BEAM TRAJECTORY SIMULATIONS FOR KIRAMS-13 CYCLOTRON

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Abstract

KIRAMS-13 cyclotron [1] is a medical PET cyclotron developed for regional cyclotron centers in South Korea. This paper describes beam trajectories from central region to extraction in the KIRAMS-13 cyclotron. The electric field distribution has been numerically calculated from an electric potential map produced by the program RELAX3D. The magnetic field distribution has been measured experimentally. The beam trajectories have been calculated by a conventional beam tracking method. In order to increase phase acceptance from central region to extraction foil, to optimize the position of the stripping carbon foil, to estimate the beam properties of the extracted protons, and finally to design the beam transport line of the target system, beam trajectory calculations have been carried out.

INTRODUCTION

The cyclotron of KIRAMS-13 has been developed to produce short-lived radioisotopes for a cancer diagnosis using a positron emission tomography (PET). The KIRAMS-13 has been modified for lower power consumption of magnet system by decreasing the hill gap and increasing the number of coil turns and also for higher beam current at extraction by increasing RF phase acceptance in the central region.

This paper has been devoted to describe the new central region of KIRAMS-13 cyclotron and the results of the simulation of beam trajectories from central region to extraction.

NEW DESIGN OF CENTRAL REGION

Using the theory of horizontal motion of ions through the successive acceleration gaps in the case of a static magnetic field and time-varying electric field [2], we can obtain the relative angles of the gaps that satisfy the best-centered ion trajectory and the maximum energy gain through the gaps.

In this approximation, the 1st and 2nd gap distance is set to 5 and 6 mm, respectively. RF phase has been scanned in the whole range possible to accelerate at each 9 gaps. The motion of orbit center, the value of RF phase with maximum energy gain through the gap, and the relative flying angle between successive acceleration gaps can be obtained. Finally the acceleration gap and beam center has been adjusted to match the predetermined Dee structure and the cyclotron center using CAD program.

The detailed boundary file was constructed to calculate the electric potential map in the central region and the whole region by RELAX3D program. The beam center and gap positions have iteratively determined to obtain the best-centered orbits and the beam trajectory with maximum energy gain. Finally the first gap position was shifted away from the second gap slightly to get the best focusing along the vertical motion at the third acceleration gap. Figure 1 shows the final CAD drawing and the electric potential map in the central region.

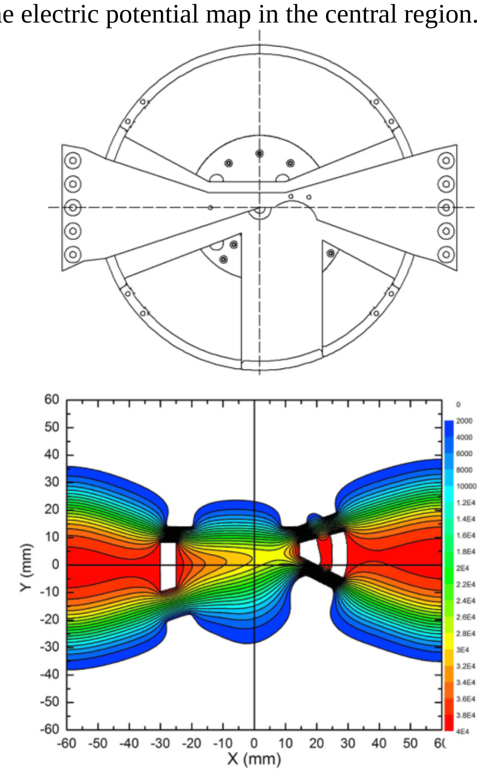

Figure 1: The CAD drawing (upper) and the electric potential map (lower) of new central region.

BEAM TRAJECTORY CALCULATIONS

In the beam trajectory simulation, we have used the measured magnetic field distribution and the calculated electric potential distribution. Table 1 and 2 describe the fundamental parameters for calculations of beam trajectories.

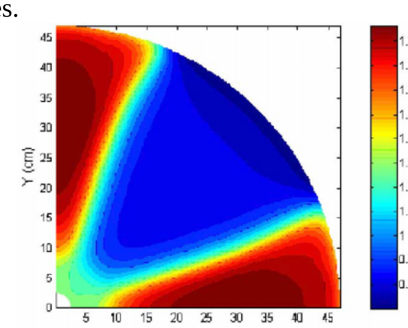

Figure 2: Measured magnet field map.

Table 1: The RF system of KIRAMS-13

Resonant Frequency	77.3 MHz
RF AMP Power	30 kW
Harmonic Number	4
Nominal Dee Voltage	45 kV
Dee Angle	39 deg.
Number of Dees	2
Ave. Energy Gain/Turn	170 keV

Table 2: The Magnet System of KIRAMS-13

Number of Sectors	4
Hill Angle	> 30 deg. with radius
Hill /Valley gap	4/12 cm
Min/Max/Average field	7.9/19.4/12.9 kG
Total Ampere Turns	2 x 145(A) x 304(Turns)
Coil Power Consumption	12 kW
Extraction Radius	0.406 m

Horizontal and vertical ion trajectories

Figure 3 and 4 show the horizontal and vertical trajectories of the ions, respectively. The starting RF phase varies from 271 to 360, and the starting angle is perpendicular to the slit and parallel to the median plane. The initial vertical positions set to 1.5 mm from the median plane.

The RF phase acceptance in horizontal and vertical motion is about 55 degrees from 271 to 325. In the First KIRAMS-13 cyclotron, the RF phase acceptance in horizontal motion is about 30 degree. Considering both of the horizontal and vertical motion simultaneously, it is about 20 degree. However, new central region has about 55 degree of RF phase acceptance in both directions.

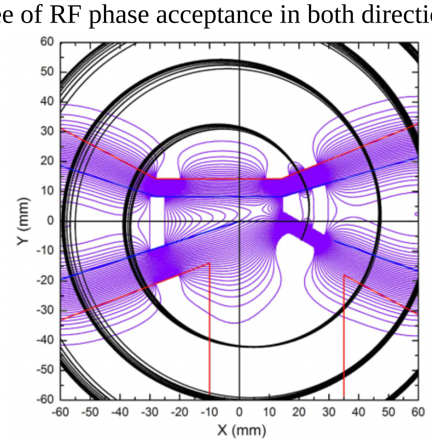

Figure 3: The horizontal ion trajectories. The blue line means the center dee, the red lines center cap or dummy dees.

The maximum vertical displacement from the median plane is about 6.8 mm. The vertical height of the center dee from the median plane is 8 mm. Therefore the scattering in the vertical direction with the center dee has been avoided by the vertical focusing which is achieved by the relative acceleration gap configuration from first to third gap[3,4].

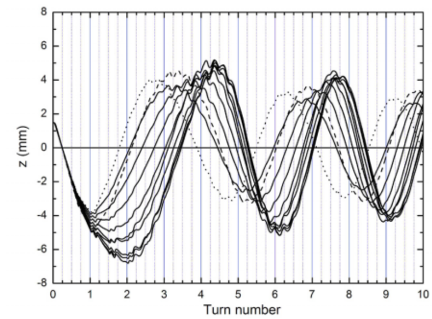

Figure 4: The vertical ion trajectories. The starting position is z=1.5 mm from the median plane and the initial direction is parallel to the median plane.

Centering of the ion trajectory

Figure 5 shows the motion of the center of the ion trajectory. The initial RF phase is 271 degree. From this centering motion of ion trajectory during the first 2 turns we can see that the position of the center during the acceleration process converges to one point rapidly. After the first 2 turns the centering motion is affected by the magnetic flutter configuration.

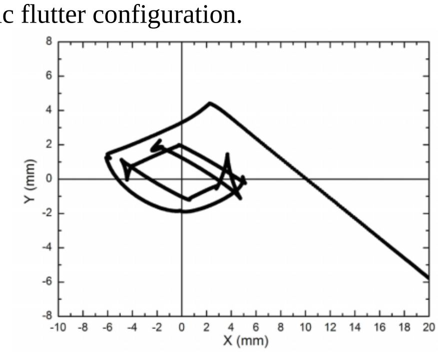

Figure 5: The motion of the center of the ion trajectory during the 2 turns.

Beam Characteristics during the acceleration

With 120 particles of the same initial RF phase, 300 deg, starting at the slit position, beam characteristics in the whole range from the central region to the extraction foil has been investigated. The starting particles are uniformly distributed at the slit and have the same initial directions normal to the slit. To investigate the beam characteristics, we obtained various values at the zero of azimuth angle corresponding to the dee axis.

Figure 6 and 7 show the energy gain per turn and the turn separation at each turn number. The energy and radius value at each turn were obtained by averaging their values of 120 particles. The averaged energy gain per turn in the whole region is about 170 keV. At the extraction the turn separation is about 2.8 mm.

Beam characteristics at the extraction carbon foil have been described in Figure 8. The carbon foil is located at the 406 mm from the cyclotron center and 56 degree from the x-axis that lies at the dee axis. The beam size at the foil is about 1.5 mm (width) x 8 mm (height). The radial and vertical effective emittance is about 29 and 6 π mm mrad, respectively.

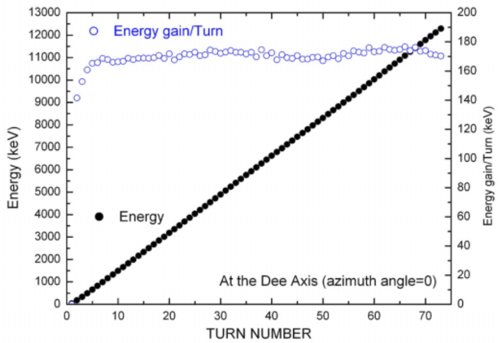

Figure 6: Energy gain/Turn and beam energy with turn number.

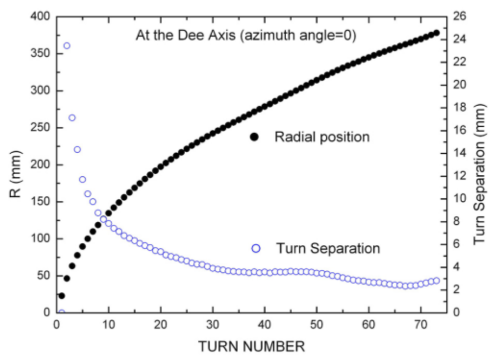

Figure 7: Turn separation and the radial position with turn number.

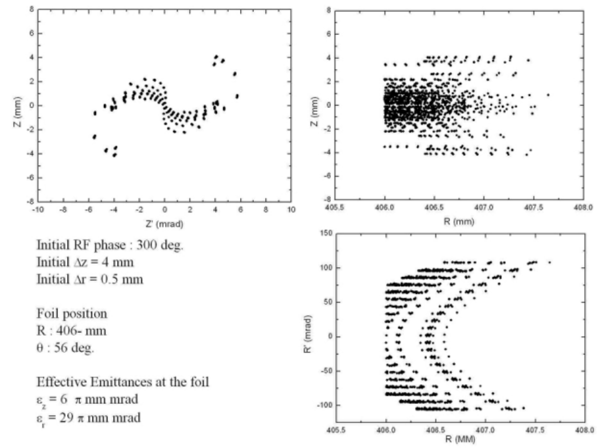

Figure 8: Beam characteristics at the extraction carbon foil.

CONCLUSIONS

Using the electric field map of new central region and whole RF structure generated by RELAX3D and the measured magnetic field map, Beam trajectories and characteristics are investigated in detail. In the central region, RF phase acceptance is about 55 deg. in horizontal and vertical direction. At the extraction carbon foil, the beam size is about 1.5 mm x 8 mm and the radial and vertical effective emittance of the beam is 19 and 6 π mm mrad, respectively.

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