THREE DIMENSIONAL FIELD ANALYSIS OF HELICAL MAGNET FOR RHIC SIBERIAN SNAKE

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Abstract

Siberian Snakes that consist of four helical dipole magnets will be installed in the Relativistic Heavy Ion Collider (RHIC) to preserve the polarization of the proton beam. To promote this project we are collaborating with Brookhaven National Laboratory (BNL) in studying helical magnet designs. At present, two types of helical magnets are being developed. One is being designed by the BNL magnet group, and the other by Advanced Magnet Technology (AML), Inc. These magnets use the same superconducting cable but have different shapes especially in the end regions. We are evaluating the performance of both magnet designs using the three dimensional (3D) magnetic field analysis code TOSCA. In particular, saturation effect, field strength, multipole component and magnet quenching features will be discussed.

1 INTRODUCTION

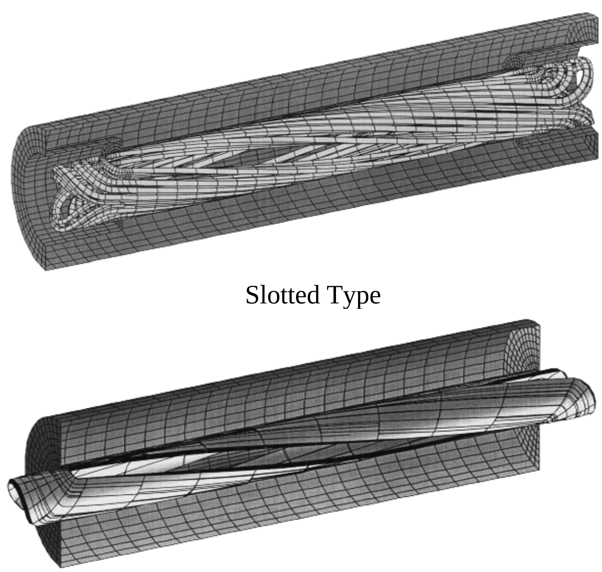
We have studied the Siberian Snake[1] for the RHIC-Spin project and the development of the super conducting helical dipole magnets are one of the key issues to the success of this project. Two types of designs for these magnets are being evaluated and the half length model magnet of each type was recently fabricated and the quench performances were tested. The first, called the Slotted Type[2], was designed by the BNL magnet group and the other, called the Direct Wind Type[3], was developed by the AML. Using TOSCA, we have calculated 3D magnetic fields of both built models and investigated these characteristics.

2 DEMANDED PERFORMANCES

The Siberian Snake magnets adopted by RHIC are a type called Full Snake, and have to flip the spin direction by 180 degrees without any influences to the beam orbit. Using the helical dipole magnet twisted by 360 degrees, the transverse magnetic fields the accelerated particles feel are cancelled and the deflection of the beams is eliminated. Furthermore the symmetric combination of the helical dipole magnets, as sequence of 1.2 T, -3.9 T, 3.9 T and -1.2 T fields, can evade the shift of the beam orbit. Therefore the required performances for each helical dipole magnet are to achieve more than 3.9 T of the field strength and zero transverse fields when integrated along the particle trajectories. The optimization of the multipole components is also important to avoid a tune shift. From the cryogenic point of view, in RHIC, it is needed to minimize the heat leak from these magnets. On this account, the Rutherford type cable which is used for usual magnets is not adopted, and a thin cable of 1 mm diameter comprise of seven wires will be applied. As a result, the design of the helical dipole magnets became different from a conservative design.

3 TWO TYPES OF THE MAGNET DESIGNS

As mentioned above, there are two types of magnet designs, the Slotted Type and the Direct Wind Type, for the superconducting helical dipole. The fabricated models have half sized length, and these are twisted by 180 degree. Figure 1 shows these magnets.



Slotted Type

Direct Wind Type

Figure: 1 The half length models for the Siberian Snake. Only halves of the yokes are drawn not to hide the coils.

In Slotted Type construction, the cables are wound along the slots machined on a column of aluminum, and finally pressuring radial direction, wound cables are hardened with epoxy in the slots. The coil winding was done by hand work basically, and mastery of skills and long production time are necessary. A study of the automation winding for this type was just begun at BNL. On the contrary, the coils of Direct Wind Type are wound by a numerically controlled machine and this procedure is completely automated. At first, a cylinder wrapped with fiber grass is grooved along the location of first layer cable. Then the cable of first layer is wound up on the groove, and the second or next layer is wound up on the gap from previous cables. Thus, the positions of each cable are fixed, once the groove on the cylinder was decided. As a result, a packing factor of the conductor is maximized. In addition, a turn number of upper layer is always less than that of lower layer. Most important difference between these models is in the shape of the coil end. As for Slotted Type, the coil end is divided into upper side and lower side and this configuration is the same as ordinary magnets. On the other hand, as for Direct Wind Type, all of the conductors turn around on one side, upper or lower, without being divided. Accordingly, length of end gets longer comparatively. About the magnetic fields at the end, non-symmetric distribution is expected. It is possible to adopt a design of the end divided into up and down as same as Slotted Type. However, in this case, the coil at the body region also should be divided into two coils. Since wound cables at the median plane except the first layer can not be accumulated, then the cables are not wound efficiently at the area which contributes most effectively to induce the dipole magnetic field.

3 3D ANALYSIS OF THE FIELDS

3.1 Peak fields survey

In both half length models, the peak field strength at body region and the end region were estimated using TOSCA. The results are shown in Table 1.

Table: 1 Peak fields in helical dipole magnets.

	Center Field	Peak Field in Body (Ratio)	Peak Field in End (Ratio)
Slotted Type	4.16 T	4.67 T (1.12)	4.59 T (1.105)
Direct Wind Type	3.91T	4.74 T (1.21)	4.43T (1.13)

In both magnets, the peaks of the bodies are found at inner edge of the coil which is nearest to the poles, and the peak of the end found at the most inside edge of the curved coils. If we can fix entire coils of the helical magnets in an ideal condition, the Slotted Type coil will reach a critical current with the body part, and the Direct Wind Type with the end part. The relationship between the critical current of the cable and expected peak fields are shown in Fig. 2. In the Slotted Type, a cable in the body part reaches a critical current at 395 A, and then the dipole field strength near beam axis becomes 5.3 T. In Direct Wind Type, a cable at the end part reaches critical current at 480 A, at that time the field strength near the axis is 4.4 T. The Slotted Type magnet was designed to be used two currents, 9 to 11, and in order to increase the maximum field strength around the axis, the coils in stronger field have a lower current. The operation current, at high field slots, for 4.0 T is expected to be 280 A. On the other hand the operation current of the Direct Wind Type is 430 A. The reason of high field in the end section of Direct Wind Type is its yoke geometry. The point at which the high peak occurs is covered by the yoke. If the length of the yoke is shorter, the strength of peak field can be reduced.

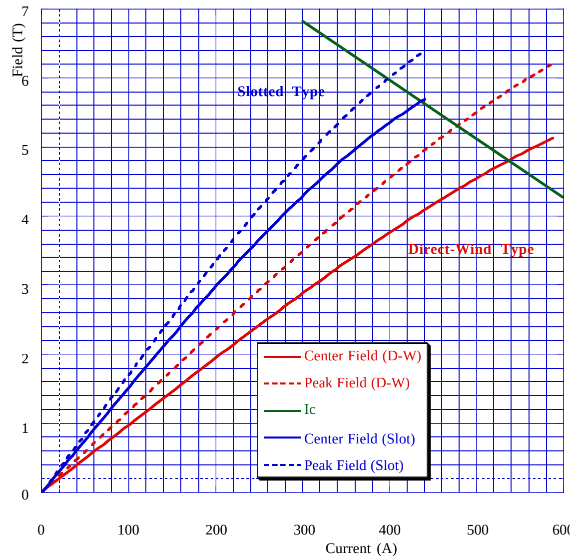


Figure: 2 Expected field strengths

3.2 The field uniformity

In the helical structure, strong longitudinal fields will be induced at off axis area. We can optimize the helical dipole magnet to eliminate the azimuthal angle dependence of the fields, however we cannot expel radial dependence[5,6,7]. Accordingly, the definition, which has been used for a two dimensional magnet, cannot be applied. Then, we calculated the multipole component of these model magnets using the Fourier expansion of the B_y component along the circle of 3.1 cm radius. The results are indicated in Table 2.

Table: 2 The expected multipole component.

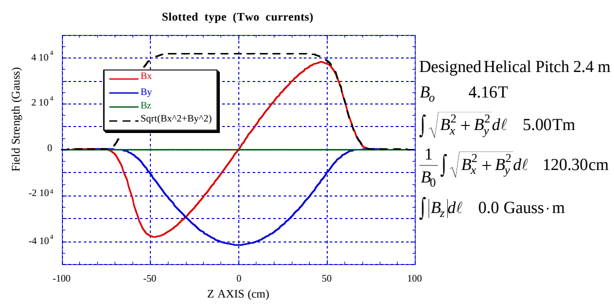
	Low Current		High Current	
Slotted Type Two-Current	C.F. 6P 10P	0.44 T -0.128 % 0.011 %	C.F. 6P 10P	4.16 T -0.133 % 0.016 %
Slotted Type One-Current	C.F. 6P 10P	1.36 T -0.609 % 0.063 %	C.F. 6P 10P	4.03 T -0.701 % 0.033 %
Direct Wind Type	C.F. 6P 10P	0.40 T -0.907 % -0.951 %	C.F. 6P 10P	3.91 T -0.278 % -0.948 %

C.F. : Center Field
6P: Sextupole component
10P: Decapole component

In Slotted Type magnet, not only two current mode but also uniform current mode is computed. In case of one current mode, of course, the multipole component is larger. We can control the multipole component by changing the ratio of two currents in the Slotted Type. In Direct Wind Type, the effect of the iron saturation to the sextupole component is large by reason of small clearance between the yoke and the coil. Anyhow, it is needed to study the adequate field strength which should be referenced by the optimization of the multipoles.

3.3 *Magnetic field distribution*

As mentioned above, there are longitudinal fields in the helical magnet. The more the distance from the axis is, the stronger the longitudinal field is. The beam orbit will not be influenced much by the longitudinal magnetic field, but the spin motion is. Figure 3 shows the calculated field distributions on the axis in the two types of model magnet. In Direct Wind Type, strong longitudinal fields were expected in end region even on axis due to the non-symmetric coil end structure.



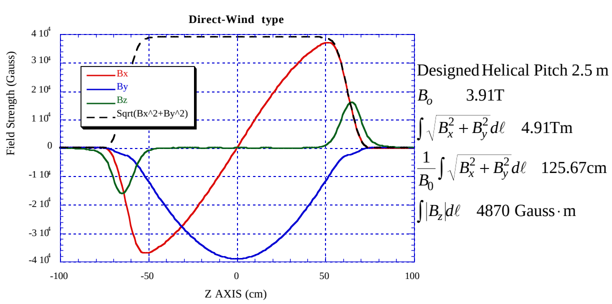
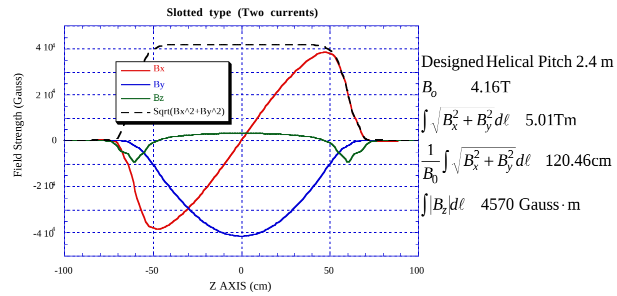


Figure: 3 Field distributions along the beam axis.

In Siberian Snake magnets in RHIC, the maximum orbit excursion will become 3 cm at injection energy of polarized proton beam. So, Fig. 4 shows field distribution at 3.0 cm above the axis. In Slotted Type, which has the symmetric end configuration, longitudinal field in yhe body and that in the end tend to be canceled. In Direct Wind Type, the non-symmetric ends make strong longitudinal field especially in the area close to the coil. Besides, this field is too strong to be canceled by the longitudinal field in the body. The longitudinal field in the end of other side emphasizes the longitudinal field of the body. So the direction of coil end in Direct Wind Type should be chosen carefully to avoid this effect. In case of both magnet types, we plan to optimize longitudinal field using modification of the yokes.



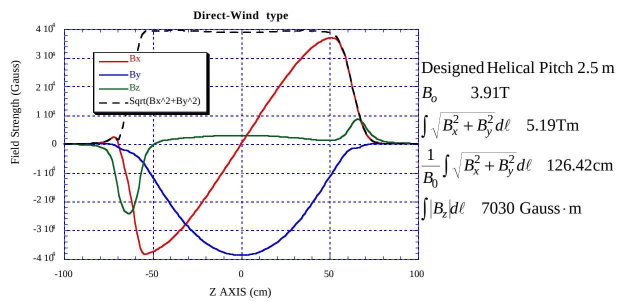


Figure: 4 Field distribution 3.0 cm above the beam axis.

4 CONCLUSION

Using 3D calculations, the two types of model magnet which are candidates for RHIC Spin project were analyzed, and the characteristics were predicted. We will optimize the design of coils and the shape of the yoke comparing the field measurement which will be held soon.

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