DESIGN STUDY OF K100 SEPARATED SECTOR CYCLOTRON FOR ISOL*

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Abstract

Starting from April 2010, KoRIA was launched in Republic of Korea; the main objects of this project are fundamental and applied researches, e.g. production of radioisotope beam for the basic science research, nuclear structure, material and life sciences and medical isotope production. A K=100 separated sector cyclotron will be used as a driving accelerator for ISOL, and it will provide 70-100 MeV, ~1 mA of proton beam and 35-50 MeV, ~1mA of deuteron ion beam, the SSC cyclotron will be injected by 8 MeV proton beam from 2 sector focused cyclotrons. In this paper we will describe briefly about the conceptual design of the cyclotron including the design of injector cyclotron, separated sector cyclotron.

INTRODUCTION

The purpose of this study is to design a separated sector cyclotron as ISOL driver for Korean National project, KoRIA (Korea Rare Isotope production Accelerator), which was started on April 2010 for radioactive ion beam production using both ISOL and in flight fragmentation. KoRIA will contribute to the fundamental research for basic science. Fig. 1 shows the layout of the KoRIA. [1]

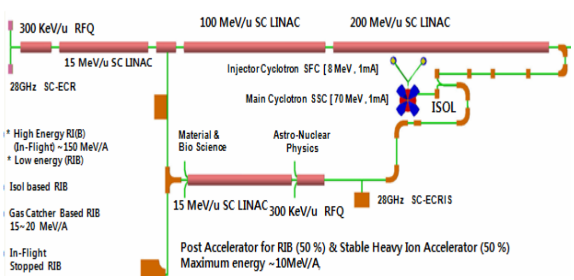

Figure 1: Layout of the KoRIA project

KoRIA facility is composed of cyclotron and superconducting linear accelerator (SC Linac). Stable and unstable ion will be accelerated with SC linac. Unstable ions, radioactive beams are produced with ISOL target bombarded by proton beams with 2 cyclotrons. Main cyclotron, separated sector cyclotron (SSC) has K100 magnet and extraction energy is 70 MeV. SSC is injected by 2 injector cyclotrons. Injection energy is 8 MeV with protons. Radioactive ion beams produced with ISOL are accelerated to 15 MeV/u post linear accelerator which is SC Linac. Accelerated radioactive beams are injected to 200MeV/u main SC Linac for getting the exotic beams.[2] For getting over 1 mA proton beams, we designed separated sector magnet cyclotron even though cost of SSC is higher than sector focus cyclotron. Beam power of protons on the ISOL target is 70kW.

Table 1: Characteristics of Cyclotrons

	SFCyclotron	SSCyclotron
Energy	8MeV	70MeV
Accelerated particles	H^- D^-	Proton Deuteron
Average field	1.155T	0.385T
Pole/extraction radius	0.4/0.35m	3.3/3.0m
Hill angle	48°	30°
Resonant frequency / Harmonics number	74.3 MHz /4th	74.3 MHz/4th
Dee Number	2	2
Dee voltage	50 kV	150kV

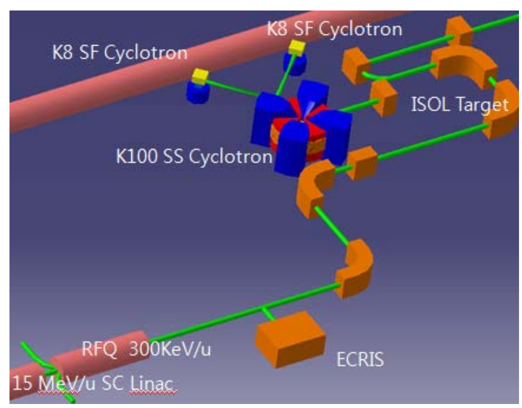

Figure 2: Layout of the cyclotron and ISOL

INJECTOR CYCLOTRON

The compact sector focus cyclotron was designed for injection of K=100 SSC. It has four magnet sectors, and maximum magnetic field is 1.92T. The magnet adopting 4th harmonics has three kinds of holes for beam injection, vacuum pumps and RF systems. Diameter of the pole was chosen to be 80cm with 50kV dee voltage and 40° dee angles. The injection system of this accelerator consists of double gap buncher, Solenoid-Quadrupole-Quadrupole (SQQ) and a spiral inflector. It will provide 8 MeV, 1mA of proton beams[3].

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Magnet

SF cyclotron for injection has normal conducting magnet with 4 sectors. The diameter of magnet is 1.4m, pole is 0.4m and height is 0.76m. The top and bottom yoke of magnet has one hole at each valley (4 holes in total). Computer simulation code for magnet analysis is used OPERA 3D, TOSCA. [4] Figure 3 shows the results of designed magnet. The maximum field on the mid-plane is 1.95 T. Precise calculations of 3D field and the tunes were performed on figure 4 Also the designed isochronous field and calculated isochronous field are shown on Figure 5. [5]

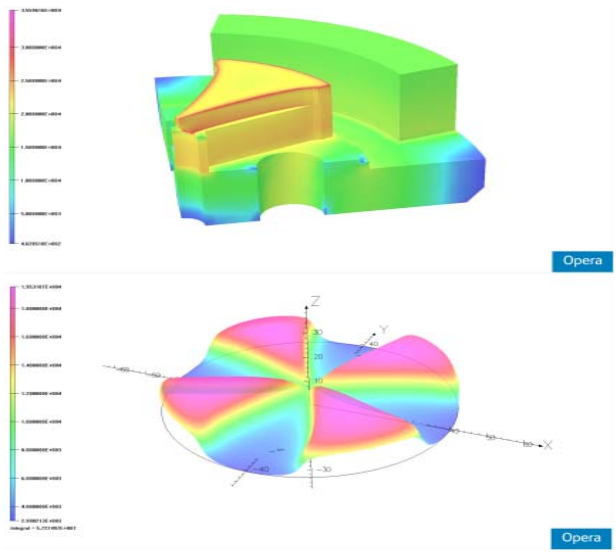

Figure 3: Simulation results of designed magnet.

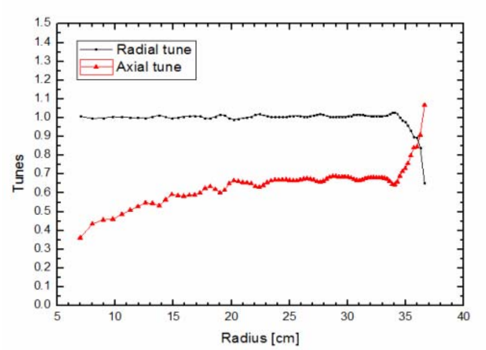

Figure 4: Radial and axial beam tunes.

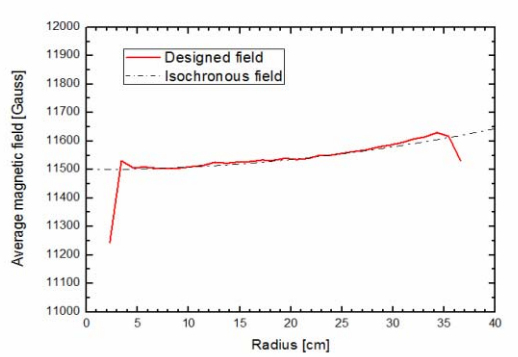

Figure 5. Average magnetic field graph of designed magnet with idle isochoronous field.

RF System

The RF system has 2 cavities with 4 vertical stems. Before designing this RF system, magnet design was preceded. Most of the parameters of whole size were decided from magnet design. Material of RF Cavity is OFHC copper to get electric conductivity better and not to affect magnetic field intensity. For the design of RF resonance cavity, CST Microwave studio is used. [6] It can show E-field and H-field in 3-dimensional. To optimize 70MHz RF frequency, various methods are used. Especially, the stem positions and shapes are primary key to decide resonant frequency and field distribution.

We suppose that the frequency is strongly influenced by the thickness of stem. Besides, it affects Q value, thus the optimization of stem thickness is very important. If thickness of stem is too much thin, the stem would be melted by RF power and Q value would be decreased.

On the contrary, the frequency becomes higher with thicker stem. RF system of Sector-focused cyclotron has resonance frequency of 74.33MHz which is based on the magnet design. $\lambda/2$ resonance mode was satisfied by optimizing stem, liner, gap of dees and so on. This 8 MeV cyclotron has 4 vertical stems in total. Dee angle is 40° and total length of each dee is about 30cm. Optimal Q value is calculated to be 5981. [7]

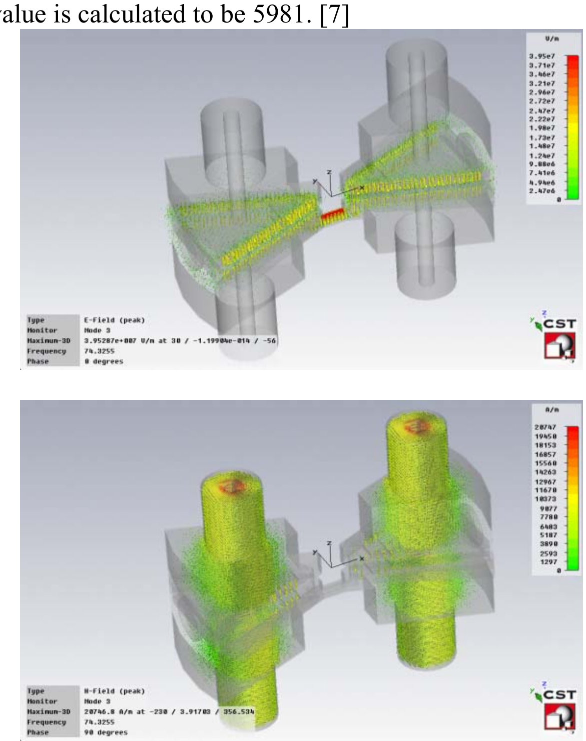

Figure 6. E-field and H-field distribution

Inflector and Central Region

To inject the pulsed beam from external ion source at dee we use the spiral inflector. It is applied 30kV DC. Figure 7 shows maps of voltage contours. We designed minimizing distortion and loss of quantity with safe arrival in the middle plane between dees including proper matching when the beam changes its orbit carefully.

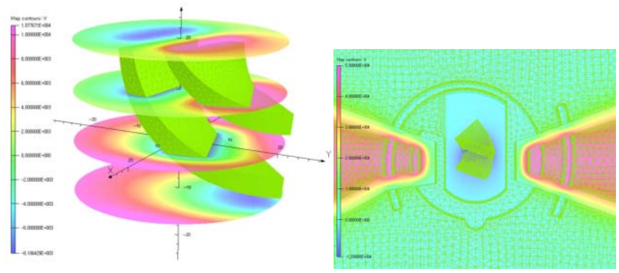

Figure 7. Inflector and central region

SEPARATED SECTOR CYCLOTRON

SSC (Separated Sector Cyclotron) was selected for accelerating high beam current about 1~2 mA. Acceleration of intense beams requires a very efficient focusing and extraction process free of beam loss. The main parameters of SSC design should satisfy the following criteria:

a) Single turn extraction: A large radial gain per turn is requested, i.e. a high energy gain per turn, in order to get an effective turn separation on the extraction radius.

b) Vertical and radial focusing: the problem of space charge effect is not fully understandable because of the very complicated nonlinearity of it. However many systems that have been designed were very successful for overcoming this problem. A deep valley sector focused cyclotrons have been designed to be an injector for separated sector cyclotron.[8]

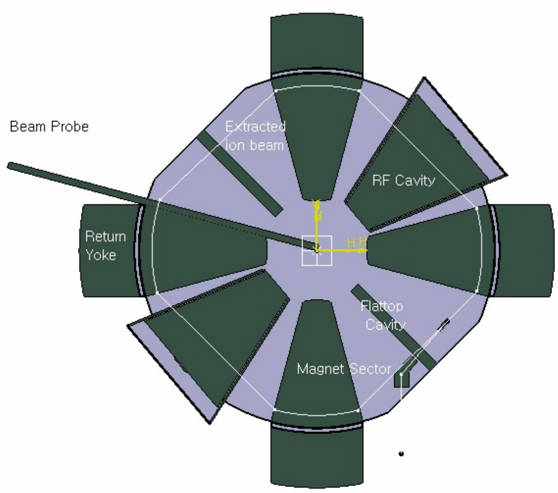

Figure 8: The layout of SSC magnet

Magnet

For accelerating high beam intensity up to 1~2mA, SSC (Separated Sector Cyclotron) was chosen. The magnet diameter is 8.8 m, injection radius is 1 m, and pole radius is 3.3m. The total weight of iron is approximately ~ 400 tons. The minimal value of 3-cm gap between sectors was defined to minimize the energy dissipation at main magnet coil. We have selected four sectors and a magnet sector angle of 30 degrees (α= 30/90=0.333). In addition, we obtained an isochronous field by using 3 groups of trim coils.

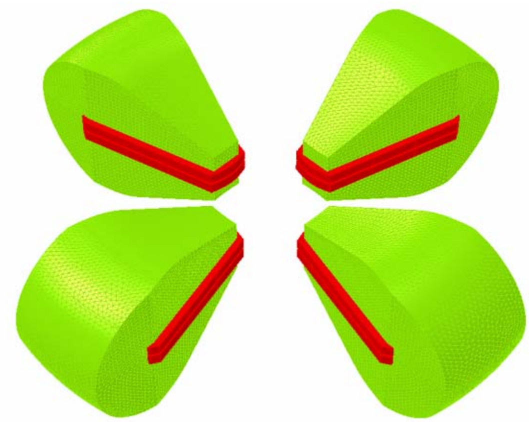

Figure 9: Meshes for magnet simulation by Opera3D

To find the total field produced by the trim coils nonlinear successive approximation technique is needed. However, in order to get a first estimate of the trim coil power requirements, linearity has been assumed. A 2D POISSON model was created consisting of a simplified azimuthally symmetric magnet with circular trim coils. [9]

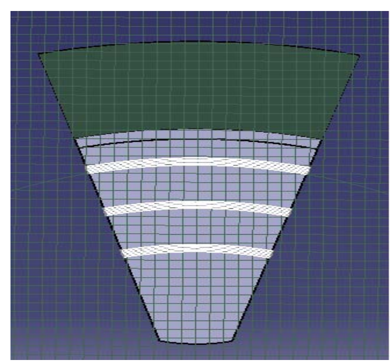

Figure 10: Trim coil position

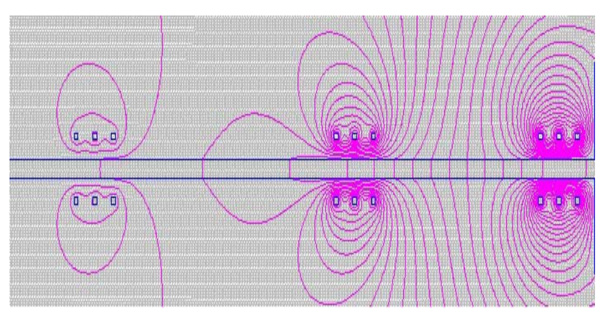

Figure 11: Trim coil simulation by POISSON

One of the first decisions to be made in the design process is the number of sectors in the magnet and the angular width of each sector necessary to achieve the final energy of approximately 70 MeV. To avoid the effects of resonances like $\nu_z = 1$ and $\nu_r = N/2$, we have selected four sectors and a magnet sector angle of 30 degrees (α= 30/90=0.333). The magnetic field of the sector magnets was studied with the finite element code TOSCA. We have adopted a minimum magnet gap of 3 cm with the assumption that the magnet surface close to the median plane will be part of the vacuum chamber.

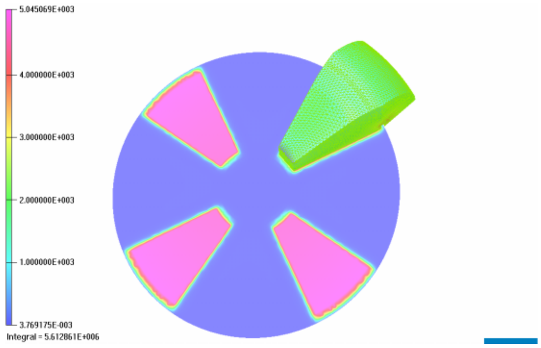

Figure 12: B-fields of simulation by TOSCA

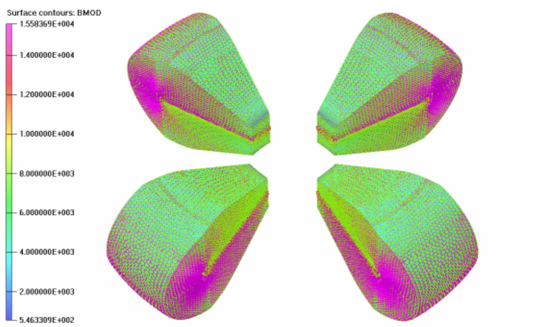

Figure 13: Flux line of simulation by TOSCA

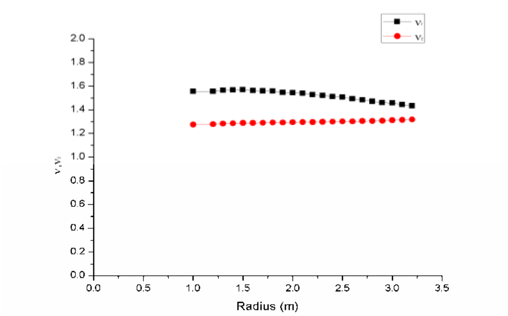

Figure 14: Beam Tunes

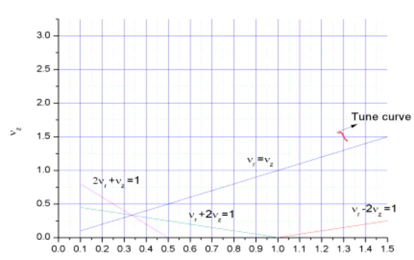

Figure 15: Tune diagram

RF System

For the design of RF system of SSC, we chose double-gap cavity with two stems. By utilizing multiple stems, voltage distribution shape is easier and power consumption is low. Resonant frequency of SSC cavity is 74.5 MHz, and it is matched with injector cyclotron as well as the magnet design. We used OFC (conductivity: 5.91e7 S/m) as a normal conductor.

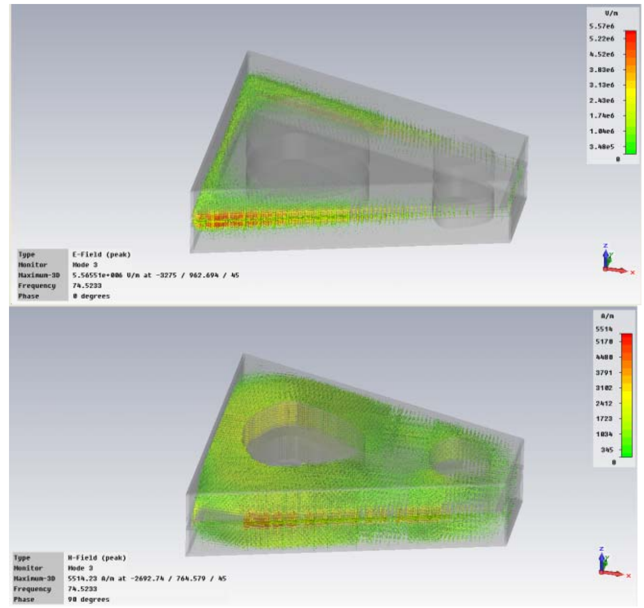

Figure 16: E-field and H-field distributions by MWS

SUMMARY

The design study of 70 MeV separated sector cyclotron is on progress. It is expected that the whole system conceptual design will be finished on November, 2010.

ACKNOWLEDGEMENT

This work was supported by Ministry of Education, Science and Technology, Republic of Korea.

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