MAGNETIC FIELD MEASUREMENT OF RIKEN IRC SECTOR MAGNETS

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Abstract

Magnetic field measurements of the RIKEN IRC sector magnets were made with a newly constructed field mapping system. Using mapping data of the base and trim coil fields for several field levels, production of the isochronous field for a typical ion beam was attempted and the measured field was compared with the expected one.

1 INTRODUCTION

The RIKEN IRC is a K980-MeV intermediate-stage ring cyclotron[1] for RIKEN RI Beam Factory project[2]. The IRC was completed this spring and will be installed in 2003 after the completion of the buildings. The IRC has four normal-conducting sector magnets. Their parameters are listed in Table 1. The sector magnets were assembled in the factory (Sumitomo Heavy Industries, Ltd.) and magnetic field measurements were performed. Because of the space limitation, only two of the four sector magnets were aligned and measured. The purposes in the field measurements are not only to verify the basic performance but also to obtain the magnetic field data in order to form the isochronous field distributions for beams with a wide range of energies from light ions to uranium. Items of the magnetic field measurement follow those performed in the measurement of the RIKEN K540-MeV existing ring cyclotron[3].

2 FIELD MESUREMENT SYSTEM

Figure 1 shows a plan view of the field measuring apparatus. Eight Hall probes are placed on the Hall assembly at intervals of 200 mm. The Hall assembly is driven in the radial and azimuthal directions with pneumatic pistons. The parameters of the driving are listed in Table 2. It takes longer than 3 sec for one driving time because the friction of air flow is large in the tube with a length of greater than 30 m. The positional error of the Hall probes was about 2 mm at the maximum, which came from alignment error of the rails and the slack of the driving system.

Table 1: Parameters of the IRC sector magnet.

Number of sector magnets	4
Sector angle	53 degrees
Pole gap	80 mm
Aperture of beam chamber	52 mm
Weight	680 tons
Maximum magnetic field	1.9 T
Maximum magnetomotive force	450 A x 396 turns
Number of trim coils	20 pairs

Table 2: Parameters for driving of the Hall assembly.

	Range	Step	Time
R	730mm	10mm, 20mm, 30mm	3.5 sec
θ	180°	0.25°, 0.50°, 0.75°	3.8 sec

The Hall probes (HHP-MU, AREPOC Ltd.) were calibrated with an NMR gaussmeter in advance. Since the temperature coefficients of the Hall probes were about 1.5 x 10^{-4} per degree, we measured the temperature of the probes and corrected the output voltages by the temperature coefficient of each probe. As a result the measuring accuracy of magnetic fields was within about 2 x 10^{-4}. The output voltages of the Hall probes and the temperature sensors (Pt resistor) were measured with data acquisition unit (AT34970A) with a GPIB interface.

3 MAGNETIC FIELD

3.1 Base and Trim Coil Field Distributions along the Sector-center Line

Base and trim coil fields were measured along the sector-center line. Figure 2 shows the normalised distributions of the E-sector base field at seven levels of main coil currents (100, 180, 240, 290, 330, 380 and 445.5 A). The magnetic field strengths of the N-sector was smaller than that of the E-sector by 0.1 % to 0.25 %.

The measurement of the trim coil fields was made for E-sector magnet. Twenty trim coils were excited one by one in order by half of each maximum current, and the

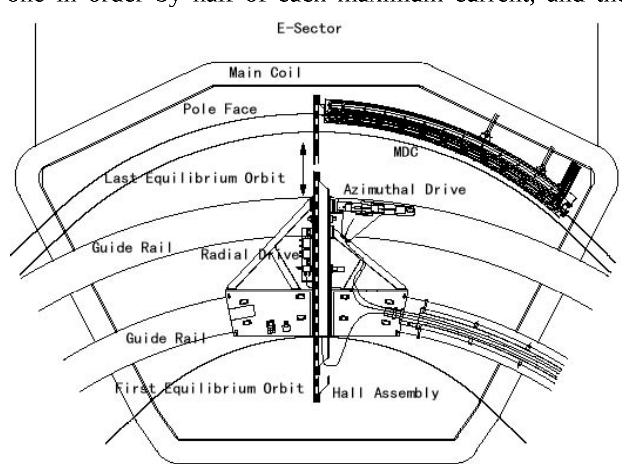

Figure 1: Plan view of the IRC magnetic measuring apparatus.

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference,* edited by F. Marti

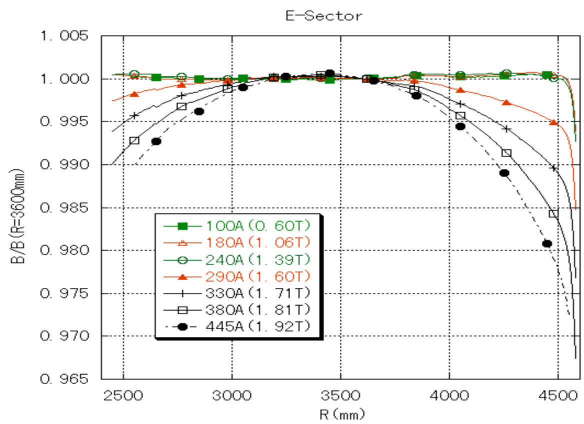

Figure 2: Normalised base field distributions along the center line of the E-sector magnet.

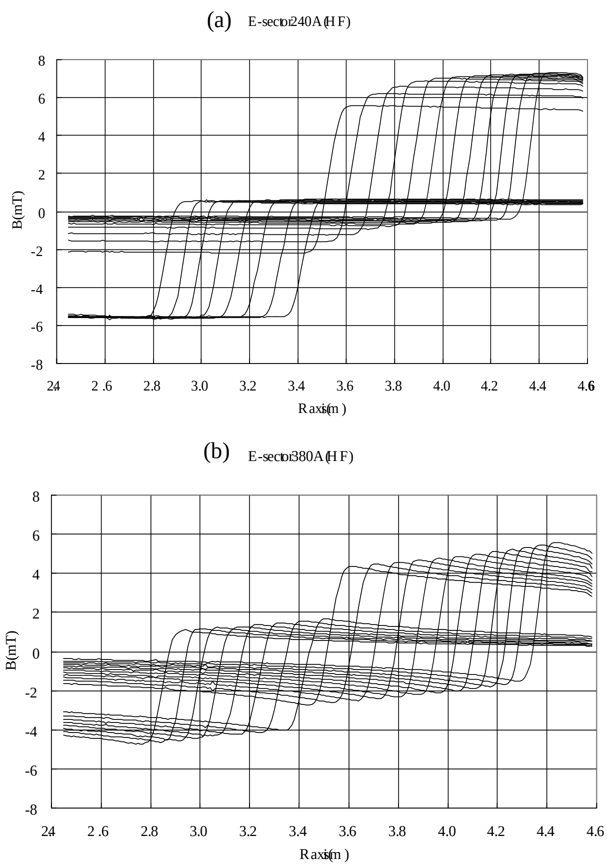

Figure 3: Trim coil field distributions along the sector center line at (a) 240A(1.4T) and (b) 380A(1.8T). Current of the trim coils was half of each maximum value.

magnetic field distribution along the sector-center line was measured in every step. After all the trim coils were excited by half strength, the measurements for the maximum strength were made in the same way. Each measurement was made after 15 min of the excitation of each trim coil. Figures 3(a) and 3(b) show examples of the field distributions of the trim coils. It is noted that the

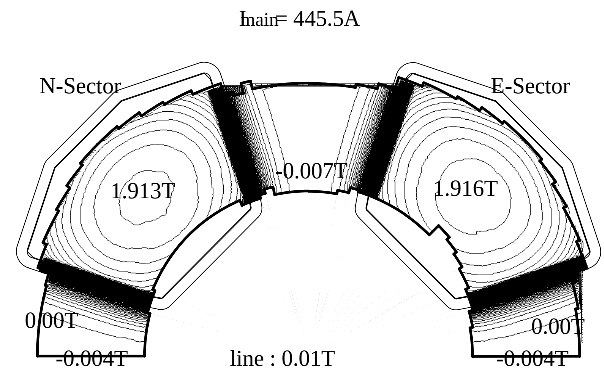

Figure 4: Contour plot of the magnetic field of the E-sector and N-sector magnets. Main coil current is 445.5 A.

eight inside coils are wound around the nose of the pole and the other around its back. These field distributions were taken at main current levels of 180, 240, 290, 330, and 380 A.

3.2 Field Map

Figure 4 shows an example of contour plot of the magnetic field obtained from the mapping measurement. The size of the mapping mesh was 10 mm and 0.25° in the radial and the azimuthal directions, respectively, in the pole edge area where the magnetic fields change rapidly. On the other hand, the mesh size was 20 mm and 1.0° in other regions. It took 13 hours to measure all of the points of 34,333. These mapping measurements in the region of 180 degrees were made at seven levels of main coil current.

4 ISOCHRONOUS FIELD

4.1 Derivation of the Isochronous Field

To obtain the required isochronous field distribution along the sector-center line, we use a conventional method[4]. In this method, two ratios are defined:

$$K_b = B_{axis}(r_{axis}) / B_{ave}, \quad K_r = r_{axis} / r_{ave}.$$

Here B_{ave} and r_{ave} are the field strength and radius averaged along the equilibrium orbits. B_{axis} and r_{axis} are those at the sector-center line. Using the two ratios, we obtain the isochronous field along the sector-center line,

$$B_{axis}(r_{axis}) = (Am_0c^2 / q)(2\pi f_{rev} / c^2)\gamma K_b$$

where A is the mass number, q is the charge of the ion, f_{rev} is revolution frequency and γ is calculated from

$$\beta = (2\pi r_{axis} / K_r) \cdot (f_{rev} / c).$$

Figure 5 shows Kb and Kr values calculated from the map measurement data of the base fields at seven current levels. The orbit calculation was done in the region of 90 degrees between E-sector and N-sector center lines. The

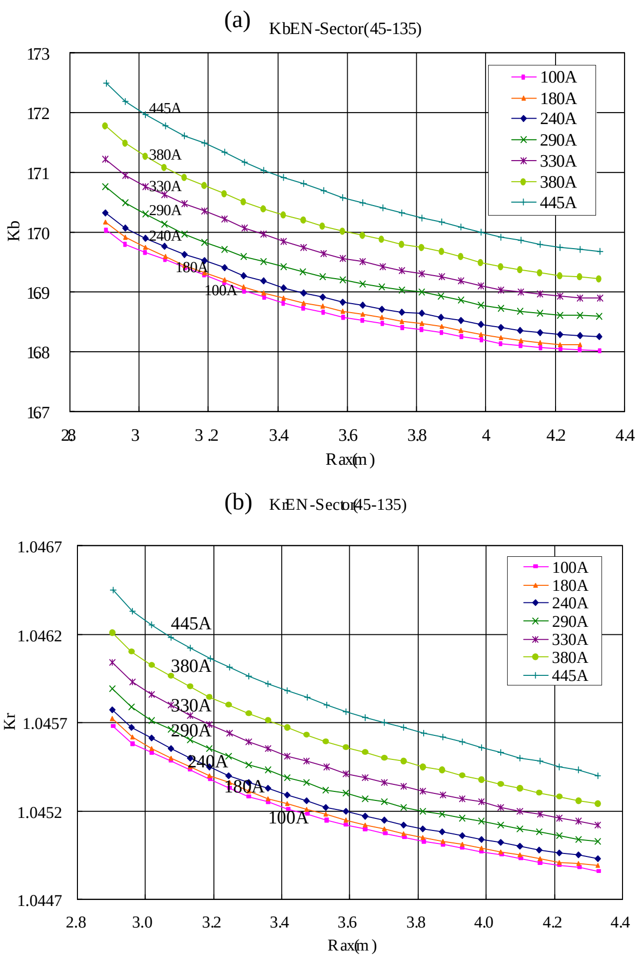

Figure 5: (a)Kb and (b)Kr calculated from the mapping data for base fields.

Kb and Kr values when all the trim coils were excited at the half and the maximum strengths made small differences from those for the base fields. The effect on the perturbation by injection and extraction elements will be measured.

4.2 Trial to Produce Isochronous Field

We tried to form the isochronous field for $^{19}F^{+7}$ beam whose an extraction energy is 127 MeV/u. The field distribution required on the sector-center line was calculated by using interpolated Kb and Kr values. Then each current of the main and trim coils was calculated from the fitting of the field distributions along the sector-center line of the base and trim coil fields. The currents thus obtained were actually fed to the coils and the field mapping measurement was made. Figure 6 shows the required and the measured field distributions along the sector-center line. The isochronous field calculated by 3D magnetic field calculation code TOSCA is also shown. Figure 7 shows the deviations between the required and the measured distribution for the field strength on the sector-center line and the average field along the equilibrium orbit. The average deviation of about 0.13% for both distributions corresponds to an error in the calculation of main coil current. By adjusting the main coil current, this constant deviation can be compensated and the beam can stay in the rf acceleration phase up to the extraction. Use of Kb values with the trim coils being excited, better selection of the trim coil fields, and so on will improve the calculation of isochronous field.

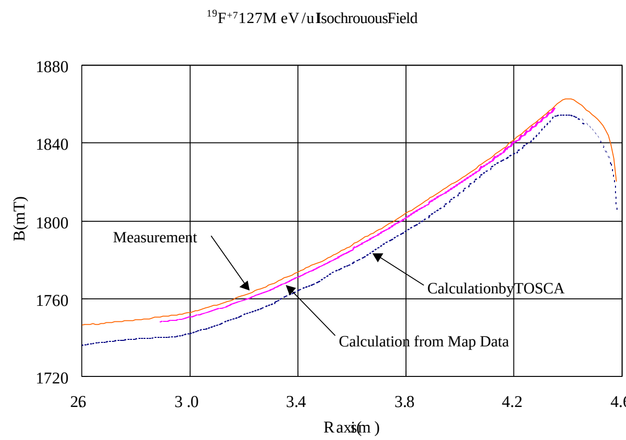

Figure 6: Isochronous field distribution along the sector-center line for 127 MeV/u F^{+7}

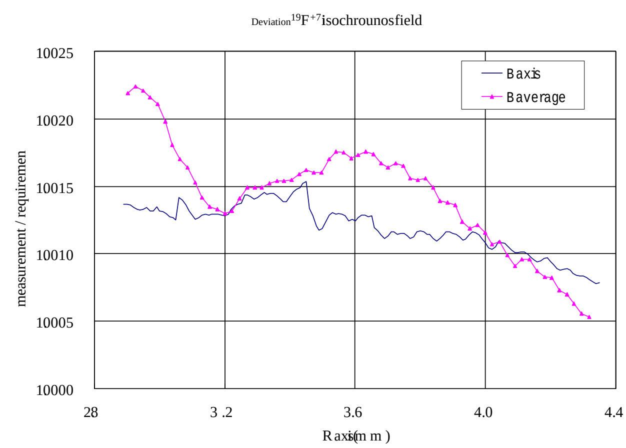

Figure 7: Deviation between the expected isochronous field and measured one.

5 CONCLUSION

We made the magnetic field measurement of RIKEN IRC sector magnets and obtained basic data for producing isochronous fields. We plan to measure the remaining two sector magnets and the magnetic perturbation from the injection and extraction elements.

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