.

The distribution of the magnetic field in central region optimized to make stable early orbit is shown in Fig. 3.

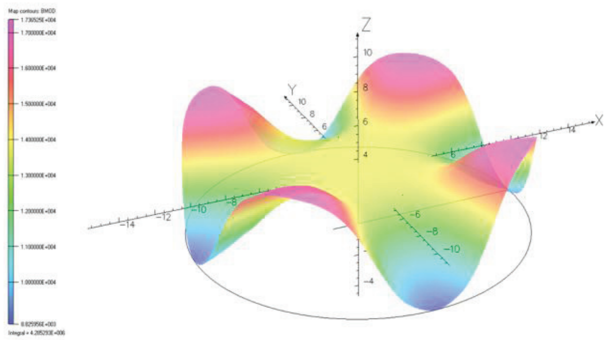

Figure 3: Magnetic field distribution in central region.

Beam Tracking in Central Region

The beam tracking simulation was carried out by own developed code written by C++ to evaluate the performance of the single particle beam accelerated in central region, The conventional way using Runge-Kutta method to solve the equation of the motion of the particle was adopted and the electric and magnetic field data was imported from TOSCA.

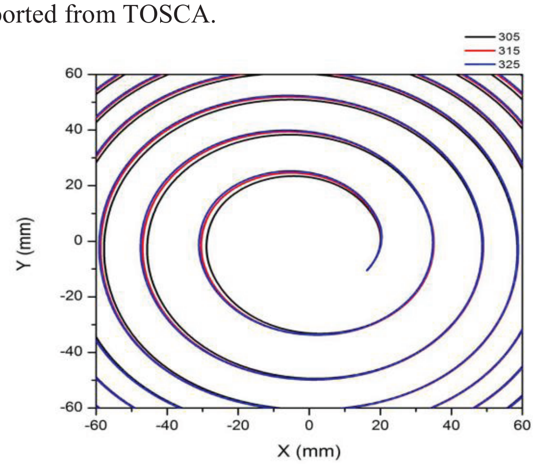

Figure 4: Particle orbit in central region.

The initial position of the beam was determined based on the information of the calculated equilibrium orbit and the space including the ion source. Based on the information resulted from the code, the early orbit in the central region is drawn in Fig. 4. The center of the orbit during first three turns was plotted in Fig. 5. The relatively higher flutter term in center was expected due to the deep valley structure and it will be improved in further work. The energy gain following the turn was described in Fig. 6. It shows the total kinetic energy after five turn is around 745 keV so the average energy gain per turn can be assumed as 149 keV. Therefore the efficiency loss during the acceleration can be estimated.

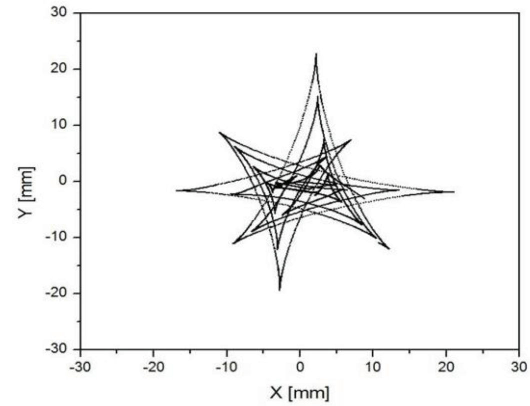

Figure 5: Motion of the center of orbit.

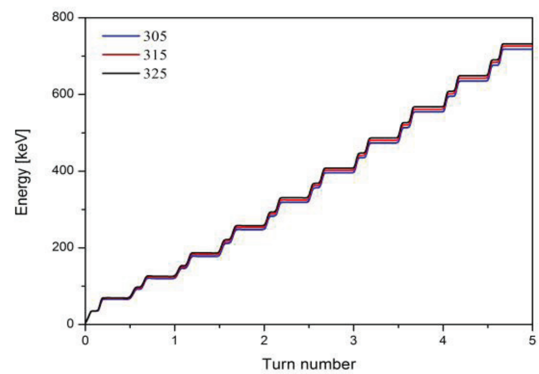

Figure 6: Energy gain in central region.

BEAM ACCELERATION

The validity of the central region design was also examined by the beam characteristic during the entire acceleration process. To estimate the accumulated phase error, the increase of the kinetic energy of the beam and the energy gain per turn were investigated and described in Fig. 7. The increase of the radius of the orbit was evaluated as well. In Fig. 8, the average radius along the turn number and the turn separation was plotted.

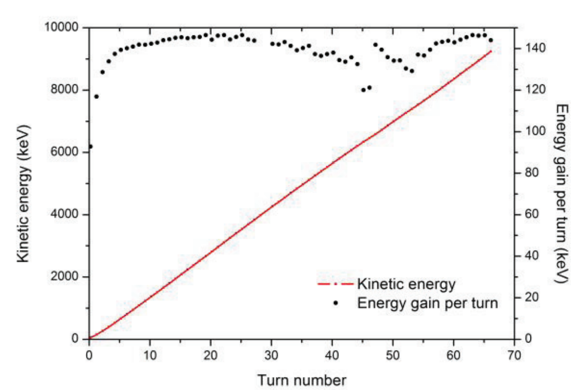

Figure 7: Kinetic energy increase during acceleration.

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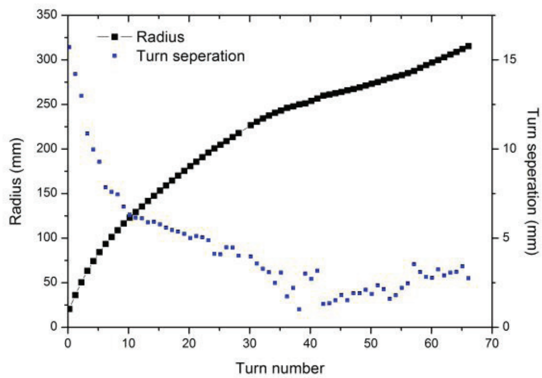

Figure 8: Radius increase during acceleration.

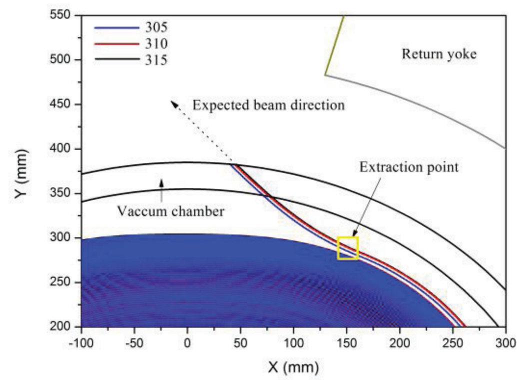

Figure 10: Extraction for different initial phase particle.

EXTRACTION

The particle accelerated until the aimed energy level was extracted by a thin carbon foil at proper position. To determine precisely the position and size of the foil, the particle tracking was also used. If the particle is detected in the position of foil determined arbitrarily, the electric field was disappeared and the charge state was reversed as a proton. In this region, the motion of particle is only affected by the magnetic field and has inverse direction of the H- beam. After few simulations, the position of the foil was determined to be placed at the radius of 310 mm and 60 degree from the x axis of the cyclotron. The electric and magnetic field near the extraction point along the radius were described in Fig. 9.

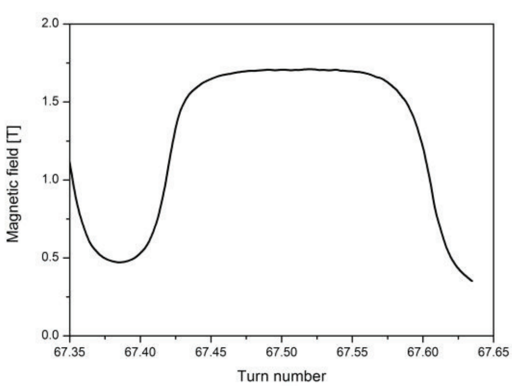

Figure 9: Magnetic field near extraction point.

The size of the foil was assumed as 1 cm X 1 cm square shape and floated to align in the median plane. As soon as it was extracted, the magnetic field was rapidly decreased due to the valley so the beam orbit has straight line. Figure 10 shows the dispersion of the orbits having different initial RF phase after the extraction point. By expecting the direction of the particle, the starting point and the size of beam line hole in the vacuum chamber will be determined.

SUMMARY

The single particle tracking simulation was carried out for a 9 MeV compact cyclotron. For the stable and well-performed performance during the acceleration, the central region was optimized. The design of the central region and the extraction characteristic at the thin carbon foil after the entire acceleration were described. The design will be improved in future work by the comprehensive adjustment of the motion of center of orbit, vertical oscillation and so on.

ACKNOWLEDGMENT

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