DESIGN STUDY OF AVF MAGNET FOR COMPACT CYCLOTRON*

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Abstract

K=100 separated sector cyclotron and its injector cyclotron design is started on April, 2010 at Sungkyunkwan University. The main purpose of the K=100 separated sector cyclotron is producing proton and deuteron beam for ISOL which generate rare isotopes to accelerate RI beam for basic science research. In K=100 separated sector cyclotron facilities, two 8MeV sector focused cyclotrons will be used as an injector cyclotron for the main cyclotron.

In this paper, an Azimuthally Varying Field (AVF) magnet for the 8MeV injector cyclotron is designed to produce 8MeV proton beam and 4MeV deuteron beam. All field simulations have been performed by OPERA-3D TOSCA for 3D magnetic field simulation. The assignments of these injector cyclotrons are generating 8MeV, 1mA proton beam and 4MeV deuteron beam that inject to the main cyclotron.

INTRODUCTION

An 8 MeV H- injector cyclotron for K=100 separated sector cyclotron is being designed at Accelerator and Medical Engineering Laboratory (AMEL), SungKyun-Kwan University. It will provide an 8 MeV, 1 mA proton and 4 MeV deuteron beams for K=100 separated sector cyclotron and it is the main cyclotron which is located before ISOL for generating RI beam.

A design study of 8 MeV H- injector cyclotron magnets is described in this paper. This injector cyclotron has normal conducting magnet with 4 sectors so that is AVF and fixed RF frequency machine. The diameter of magnet is 1.4 m, pole is 0.4 m and height is 0.76 m. The top and bottom yoke of magnet has one hole at each valley (4 holes total) and those holes will be used for other subsystem devices - vacuum pumps and RF system [1]. The maximum field on the mid-plane is 1.95 T. Other magnet parameters are shown in Table 1 and the 1/8 model of designed magnet is shown in Figure 1.

3D modelling process was done by 3D CAD system, CATIA P3 V5 R18 [2] and whole field calculations were processed under computer simulation. Precise 3D field calculations had been performed by OPERA-3D TOSCA [3]. To reduce the field calculation time, batch files were developed which can generate model, mesh and field map automatically in TOSCA modeller and post processor. The beam dynamics program OPTICY [4] is used for calculation of the tunes.

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MAGNET DESIGN

Three steps were done to design isochronous cyclotron magnet. Some basic calculations were done first to determine parameters of magnet. Harmonic number and RF frequency was set before the calculation of gamma value, magnet rigidity at maximum beam energy and extraction radius. After the consideration of parameters 3D CAD drawing with CATIA P3 V5 R18 [2] is followed. 3D field simulation using OPERA-3D TOSCA [3] is done with those 3D drawings.

Table 1: Parameters of magnet

Parameters	Values
Maximum energy	8 MeV / 4 MeV
Beam species	H-, D-
Central field	1.15 T
Pole radius	0.40 m
Extraction radius	0.35 m
Number of sectors	4
Hill / Valley gap	0.03 / 0.39 m
Hill angle	48°
B-field (min.,max)	0.30, 1.95 T

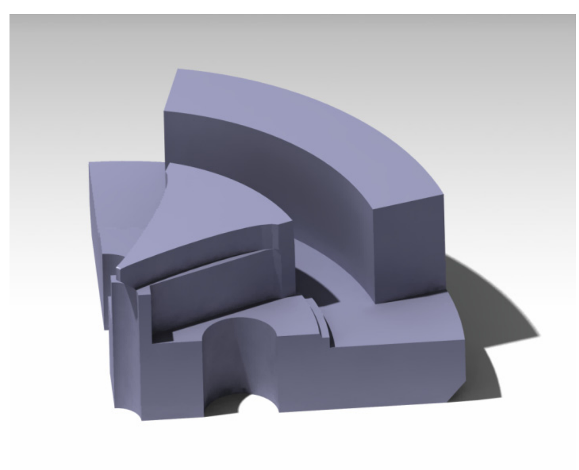

Figure 1: 1/8 model of designed magnet.

0.41 T-m magnet rigidity is needed at the extraction radius and the proton beam energy is 8 MeV at there. The RF frequency is set to 70 MHz, so central field of the magnet is 1.15 T.

3D CAD drawing can be converted to 2D drawings with CATIA P3 V5 R18 [2], and Figure 2 shows that result. 3D drawing-Figure 1 is converted and specific magnet parameters are shown.

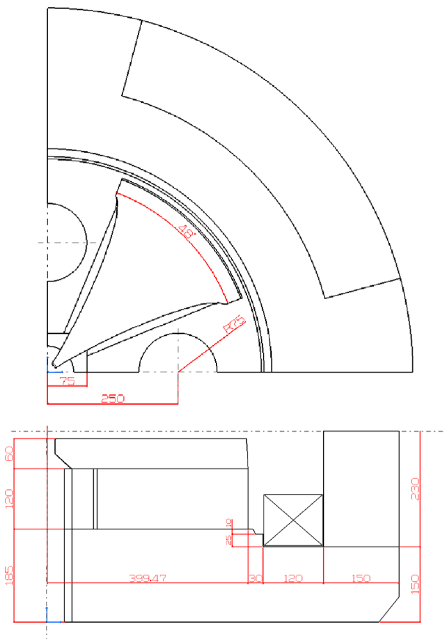

Figure 2: 2D drawings converted from 3D drawing

All 3D field simulation was done by OPERA-3D TOSCA [3]. The drawings from CATIA are imported to OPERA-3D modeller and modified to generate surface and volume mesh.

The material of magnet is determined on this step. Low carbon steel, ANSI 1008 and ANSI 1010, were considered to main material and ANSI 1008 is selected to main material of magnet. Both steels are good magnetic materials but saturation point of ANSI 1008 is slightly higher than ANSI 1010. The difference of saturation point between two materials is approximately 0.2 T.

Local mesh is used to increase accuracy of simulation. The mesh size adapted to pole part is much smaller than boundary part and return yoke part. Figure 3 shows the meshing result before start field calculation. Total number of calculated node is about 2.2 million and only 1/8 nodes were simulated because of the symmetrical model geometry. Dummy vacuum gap is used to check the precise magnetic flux density on mid-gap. It contains a lot of mesh so that can show the smooth field distribution on mid-gap plane.

After the field calculation, the results were reprocessed with OPERA-3D post processor to check the field on the surface of model, vector map of magnetic flux and field map of mid-plane. Figure 4 shows the result of post processing.

The batch files for OPERA-3D modeller and OPERA-3D post processor were made to accelerate the modelling process and reproducing time. Files for OPERA-3D modeller import the 3D CAD file automatically and modifies the model. After the modification, meshing is also automatically done by itself. Files for OPERA-3D post processor performed that generating field on the surface of model, vector map of magnetic flux and field map of mid-plane.

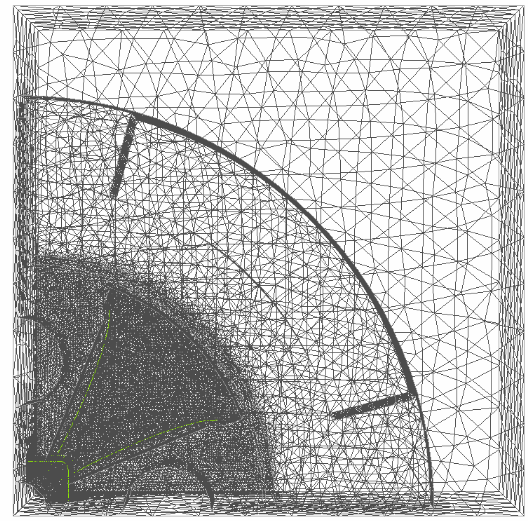

Figure 3: Local meshed model for precise simulation.

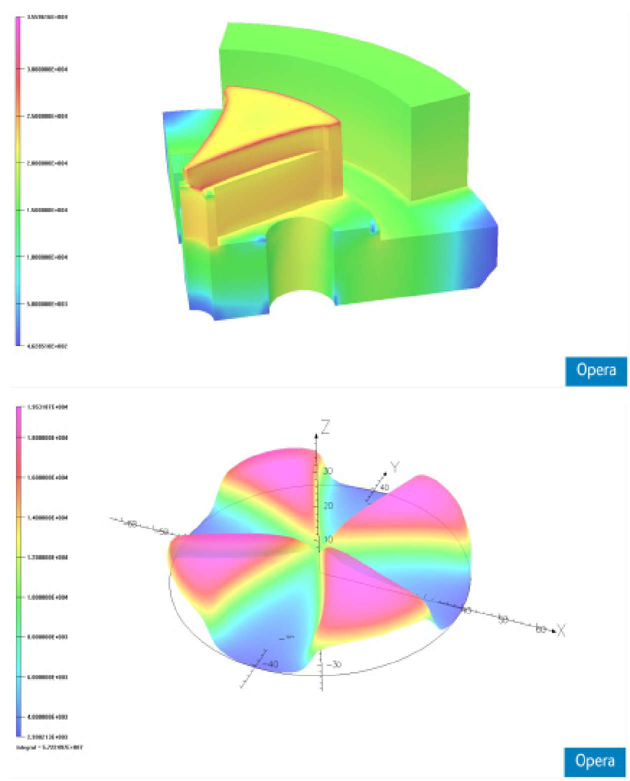

Figure 4: Results of post processing; field on the surface of model and histogram of magnetic field on mid-gap.

Shimming process is necessary to make isochronous field. The average magnetic field of mid-gap must increase gradually with radius of pole [5]. The method that change hill-valley ratio along the radius is a way to make isochronous field. Using the spline curve, 37 points were set along the pole radius and they have specific angles to make the isochronous field. Figure 5 shows the designed side shim.

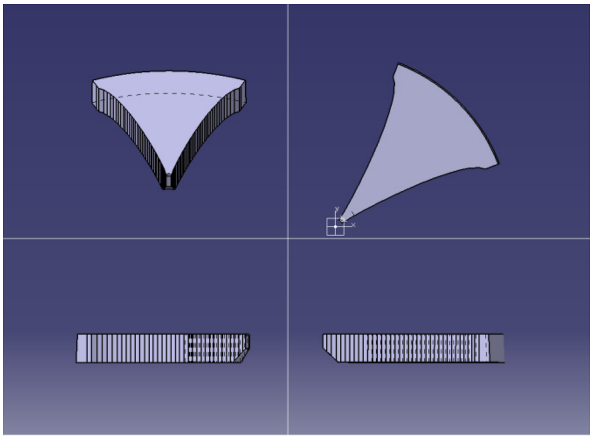

Figure 5: Side shim design using CATIA V5.

The designed isochronous field and calculated isochronous field are shown in Figure 6. Designed field is increased with pole radius and that field have 25 gauss error boundary.

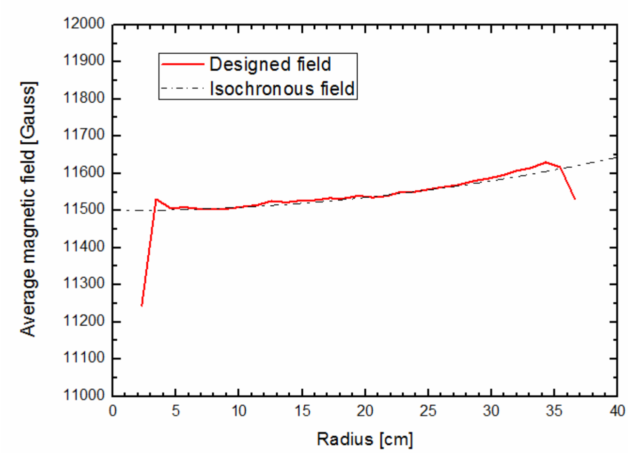

Figure 6: Average magnetic field graph of designed magnet with idle isochronous field.

The OPTICY [4] is own-made program to calculate the tunes and phase error for beam dynamics. Fig. 7 contains the tune diagrams from OPTICY.

CONCLUSION

The design study of 8 MeV injector cyclotron for K=100 separated sector cyclotron facility is almost done. Designed magnet shows isochronous field with high precision. The OPTICY [4] will be modified to be suitable for beam tracking calculation. It is expected that the full analysis and whole conceptual design report of 8 MeV injector cyclotron magnet will be finished in November, 2010.

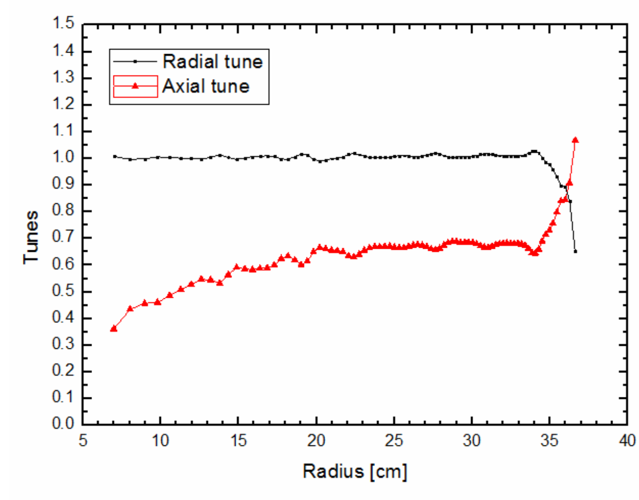

Figure 7: Radial and axial beam tunes.

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