DESIGN STUDY OF THE 30 MeV CYCLOTRON MAGNET*

J. Kang, B.H. Hong, D.H. An, H.S. Chang, I.S. Jung, J.S. Chai†,
M.G. Hur, T.K. Yang, Y.S. Kim, KIRAMS, Seoul, Korea

Abstract

Korea Institute of RAdiological & Medical Sciences (KIRAMS) has been developing a 30 MeV cyclotron that is planned to be installed at Advanced Radiation Technology Institute, Jeongeup in late 2006. The AVF (Azimuthally Varying Field) magnet of the cyclotron was designed to produce 15–30 MeV proton beam with movable stripper foil. Four directions of extractions are available with two switching magnets. The overall shape of the magnet is cylindrical. The magnet has three kinds of holes for beam injection, vacuum pumps and RF system. The valley and hill gap ratio is about 20 for higher axial focusing. The designed magnet model and its magnetic properties of the KIRAMS-30 are presented.

INTRODUCTION

Advanced Radiation Technology Institute (ARTI) was established in Jeongeup, Korea in 2005, which pursues R&D in industrial applications, food and agriculture fields. The institute had decided to introduce 30 MeV cyclotron for the production of radioisotopes. The 30 MeV cyclotron is being developed by KIRAMS (KIRAMS-30).

KIRAMS-30 consists of main magnet, two switching magnet, one solenoid and two quadrupoles. The main magnet of the cyclotron has a cylindrical shape like other general cyclotrons and supplies azimuthally varying field with four sectors. One hole is placed at the magnet center for beam injection from an external multicusp ion source. And SQQ (Solenoid-Quadrupole-Quadrupole) for beam matching between an ion source and a cyclotron is installed in that hole [1]. Four holes are placed at the valley and used by vacuum pumps and RF system [2]. It is possible to extract the beam in dual and opposite direction simultaneously using two extraction systems. The switching magnets are placed on the return yoke of the main magnet with their own return yoke. They are adjustable to bend the 15–30 MeV of proton beam from the extraction systems. In Table 1, design results of the KIRAMS-30 magnet are summarized. The cross-section view of the designed magnet when the upper part open is shown in Fig. 1.

Table 1: Parameters of KIRAMS-30 magnet.

Parameters	Values
Central field	1.05 T (63.96 MHz)
Pole radius	0.81 m
Extraction radius	0.72 m
No. of sectors	4
Hill/Valley gap	0.03 / 0.62 m
Hill angle	48°
B-field (min., max.)	0.2, 1.9 T
Tunes (ν_r, ν_z)	1.05–1.1, 0.7
Dimension	D2700 mm, H1440 mm
Weight	50 ton

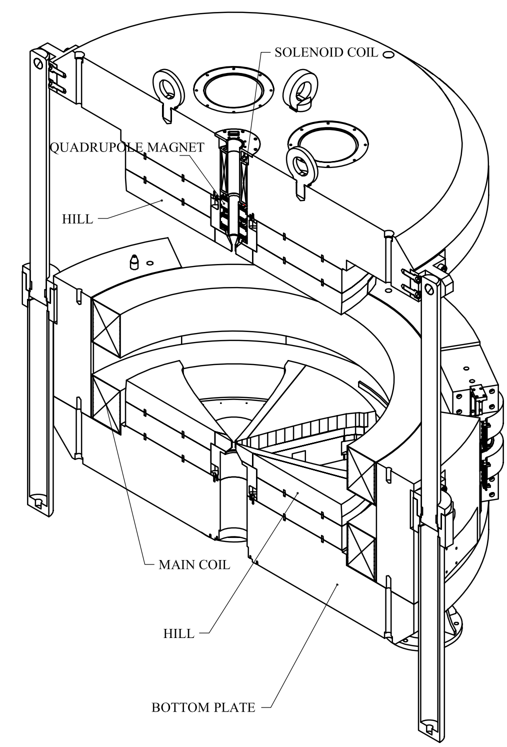

Figure 1: Cross-section view of the KIRAMS-30 magnet.

MAGNET DESIGN

The initial models of the magnets were designed by analytic calculation firstly, then 3D magnetic field analysis was carried out using OPERA-3d TOSCA solver [4].

To accelerate the H$^-$ beam to 30 MeV, 0.8 T·m magnet is needed. The central magnetic field has been set to 1.05 T. For the higher flutter and RF Q-value, the ratio of the valley to hill gap has been large.

The low carbon steel was used for the magnetic material of the magnet yoke and the BH curve of the material is plotted in Fig. 2 [3]. This BH curve was also used for non-linear computation of magnetic field.

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† jschai@kcch.re.kr

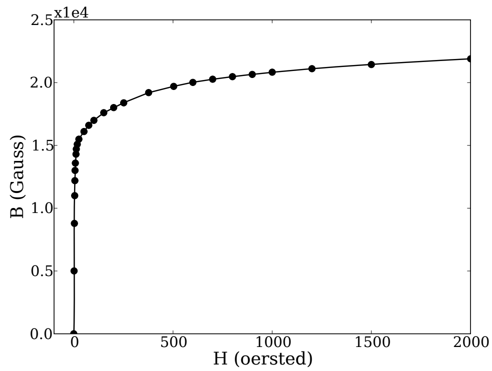

Figure 2: BH curve of the low carbon steel.

Shimming

In order to make the isochronous field of the main magnet, the sectors were azimuthally shimmed. For the shimming process, 19 design variables were considered like as Fig. 3. Each design variables are constrained radially and available in azimuthal direction. The whole shimming process was carried out using the COMI [4] and home-made batch program.

To improve the magnetic flux in the hill parts, the outer edge of the hill was tapered [5]. As a result, the mean field was gradually increased with radius as shown in Fig. 4.

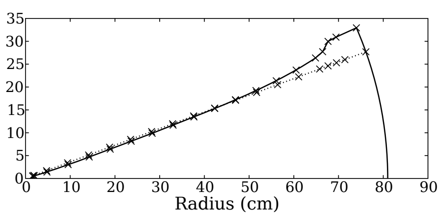

Figure 3: Design variables for hill shimming ($\times$ markers). Dotted line is initial hill shape and solid line is designed shape.

Beam Properties

After the shimming, the beam properties for the designed magnetic field were calculated. Fig. 4 shows the designed magnetic field compared with an ideal isochronous field. The radial and axial beam tunes and integrated phase shift are shown in Fig. 5–6 those were calculated from equilibrium orbits. It can be seen that the final RF phase shift is less than $\pm 3°$ in Fig. 6.

Fig. 7 shows the successive beam trajectory from 1 MeV to 30 MeV when acceleration field is applied. The field was assumed to be 50 keV at peak energy gain. The number of turns is about 200 turns. For the sake of the fine view, some trajectories are hidden. The solid lines over the trajectory shows the acceleration phase. These are well matched with the acceleration gaps that is plotted with dashed lines. The angle of the acceleration gap is 39°.

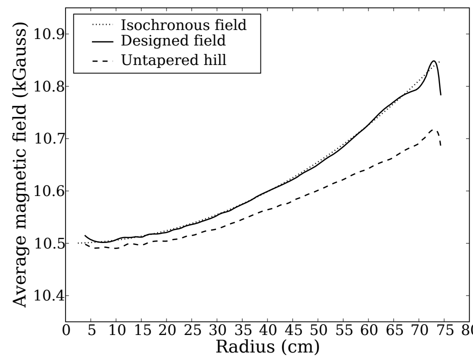

Figure 4: Average magnetic field compared with ideal isochronous field. Dashed line indicates the case of untapered hill edge.

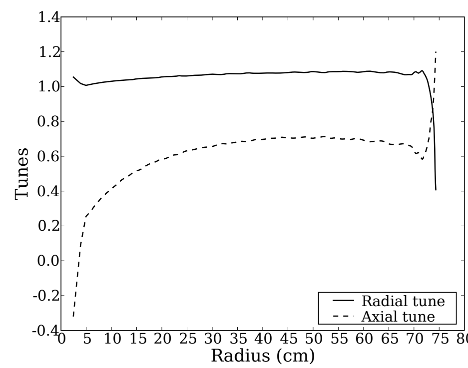

Figure 5: Radial and axial beam tunes; ν_r and ν_z.

EXTRACTION

In KIRAMS-30, H^- ions are accelerated and protons are extracted through a carbon foil. Two extraction systems are installed at return yoke in opposite side and carbon foils are horizontally movable between hill gap from 15 to 30 MeV range.

Beam tracking was simulated by OPERA-3d post processor [4] without consideration of space charge. Extraction tracks of beams at 15, 20, 25 and 30 MeV are presented

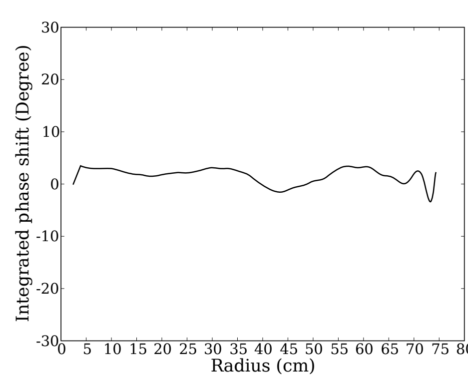

Figure 6: Integrated phase shift.

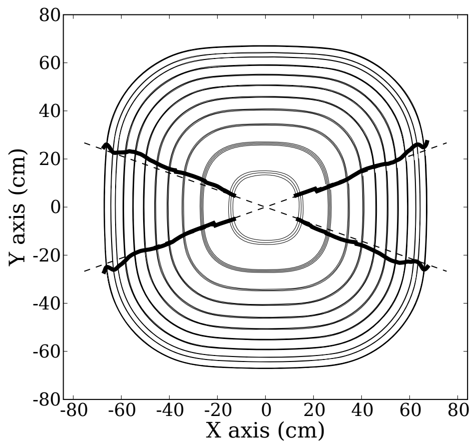

Figure 7: Spiral beam trajectory with acceleration from 1 MeV to 30 MeV. The solid lines and dashed lines indicate the acceleration phase and the acceleration gaps, respectively.

in Fig. 8. According to the polarity of the switching magnet, proton beam can be bended left or right within 20°, respectively.

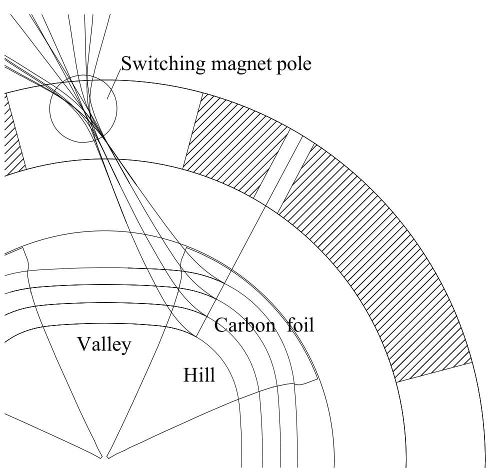

Figure 8: Tracks of electron stripped beams by carbon foil at positions of 15, 20, 25 and 30 MeV. The hatched region is return yoke.

CONCLUSION

The magnet design of a 30 MeV cyclotron was finished. Now the magnet system is being manufactured by KR Tech Ltd. [3]. The shimming work with field measurement is scheduled to be started in mid July. We are expecting to finish the development of the cyclotron magnet in September.

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