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The Use of Helical Dipole Magnets in the RHIC Spin Project

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Spin Note

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ABSTRACT

Superconducting helical dipole magnets will be used in RHIC to maintain polarization and to perform localized spin rotations at the two major experimental detector regions. Requirements for the helical dipole system are discussed, and the status of magnet prototypes is reported.

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory allows for the unique possibility of colliding high energy polarized proton beams. To maintain polarization during the acceleration process, two full "Siberian Snakes" are to be inserted on opposite sides of the RHIC lattice for each of the two counter-rotating rings. In addition, other magnetic components – spin rotators – will be located on each side of the two major interaction points (again, for each ring) which allow the spin orientation to be altered from the vertical direction to the longitudinal direction. Superconducting magnets are used in order to contain the magnetic elements for a Snake within a 10 m longitudinal space so as to fit within available room in the RHIC lattice. The use of helical dipole fields to produce spin rotations in RHIC was first suggested by Ptitsin and Shatunov.[1] Four right-handed helical dipole magnets, each 2.4 m long and operating near 4 T or less can produce a Siberian Snake. The strong helical fields also reduce the orbit excursions produced by these devices. Furthermore, a combination of right-handed and left-handed helical dipole magnets also within a 10 m space can perform the desired local 90° rotations of the spin at the major detector regions.

Helical Magnet System

The original proposal of Ptitsin and Shatunov has been refined over the past two years. The Snake helical dipoles are all 360° right-handed helices whose fields begin pointed vertically upward or downward. The "Rotator" magnets are either left-handed or right-handed, but each begins with its field pointed in the horizontal plane. The field strengths of the Snake magnets are essentially constant during the acceleration process, while the appropriate fields in the Rotator magnets are beam energy dependent. Table I shows Rotator fields for 250 GeV proton operation. The maximum orbit deviations listed are for an injection energy of 25 GeV.

The effects on RHIC operation of helical dipole magnet error fields and misalignments have been studied. In contrast to a "regular" dipole magnet error which can be thought of as producing a kink in the slope of the particle trajectory at the source of the error, a "helical dipole" error will introduce a step in the trajectory. To keep the vertical orbit distortions under control, the helical dipole field errors $\Delta(B\ell)/(B\ell)$ should be kept reasonably below 1%, and rotational misalignments should be less than about 10 mrad. The more important parameter will be the total integrated field strength ($\int B_x ds$, $\int B_y ds$) which should be zero, or equivalently the total equivalent integrated twist of the magnet should be 360°. This last requirement is especially sensitive in the case of the Rotator magnets (horizontal fields at the entrance and exit of the magnets), for which the integrated twist must be 360° to within ±1 mrad. This may imply special correction coils in the Rotator assemblies to fine tune the orbit while the Rotators are turned on.[2] The ends of the magnets will need to be carefully designed to obtain not only the desired integrated field strength but also the desired total field twist.

Table I: Helical Dipole Magnet Parameters.

Snake	inj. orbit dev. = 32 mm		
Length	start	helicity	max. field
2.4 m	V	RH	1.2 T
2.4 m	V	RH	-3.9 T
2.4 m	V	RH	3.9 T
2.4 m	V	RH	-1.2 T
Rotator	inj. orbit dev. = 24 mm		
Length	start	helicity	max. field
2.4 m	H	RH	3.4 T
2.4 m	H	LH	3.1 T
2.4 m	H	RH	3.1 T
2.4 m	H	LH	3.4 T

Field quality is also an issue for the helical magnets. The intrinsic helical nature of the field will itself produce nonlinear terms in the field expansion. In addition, magnet design and construction errors will add nonlinearities to the field as well. While the nonlinear field components tend to average to zero over the length of the helical dipole, the protons follow a trajectory which is not centered within the magnet. Thus, one expects to see feed-down effects. For example, a sextupole component in the magnet will generate a tune shift due to the off-centered orbit. Analytical estimates indicate that the intrinsic tune shift at 25 GeV due to two Snakes in RHIC is on the order of $\Delta\nu \approx 0.015$, and that a sextupole component in the magnet design of strength $b_2 \approx 2 \times 10^{-4}/\text{cm}^2$ (measured at 3.1 cm) will give approximately the same tune shift.[3] Particle tracking results are in qualitative agreement with these estimates.[4]

Magnet Development

A total of 48 individual full-helical dipole magnets will be required for the project. The four magnets needed to create one Snake or one Rotator will be mounted inside of a standard RHIC Dipole Magnet cryostat. Since it is desirable to independently power the four magnets within the cryostat, the required current should be minimized in order to keep the heat leak due to the power leads as small as possible. Thus, the magnets will have hundreds of turns of superconducting cable as opposed to a smaller number of turns, posing a technical challenge to the construction of these high-field magnets. At present, two possible techniques for producing helical coils are being investigated. (See Fig. 1.) The first method consists of an ordered wound cable placed into a helical groove which is cut into an aluminum cylinder. Thin sheets of epoxy-impregnated fiberglass are placed between layers of cable, and the entire assembly is cured to produce a firm wire matrix. A first prototype coil using this technique has been built and tested at BNL, and a second full field, half length magnet is now being built. Meanwhile, a parallel strategy is being studied, in which the cable is bonded directly onto a stainless steel cylinder, the cable being wound into a helical pattern using a computer controlled multiple-axis winding machine. A full field, half length prototype of this "direct wind" method has been completed by AML, Inc., in Palm Bay, Florida, under contract with BNL and should be ready for testing by November, 1996.

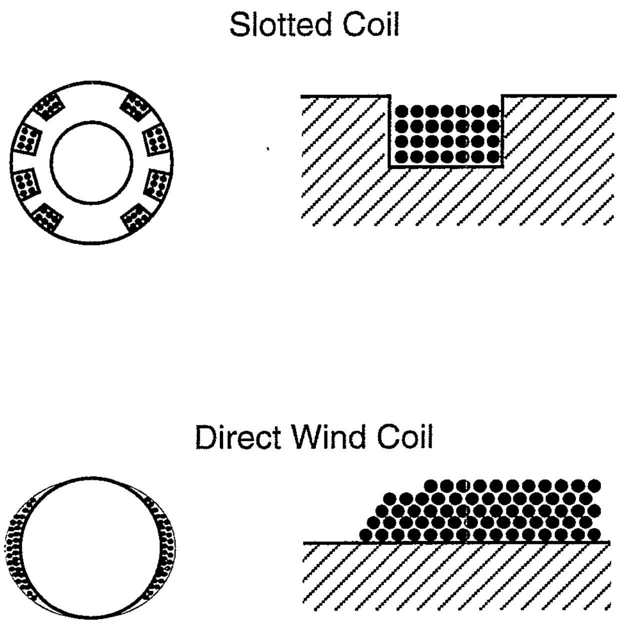

Figure 1: Possible Magnet Technologies.

[1] V. I. Ptitsin and Yu. M. Shatunov, Helical Spin Rotators and Snakes, Proc. Third Workshop on Siberian Snakes and Spin Rotators (A. Luccio and Th. Roser Eds.) Upton, NY, Sept. 12-13,1994, Brookhaven National Laboratory Report BNL-52453, p.15.

[2] M. J. Syphers, "Closed Orbit Errors from Helical Dipole Magnets, " BNL Internal Report AGS/RHIC/SN-016, January, 1996.

[3] M. J. Syphers, "Field Quality Issues for RHIC Helical Dipole Magnets," BNL Internal Report AGS/RHIC/SN-015, January, 1996.

[4] W. Fischer, "Preliminary Tracking Results with Helical Magnets in RHIC," BNL Internal Report AGS/RHIC/SN-034, August, 1996.