

HADRON STORAGE RING SPIN ROTATORS & SPIN TUNE COMPENSATION

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Abstract

The Electron Ion Collider (EIC) calls for collisions of longitudinally polarized protons and helium-3 on polarized electrons. The polarized hadron beams will be accelerated and stored in the Hadron Storage Ring (HSR). To achieve longitudinal polarization at the interaction point (IP), spin rotators are placed on either side of the IP at 35.28 and -61.35 mrad. Due to the asymmetry of the rotator placement, their ramping and use at store will result in a shift of ν_s from 1/2. The HSR has six snakes that can be used to compensate for the $\Delta\nu_s$. The planned storage energies for protons are 41, 100, and 275 GeV, and for helium-3 are 41, 100, and 183 GeV/u. The updated rotator currents at each of these energies is provided, in addition to the $\Delta\nu_s$ and the compensation requirements of the snakes.

INTRODUCTION

The EIC HSR will be primarily constructed using existing components from the Relativistic Heavy Ion Collider (RHIC). The HSR will have rotator magnets outside of the interaction regions to facilitate longitudinal polarization at the interaction point (IP). The helical dipoles have a period $\lambda=2.4$ m. The magnet period is defined as [1]

$$k = H \frac{2\pi}{\lambda} \quad (1)$$

with H being the helicity. The magnet coils have either left-handed (LH, $H=-1$) or right-handed (RH, $H=+1$) helicities. The spin rotation from one coil is,

$$\phi = 2\pi\sqrt{1 + \chi^2} \quad (2)$$

and

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

where G is the anomalous gyromagnetic g -factor, γ is the Lorentz factor, q and m are the charge and mass, βc is the velocity, and B_o is the magnetic field. The maximum $B_o = 4$ T which corresponds to a power supply current of 322 A. The relevant parameters for protons and helions are found in Tab. 1.

Table 1: Relevant parameters for polarized protons and polarized helions.

	G	q	m (GeV/c ²)
proton	1.7928474	1	0.93827209
helion	-4.1841536	2	2.80839148

The rotation from a single helix occurs in the laboratory frame about the precession axis defined as,

$$u = \left[-\frac{\chi}{\sqrt{1 + \chi^2}}, -\frac{H}{\sqrt{1 + \chi^2}}, 0 \right]. \quad (4)$$

The full rotator assembly consists of four helical dipoles. After transiting the full rotator assembly, the spin been rotated into the horizontal plane. The residual angle from the horizontal plane is $\theta_y = 0$. After the spin is placed in the horizontal plane, it will precess by an amount θ_s , defined as

$$\theta_s = G\gamma\theta_R \quad (5)$$

where θ_R is the bend angle from the IP to the rotator.

The existing RHIC rotators have a helicity pattern of RLRL. These magnets are powered similar to the snakes where the inner and outer coils are powered independently with current I_{in} and I_{out} , but all coils have the same sign for current, such as R+L+R+L+ [2]. The RHIC rotators are placed symmetrically on either side of the IP with an angle of $\theta_R = \pm 3.675$ mrad from the IP. These rotator assemblies will be used for the HSR.

In the HSR, the beam circulates in the counter-clockwise direction, equivalent to the yellow RHIC ring. Thus, the sector 6 rotator is to be the V2H (vertical to horizontal) rotator, and the sector 5 rotator is the H2V (horizontal to vertical). The V2H rotator is located at $\theta_R = -61.35$ mrad from the IP, and the H2V rotator is at $\theta_R = 35.28$ mrad from the IP. This report builds on previously reported results from [3,4]. The outer and inner currents that satisfy longitudinal polarization at the IP is found in Tab. 2.

Table 2: Summary of rotator currents for protons at 41, 100, and 275 GeV, and one set of solutions for helions at 41, 100, and 183 GeV/u.

E (GeV/u)	protons			helions		
	41	100	275	41	100	183
$I_{out,H2V}$ (A)	104	-90	-184	75	174	174
$I_{in,H2V}$ (A)	246	-259	-198	150	221	192
$I_{out,V2H}$ (A)	264	235	75	171	47	174
$I_{in,V2H}$ (A)	215	185	282	160	181	225

ROTATOR RAMP

To satisfy $\nu_s = \frac{1}{2}$, the six snakes will nominally be at $\pm 45^\circ$. That is in a synchrotron with n snakes, ν_s follows

$$\nu_s = \frac{1}{\pi} \sum_{k=1}^n (-1)^k \theta_{s,x} \quad (6)$$

where k is the snake number around the ring. These snakes are spaced symmetrically through the lattice every $\theta = 60^\circ$ which corresponds to the YO1, YI3, YO5, YI7, YO9, and YI11 arc locations. The allowed operational current ramp has a maximum ramp rate of 0.47 A/s. As an example, a configuration of protons at 41 GeV that require $I_{out,H2V}=104$ A, $I_{in,H2V}=246$ A, $I_{out,V2H}=264$ A, and $I_{in,V2H}=215$ A has a ramp time dictated by the maximum current. In this case 264 A is the maximum current with a minimum ramp time of all modules being approximately 9.5 minutes [5].

SPIN-TUNE COMPENSATION

Due to the asymmetric placement of the rotators, the spin rotation on either side of the IP will not cancel, resulting in a spin tune shift of $\Delta\nu_s$. A change in the snakes precession axis angle will be used to compensate for the $\Delta\nu_s$. Here, the compensation is defined as the change of the precession axis angle, $\Delta\theta_{s,x}$ [2]. Fig. 1 shows ν_s with and without compensation as a function of rotator scaling (where 1 corresponds to the full rotator fields), and the associated compensation schemes with multiple snakes axes for compensation.

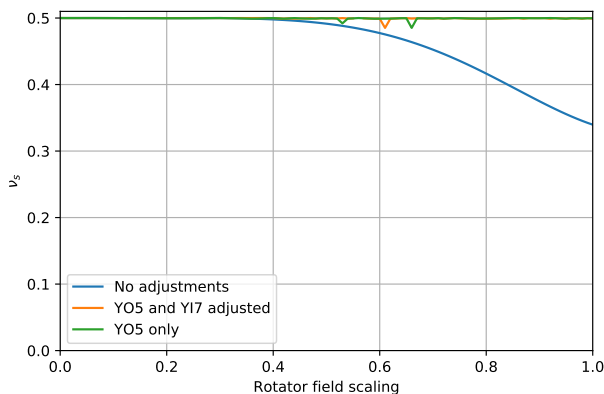


Figure 1: Proton $\Delta\nu_s$ as a function of rotator scaling at 275 GeV without compensation, and compensation using one and two snakes.

The change in the snake PS currents for the single snake compensation case is found in Fig. 2, which moves along the trajectory shown in Fig. 3. As seen in Fig. 3, as long as the axis change is in the negative direction and does not require changing the sign, there is sufficient current to compensate it. As evident in Fig. 3, there is no solution if the change in axis angle flips signs, as this would require ramping the power supplies to zero which would move the snake off of the 180° spin-flip line, resulting in loss of polarization. Similarly, if the axis change was above 45° , the initial currents would need to be at the alternate 45° angle (corresponding to $I_{out}, I_{in} = 274, 120$ A) which has unfavorable orbit matching requirements, and would support a maximum precession axis of 60° .

The summary of $\Delta\nu_s$ and $\Delta\theta_{s,x}$ at 41, 100, and 275 GeV are shown in Tab. 3. The $\Delta\nu_s$ here refers to the uncompensated shift in ν_s from the rotators ramping.

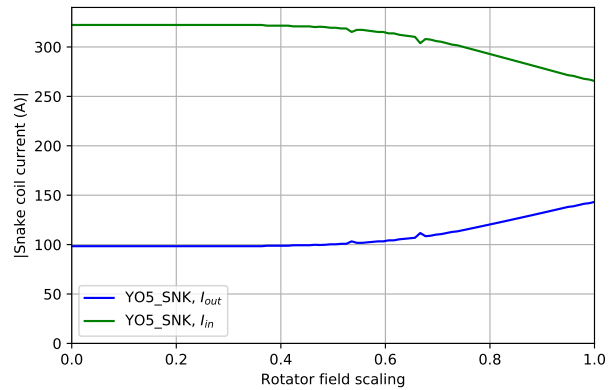


Figure 2: The inner and outer snake currents to compensate the $\Delta\nu_s$ from the rotator ramping with protons at 275 GeV.

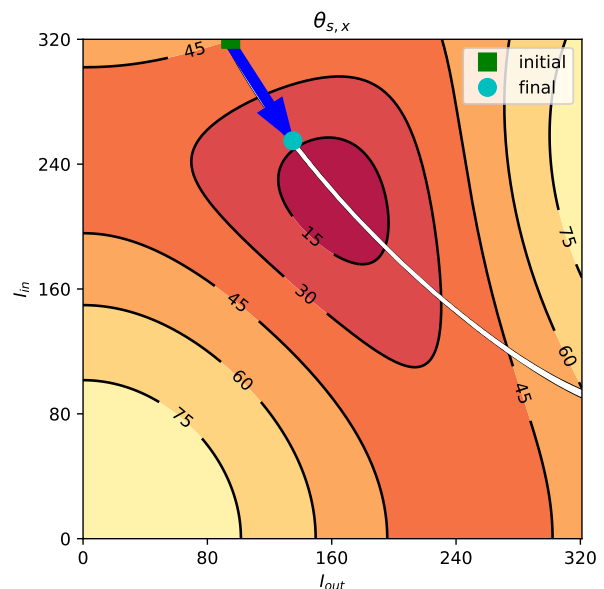


Figure 3: The trajectory of the current shown in Fig. 2 from its initial to final precession axis.

Table 3: Summary of ν_s compensation with six snakes at each energy for protons and helions.

Species	Energy	$\Delta\nu_s$	Snakes used	$\Delta\theta_{s,x}$
p	41	0.107	1	-38.9°
	100	0.346	4	-20.8°
	275	0.169	1	-28.8°
h	41	0.392	4	$+13.2^\circ$
	100	0.294	4	$+30.8^\circ$
	183	0.217	4	$+19.4^\circ$

Considering the case of protons at 275 GeV, the $\Delta\nu_s = 0.169$ requires only one snake be changed by $\Delta\theta_{s,x} = -28.8^\circ$. If Eq. 6 is calculated with all snakes with $\theta_{s,x} = \pm 45^\circ$ and one snake is given a defect of $\Delta\theta_{s,x} = -28.8^\circ$, $\nu_s = 1.67$ which corresponds to the opposite of the $\Delta\nu_s$ from the rotators ramping.

REQUIREMENTS WITH FOUR SNAKES

Although the ultimate polarization performance of the EIC is achieved with six snakes, the four snakes configuration is considered. This four snake configuration will have them located at the YI3, YO5, YI7, and YI11 locations. To satisfy $\nu_s = \frac{1}{2}$, the snake axis angles can either be $\pm 22.5^\circ$ or alternating 45° and 0° . The snake compensation scheme with only four snakes is evaluated at 100 GeV and summarized in Tab. 4 where a \checkmark is assigned to a configuration that can effectively compensate for $\Delta\nu_s$ and a \times if it cannot be compensated. An example snake ramping using four snakes in a six snake scheme and four snakes in a four snake scheme is shown in Fig. 4.

Table 4: Summary of snake compensation schemes and their compensation status for protons at 100 GeV.

YI3	YO5	YI7	YI11	compensation
45	0	45	0	
0	45	0	45	\times
22.5	-22.5	22.5	-22.5	\times
-45	0	-45	0	\times
0	-45	0	-45	

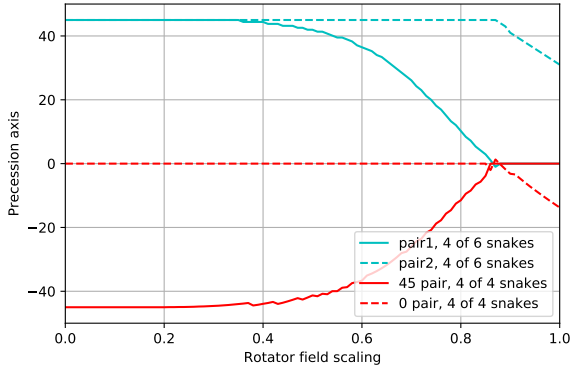


Figure 4: Snake precession axis change using four snakes when six and four snakes are available.

SUMMARY

The EIC requires longitudinal polarization of polarized protons and polarized helions at the colliding IP by using helical rotator magnet assemblies to rotate the spin into the horizontal plane. Due to the asymmetric placement of these rotator assemblies there is a shift in ν_s . This shift can be compensated for by changing the snake precession axis angle. In the case where the HSR only has four snakes, the possible solutions are limited, prohibiting certain snake configurations at 100 GeV where the $\Delta\nu_s$ cannot be compensated.

ACKNOWLEDGEMENTS

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