THE STUDY OF THE CENTRAL REGION OF KIRAMS-30 CYCLOTRON

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Abstract

Recently KIRAMS-30 cyclotron has been developed by KIRAMS. This paper describes the central region of KIRAMS-30 cyclotron with a spiral inflector. The electric and magnetic field distribution in the central region has been calculated by TOSCA, OPERA3D. The beam trajectory calculations from the entrance of spiral inflector with a conventional charged particle's equation of motion in EM field has been carried out. For the smooth landing on the median plane, the height of the spiral inflector with $A = 2.0$ and $k' = 0$ is 1.872 cm and the operating electric potential is determined as ±9.02 kV by the full 3D calculation. In order to get the best beam centering, the rotation of spiral inflector about the cyclotron axis and the variation of initial beam energy has been carried out. The 24 keV of negative hydrogen beam has the best motion of the beam centering. At the same time, the RF accelerating gap position and gap geometry has been optimized to get the more than 50 deg of RF acceptance.

INTRODUCTION

KIRAMS-30 Cyclotron has been developed to produce radioisotopes for a Positron Emisstion Tomography(PET) and a Single Photon Emission for Computer Tomography(SPECT) and is now under commissioning at KAERI, Korea. KIRAMS-30 Cyclotron consists of an external Multi-cusp ion source to generate negative hydrogen ions about 10 mA with 22-30 keV[1], SQQ injection system to focus and manipulate injected beam[2], a spiral inflector and its central region to bend the axially injected beam into its horizontal median plane and accelerate negative hydrogen ions with a good beam centering and a wide RF acceptance, an isochronous four-sector electromagnet with a bending limit up to 30 MeV proton[3, 4], 63.95 MHz RF Amplifier to input 50 kW power into the cyclotron RF resonator with Q=7565[5], two stripping foils to extract proton ions through two opposite extractin ports, and four beam transport lines.

This paper devotes to describe properties of the central region of KIRAMS-30 Cyclotron with a spiral inflector.

CENTRAL REGION OF KIRAMS-30 CYCLOTRON

The central region of KIRAMS-30 cyclotron shown in Fig. 1 has a spiral inflector to deflect a negative hydrogen beam into the horizontal median plane and RF acceleration gaps for a good beam centering and a wide RF acceptance.

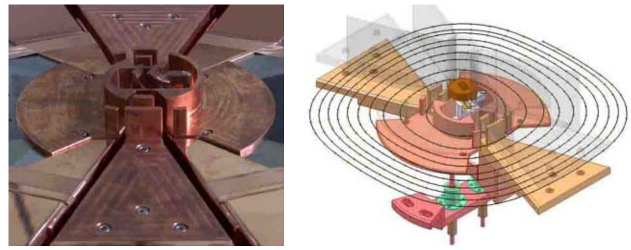

Figure 1: The Central Region of KIRAMS-30 Cyclotron

Spiral Inflector

In order to bend axially injected negative Hydrogen ions into the horizontal median plane of KIRAMS-30 cyclotron, a Spiral Inflector is used. First a central ray trajectory in the spiral inflector for the condition of z=0 at the exit of inflector is obtained with 3D magnetic fields and analytic electric fields . Table 1 shows several design parameters of the spiral inflector. In the view of the dependence of beam acceptance on tilt parameter k′ for an inflector with the aspect raio of 2, the correlated acceptance falls to 50% of the untilted value at k′=-1.0.[6]

Figure 2 shows 3D-CAD drawing of the spiral inflector and electric field distribution simulated by TOSCA.

Table 1: Parameters and Results of the Spiral Inflector

Beam Energy	24 keV
Inflector Height Z_{inf}	1.872 cm
Fringe Constant δ	0.147
electric Radius A	2.0 cm
tilt parameter k′	0.0

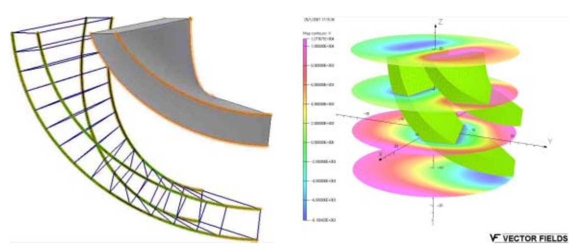

Figure 2: Spiral Inflector

Figure 3 shows a comparative study of central ray trajectories obtained from CASINO and 3D beam simulation.

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The difference in the fringing field at the entrance of a spiral inflector makes the beam trajectory shift in y-z plane. From the results of 3D beam simulation, the operating electric potential of each electrodes can be determined as $\pm$ 9.02 kV for 24 keV H^- ions for the z=0 condition at the exit of the spiral inflector.

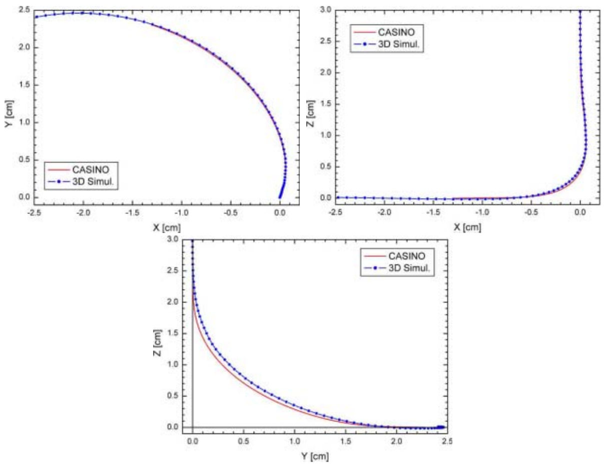

Figure 3: The Central Rays of the Spiral Inflector

Figure 4 shows the beam acceptance of the spiral inflector. The initial beam of 20$\times$20 mm, $\pm$ 100 mrad in trace spaces is generated at z=52mm. The range of beam energy is 24 $\pm$ 1.2 keV. After passing through the spiral inflector, the initial distribution of the final survivals gives the beam acceptance of the spiral inflector. The beam acceptance is 581 mmmrad and 300 mmmrad in x-x$'$ and y-y$'$ trace plane, respectively. The beam center at the initial position is shifted to (-0.25 mm,-0.98 mm) due to the fringing fields at the entrance of the sprial inflector.

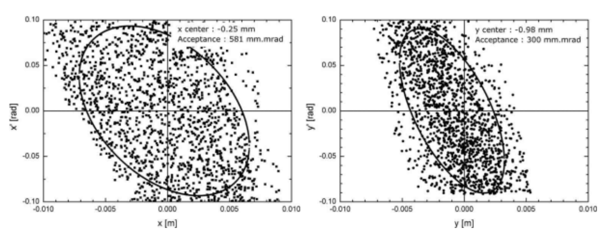

Figure 4: Beam acceptance of the spiral inflector

Central Region of KIRAMS-30 Cyclotron

A linear configuration of successive RF gaps has been used to determine the relative gap postions for a wide RF acceptance in the central region. The initial beam energy, inflector potential, and rotation angle of inflector about cyclotron's axial axis have been adjusted iteratively for the good beam centering.

Figure 5 shows final geometry of the center region of KIRAMS-30 cyclotron and electric field distribution in the median plane calculated by electrostatic solve, TOSCA.

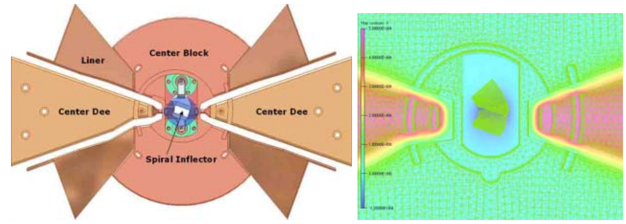

Figure 5: Drawing and E-field Distribution of the Central Region

Dee Voltages

The RF frequency of KIRAMS-30 cyclotron is 63.95 MHz, Q=7565 from the results of Microwave Studio simulation. The Dee voltage with radius can be estimated from the integration of calculated electric field distribution with RF input power. Figure 6 shows the dependence of Dee voltage on Q and RF input Power. Also the beam trajectories with different dee voltages denotes in Fig. 6. The Dee voltage for the best beam centering is about 52 kV.

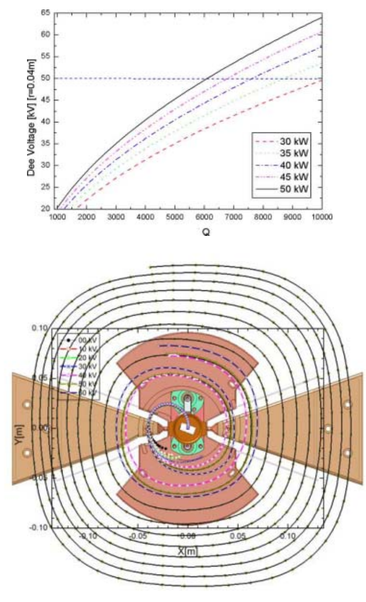

Figure 6: The relation between RF Input Power and Dee Voltage, beam trajectories with several Dee voltages

RF Acceptance

In order to determine the RF acceptance of KIRAMS-30 cyclotron, a beam train in front of spiral inflector is generated. The beam train is 33.5 mm long corresponding to $\beta\lambda$ of 24 keV H^- ions and has been aligned along the cyclotron axis. After a bending by the spiral inflector and a acceleration during 2 turns in the central region, RF acceptance can be obtained from the energy distribution of the beam train with a initial RF phase.

Figure 7 shows RF acceptance with several values of energy spread. In the case that energy spread, $\Delta E/\bar{E}$ is 0.05, RF acceptance is 60 deg.

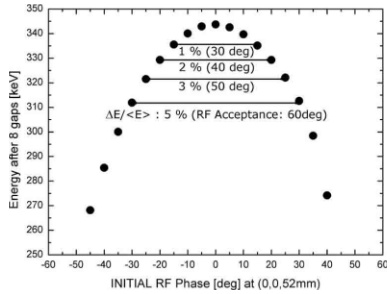

Figure 7: The results of beam train simulatin and RF acceptance with several eneryg spreads.

Beam Acceptance

Figure 8 shows beam acceptance of the central region of KIRAMS-30 cyclotron in trace space. The beam acceptance or beam boundary in front of the entrance of the spiral inflector is 293 mmmrad and 149 mmmrad in x-x′ and y-y′ plane, respectively. For the best matching with spiral inflector and central region, the initial beam center should be located at (-0.84 mm,-0.76 mm).

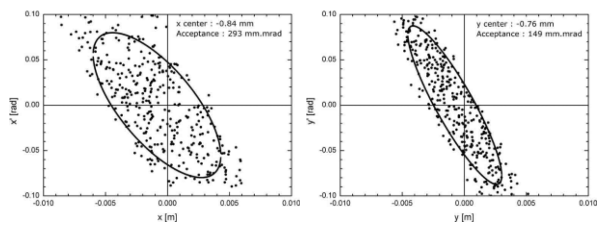

Figure 8: Beam acceptance of the whole central Region of KIRAMS-30 Cyclotron

Beam trajectories in the central region

Figure 9 shows the results of full 3D beam simulation in the motion of beam envelope and acceleration upto 1.69 MeV during 10 turns. The radial size of beam envelope increases due to energy spread during the acceleration. It is necessary to have a blocking structure in the central region to remove the radially diverged particles.

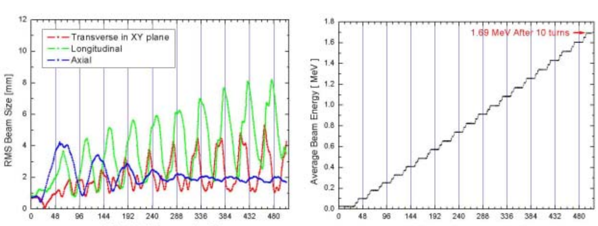

Figure 9: Beam envelope and Beam energy during 10 turns

The beam is abruptly defocused between the inflector exit and the first RF gap. An additional focusing unit or magnetic field bump which have a proper field index to focus the beam axially should be instrumented. Figure 10 shows several beam spots before passing through the first RF gap.

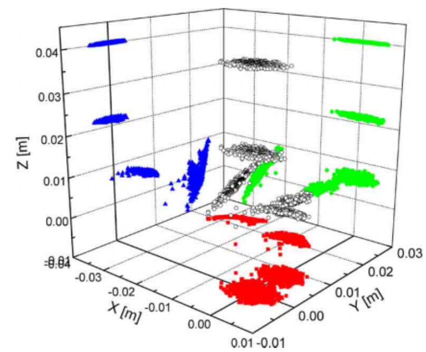

Figure 10: Several beam spots between the inflector exit and the first RF gap

SUMMARY

The spiral inflector with A=2.0, k′=0, and Z_{inf}=1.872 has been developed to bend the axially injected 24 keV H^- beam into the horizontal median plane of KIRAMS-30 cyclotron. The whole central region of KIRAMS-30 cyclotron has 293(139) mmmrad of Beam acceptance in x-x′(y-y′) trace space and more than 50 deg of RF acceptance. The output emittance of multicusp ion source has 100 mmmrad with 90% confinement. It needs an additional focusing instrument or magnetic field bump to focus the beam axially between exit of inflector and the first acceleration RF gap.

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