# MAGNET DESIGN OF 70 MEV SEPARATED SECTOR CYCLOTRON (KORIA)*

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*Abstract*

A K=100 separated sector cyclotron is being designed in SKKU in South Korea, this cyclotron is considered the main drive for ISOL to produce ~ 70MeV proton beam and 35 MeV deuteron beam for production of radioactive material as a basic nuclear research.

In this paper we will describe CST numerical simulation for determining the basic magnet parameters, magnet material, deformation, imperfection fields and preliminary ion beam dynamics study for verifying the focusing properties of the designed magnet.

## INTRODUCTION

The purpose of this study is to design a separated sector cyclotron magnet for Korean National project, KORIA, which was started on April 2010 for radioactive ion beam (RIB) production using both ISOL and In Flight Fragmentation. KoRIA will contribute to the various research fields such as nuclear, atomic, material, bio and medical science. Its facilities consist of 3 blocks. Fig 1 is the layout of the KoRIA and the Fig 2 shows separated sector magnet layout.

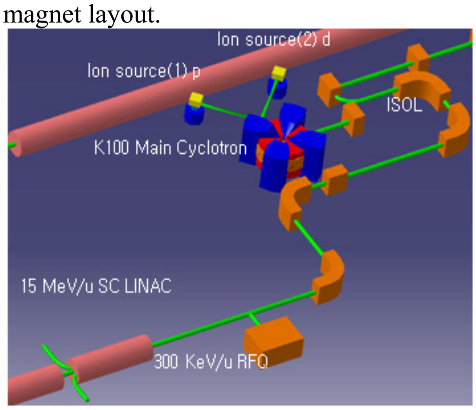


Figure 1: Block 1 layout of the KoRIA project

## MAIN PARAMETERS AND DESCRIPTION OF SSC

SSC (Sector Separated Cyclotron) was selected for accelerating high beam current about 1~2 mA. The magnet diameter is 8.8 m, injection radius is 1 m, pole radius is 3.3m and approximately the total weight of iron is ~ 400 tons. For minimizing the energy dissipation at main magnet coil the minimal 3-cm gap between sectors was defined. Cyclotron Parameters cyclotrons are shown in Table 1.

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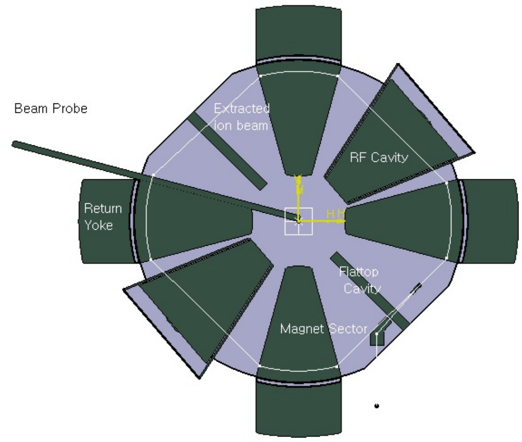


Figure 2: Separated Sector magnet Layout

Table 1: General cyclotron data

| Parameters | Values |
|---|---|
| Energy | 70MeV/35MeV |
| Ion Beam | $H^+$,$D^+$ |
| Average field | 0.385 T |
| Relative Field variation | 0.38-0.415 T |
| Sector Gap | 0.03m |
| Number of sectors | 4 |

## DESIGN REQUIREMENT FROM BEAM DYNAMICS

Acceleration of intense beams requires a very efficient focusing and extraction process free of beam loss. The main parameters of magnet design should satisfy the following criteria:

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.

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 cyclotron have been designed to be injector for a separated sector cyclotron.

## SECTOR MAGNET DESIGN

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 ($\alpha$= 30/90=0.333).

The magnetic field of the sector magnets was studied with the finite element code CST. 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. We obtain an isochronous field by using 3 groups of trim coils

To achieve these goals, firstly hand calculations were done for determining the basic geometry of the magnet, the isochronous magnetic field was calculated by the equation [1],

$$B_{iso}(r) = \gamma \cdot B_c = (1 + T / E_0) \cdot B_C$$

Relativistic factor $\gamma$ is a function of radius; we have calculated it from the equation [1]

$$B(r) / B_0 = \gamma(R) = [1 - (qB_c / m_i c)^2]^{-1/2}$$

2D simulation had been carried out for determining the basic magnet dimensions, trim coil. LANL Poisson 2D code had been used, the advantage of 2D simulation is the ability to use small mesh size for areas with high magnetic field gradient[2] , Fig (3)

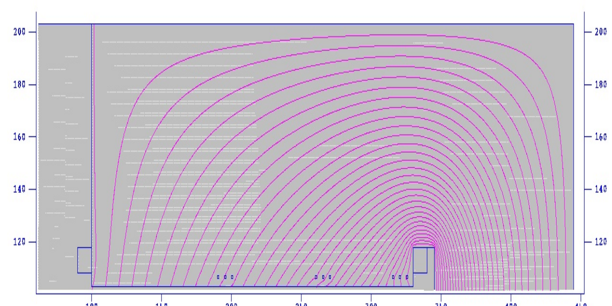

Figure 3: Poisson simulation (main magnet)

After determining the basic parameters of the magnet we draw the whole magnet using CATIA P3 V5 R18 [3] Fig (4), for drawing the whole magnet in 3D perspective, Followed by a 3D FEM (TOSCA and CST) code for the final calculations of the model [4] ,Fig (5).

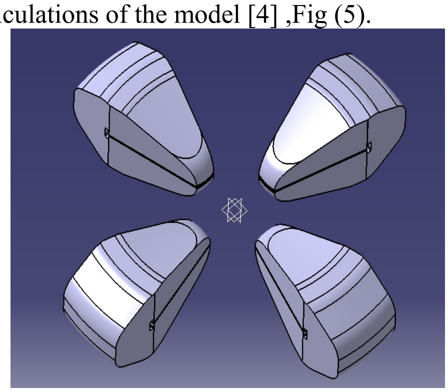

Figure 4: CATIA drawing

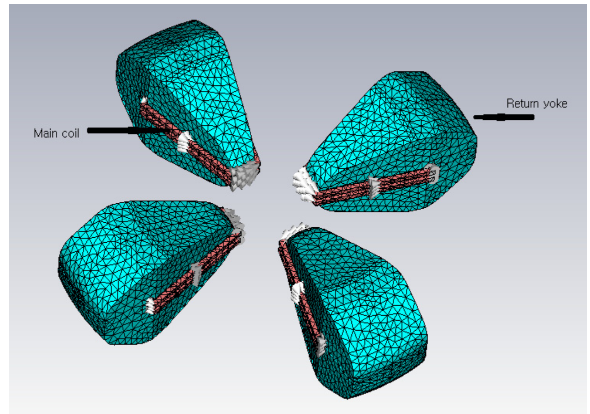


Figure 5: CST magnet simulation

## SIMULATION RESULTS

After simulation of magnet using CST code , it was found that the average magnetic field of magnet was increasing with respect to radius fig(6) , this increase of the average magnetic can be adapted by using 3 set of trim coils which is feed by 3 separated power supplies.

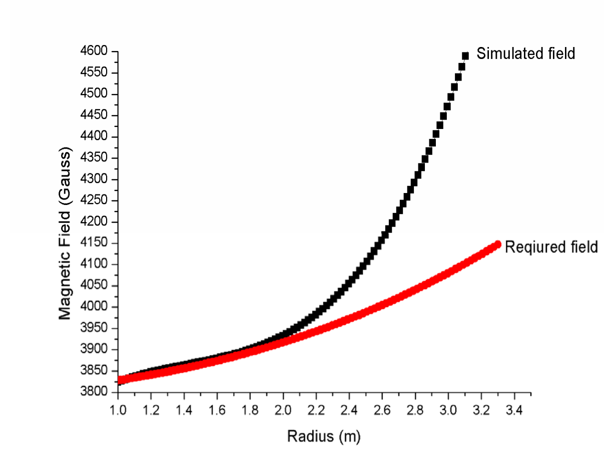


Figure 6: Simulated verse required field

Because of the small magnet gap, it was decided not to locate the trim coils in the gap space, but rather to place them inside the steel of the pole tip fig (7); it was impeded at a 5 cm distance from the pole surface.

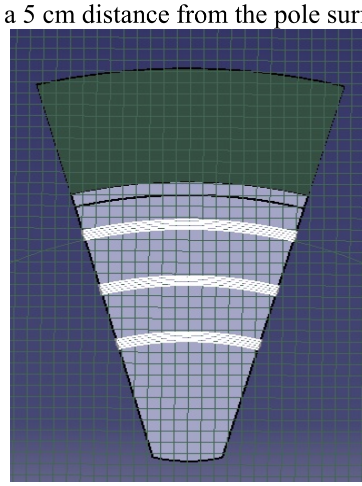

Figure 7: Trim coils position

Though not fully saturated, the field in the steel is nonlinear, and ultimately will require a nonlinear successive approximation technique to find the total field produced by the trim coils. However, in order to obtain 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. The return path for the trim coils will either be on the outer radius of the magnet (for those at larger radii) or the inner radius (for those at smaller radii). This model gives an approximation to the 3D model that will later be constructed with TOSCA or CST program. To simplify the POISSON grid, the holes were represented by regions of 1cm by 10 cm. A small section of the POISSON model is shown in Fig 8.

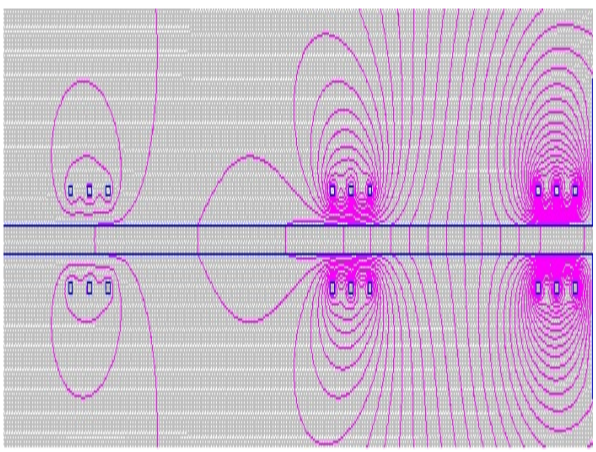

Figure 8: A vertical cross section of the POISSON model showing holes in the pole tip for the trim coils

By changing the direction and value of electric current in trim coils, we can obtain the required magnetic field which is isochronous for both Hydrogen and deuterium

## TUNE DIAGRAMS

Calculations of betatron oscillations have been done by using simple homemade code the results is shown in fig .9.

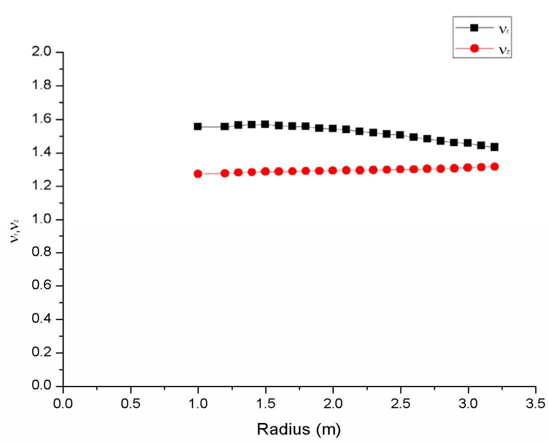


Figure 9: Radial and Axial beam tunes

Study of betatron resonance diagram Fig.10 we found that the work point of cyclotron is almost far away from dangerous resonance zones.

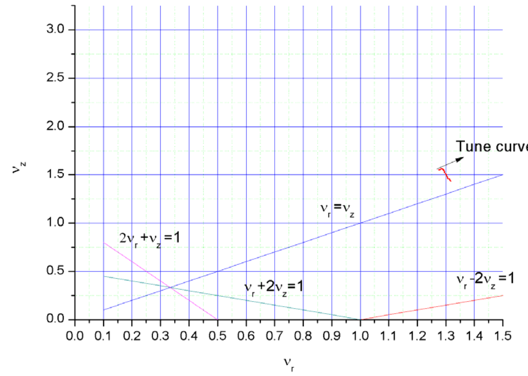


Figure 10: Tune diagram

## CONCLUSION

The design study of 70 MeV separated sector cyclotron is almost done. The study of trim coils show that it is possible to obtain the isochronous magnetic field within high range of precision , harmonic coils will be studied in details to offer more stable magnetic field , it is expected that the whole system conceptual design will be finished on November, 2010.

## REFERENCES

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[3] Dassault Systems, FR
[4] CST Microwave studio manual