FIELD CALCULATION AND MEASUREMENT OF A FULL-LENGTH SNAKE MAGNET FOR RHIC

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Abstract

Design of the helical dipole magnet for the Siberian Snake of RHIC is finalized. Effective rotation angle and multipole components as calculated by TOSCA are presented. Plans for production and measurement of these magnets are described.

1 THE FABRICATION METHOD AND THE STRUCTURE OF THE MAGNET

Fig. 1 shows an overview of the helical dipole magnet. From a cryogenic point of view, it is necessary to minimize the heat leak from the independently powered helical dipole magnets for RHIC [1]. Therefore, a thin, round cable of 1 mm diameter comprised of seven wires will be used instead of the Rutherford-type cable used in the regular arc magnets. The Kapton-wrapped cables are wound in precisely machined helical slots on an aluminum cylinder. Thin fiberglass sheets containing B-stage epoxy are inserted between layers. Finally, the wound cables are locked in the slots by heating, while applying radial pressure. The fabrication technique was applied to build a half-length model, which showed a good quench performance. Also, 3D magnetic field calculations by using TOSCA [2] agreed well with the measured properties of the half-length model [3]. It was thus confirmed that the fabrication method and structure of the magnet can be applied to production.

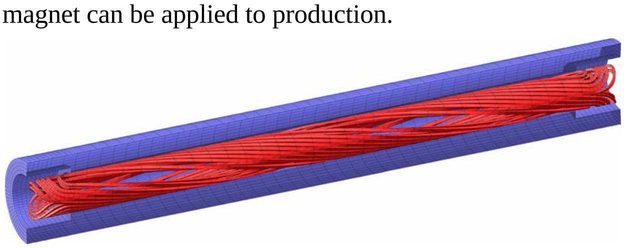

Fig. 1: Helical dipole magnet.

2 THE FIELD CALCULATION

The field in the helical magnet was computed by using the computer code TOSCA. Only the upper half of the magnet was modeled and a periodicity condition was used. The coils were divided into 910 'BR20' blocks. Thermal contraction factors of 0.99806 for the yoke and 0.99594 for the coils were taken into account. It was assumed that the shape of coils is determined by the shrunk aluminum cylinder.

2.1 Peak Field Survey

Peak fields were searched using a 300A/cable calculation model which is expected to produce 3.88 T at the magnet center. A peak field of 4.38 T was found in a cross-sectional plane, perpendicular to the beam axis and at the center of the magnet. This peak field is expected to be 0.02 T higher than a peak field which was found in the end region, where the inner radius of yoke is increased to prevent quenches, of the magnet.

2.2 The Multipole components

The multipole components were estimated by calculating the field at 100 points on a circle of 3.1 cm radius at the center of the magnet. In the case of the helical magnets, the multipoles derived from the expansion of the vertical component of the field are not the same as those derived from an expansion of the azimuthal field component, due to the presence of a longitudinal field component. This 3D effect is a unique intrinsic feature of this type of magnet [4]. Fig. 2 shows the sextupole and the decapole components as a function of the operating current per cable. The amplitude of each component is expressed as a ratio to the field strength at the center of the magnet.

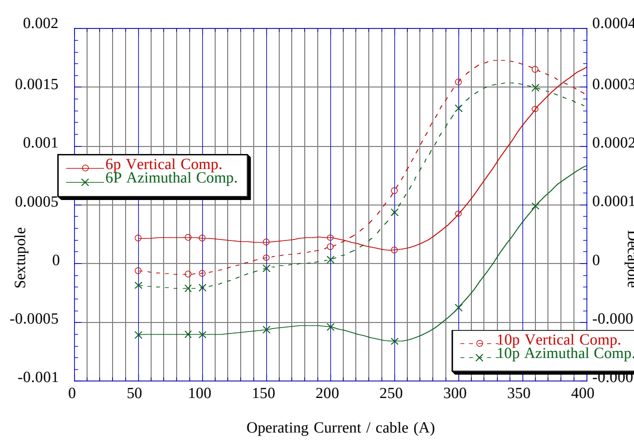

Fig. 2: Multipole components

Dips are observed around 250A/cable in the sextupole components and are consistent with the results of field measurements in the half-length model. This saturation effect is due to the 3D helical structure. In the case of a 2D analysis, the dips are not found. Planned operating current is from 90A to 320A, corresponding to a dipole field of 1.2 T to 4.1 T.

2.3 *Rotation Angle of the Helical Structure*

In the helical dipole magnets employed for the Siberian Snakes, deflections of beam orbits are expected to cancel due to a 360 degree rotation of the magnetic field. However, in actual magnets, there are fringe fields, requiring a careful adjustment of the rotation angle in the straight section to cancel the orbit deflections. In Fig. 3, the vertical, B_y, and the horizontal, B_x, components of the dipole field in a typical helical magnet are shown. A symmetry condition implied in the choice of coordinate system makes an integral of B_x component along the beam axis automatically zero. Therefore, we have to pay attention only to the B_y component, and have to ensure that the integral of this component becomes zero. When this condition is achieved, we may say that this magnet effectively has a rotation angle of 360 degrees.

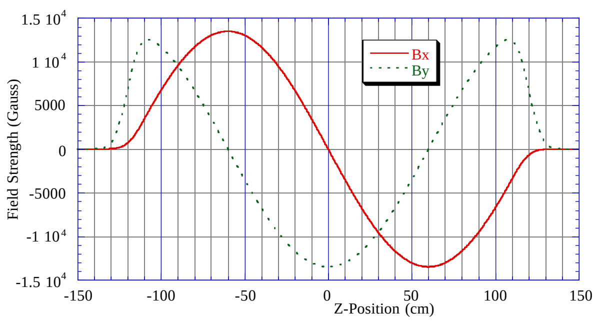

Fig. 3: Typical fields in the helical dipole.

In order to optimize the rotation angle, we need to define it in the actual magnet. There is a reference point at the center of curvature of conductors at each end. The difference between the dipole field directions at these two reference points was defined as the mechanical rotation angle. In Fig. 4, the integral of the vertical, B_y, component was plotted as a function of the mechanical rotation angle. An operating current of 300 A/cable was assumed for this plot. Based on this, it was decided to use a mechanical rotation angle of 340 degrees.

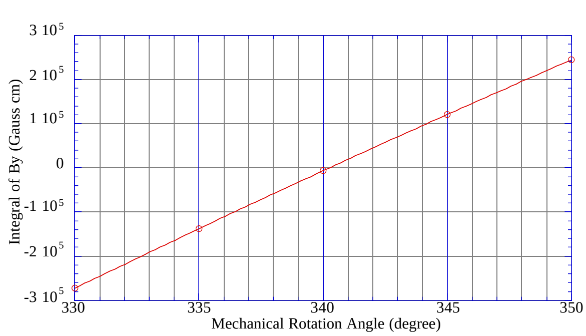

Fig. 4: Integral of B_y vs. mechanical rotation angle

Fig. 5 shows variation of integrated B_y as a function of the operating current. The indicated integral of B_y is normalized to the integral of dipole field strength.

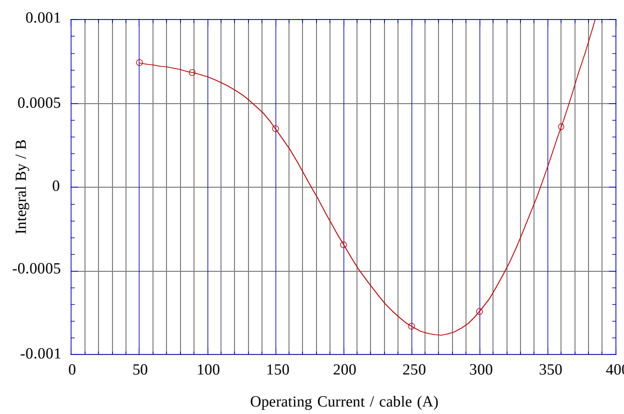

Fig. 5: Integral of B_y vs. operating current

All the values of the integrated B_y are well within the requirements from beam optics considerations. Furthermore, we can make small adjustments to the effective rotation angle, if necessary, by modifying the iron yoke length after measurements of the first full length helical dipole magnet are completed.

3 EFFECTIVE MULTIPOLE COMPONENTS

One Siberian Snake unit consists of four helical dipole magnets. Since, the dipole field effectively rotates through a full 360 degrees, the beam deflections are cancelled. Furthermore, the symmetric combination of the four helical dipole magnets, altering polarity, prevents any shift of the beam orbit. Thus, the spin direction of the beam can be flipped without any effect on the beam orbit. However, during passage of particles through the Siberian Snake unit, orbit excursions will reach 3.0 cm away from the magnet axis. The real beam might, therefore, be affected by more complex multipole components at off axis regions.

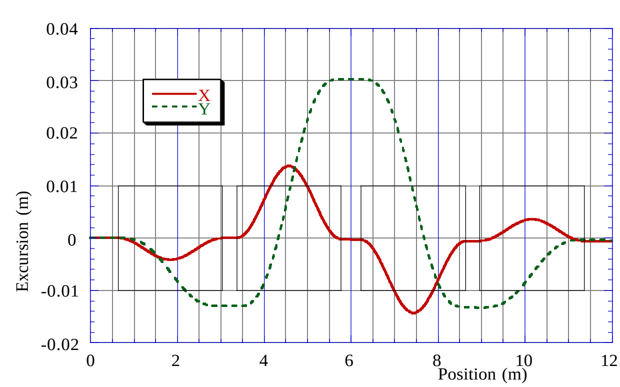

Fig. 6: Beam Orbit in a Siberian Snake.

Figure 6 shows the orbit of 25 GeV Proton beam in the Siberian Snake unit. The four rectangles denote the four helical dipole magnets. Due to the large excursions, the multipole components seen by the real beam do not coincide with the multipole components mentioned earlier in this paper. Therefore, the multipole components around the shifted beam center were analyzed. Figure 7 and 8 show the sextupole and the decapole components respectively along the beam orbit in the first helical magnet of the Snake unit, which has 1.23 T dipole field. The reference radius is again 3.1 cm.

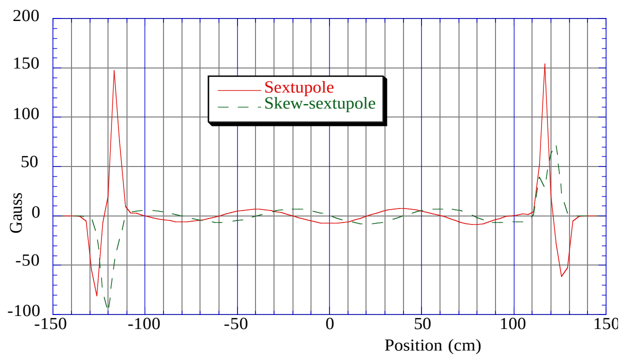

Fig. 7: Sextupole component along the trajectory.

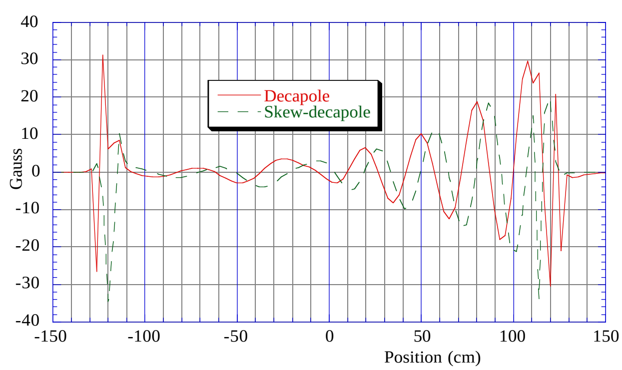

Fig. 8: Decapole component along the trajectory.

By integrating each multipole component through each of the helical dipole magnets, we can investigate effective multipole components. The integrated multipole components are listed in Table 1.

Table 1: Integral of multipole components

	First Magnet	Second Magnet
Field	1.23 T	4.10 T
2-Pole	1968 Gauss cm	-5226 Gauss cm
S 2-Pole	33 Gauss cm	-1501 Gauss cm
6-Pole	413 Gauss cm	-4498 Gauss cm
S 6-Pole	-120 Gauss cm	-20 Gauss cm
10-Pole	319 Gauss cm	16300 Gauss cm
S 10-Pole	-248 Gauss cm	3475 Gauss cm
14-Pole	-910 Gauss cm	3892 Gauss cm
S 14-Pole	664 Gauss cm	-9235 Gauss cm

S: Skew component

In spite of the high peak values indicated in Figs. 7 and 8, the integrated components shown in Table 1 are not so large, because of phase rotation of each component. All the values in the third and fourth magnets are of the same magnitude, but of opposite sign, as those in the second and first magnets respectively. This means, under ideal condition, integrated multipole components through the entire Siberian Snake unit should be zero.

4 COIL WINDING

In the half-length model magnet, the coil was wound by hand over 1800 turns, requiring considerable skill and time. To solve this issue, an automatic winding machine, having a 11-axis control and an ultrasonic bonding head, has been constructed. This winding machine is now in the final stages of development.

5 LONGITUDINAL HARMONIC COIL

To measure the magnetic field in the half-length model magnet, we used two types of methods — a rotating Hall probe and a 23 cm long rotating tangential coil. The Hall probe can measure local field strength, but does not have high enough accuracy to get good harmonics. On the other hand, the harmonic coil can measure the field precisely, however the phase of the multipole components varies along the length, reducing its sensitivity and complicating the analysis of data. In order to eliminate these demerits, a short tangential coil of 5 cm length has been built. This coil also has a special winding to measure the longitudinal component of the field. In the helical dipole magnets, there is a strong longitudinal component of the magnetic field, which could be used to obtain information about the field quality.

6 CONCLUSION

The design of the helical dipole magnet for the Siberian Snake of RHIC is completed, including a detailed 3D analysis of the field. It is expected that the first full-length helical dipole magnet will be tested in a few months.

ACKNOWLEDGMENT

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