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A LEFT-HANDED HELICAL SNAKE FOR THE HSR

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Abstract

The Electron Ion Collider calls for collisions of polarized proton and helion beams on polarized electron beams. To preserve polarization of these polarized hadron beams during acceleration, six full helical snakes will be installed. As there are currently 4 snakes in RHIC, the remaining two snakes will be made from existing rotator magnet coils. The existing snakes are made from only right-handed helices where the rotator magnets are made from both right handed and left handed helicity magnets. In order for a sufficient stock of spare coils, one snake will be made of left handed coils. Simulations using zgoubi show the left handed snake has sufficient range to provide the desired snake precession axes for helions and protons with the existing power supplies.

INTRODUCTION

The Electron Ion Collider (EIC) is a next generation collider to be constructed at Brookhaven National Laboratory. The EIC Hadron Storage Ring (HSR) will be primarily constructed using existing components from the Relativistic Heavy Ion Collider (RHIC). The HSR will have six snakes, each of which are comprised of four helical dipoles, to preserve polarization of protons and helions up to their maximum collision energies. The purpose of these snakes is to rotate the spin vector 180 degrees. To produce the six snakes, four will be directly repurposed from RHIC. The remaining two snakes will be modified from existing RHIC rotator magnets. The existing RHIC snakes are comprised of four right-handed helicity (RH) helical dipole coils. The existing rotators are also comprised of four helical dipoles, however they alternate between left-handed helicity (LH) and RH. In addition, the coils in the rotators are rotated ninety degrees about the longitudinal axis relative to the coils found in the snakes. To maximize the amount of spare coils, one of the remaining two snakes will be made of only LH helical dipoles. This will allow for four spare LH coils and four spare RH coils. Each coil has a maximum supported field of 4 T which corresponds to 322 A in the power supply [1].

The helical dipoles have a period λ=2.4 m. The magnet period is defined as [2]

$$k = R\frac{2\pi}{\lambda}, \tag{1}$$

with R being the helicity (that is -1 for LH and +1 for RH). The spin rotation from one coil is,

$$\phi = \pi\sqrt{1+\chi^2}, \tag{2}$$

where

$$\chi = (G + 1/\gamma)\frac{qB_o}{m\beta c|k|}. \tag{3}$$

This rotation occurs in the laboratory frame about the precession axis defined as,

$$u = \left[-\frac{R}{\sqrt{1+\chi^2}}, 0, -\frac{\chi}{\sqrt{1+\chi^2}} \right]. \tag{4}$$

The precession axis following all four coils, U, is typically referred to the value of its angle in the horizontal plane, such that 45° corresponds to U=[U_s, U_x, U_y]=[0.707, 0.707, 0]. The notation for representing the sign of the field of the coil is denoted either (+) or (-). For the standard helix configuration of right handed helices and alternating the sign of B_o is labelled as R+R-R+R-.

PROTON CASE

For the case of protons at RHIC, the anomalous gyromagnetic g-factor is $G = 1.7928$ with the nominal configuration to rotate the spin vector for protons 180 degrees about a precession axis of 45° requires I_{out}=100 A, and the inner coils at I_{in}=322 A. For powering an equivalent magnet that is only made of left handed coils in the same manner, results in a precession axis of 135 degrees. The attainable precession axis while remaining under the PS limits is seen in Fig. 1 where the symmetry between left and right handed helices is apparent. To calculate which configurations can be satisfied using the left handed and right handed snakes, an optimizer is used to constrain the desired precession axis and rotation at the end of the snake, using zgoubi and tracking through field maps of the helices [1, 3].

The current on the power supplies for the inner and outer currents, with different field configurations, and with different handed helices, is shown in Fig. 2. From this figure, it is apparent that only axes from −45° to +45° and 135° to 225° can be achieved. For a nominal 6-snake configuration, snake axes of ±15° would be the naive choice [4]. This follows the calculation of ν_s to achieve ν_s=0.5 [5]

$$\nu_s = \frac{1}{\pi}\sum_{k=1}^{N_s}(-1)^k\phi_k. \tag{5}$$

HELION CASE

For the case of helion, $G = -4.1842$ with the equivalent configuration as protons to rotate the spin vector for protons 180 degrees with a precession axis of 45 degrees in the horizontal plane is to have the outer coils powered at I_{out}=65.5 A, and the inner coils at I_{in}=211 A. For powering an equivalent magnet that is only made of left handed coils rotates the spin vector about a precession axis of 135 degrees, equivalent to a -45° rotation. Due to the higher G of helions compared to protons, the snakes are able to satisfy almost all possible snake precession axes. The precession axis is

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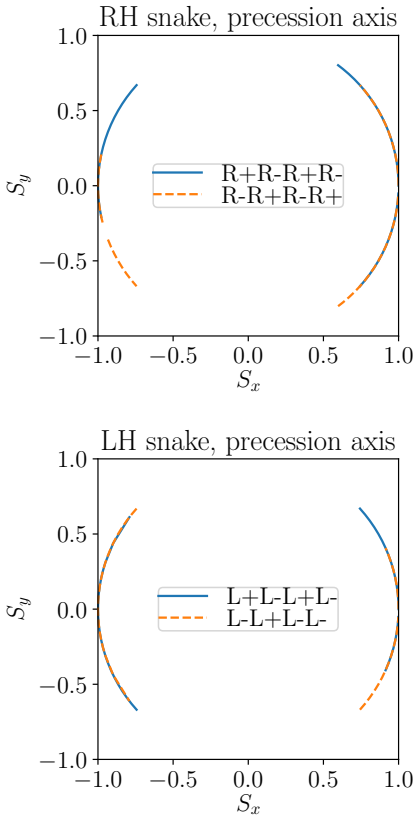

Figure 1: Attainable snake axes for protons, using right-handed (top) and left-handed (bottom) helices.

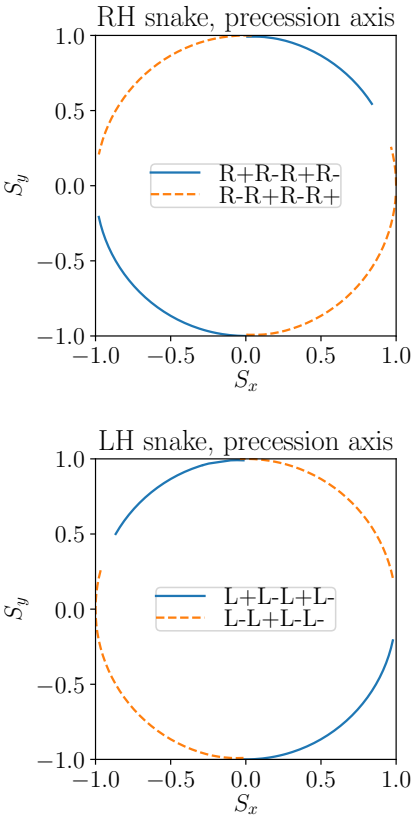

Figure 3: Allowable snake axes for helions, using right-handed (top) and left-handed (bottom) helices.

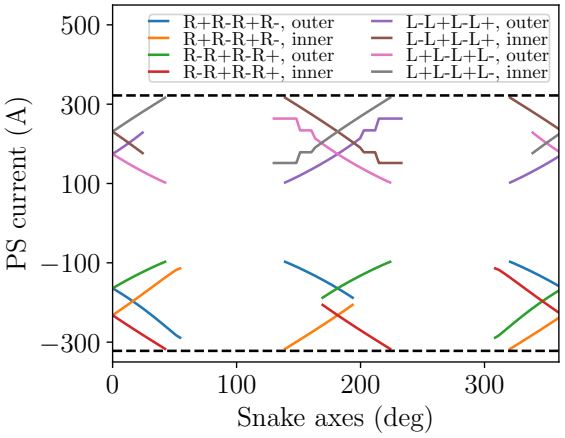

Figure 2: Proton case of inner and outer PS currents required to achieve the specified precession axis for RH and LH helices and different B_o.

seen in Fig. 3 where the symmetry between left and right handed helices is apparent. Note that nearly the full array from 0 to 360° can be satisfied while remaining under PS limits.

The current on the power supplies for the inner and outer currents, with different field configurations, and with different helicities, is shown in Fig. 4. This figure also shows that the snakes with polarized helions can support almost all snake axes.

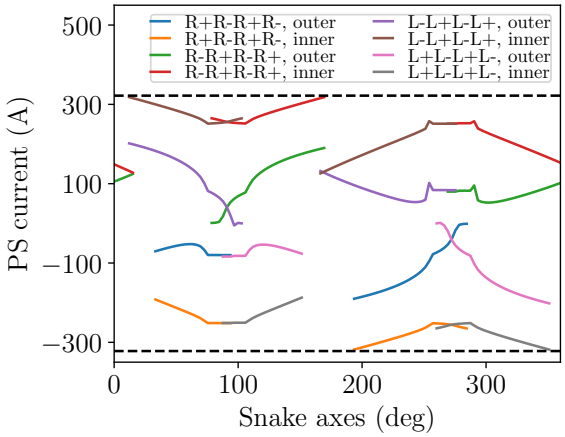

Figure 4: Helion case of inner and outer PS currents required to achieve the specified precession axis for RH and LH helices and different B_o.

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SUMMARY

The snake made up of only left-handed helices will perform equivalently to the snake made up of only right handed helices, albeit with different power requirements for equivalent precession axes. Due to the higher G of helions compared to protons, snakes comprised of right-handed or left-handed helices can achieve almost any precession axis.

ACKNOWLEDGEMENTS

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