STATUS OF AC-DIPOLE PROJECT AT RHIC INJECTORS FOR POLARIZED HELIONS

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Abstract

Polarized helions will be used in the eRHIC collider to collide with polarized electrons. To allow efficient transport of polarized helions in the Booster, to rigidities sufficiently high ($B\rho = 10.8$ T·m, $|G\gamma| = 10.5$) for minimizing the optical perturbations from the two partial helical dipoles in the AGS, an upgrade for overcoming depolarizing intrinsic resonances is needed. An AC-dipole is being designed to induce spin flips through intrinsic resonances. Booster AC-dipole operation will be established with protons while the polarized helion source is being completed. This paper reports the status of the project (which is now well advanced after two years of theoretical and design studies) and provides an overview of proof of principle experiments to take place after successful installation of the AC-dipole, during RHIC Run 19 with polarized proton beams.

INTRODUCTION

Polarized helions are an important part of the eRHIC physics program[1]. They have potential injection points into the AGS, from the Booster, at $|G\gamma| = 7.5$ and at $|G\gamma| = 10.5$. Injection at $|G\gamma| = 7.5$ which is similar to nominal proton AGS injection rigidity at $G\gamma = 4.5$, $B\rho = 7.2$ T·m and $B\rho = 7.2$ T·m respectively. From polarized proton experience, it is known that the large optics distortion from the AGS partial snakes generate significant beam loss if the vertical tune is set inside the spin tune gap. The plan for helions is to raise both betatron tunes into the spin tune gap, using partial snake magnetic fields similar to those used for protons. The optical perturbations from the two partial snakes are stronger at low rigidity[2], so raising the injection energy to $|G\gamma| = 10.5$, compared to$|G\gamma| = 7.5$, is needed to mitigate their effects. Additionally, the higher injection energy allows the $|G\gamma| = 0 + \nu_y$ resonance in the AGS to be avoided. This results in several unavoidable intrinsic resonances in the Booster, which must be crossed without polarization loss.

A vertical AC-dipole is being designed for installation in the Booster to induce a full spin-flip through these resonances[3, 4]. An AC-dipole forces the bunch to undergo large betatron oscillations, causing all particles of the bunch to sample the strong depolarizing horizontal fields in quadrupoles, enhancing the strength of the resonance [5]. By increasing the strength of intrinsic resonance, it also generates a small spin resonance at the tune of the AC-dipole. Because of these two resonances within close proximity to each other, simulations are required to determine the magnet strength to induce the spin-flip.

Requirements for protons to fully spin-flip while crossing the $G\gamma = 0 + \nu_y$ resonance are similar to polarized helions crossing the $G\gamma = 12 - \nu_y$. This provides a convenient proof-of-principle experiment with protons while the polarized helion source is constructed.

BOOSTER

The Booster is a 201.78 m synchrotron that is the intermediary between ion sources and the AGS. Protons are injected into the Booster at 200 MeV ($G\gamma$=2.18) from the LINAC. Because of the two partial helical dipoles in the AGS, extraction from the Booster needs to occur when the stable spin direction is nearest vertical. This condition occurs once every,

$$G\gamma = 3n + 1.5 \tag{1}$$

and so extraction occurs at $G\gamma = 4.5$[6]. The vertical tune in the Booster, ν_y, is approximately 4.7, so the $G\gamma = 0 + \nu_y$ resonance in the Booster is avoided.

The amplitude of the driven oscillations in the Booster caused by the AC-dipole is defined as,

$$Y_{coh} = \frac{B_m l}{4\pi\delta_m B\rho} \tag{2}$$

where $\delta_m = |\nu_y - \nu_m|$ is the distance between the vertical betatron tune and the AC-dipole tune, $B\rho$ is the rigidity, and $B_m l$ is the AC-dipole strength.

AC-DIPOLE SIMULATIONS

Simulations were performed in the Booster with an AC-dipole for protons crossing the $G\gamma = 0 + \nu_y$ resonance, and for helions crossing the $G\gamma = 12 - \nu_y$ and the $G\gamma = 6 + \nu_y$ resonances[3, 4]. These simulations were performed using the Zgoubi[7]. The crossing speed, $\alpha = G d\gamma/d\theta$, for protons is $\alpha = 5.105 \times 10^{-}6$ with a normalized 95% emittance of $\varepsilon_{\mathrm{N,95\%}} = 3.5\ \pi$ mm mrad. Helions have a crossing speed of $\alpha = 7.961 \times 10^{-}6$ for the $G\gamma = 12 - \nu_y$ resonance, and $\alpha = 2.654 \times 10^{-}6$ for $G\gamma = 6 + \nu_y$, with a normalized 95% emittance of $\varepsilon_{\mathrm{N,95\%}} = 5.0\ \pi$ mm mrad. Table 1 shows relevant parameters and the required AC-dipole strength to spin-flip at each resonance.

These simulations are done with a fixed AC-dipole frequency of 250 kHz, where $\nu_m = f_m/f_{rev}$. Due to the large frequency sweep in the Booster, ν_m can change as much as 0.002 over the course of an AC-dipole cycle and so the average resonance proximity parameter $\bar{\delta}_m = 0.01$. An example of protons crossing the $0 + \nu_y$ resonance is shown in Fig. 1.

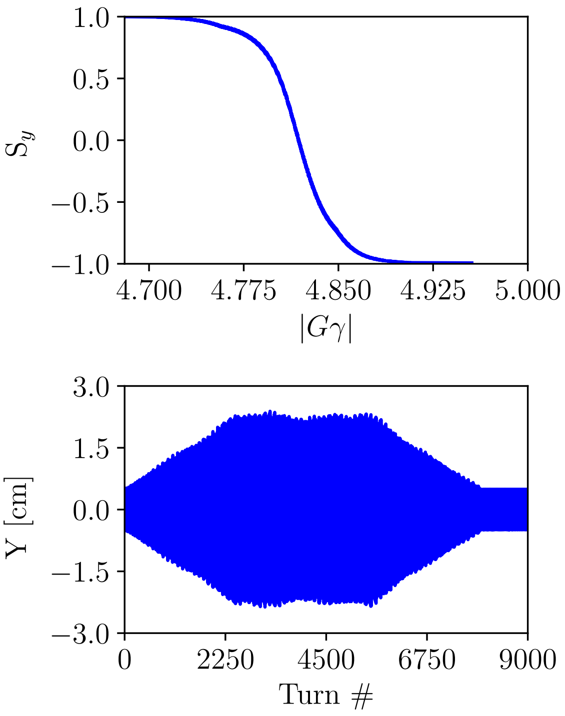

Figure 1: (Top) Polarized protons crossing the $0{+}\nu_y$ resonance. (Bottom) Amplitude of the bunch as it is excited by the AC-dipole. These simulations were performed with Zgoubi.

Table 1: Shows relevant parameters of the AC-dipole for protons and helions and their corresponding resonances. ϵ_k is the resonance strength, σ_y is the RMS width of the beam, $B_m \cdot l$ is the AC-dipole strength, ε_r is the ratio of normalized emittance after and before the AC-dipole ramps.

	Protons	Helions	
Parameter	$0+\nu_y$	$12-\nu_y$	$6+\nu_y$
ϵ_k	0.00246	0.00304	0.00440
σ_y $[mm]$	1.83	2.75	2.31
$B_m \cdot l$ $[G \cdot m]$	15.5	16.5	20.5
ε_r	1.03	1.02	1.00

AC-DIPOLE DESIGN AND INSTALLATION

The AC-dipole is being designed with a strength, $\mathrm{B_m} \cdot \mathrm{l} = 25\ \mathrm{G} \cdot \mathrm{m}$ at a length of 0.50 m. An AC-dipole is a magnet operating as part of a resonant network with a sinusoidally varying field. The resonant network will be designed to resonate at 250 kHz and match the resonant impedance to the amplifier. The physical aperture of the magnet is 8.6 cm×8.2 cm, horizontally×vertically, which is sufficiently large to prevent the magnet from becoming the limiting aperture in the Booster. Simulations of the field were performed using Opera3d and show the feasibility of the magnet design. These simulations show good field uniformity in all planes. The mechanical design is shown in Fig. 2, and shows no programmatic drawbacks.

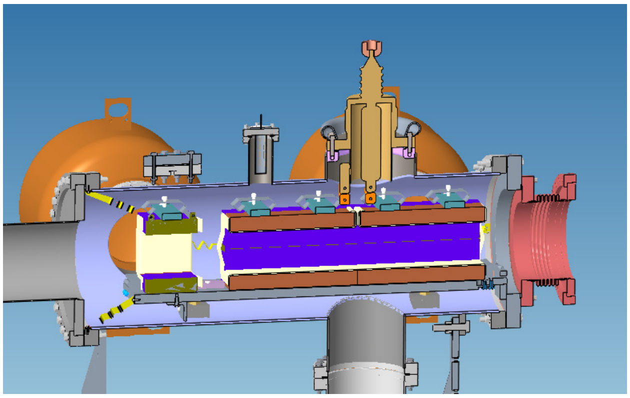

Figure 2: Cross section of the new assembly for the E3 section of the Booster. Inside the transparent vacuum chamber is the new AC-dipole, and a new tune kicker, can be seen. On the exterior of the vacuum chamber are the feed-throughs for the two magnets.

PROOF OF PRINCIPLE EXPERIMENT

The proof of principle experiment for protons will involve: extracting from the booster at $G\gamma = 4.9$, so the $G\gamma = 0 + \nu_y$ resonance can be crossed; ν_y=4.809 as a constraint since the separation of ν_y and the average AC-dipole tune, $\bar{\nu_m}$, is $\delta_m = 0.01$ and the AC-dipole frequency, f_m, is fixed at 250 kHz; Keeping the AGS partial snakes off since a lack of polarimetry in the Booster requires the polarization after crossing the $G\gamma = 0 + \nu_y$ resonance in the Booster to be measured in the AGS. Because extraction from the Booster occurs at $G\gamma = 4.9$, the partial snakes in the AGS need to be off, so condition of Eq. 1 does not need to be met, and the stable spin direction between the Booster and AGS are well matched.

CONCLUSION

Simulations show that an AC-dipole in the AGS Booster is effective at inducing a full spin-flip through strong depolarizing intrinsic resonances. This will allow injection to AGS at higher rigidity, and above the AGS $G\gamma = 0 + \nu_y$. Because of the promising simulation results, a magnet is being constructed for installation in the E3 section. The electromagnetic design shows a high purity dipole field in all planes, whereas the mechanical design is conservative and shows no potential for a programmatic impact. The AC dipole will be installed in Booster by the end of 2018, with the AC-dipole experiment with protons occurring in 2019.

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