DESIGN STUDY OF ELECTROMAGNET FOR13MEV PET CYCLOTRON

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Abstract

Cyclotron electromagnet for Radio-Isotope production which is used for PET scanning has been designed. Designed pancake-shapedelectromagnet hasandifference structure of KIRAMS-13's electromagnetwhich has the H-type electromagnet. The AVF structure with hill and valley was used for getting strong axial focusing and producing the energy of proton beam up to 13MeV with a thin stripper foil. To design and analyse the magnet,3D CAD(CATIA V5) and TOSCA(OPERA-3D) were used, respectively.The beam dynamics program OPTICY is used for calculation of the tunes.

INTRODUCTION

Electromagnet which can accelerate negative hydrogen beams up to 13 MeV has been designed at Sungkyunkwan University. It will provide the 13 MeV proton beams for Radio-Isotope production.

Table 1 shows the specifications of theelectromagnet. The particle of negative hydrogen is accelerated at the end of the procedure and it generates a proton beam through a carbon stripper. The H- ion created from ion source is accelerated to 13MeV at the middle plane of upper and lower magnet poles. The magnet is designed to produce isochronous magnetic field by shimming and RF system is structured to obtain resonance at 77.3MHz.

ELECTROMAGNET DESIGN

To design isochronous magnetic field, three steps are needed.[1]At first, calculations were performed to determine parameters of magnet.[2]RF resonance frequencyandharmonic number were settled before the calculation of gamma value, magnet rigidity at the maximum beam energy and extraction radius. After the consideration of parameters 3D CAD[3] drawing is followed. Magnetic field simulation wascarried out with OPERA-3D.[4]

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Table 1: Specifications of Designed Magnet

Parameters	Values
Maximum energy	13 MeV
Beam species	H-
Central field	1.2679 T
Pole radius	0.48 m
Extraction radius	0.395 m
Number of sectors	4
Hill / Valley gap	0.04 / 0.12 m
Hill angle (Max.)	37° (44°)
B-field (Max. / Min.)	0.551 / 1.943 T

Magnetic rigidity was fixed at 0.522 [T· m] by calculation and proton beam energy at the extraction radius was 13 MeV. Because of 77.3 MHz RF frequency, the central field of the magnet was set to 1.269 T.

Figure 1 shows 1/8 Model of designed magnet. It has a centre pole to intensify axial focusing of central region and has holes for vacuum system and space to locate the stem of RF resonator.

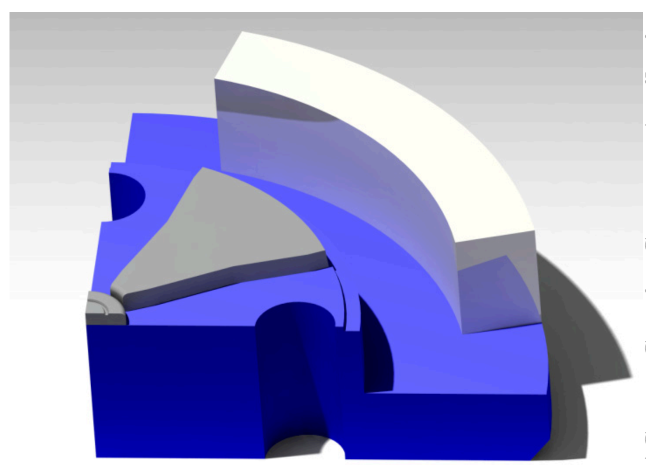
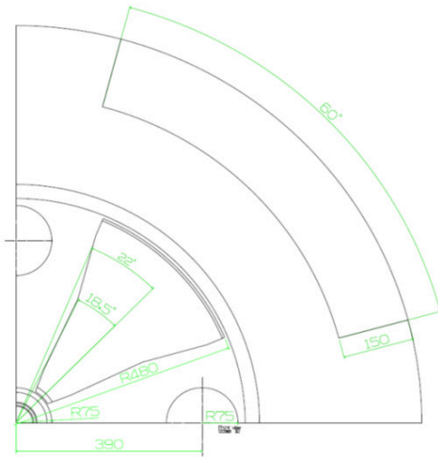


Figure 1: 1/8 Model of 13MeVMagnet.

2Dimensional schematic diagram of electromagnet designed by CATIA v5 is describedin Figure2. The gap between upper and bottom hills is equal to KIRAMS 13's one[5] as 4cm. To ensure the space for extraction, side york angle is restrictedto 60°.



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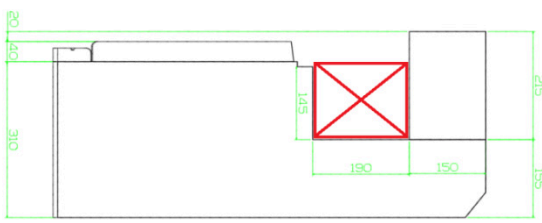

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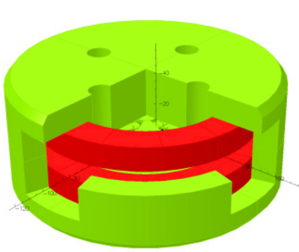
Figure 2: 2D Schematic diagram of designed magnet: Front view (b) Cross-sectional view

All magnetic field calculation was performed by OPERA-3D. The structure from CATIA is imported to OPERA-3D modeller and modified to generate surface and volume mesh. Before the meshing, analysis type and boundary condition have to be fixed. The material of magnet is determined at this step. Low carbon ANSI 1010 steel is selected to the main material of electromagnet. From the libraryof OPERA 3D hysteresis curve is imported and the saturation point of this steel is 2.1 T.[1]



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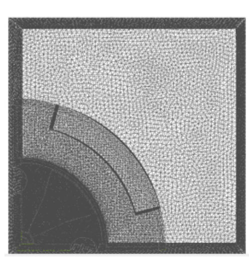

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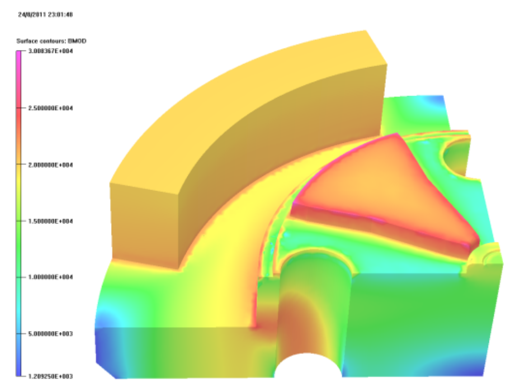
Figure 3: Model body of 13 MeV Cyclotron: (a) Model body before creating mesh. (b) Local meshed model of modeller in OPERA-3D

Local mesh is used to increase the accuracy of simulation. The mesh size adapted to the pole part is much smaller than the bottom and return yoke part. Figure 3 shows the meshing result before start field calculation. Total number of calculated node is about 4.8 millionand only 1/8 nodes were simulated because of the symmetric nature of model geometry. Cylinder shape air block is used to check the precise magnetic flux density on mid-plane. It contains a lot of mesh so it can show the smooth field distribution on mid-plane. The coil of magnet has a 15cm×19cm structure.

Figure 4 shows the result of field calculation of OPERA-3D with FEM (Finite Element Method). At this point the Magnetic field of mid- plane is found to have 0.55 to 1.94 Tesla. The current density of coil is fixed at $200\mathrm{A/cm}^2$ and total A-turn is 57,000. The inner radius of coil from the middle point is 51cm.



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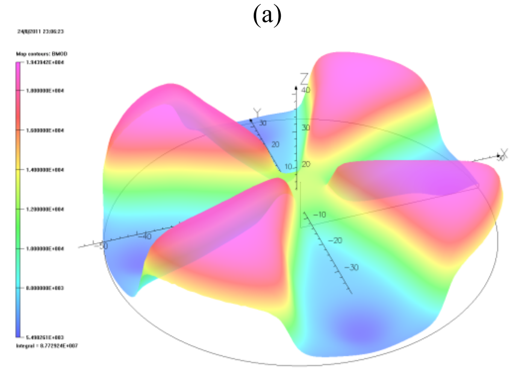

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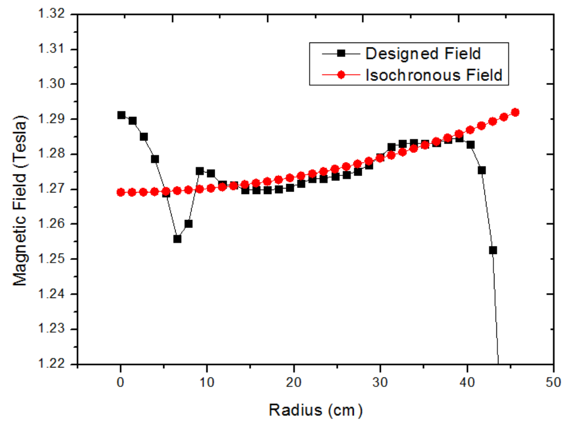
Figure 4: Results of magnetic field calculation with OPERA-3D: (a) Component contour of magnetic field (b) Histogram of magnetic field on mid-plane.

Designed isochronous and calculation are shown in Figure 5(a). Designed field is increased with the radius of pole and every point means average magnetic field at each radius. Because of centre pole, central region has a different value with isochronous field. After extraction radius, 39cm, magnetic field is fallenbelow the isochronous field. All graph range hasan inner 30 gauss error boundary excluding central region.To reduce the calculation time,routine files were developed which can generate model, mesh and field map automatically in TOSCA modeller and post processor. The OPTICY[6] is used to calculate the tunes and phase error for beam dynamics. Figure5(b)shows the tune diagrams fromOPTICY.



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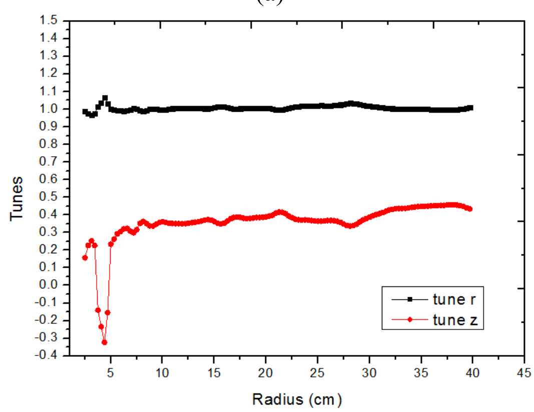

(b)

Figure 5: (a)Average magnetic field of magnet with idle isochronous field (b) Radial and axial beam tunes of magnet

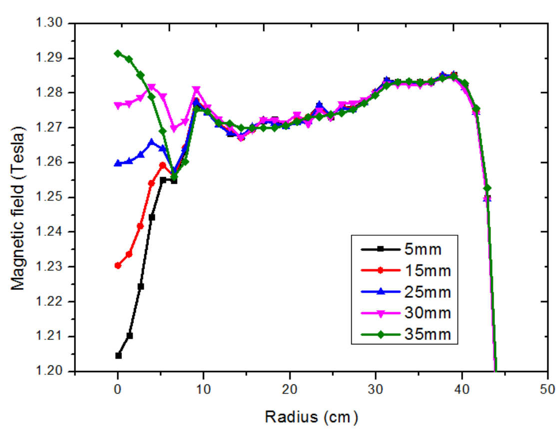

Figure 6: Magnetic fields change the height of variable part in centre pole.

Centre pole is designed to strengthen the axial focusing of central region. Initial magnetic field can be varied with control of height level of inner circular structure. In figure 6, multiform of graphs by alteration of centre pole are described. When the variable part of centre pole has the height of 35mm,which is the green line, the magnetic field has the significant value.

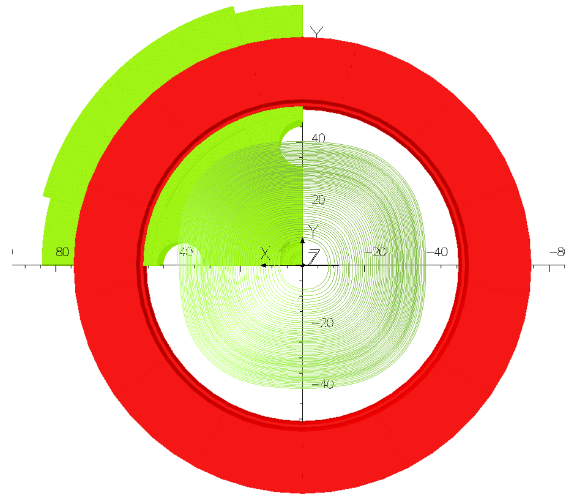

Figure 7: Single turn trajectory of negative hydrogen in electromagnet.

CONCLUSION

The 13MeV PET cyclotron electromagnet has been designed for RI production. Designed electromagnet follows isochronous field within 30 gauss error boundary. The ideal RF cavity structured for single turn monitoring is applied to electrostatic mode in OPERA-3D. It consists of four 23°blocks and each block has 40KeV energy. In Figure 7 the single turn trajectory was introduced to demonstrate stability of designed electromagnet.

The maindifference between H and pancake type magnet is the constitution of return york. As the volume of return path increases, it can reduce the leakage field from body. And also it can increase the precision of simulation data because of symmetric structure. The pancake-shaped 13 MeV electromagnet will begin itsdevelopment after verification of design.

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