FIELD SHAPING OF KIRAMS-30 CYCLOTRON MAGNET*

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Abstract

A KIRAMS-30 cyclotron has been developed for radioisotope production by Korea Institute of RAdiological & Medical Sciences (KIRAMS). Magnetic field of the main magnet was measured and shimmed for isochronous field. Two hall probes were used for field measurement. A removable hill was introduced and shimmed by a machining center. The final field was obtained after 12 iterations of shimming process. Besides, operating current of the main magnet was examined according to energies and directions of extraction beam.

INTRODUCTION

KIRAMS has developed a cyclotron for radioisotope production in various range, 15–30 MeV. The KIRAMS-30 accelerates H^- ions from multi-cusp ion source. The central field of the main magnet is 1.05 T and the pole radius of that is 0.81 m with four sectors.

Design study of the 30 MeV magnet was achieved in 2005 [1]. Manufacture and shimming process of the magnet was started in April 2006 and finished in November 2006. The magnet comprises a main magnet, two switching magnets and solenoid-quadrupole-quadrupole (SQQ). There are four beam-lines. Each switching magnet is used to select beam direction to one of the two beam-lines. The SQQ is placed in the center hole of the top plate yoke and used for injection beam matching. Yoke of magnet was made of low-carbon-steel. The estimated weight of the magnet is about 52 tons. The height included supporters and diameter of the magnet is 1.94 and 2.7 m, respectively.

When developing the magnet of the KIRAMS-13, a lot of slice side shims were used for isochronous field [2]. This method was simple but finite to make isochronous magnetic field. In development of the 30 MeV cyclotron magnet, a removable hill was introduced for easy and precise shimming. Additionally, practical operating currents of the main coil were tuned according to the energies of 18, 28 and 30 MeV for ^{18}F, ^{123}I and ^{201}Tl, respectively.

FIELD MAPPING & SHIMMING

Field Mapping Set-up

Magnetic field measurement system consists of driving and instrument parts. The driving part comprises a linear motor, a rotational motor and an encoder for Hall probe movement. The instrument part comprises two Hall probes, two tesla meters, two digital voltmeters and a computer with control program written by LabView [3]. The range of field mapping is 0–0.805 m in radius and 0–360° in angle. The driving part was installed under the bottom plate of the magnet (see Fig. 1). The supporters are extended during field measurement, since the driving part has the length as the range of the Hall probe carrier movement. Two Hall probes are used to reduce measurement time those have been calibrated by NMR tesla meter and calibration magnet. The probes are mounted separately on a carrier and the distance between them is 0.405 m. The Hall probe carrier is boarded on a rotating plate (see Fig. 2). Mapping sequence is as followed: clockwise rotation, Hall probe carrier movement by 1 cm and counterclockwise rotation. For each rotation, 9000 points are measured. It takes 75 minutes to measure the field map of the mid-plane. The field measurement error is ±0.2 mT.

Figure 1: KIRAMS-30 magnet and field mapping system.

After the field mapping and the data acquisition, field properties and beam stability were analyzed by an equilibrium orbit calculation to minimize the field and phase errors.

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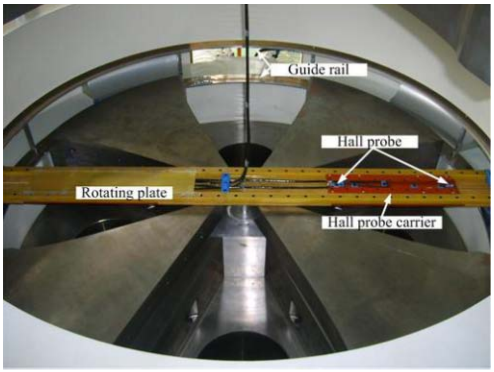

Figure 2: A rotating plate with a Hall probe carrier in a magnet. The distance between two Hall probes is 0.405 m.

Shimming

A hill is made of a big fixed part and a small removable part. This removable part is used for field shimming. There are four sets of removable hills that are called shims, totally eight shims. As a result of the field analysis, the shims are machined by a machining center. The number of shimming points is 20.

Main Coil Current Tuning

Extraction energy can be chosen from 15 MeV to 30 MeV by movable carbon stripper foil. Extraction direction is selected by the switching magnet. The field and polarity of the switching magnet is variable as extraction energies and directions. The operating current of the main coil is related to the switching magnet operation, because the main magnet and the switching magnet share return yoke. Points mapping was performed instead of whole mapping. The current of the main coil was tuned in three bend cases for two switching magnets: right-right (RR), left-left (LL) and right-left or left-right (RL or LR).

RESULTS

The SQQ and the switching magnet did not affect the field distribution of the mid-plane. Field mapping was carried out with SQQ and switching magnet powered down. The test current of the main coil was 134.064 A and the voltage was 89.6 V. The power loss was about 12 kW.

Shimming Result

The final field shape was obtained after 12 shimming iterations. Only one set of shims was machined during shimming iterations to reduce machining process. All four sets of shims were machined after the final shimming work. The thickness of the machined shim was more than 4 mm from 0.1 m to 0.76 m (see Fig. 3). At the first shimming work, some points were over-machined, consequently other points were treated.

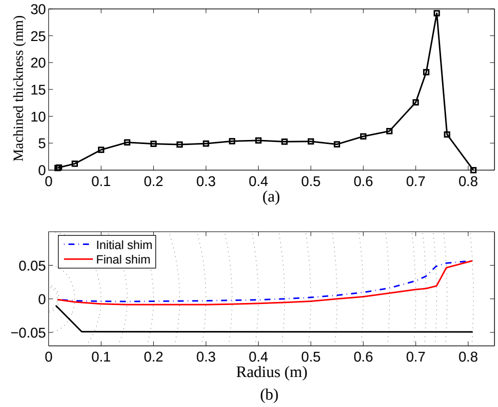

Figure 3: (a) The thickness of the machined shim. (b) Comparison between initial and final shim. There are 20 shimming points.

Field Properties

The final field map is shown in Fig. 4. There was large difference between simulation and first mapped field (see Fig. 5). The estimated extraction radii of the final mapped field are 0.5656, 0.7007 and 0.7243 m at 18, 28 and 30 MeV, respectively. The phase error of the final field is within $\pm 7 \times 10^{-4}$. The integrated phase shift is within $\pm 12°$ (see Fig. 6). The mean vertical tune was increased about 4% compare to the simulation (see Fig. 7). Accordingly, the beam is in safer region against the resonances during beam acceleration (see Fig. 8).

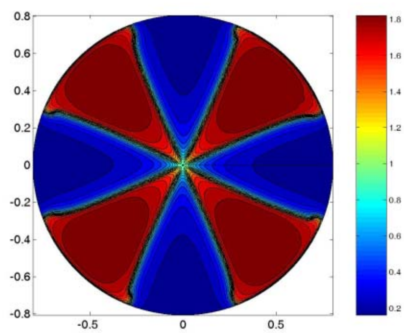

Figure 4: The magnetic field distribution of the final mapping.

Practical Operating Current

The operating currents of the main coil for the three cases are shown in Fig. 9. In the case of bending beam right, the magnetic flux of the main magnet and that of the switching magnet flow opposite direction in the return yoke. As a result, in the case of including R, higher current is needed.

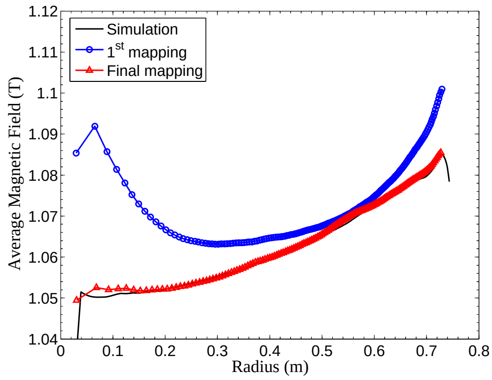

Figure 5: The averaged magnetic field of the simulated, the first and the last measured field.

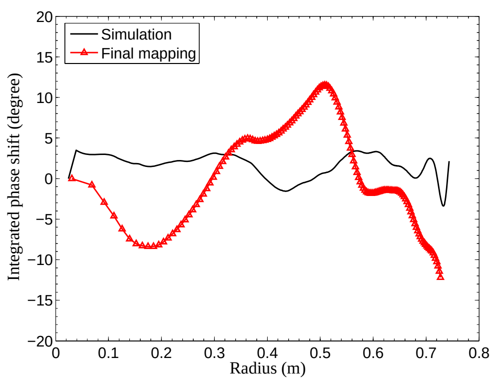

Figure 6: The integrated phase shift of the simulated and the measured field.

CONCLUSION

It was possible to obtain satisfactory field map after 12 shimming iterations. The magnet was moved to Advanced Radiation Technology Institute (ARTI), Jeongeup, Jeonbuk, Korea, December 2006 and vacuum chamber, RF resonator, ion-source and etc. were installed in turn. Beam injection test from multi-cusp ion source to inflector is in progress currently [4]. The beam focusing problem at first and second acceleration is expected. This will be managed as central region acceleration situations. Current agenda for beam extraction and delivery test is aiming 2008.

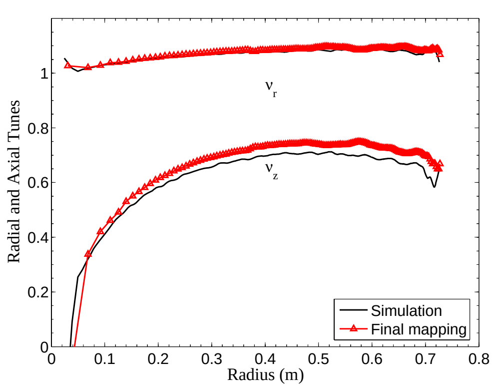

Figure 7: The radial and axial tunes of the simulated and the measured field.

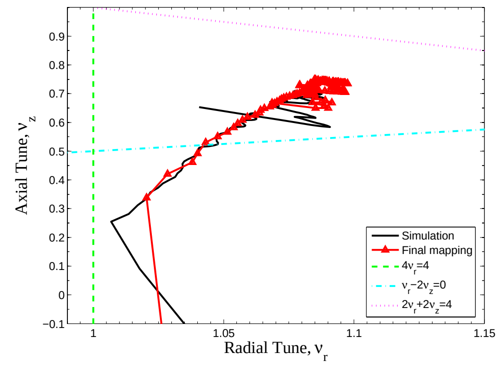

Figure 8: The operating diagrams of the simulated and the measured field with critical resonance lines.

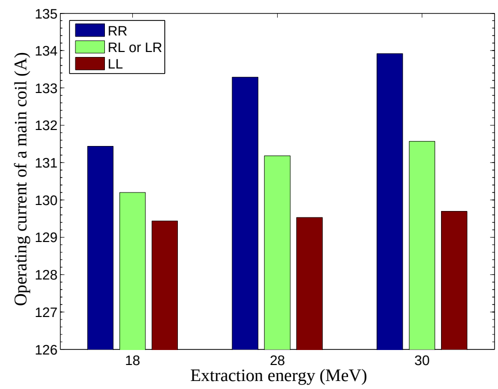

Figure 9: The operating currents of the main coil according to the extraction energies and direction of beam. R and L indicates right and left direction.

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