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Three Dimensional Field Analysis of Helical Snake Magnets for RHIC

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Spin Note

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THREE DIMENSIONAL FIELD ANALYSIS OF HELICAL SNAKE MAGNETS FOR RHIC

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Abstract

RIKEN - Brookhaven National Laboratory (BNL) Spin Project is in progress. The accelerator aspect of this project is to accelerate polarized proton beams to the top energy of Relativistic Heavy Ion Collider (RHIC). For this purpose, it is necessary to develop super conducting magnets of helical structure as a Siberian Snake for the control of the polarized beams. In this design work, it is shown that the two dimensional analysis was insufficient to estimate the multipole components, fringing field and longitudinal component of the field. Then we calculate three dimensional (3D) magnetic field using the computer code TOSCA. Also the analysis of beam orbit and spin motion of polarized protons in Siberian Snakes are done using the results of 3D field calculation.

1 INTRODUCTION

The RHIC - Spin Project, a joint project between BNL and RIKEN, was started in 1995 as a 5 year venture. We are collaborating with BNL-accelerator group and promote research in polarized beam acceleration from 25 GeV to the top energy of 250 GeV at RHIC.

Generally, precession of the particle being accelerated in synchrotrons is resonant with the alternative magnetic fields which decrease the beam polarization. A device called Siberian Snake controls an axis of spin by making magnetic fields and can overcome the depolarization in Synchrotron. In RHIC a method called Full-Snake is adopted and a pair of snake magnets will be arranged at each ring. To minimize the excursion of beam orbit, the combination of four super conducting helical magnets will be used. These magnets have twisted dipole structure and are expected to reach a magnetic field strength of approximately 4 T. The role of the snake magnet is to rotate the spin axis by 180 deg. precisely without any orbit displacement and any deflection.

Three dimensional analysis had not applied for the Snake magnet because of its complex structure, 3D field calculation is, however, indispensable to designing the helical dipole magnets considering parallel field component to the beam axis and studying spin motion in fringe fields. Thus, we have begun to analyze 3D magnetic field using computer code TOSCA.

2 COMPARISON WITH MODEL MAGNET

Part of a helical magnet was built as a model by BNL, and the magnetic field measurement was done last year. This model corresponds to the inner part of helical magnet that consists of two layer coils, and rotation angle becomes 140 deg. The inner bore diameter is 10 cm, and the length is approximately 1 m. The conductors are arranged in a groove machined on the outside of an aluminum cylinder. We input conductor arrangement of this model into OPERA-3d which is pre and post-processing system of TOSCA, and did comparison with model test measurement.

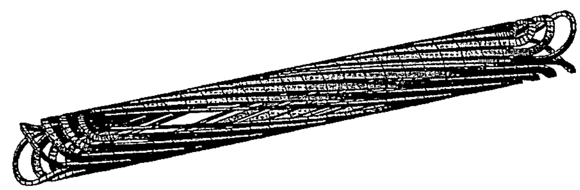

Fig. 1 The model of helical dipole magnet.

Fig. 1 shows coil structure drawn by OPERA-3d. The end regions of inputted coils are different from the fabricated model, because the conductors were not arranged along grooves at that region of the actual model.

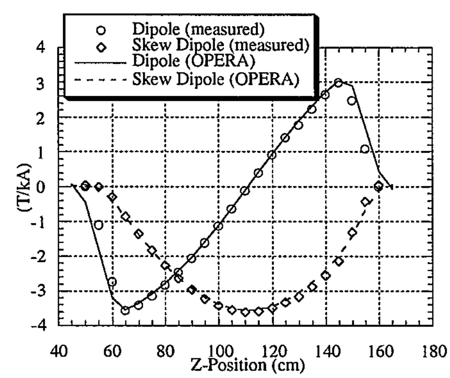

Fig. 2 Dipole component of the model magnet.

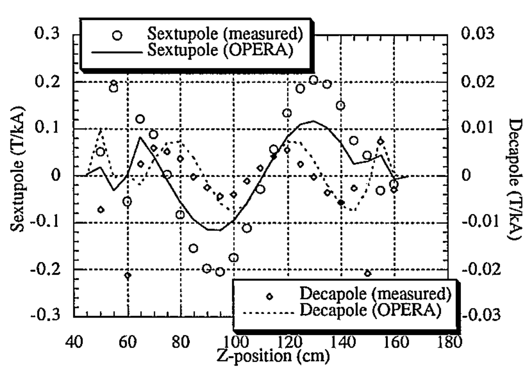

Fig. 3 Sextupole and decapole component of the model magnet

Effective length	2.402	2.401	m

The measured and calculated multipole components of magnetic field are shown in Fig. 2 and 3. The vertical axis is normalized by a current running down super conductive cables. The horizontal axis indicates position along the beam axis. Each value was found by Fourier analysis of measured and calculated azimuthal fields along the circle at a distance of 2.24 cm from axis. The reference radius of Fourier expansion is 2.5 cm. In the helical dipole magnets, the expression of multipole component should be more complex so that a longitudinal magnetic field exists. Figure 2 shows dipole component (Bv) and skew dipole component (Bh). Figure 3 presents sextupole and decapole components. The large differences of these shapes at both sides of graphs are due to the different shape of coil at end region.

3 MAGNETIC FIELD CALCULATION OF THE HELICAL DIPOLE MAGNET

We have converted a half length model which is now being fabricated by Magnet Division of BNL to whole length magnet twisted by 360 deg., and analyzed the 3D magnetic field using TOSCA. The bore diameter and the effective length of the magnet with two layer coils are 10 cm and 240 cm. As for yoke, the length, inner diameter and outside diameter are 262 cm, 16.8 cm and 35.6 cm respectively, and inner diameter at end part only is widened to 22.9 cm to prevent quench. The whole of helical magnet drawn by OPERA- 3d is shown in Fig. 4.

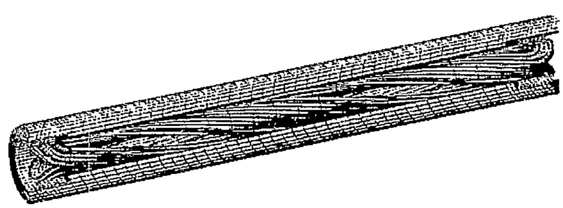

Fig. 4 Helical magnet with yoke.

Table 1 Results of 3D feild analysis for two helical magnets

	Low current	High current	
Field strength at the center of the magnet			
	1.179	4.131	T
Integrated field along the axis			
$\int B_{total} dl$	2.841	9.940	Tm
$\int B_v dl$	1.14E-2	1.322E-2	Tm
$\int B_h dl$	-1.044E-4	-4.718E-4	Tm
Effective length	2.401	2.401	m
Integrated field above 3 cm from axis			
$\int B_{total} dl$	2.885	10.12	Tm
$\int B_v dl$	9.097E-3	8.900E-3	Tm
$\int B_h dl$	-2.954E-4	-8.781E-4	Tm

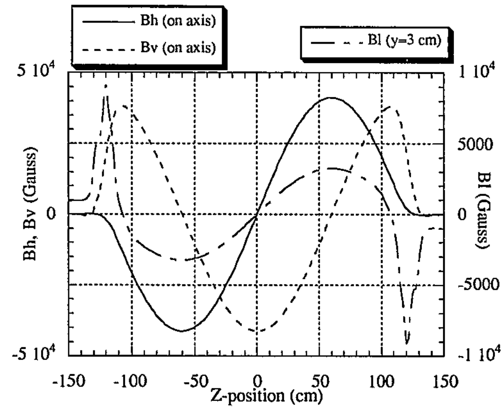

Fig. 5 Calculated magnetic field distribution in helical dipole magnet.

Fig. 5 shows calculated results. Bh and Bv indicates horizontal and vertical components of the field on the magnet axis of magnet. The component parallel to beam direction on the axis should be zero, but Bl shows the value of the longitudinal field along a line 3 cm from the axis. Bl reaches 0.9 T at the end section and reaches 0.3 T at helical section when maximum field strength is 4.1 T on the axis. The integrated fields of each component are shown in Table 1.

4 SPIN TRACKING

As for ideal Snake magnet, the field can be decomposed simply into the vertical component expressed as cosine. function and the horizontal component expressed as sine function. According to our estimation, the spin axis completely turns over 180 deg. without any displacement of beam orbit, when the series of field strengths in each ideal four helical magnets are +1.25 T, -3.99 T, +3.99 T, -1.25 T. Then we calculated particle orbit and spin motion described by the Thomas- BMT equation[1], using the field maps created by TOSCA.

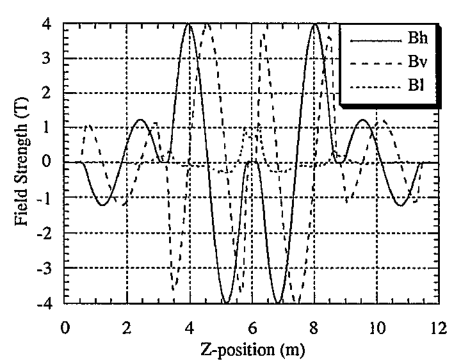

Fig. 6 Magnetic field along the particle trajectory in the Snake magnet.

Figure 6 shows magnetic field along the trajectory of the particle injected at γ=27 on axis. Figure 7 shows diceplacement of that particle. The displacement of particle increases up to 3.0 cm at the center of Snake magnet, and the particle will pass through strong fringe field. The effect of the longitudinal field becomes significant in the region between the inner magnets of the Snake, first because of the 3 cm excursion of the beam and second because of the contribution from the two magnets enhance the strength of the longitudinal field. The calculated spin motion in the Snake magnet is shown in Fig. 8.

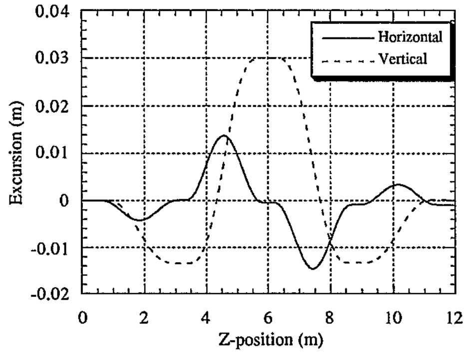

Fig 7 Calculated orbit in Snake magnet.

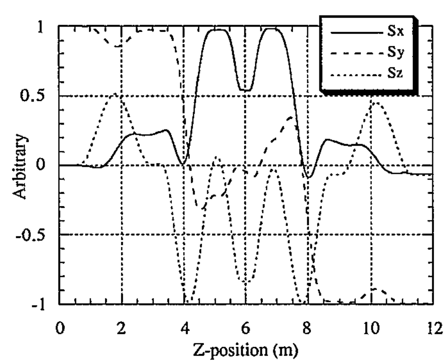

Fig. 8 Spin motion in the magnetic field created by 3D analysis.

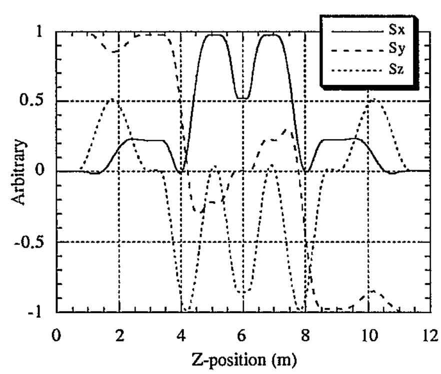

Fig. 9 Calculated Spin motion neglecting the longitudinal magnet field component.

The spin axis pointing to up of spin precession is almost flipped after passing through the Snake magnet, yet the axis inclines 5.56 deg. from ideal. Figure 9 indicates the result using same field map but neglecting the longitudinal field component. In this case, the direction of spin axis completely turns over 180 deg., so the effect of the longitudinal field component is clear. It is important that the influence of fringe field on spin motion varies as a function of an energy of polarized particle. In high energy particle case, both of orbit displacement and the effect of fringe field including longitudinal component become smaller, and the motion of spin axis towards to ideal.

5 RIKEN MODEL MAGNET

At present two types of the half length super conducting helical magnets are being fabricated by BNL and Advanced Magnet Laboratory (AML), inc. In both types, thin cables (ϕ=1 mm) are used with the low current operation about 400 A to reduce the heat leak through power feeds. Fabrication of thele types of the helical magnest may includes many challenging techniques to fix such thin cables in helical shape not to cause quench. The alternative designing way is in progress at RIKEN. We will use Rutherford cables with operational current of about 3000 A. The heat leak of this rather high current flowing should not be exceeded the present capacity of the cryogenic system of RHIC. The 3D field analysis is taken into the consideration to optimize the longitudinal field at the end region and the multipole component of the magnet. Including these analyses, the engineering design work of RIKEN type magnet will be finished.

6 CONCLUSION

Three dimensional magnetic field analysis in complex helical magnet was done with computer code TOSCA. We studied the spin motion in Snake magnet, and showed the effect from the field component parallel to magnet axis can not be neglected.

7 ACKNOWLEDGMENT

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