OPTICS SETUP IN THE AGS AND AGS BOOSTER FOR POLARIZED HELION BEAM *

H. Huang, L. Ahrens, J. Alessi, M. Bai, E. Beebe, M. Blaskiewicz, K. Brown, Y. Dutheil, W. Fischer, C.J. Gardner, W. J. Glenn, T. Hayes, F. Meot, A. Poblaguev, V. Ranjbar, T. Roser, V. Schoefer, K. Smith, S. Tepikian, N. Tsoupas, K. Yip, A. Zelenski, K. Zeno, Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

Future RHIC physics program calls for polarized helion beam. The helion beam from the new EBIS source has a relative low rigidity which requires delicate control of injection and RF setup in the Booster. The strong depolarization resonance strength in both AGS and AGS Booster requires careful consideration of beam energy range and optics setup. Recently, the unpolarized helion beam was accelerated to 11GeV/n in the AGS. The optics with special tune path has been tested in both AGS and the Booster. The near term goal of 4×10^{10}/bunch at RHIC injection requires several RF bunch merges in both AGS and the Booster. The beam test results are presented in this paper.

INTRODUCTION

There are experiment interests in the Relativistic Heavy Ion Collider (RHIC) to study the spin of neutrons. Since we cannot accelerate neutrons directly, the two candidates are deuteron (p+n) and helion($p^{\uparrow}$+$p^{\downarrow}$+n). Acceleration of polarized deuteron will have other technical difficulties, so polarized helion is the next choice. Currently, a polarized helion source is under development with a collaboration between MIT and BNL [1]. As a preparation for the injector, the possible optics for polarized helion acceleration in both Booster and Alternating Gradient Synchrotron (AGS) have been explored by simulation and beam study. In addition, the existing carbon-target polarimeter has been tested with helion beam. Since $^3He^{2+}$+C->$^3He^{2+}$+C is a new process, the analyzing power is unknown. The absolute polarization has to come out from a polarized helium jet.

BOOSTER AND AGS SETUP

During acceleration, two types of depolarizing resonances are crossed whenever the spin precession frequency equals the frequency with which spin-perturbing magnetic fields are encountered. The spin precession frequency is defined as the number of full spin precessions per orbital revolution and is also called spin tune ν_{sp}. For a synchrotron with only vertical bending field, spin tune is equal to $G\gamma$, where G is anomalous magnetic moment of the beam particles, γ is Lorentz factor. The resonance condition for imperfection depolarizing resonances arises when $\nu_{sp} = n$, where n is an integer. The condition for intrinsic resonances is $\nu_{sp} = kP \pm \nu_y$ where k is an integer, ν_y is the vertical betatron tune, and P is the superperiodicity. For the AGS, $P = 12$. For AGS Booster, $P = 6$.

For protons, a dual partial snake scheme [2] has been used in the AGS to overcome both imperfection and vertical intrinsic depolarizing resonances. The two imperfection resonances in the Booster are overcome by orbit harmonic correction. The first intrinsic resonance in the Booster at $G\gamma = 0 + \nu$ is avoided by pushing the vertical tune as high as 4.8, which is higher than the extraction energy $G\gamma = 4.5$.

For normal synchrotrons, the intrinsic resonance is only associated with the vertical betatron tune ν_y for vertical polarization, as the vertical spin can only be affected by the horizontal magnetic field. However, in the presence of a partial snake, the stable spin direction is not purely vertical. Therefore the perturbing fields that rotate the spin away from the stable spin direction have vertical as well as horizontal components. Particles undergoing horizontal betatron oscillations encounter vertical field deviations at the horizontal oscillation frequency. As a result, resonances with the spin tune are driven by the horizontal betatron oscillations, and will occur whenever the spin tune satisfies $G\gamma = k \pm \nu_x$. Since all these resonances are relatively weak compared to the vertical counterpart, a modest tune jump system (0.04 horizontal tune jump in $100\mu s$) has been used in the AGS to increase the effective resonance crossing rate to mitigate the polarization loss. The question is how much of these techniques still work for polarized helion beam.

There is a big difference in the G values for proton and helion. For proton, $G = 1.7928$. For helion, $G = -4.18$. To avoid confusion, $|G\gamma|$ is used. The velocity of different ions out of Electron Beam Ion Source(EBIS) [3] is fixed. The Booster input $|G\gamma|$ is fixed at 4.19. Booster tunes are usually around 4.82, which is inside the Booster acceleration $|G\gamma|$ range. The first few Booster intrinsic resonances are located at $|G\gamma| = 0 + \nu_y = 4.82$, $12 - \nu_y = 7.18$, $6 + \nu_y = 10.82$. The first task is to push vertical tune below 4.1 near injection, so that $G\gamma = 0 + \nu$ can be avoided. At injection, the tune quadrupoles have enough muscle to push vertical tune low. During acceleration, the vertical tune has to be raised to higher value, but the crossing time can be chosen such that no major resonance is crossed. In addition, it can not be higher than 4.43, so that a extraction at $|G\gamma|$=7.5 is below Booster resonance $12 - \nu_y$. Unless additional spin manipulating device such as partial snake or AC dipole is installed in the Booster, the extraction $|G\gamma|$ can not be higher than 7.5. So the Booster $|G\gamma|$ range is

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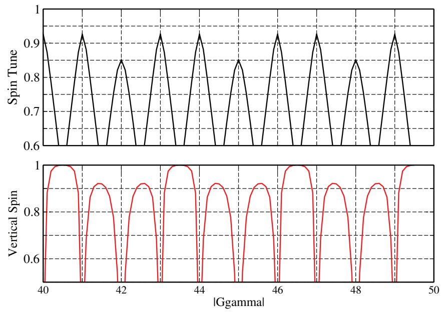

Figure 1: Top: Fractional spin tune as function of $|G\gamma|$ near the AGS extraction. Bottom: The vertical spin component as function of $|G\gamma|$ near the AGS extraction. The modulation is due to the 1/3 ring separation of the two partial snakes.

determined to be 4.19 to 7.5. Similar to proton case, the imperfection depolarizing resonances are going to be corrected by vertical orbit harmonics when $|G\gamma|$=5, 6, and 7.

AGS injection happens at $|G\gamma| = 7.5$. This is actually a good choice for spin match. The two partial snakes in the AGS are separated by 1/3 of the ring. As the results, the spin tune and vertical component of stable spin direction are modulated with energy. The vertical component reaches maximum every three integers as shown in Fig. 1. Near the injection, vertical component reaches maximum at $|G\gamma|$=4.5, 7.5 and 10.5. The extraction energy is determined from the same consideration in addition to AGS to RHIC spin match. $|G\gamma|$=49.5 is the choice. The next strong intrinsic resonance at $|G\gamma| = 60 - \nu_y = 51.03$ will be too strong for the dual partial snakes.

The AGS $G\gamma$ range is 7.5 to 49.5. The resonance strength can be calculated from DEPOL program [4] for both proton and helion cases. For ν_y=8.99, the resonance strength ϵ of a few intrinsic resonances are give in Table 1. As shown in Table 1, the resonance strength is stronger for helion by a factor 1.5, or $\sqrt{|G_{He}/G_p|}$.

Table 1: Intrinsic Depolarizing Resonance Strength ϵ

Resonance	γ_P	ϵ_P	γ_{He3}	ϵ_{He3}
$0+\nu$	5.014	.00160	2.149	0.0230
$24-\nu$	8.372	0.0019	3.587	0.0028
$12+\nu$	11.708	0.0070	5.017	0.0107
$36-\nu$	15.065	0.0145	6.455	0.0222
$24+\nu$	18.401	0.0021	7.885	0.0032
$48-\nu$	21.759	0.0029	9.323	0.0044
$36+\nu$	25.094	0.0297	10.753	0.0453

Since the intrinsic resonance strength only goes up with $\sqrt{|G|}$ but snake strength goes up with $|G|$, the partial snake field used for proton can be reduced by a factor $\sqrt{|G_{He}/G_p|} \approx 1.5$ and the polarization is still maintained as well as in the proton case. This means 1.5T cold snake for helion. It also reduces the horizontal res-

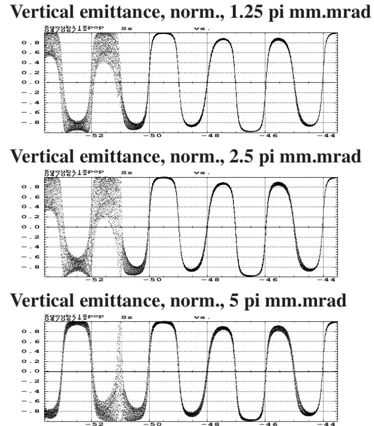

Figure 2: The ZGOUBI simulation for last a few units of $G\gamma$ near AGS flattop with 2.1T cold snake. The tracking was done for particles on various vertical emittance ellipses. The vertical axis is polarization and the horizontal axis is $G\gamma$. Note the acceleration starts from right to left.

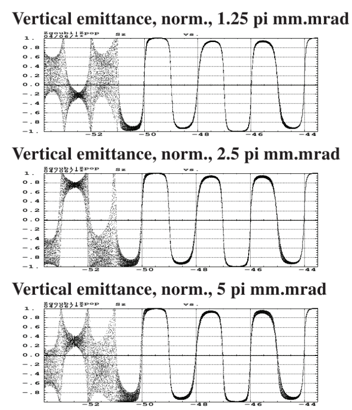

Figure 3: The ZGOUBI simulation for last a few units of $G\gamma$ near AGS flattop with 1.5T cold snake. Up to $|G\gamma|$=49.5, 1.5T is as good as 2.1T. The axes are defined similarly to Fig. 2.

onance strength. Due to its magnet design, the warm snake only works at one current and the warm snake has to run at the same current as before, namely, 1.5T. To test this partial snake combination, spin tracking simulations with ZGOUBI [5] (see Figs. 2 and 3) have been done to see if the cold snake strength can be reduced. The spin tracking simulations were done for two different cold snake fields, 2.1T (corresponding to 25% snake strength at flattop) and 1.5T(about 15% snake strength at flattop). The results show that two 15% partial snakes are enough for the strongest intrinsic resonance at 36+ν_y. The simulations were done with particles on a few vertical emittance ellipses. For simplicity, the horizontal emittance was kept near zero and no orbit error are considered. The vertical tune was 8.97 in the simulation. The direct benefit of weaker cold snake is that the corresponding horizontal intrinsic resonances will be weaker, as the stable spin direction will have less horizontal component, and consequently less horizontal resonance strength. In addition, this will reduce the effect of the snake on optics at low energy.

One potential issue is with the horizontal tune jump quads. The resonance strength in general is stronger for two reasons: larger $|G|$ value and stronger snake strength. Even with weaker magnetic field of the cold partial snake, the combined snake strength is near 30%, compared to the 16% in the proton case. Time wise, the spacing of resonances is smaller for helion than for proton beam. It requires 43 jumps in 335ms for helion compared to 42 jumps in 430ms for protons. The existing tune jump quad power supplies and controls probably need to be upgraded.

Given these analyses, one polarization preservation option for AGS and the Booster is following: 1. to push ν_y below 4.11 and keep it lower than 4.43 through the cycle in the Booster; 2. to correct imperfection resonances in the Booster with harmonic orbit correction; 3. to overcome vertical intrinsic and imperfection resonances with dual partial snakes in the AGS, but weaker cold snake; 4. to overcome horizontal intrinsic resonances with modest tune jump system(requires upgrade).

EXPERIMENTAL RESULTS

To avoid the two intrinsic resonances in the Booster (0+$\nu_y$and 12-ν_y), the vertical tune needs to be 4.1 at injection and below 4.43 at extraction. To reach bunch intensity of 10^{10} in the AGS, bunch merges are needed in the Booster and AGS. Since the Booster injection is a very low energy, the Booster has to start with h=4, which fits well with needed bunch merge. The bunch merge (4->2->1) happens at$|G\gamma|$=4.5. A vertical tune of 4.09 actually was achieved near injection.

Helion beam was accelerated to the AGS flattop with both partial snakes on. The intensity out of EBIS is 3.9×10^{10} and is 1×10^{10} at AGS flattop. For polarization preservation, the vertical tune needs to be higher than 8.97 at $0 + \nu_y$ and after. The measured tune met that requirement as shown in Fig. 4. In the latest beam test, AGS bunch merge was tested without snake on in the AGS. The merge was done with 8 Booster transfers into 8 out 12 buckets. At injection, two bunch merges(12->4->2) gave 3.9×10^{10} bunch intensity. The emittance is about 11π in horizontal and 7π in vertical as reported by AGS IPM.

POLARIMETER TEST

The existing carbon target polarimeter [6] is expected to work for the AGS. However, it still needs to be confirmed that the polarimeter Si detectors can detect recoil carbons from C-helion scattering. The event rate gain for helion due to elastic cross section is estimated to be $A^{2/3} = 3^{3/2} = 2.08$. The actual observed gain is about 2. The so-called carbon banana is measured as shown in Fig. 5. The polarization is consistent with zero as expected: $0.89 \pm 1.84\%$. The kinematics only tells us these are slow carbons. The asymmetry associated with polarization only comes from recoil carbons out of elastic scattering. Further analysis of possible inelastic scattering process shows

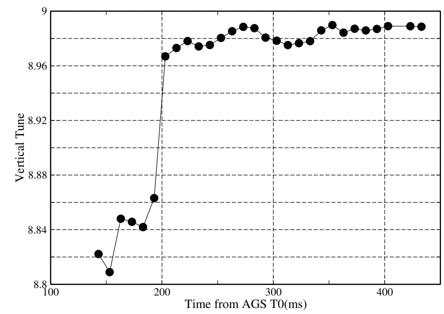

Figure 4: Vertical tune path on the ramp. The $0 + \nu_y$ resonance is at 213ms and $36 + \nu_y$ resonance is at 332ms. Vertical tune is high at these resonance locations.

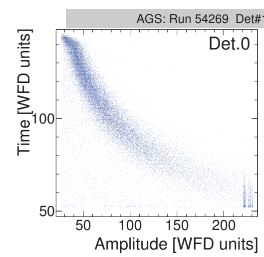

Figure 5: Carbon bananas from helion-Carbon scattering. The axes of Time of flight and amplitude (energy) are in the wave form digitizer units.

that only one possible helion breakup process could generate carbons in the 2mm detector acceptance, no process could generate inelastic process into the 1mm detector acceptance. We will need polarized helion beam to see if 2mm detectors can still be used.

SUMMARY

The experiments requiring polarized helion beam are still several years away. The beam test with unpolarized helion beam has shown that the desired optics can be achieved without problem in both AGS and the Booster, which includes the high vertical tune in the AGS and low vertical tune in the Booster. The beam test shows that carbon target polarimeter can detect the recoil carbons. The bunch merges required for the higher bunch intensity have been demonstrated in both AGS and the Booster. The remaining work are to raise intensity and to use polarized helion beam for polarization preservation study.

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