DESIGN STUDY OF 10 MeV H- CYCLOTRON MAGNET

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Abstract

For the past decades, PET (positron emission tomography) has been remarkable growth in market. PET using ^{18}F is widely provided for cancer screening and expected to be installed at small and medium hospital for convenience of patients. At Sungkyunkwan University, 10 MeV H^- cyclotron, which produces ^{18}F is being developed. In this paper, we demonstrated main magnet design and whole design procedure was explained. The result of design is verified by orbit analysis and single particle tracking. The description of the obtained result is presented in this paper.

INTRODUCTION

9 MeV H^- cyclotron for production of ^{18}F has been designed and manufactured and successfully operated at Sungkyunkwan University. In this research, 10MeV energy cyclotron is selected in order to yield more ^{18}F [1]. Design procedure is described from initial calculation to verification of the result. Modelling and optimization method with the assistance of three dimensional magnetic field calculation are simulated by OPERA-3D [2]. The magnetic field analysis is performed by beam code CYCLONE [3]. It consists of 3 part. Part 1 and 2 is used at centre of the cyclotron and at first 5 turns. Part 3 is suitable for turn 5 to extraction. Based on CYCLONE Part 3, we could manufacture magnet in accordance with our designed magnetic field which satisfies focusing and isochronous condition. In addition, magnet shimming was carried out by analysis of obtained results by simulation codes. Design requirements were satisfied by iteration process.

MAGNET DESIGN

Magnet design started from determining RF frequency, harmonic number and magnetic rigidity.

$$B \bullet \rho = \frac{1}{300\ Z}[T^2 + 2\ T\ E_0]^{1/2}. \qquad (1)$$

From equation (1), size of magnet pole can be approximately determined. Cross-section view is shown as Fig. 1. Radius of magnet and pole is 830 mm and 460 mm. The gap ratio of valley/hill is 15 and hill sector angle is 47°. Differences between hill and valley magnetic field could increase vertical tune by 0.6. However, the above geometry need more ampere turn. To reduce it, radio frequency was set at 67.23 MHZ. Main parameters of magnet are shown in Table 1.

Magnetic field calculation was done by OPERA 3D. Material adapted in this magnet is a low carbon steel AISI 1008 that contains maximum 0.1% of carbon and used to enhance magnetic properties. Figure 2 shows the B-H curve of magnet material. Local mesh method with 8732146 elements and 1/8 boundary condition was used for fast and accurate calculation. Calculated vertical magnetic field component data in midplane is used as an input of beam code. In CYCLONE code, it is extended to field out midplane. Figure 3 shows field distribution in magnet pole.

Table 1: Main Parameters of 10 MeV Cyclotron Magnet

Parameters	Values
Maximum Energy	10 MeV
Accelerated particle	Negative hydrogen
Radio frequency	67.23 MHZ
Harmonic number	4
Pole radius	0.46 mm
Hill / Valley gap ratio	15 (360 mm/24 mm)
Sector angle	47°
B-field (min., max.)	0.26, 1.96 T
Dimension (Diameter, Height)	1660 mm×860 mm

EQUILIBRIUM ORBIT ANALYSIS

In order to get a stable isochronous field, tunes and phase error should be considered. Equilibrium orbit information was calculated by CYCLONE code. Energy gain per Dee is 0.0398 MeV. Equilibrium orbit is spaced from 0.0150 MeV to 10.6364 MeV. Energy gain per Dee is used for spacing among adjacent orbits. Figure 4 shows that energy of orbit at average radius.

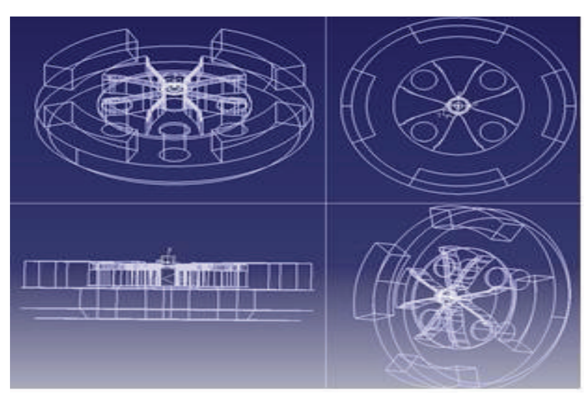

Figure 1: Cross section view of magnet.

To satisfy isochronism, field is corrected by

$$\frac{\Delta B(r)}{B_R} = \gamma^2(r)\frac{\Delta f_p(r)}{f_p(r)}. \qquad (2)$$

Where $\Delta B(r)$ and B_R are difference between isochronous field and average field at radius r. $\gamma(r)$ is term that include energy variable. $\Delta f_p(r)$ is the difference between calculated gyration frequency and orbital frequency [4]. From OPERA-3D magnet field input data, field is repeatedly adjusted until the field satisfies isochronism. Numerical calculation is only used for reducing time by correction of $\Delta B(r)$. Isochronous field acquired by numerical calculation is the reference for magnet shimming. It is performed by side cutting of hill. Designed hill has a constant gap. It is easier than variable gap for expecting shimming result. Hill side is divided by 15mm length interval. Height of cutting block is 4.5 cm. In centre of pole, shimming is performed by adjusting gap. By iterative shimming process, field in OPERA-3D satisfied isochronous condition. Figure 5 shows a final result in OPERA-3D field simulation and reference field

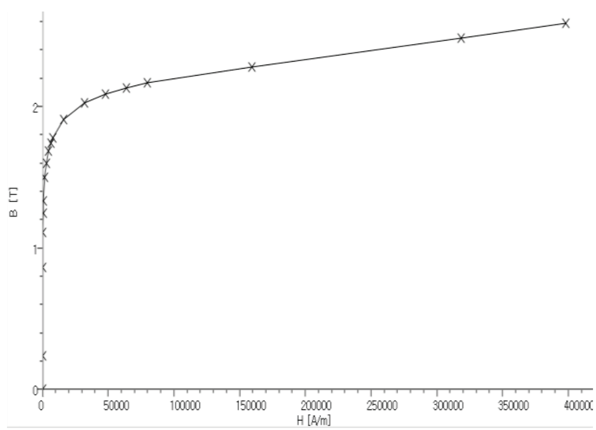

Figure 2: B-H curve of magnet material.

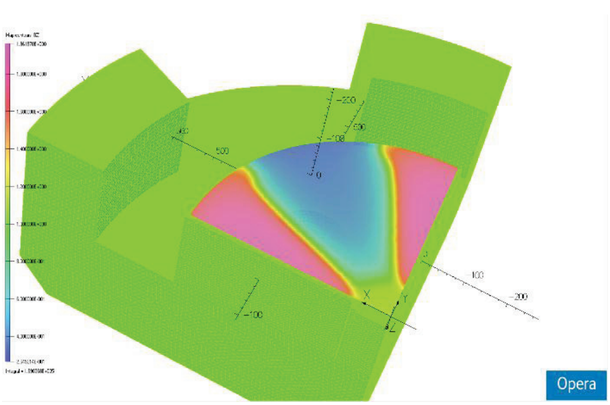

Figure 3: Magnetic field distribution in magnet pole.

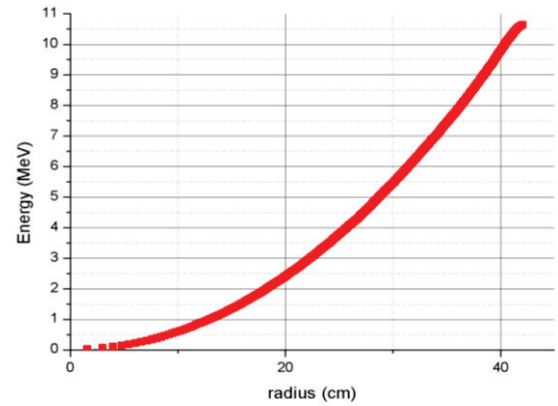

Figure 4: Energy of orbit as a function of radius.

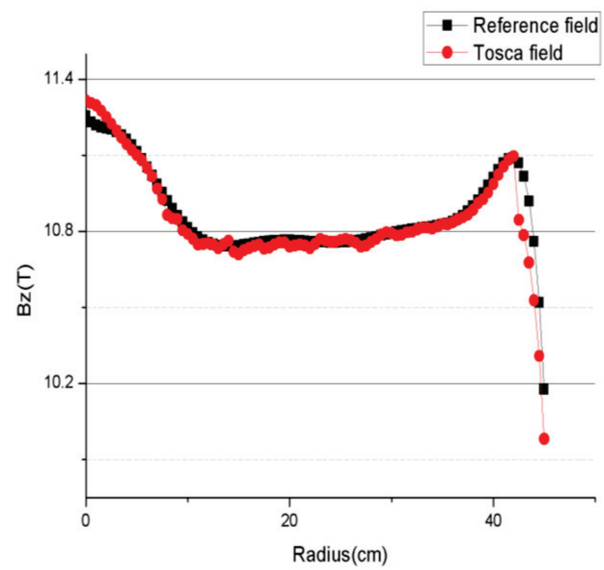

Figure 5: Comparison between Reference and Final field.

DESIGN RESULT AND CONCLUSION

In verification stage, it is checked whether integrated phase error and tunes are acceptable or not. Figure 6 shows integrated phase error. At central region, 250 gauss is bumped. So phase error is increased by -11° however, it is acceptable for isochronism. Added field is used for creating negative field gradient for more vertical focusing [5]. Vertical tune and radial tune is plotted as shown in Figure 7. Radius tune value ranges from 1.025 to 1.10 except central region and vertical tune value is from 0.55 to 0.65. Optimized field was verified by part 3 of CYCLONE code. In part 3, single particle tracking is simulated. Dee angular width 43° and Dee voltage 40 kV was set. Particle tracking is shown as Fig. 8. Tracking simulation start from an equilibrium orbit at 10.6364 MeV and decelerate for finding injection point.

ISBN 978-3-95450-128-1

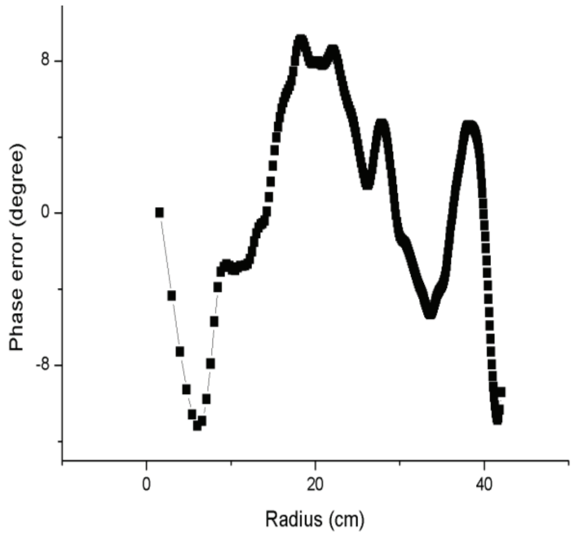

Figure 6: Integrated phase error as a function of radius.

In decelerating, orbit keeps turn separation and energy always decrease in all Dee gap. (0.0390 MeV per Dee).

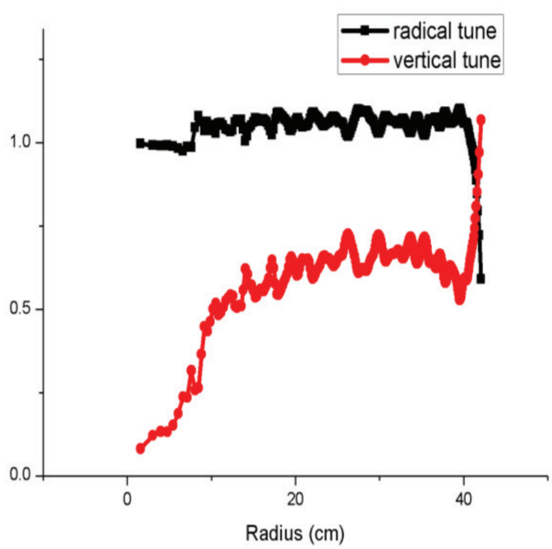

Figure 7: Tunes as a function of radius.

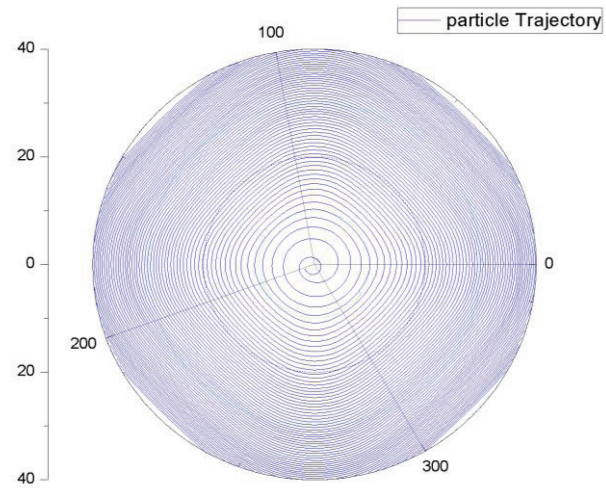

Figure 8: Particle tracking in Cyclone part 3.

DISCUSSION

Modelling of magnet and verification of simulation result are carried out in this paper. Stable isochronous field is satisfied and the parameters of the magnet depend upon other subsystem such as RF frequency and ion source. In spring of 2014, detailed magnet design including coil design, and magnetic field measurement system will be implemented.

ACKNOWLEDGMENT

This work has been supported by National Research Foundation of Korea funded by the Ministry of Science, ICT and Future Planning (NRF-2010-0025952).

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