FIELD MAPPING SYSTEM FOR KIRAMS-30 CYCLOTRON MAGNET*

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Abstract

This paper presents a Hall probe mapping system for measuring a cyclotron magnet, which was fabricated for the 30 MeV cyclotron at the Korea Institute of Radiological and Medical Sciences. The Hall probes were mounted on a precision mechanical rotational stage and mapped magnetic field in the cylindrical coordinate system. The mapping system used the "flying" mode field mapping method to reduce data-acquisition time. The time required for mapping the whole gap-area of the cyclotron magnet was ~75 minutes. The relative random fluctuation error during the entire mapping process was less than ±0.01 %. The cyclotron magnet was corrected using the measured data of magnetic field. After the correction, the total phase excursion of the cyclotron was less than ±12°, which is within the total phase excursion tolerance of ±20 º.

INTRODUCTION

The 30 MeV cyclotron at the Korea Institute of Radiological and Medical Sciences (KIRAMS-30) has been developed for producing radio-isotopes, such as ^{18}F and ^{123}I, for positron emission tomography (PET) applications, and for ion-beam experiments [1]. The major machine parameters and the requirements of magnetic field mapping system for KIRAMS-30 are listed in Table 1. The specified relative accuracy for the magnetic field measurement is ±0.01 %.

The magnet measurement system for the KIRAMS-13 cyclotrons, which were installed on five different locations in South Korea for PET experiments, used a rectangular coordinate Hall probe mapping system because of simplicity in the drive hardware and in the measurement scheme [2]. The KIRAMS-30 cyclotron has a cylindrical type of magnet. So, the magnet measurement system for KIRAS-30 should be more complicated than the one for KIRAMS-13 and had to use a different method.

The Teslameter and Hall probes have been used widely to measure the cyclotron magnets and insertion devices, such as undulators, wigglers, and solenoids, which require a highly accurate magnetic field measurement [3, 4]. The Hall probe mapping systems for the cyclotron magnet measurement at many laboratories used the polar coordinate system [5]. However, it is very difficult to build a large wheel for the mapping stage at a moderate cost; and a thin wheel deforms in time while a thick wheel tends to be too heavy to handle.

This paper presents a Hall probe mapping system for the KIRAMS-30 cyclotron magnet and the results of the magnetic measurement.

Table 1: Major parameters of the KIRAMS-30 cyclotron

System spec.	Unit	Val	System spec	Unit	Val.
Maximum energy	MeV	30	Radio frequency	MHz	63.96
Number of sectors		4	Beam Current	μA	500
Hill gap	mm	30	Hill angle	Deg	48

Two Hall probes were mounted on one Hall probe carrier, which was driven using two motors: one for circular motion and the other for radial motion. They mapped the magnetic field in the cylindrical coordinates. To reduce the time for data acquisition, the system used the "flying" mode field-mapping method in which the data acquisition is made while the Hall probe moves [2]. Details of the mechanical mapping stage and a brief description of the electrical measurement system are given in section 2, the results of magnetic measurement are given in section 3, and a conclusion is given in section 4.

HALL PROBE MAPPING SYSTEM

Mechanical system

The magnet and measurement system were mounted on a steel plate and a rubber pad to absorb floor vibration and to compensate for uneven floor surface. Cross sectional views of the Hall probe mapping system and the KIRAMS-30 cyclotron magnet ① are given in Fig. 1. The Hall probe mapping system consists of two stages: the driving stage ② and the mapping stage ③, as shown in figure 1. The mapping stage consists of the Hall probe carrier ④, a guide frame ⑤, and two roller modules ⑥ which are mounted at both ends of the guide frame. Three small wheels are attached to the roller module: one wheel at the top and the other two wheels at the bottom side. Two circular guide panels ⑦ are installed between the magnetic coils to support the roller modules. By the help of the roller modules, the guide frame rotates continuously at the mid plane of the magnet pole gap without any friction or slow mechanical vibration.

The Hall probe carrier is installed on the guide frame. The guide frame has two v-shape grooves, which guides the Hall probe carrier smoothly to the radial direction. Each side of the Hall probe carrier has four small v-shape wheels which fit in the v-grooves on the guide frame.

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Two Hall probes are placed on the longitudinal axis of the Hall probe carrier. The separation between two Hall probes is 400 mm. The guide frame, Hall probe carrier, and roller modules are made of nonmagnetic epoxy-fiber-glass, Bakelite, and engineering plastic materials, respectively.

The driving system of Hall probe carrier for the radial motion is shown in Fig. 2. A string attached on the linear motor converts the up-down motion of the linear motor into a radial motion of the Hall prove carrier. The string is a fish-line MAX Challenge 1.2 from Samchil Co. This string was chosen after several experiments with different kinds of strings, because it should be a thin nonmagnetic string which could support very high tension. The mechanical damper adjusts tension of the string.

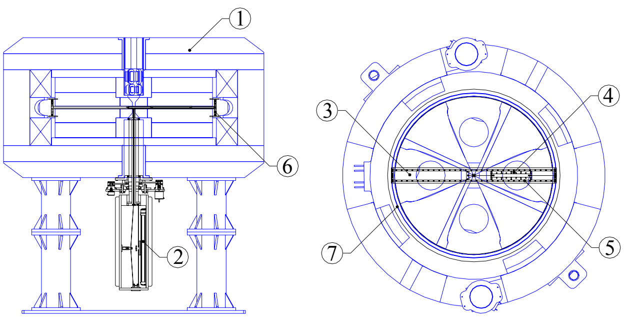

Figure 1. Cross sectional views of the Hall probe mapping system and the KIRAMS-30 cyclotron magnet. ①: KIRAMS-30 cyclotron magnet, ②: driving stage, ③: guide frame, ④: Hall probe carrier, ⑤: guide frame, ⑥: roller modules, and ⑦: circular guide panel.

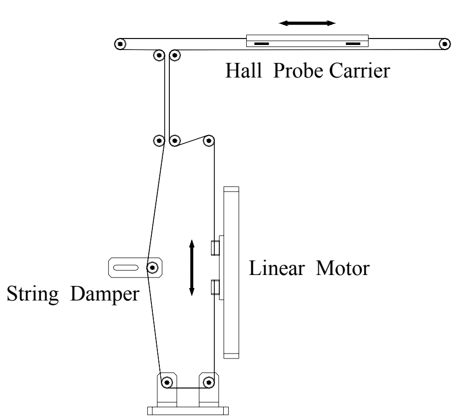

Figure 2: The drive system of Hall probe carrier for the radial motion.

Driving and data acquisition system

A block diagram of the electrical system for field mapping is shown in Fig. 3. It consists of two Teslameters, two digital voltmeters (DVMs), a stepping motor, a rotary encoder, a trigger pulse generator, a linear actuator, and a data acquisition computer. The magnetic field was measured using the DTM-141 Teslameter and MPT-141 Hall probe from Group3 Technology Ltd. The active area of the Hall probe is 1.0 mm × 0.5 mm. The output voltage of the Teslameter is digitised in HP3458A DVM from Agilent Technologies, whenever a pulse from the trigger pulse generator triggers DVM.

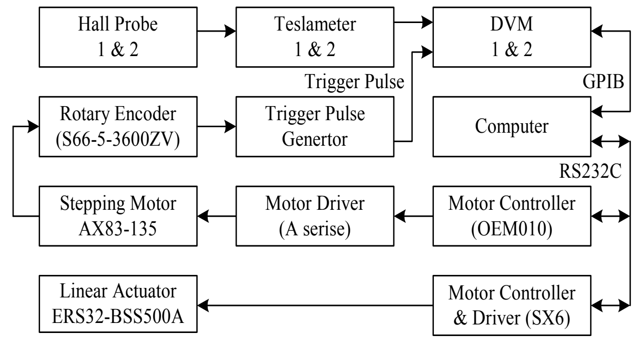

Figure 3: A block diagram of the electrical system for field mapping.

The stepping motor AX83-135, driver A-series, and controller OEM010 from Paker were used to rotate the guide frame. The stepping motor was operated by the micro-step mode in 25000 steps / revolution to obtain a smoothing movement. The rotary encoder S66-5-3600ZV from Metronics Co. and homemade trigger pulse generator outputs the 9000 pulses / revolution. Accordingly, the output voltage of the Teslameter is digitised at every 0.4° rotation of the guide frame, while the guide frame rotates continuously for the "flying" mode field measurement. The rotary encoder outputs one z-clock for every 360° revolution. The first z-clock was used as the starting point of measurement. To reduce measurement time, the magnetic fields were measured while rotating the guide frame in clockwise and counter clockwise directions. The linear actuator ERS32-BSS500A and SX6 stepping motor driver from Paker provide the radial movement of the Hall probe carrier. The stroke of linear actuator was 500 mm which is sufficient for the 400 mm distance.

MEASUREMENT RESULTS

The voltages measured using DVMs were converted into magnetic fields using the off-line calibration table and were interpolated using the cubic spline method. To measure the noise level of the measurement system, the Hall probes were put into zero-gauss chambers to shield the terrestrial magnetic field and they were mapped on the mapping stage. The system noise data were sampled every 0.4° for 360° and the results are about ±2.0 Gauss.

The results of Hall probe mapping for the KIRAMS-30 cyclotron magnet at an excitation current of 134 A is shown in Fig. 4. This figure shows a typical profile of a magnetic field for a cyclotron magnet. The measured magnetic fields at the hill and valley are ~ 1.9 T and ~ 0.2 T, respectively.

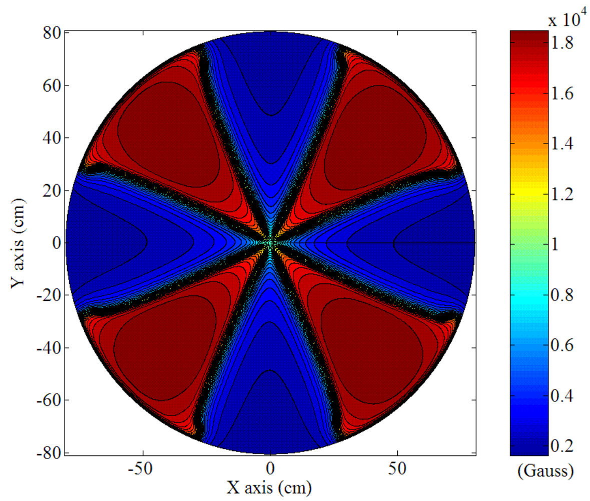

Figure 4: The measured field profile of the KIRAMS-30 cyclotron magnet.

The magnetic field profile of initial magnet was significantly different from the designed one, due to various reasons, such as differences in magnet material, fabrication error, etc. The measured magnetic field data were used to correct the magnet. The correction was made on the sidewalls of magnet by adding or removing iron shims, and it was repeated until the magnetic field profile was close to the designed one.

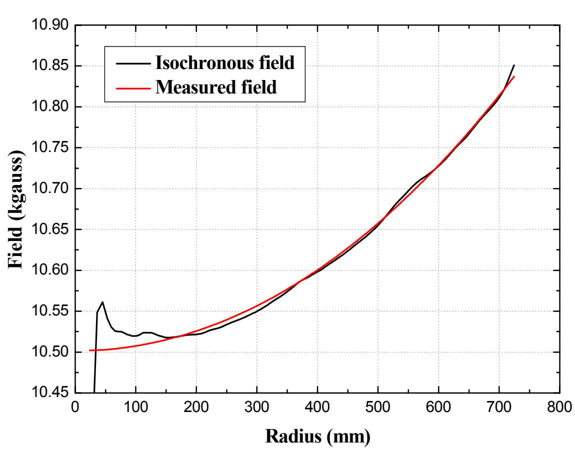

Figure 5: The average magnetic field along the isochronous field as a function of the average radius.

The model and measured average magnetic field along the isochronous field is shown in Fig. 5. The difference between the designed and measured fields is ~0.1% which can be compensated easily by adjusting the RF frequency.

The total phase excursions versus average radius for the measured field are shown in Fig. 6. These results indicate that total phase excursion after correction is less than ±12°, which is well within the tolerance of ±20 ° for the KIRAMS-30. Further details on the magnetic measurement and analysis are described in [6]. The KIRAMS-30 cyclotron was installed at the Advanced Radiation Technology Institute in Jungup city in 2007, and it is operating well at a beam current of 500 μA .

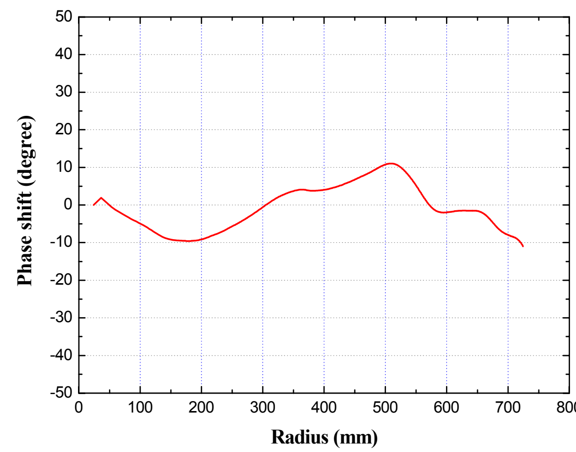

Figure 6: Phase excursion of a particle versus average radius.

CONCLUSION

A Hall probe mapping system has been developed for measuring the KIRAMS-30 cyclotron magnet. It uses the "flying" mode field mapping method to reduce data-acquisition time, and maps the magnetic field in the cylindrical coordinates. The time required for mapping the whole gap-area of the cyclotron magnet is ~ 75 minutes, the field data are sampled at a step of 0.4° in the circular-direction and 10 mm in the radial-direction. The relative random fluctuation error during the entire mapping process is less than ±0.01 %. The cyclotron magnet has been corrected using the field measurement data, and the achieved total phase excursion of the cyclotron after correction is less than ±12°.

REFERENCES

[1] J. Kang, et al., "Design Study of the 30MeV Cyclotron Magnet", EPAC 06, Edinburgh, England.
[2] K. H. Park,, et al, " Field Mapping System for cyclotron Magnet", NIMA 545, 2005, pp 533-541
[3] S. Marks, " Precise integration of undulator Hall probe scans", IEEE transactions on magnetics, Vol. 30, No. 4, 1994, pp. 2435-2438,
[4] K. H. Park, et al, "A New Method of Field Measurement for Solenoid Magnet", JKPS, Vol. 50, No. 4, April 2007, pp.950-954
[5] M. Fan et al., "Measurement and adjustment of CIAE medical cyclotron magnet", PAC 1993, Vol. 4, 1993, pp. 2841-2843
[6] S. H. Shin, et al., "Measurement and Analysis of a 13 MeV Cyclotron Magnetic Field", JKPS, Vol. 45, No. 4, October 2004, pp.1045-1051