# RHIC SPIN FLIPPER STATUS AND SIMULATION STUDIES*

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*Abstract*

The commissioning of the RHIC spin flipper in the RHIC Blue ring during the RHIC polarized proton run in 2009 showed the detrimental effects of global vertical coherent betatron oscillation induced by the 2-AC dipole plus 4-DC dipole configuration [1]. Additional three AC dipoles were added to the RHIC spin flipper in the RHIC Blue ring during the summer of 2010 to eliminate the vertical coherent betatron oscillations outside the spin flipper [2]. This new design is scheduled to be commissioned during the RHIC polarized proton run in 2011. This paper presents the status of the system as well as latest simulation results.

## INTRODUCTION

In order to minimize the systematic errors for the RHIC spin physics experiments, a spin flipper was installed in the Blue ring of RHIC (Relativistic Heavy Ion Collider) at Brookhaven National Lab to reverse the spin direction of the two colliding beams multiple times during the store when data are taken. RHIC as a high energy polarized proton collider employs two pairs of full Siberian snakes to avoid polarization loss during acceleration and store [5]. In each accelerator, the two snakes are located diametrically opposed with their spin precession axes perpendicular to each other, and the nominal spin precession tune [6] in RHIC is $Q_s = \frac{1}{2}$ [5]. This makes the traditional spin flipping technique of using a single RF spin rotator (a dipole or a solenoid) not possible because it induces a spin resonance not only at $Q_s = Q_{osc}$ but also $Q_s = 1 - Q_{osc}$ [1]. Here, $Q_{osc}$ is the RF spin rotator tune, its oscillating frequency in units of the orbital revolution frequency.

The first design of the RHIC spin flipper employed two AC dipoles with a DC spin rotator in between to achieve a rotating field, i.e. with its axis rotating in the horizontal plane [7]. Unlike the traditional technique of single RF spin rotator, this rotating field only induces one spin resonance at $Q_s = Q_{osc}$. Since the resonance at $Q_s = 1 - Q_{osc}$ is eliminated, a full spin flip can be obtained with spin precession tune staying at half integer. Fig. 1 shows the schematic layout of the first design of RHIC spin flipper, which consists of two AC dipoles and two side-by-side DC dipoles with the axis along the vertical direction in between. The strength of the two DC dipoles on either side of the two ac dipoles is the same as the strength of each of the two center DC dipoles but with opposite polarity to cancel the spin rotation by the center dipoles and keep the spin tune

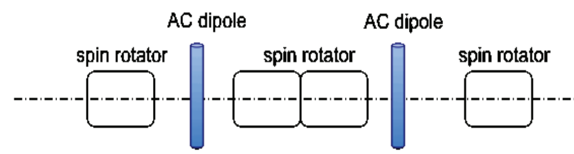


Figure 1: The schematic layout of the first design of RHIC spin flipper with two AC dipoles

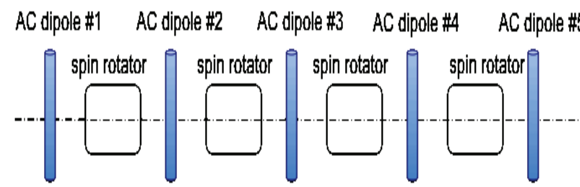


Figure 2: The schematic layout of RHIC spin flippers new design.

unchanged. This arrangement also localizes the horizontal orbit deflection by the DC dipoles inside the spin flipper.

In 2009, a set of measurements with the two AC dipole design of RHIC spin flipper was taken. The four DC dipoles, also known as DC spin rotators, were first energized to their design currents to confirm that the horizontal orbital bump from the DC spin rotators was localized. The coherent betatron oscillation driven by the AC dipoles, however is global. This, in turn, drives a spin resonance at $Q_s = Q_{osc}$ as well as at $Q_s = 1 - Q_{osc}$. If this effect is not neglibible in comparison to the spin resonance due to the rotating field from the spin flipper, the condition of inducing a single isolated resonance can't be met and spin flipping can't be achieved in the presence of 1/2 spin tune [8]. The effect of global ac dipole driven vertical coherent betatron oscillation on beam polarization was also measured as function of spin tune at injection energy. The experimental data confirmed that the global ac dipole driven betatron oscillation broke the single resonance condition [2].

Hence, it is critical to eliminate the global ac dipole driven vertical betatron oscillaton for achieving full spin flipping in RHIC. A new design with three additional ac dipoles was then proposed to accommodate this requirement [2]. Fig. 2 shows the schematic drawing of the current RHIC spin flipper design where five AC dipoles are arranged with equal spacing between them. AC dipole #1, AC dipole #2 and AC dipole #3, the AC dipole in the middle can be powered to form a closed orbital bump by energizing AC dipole #1 and AC dipole #3 with half of the cur-

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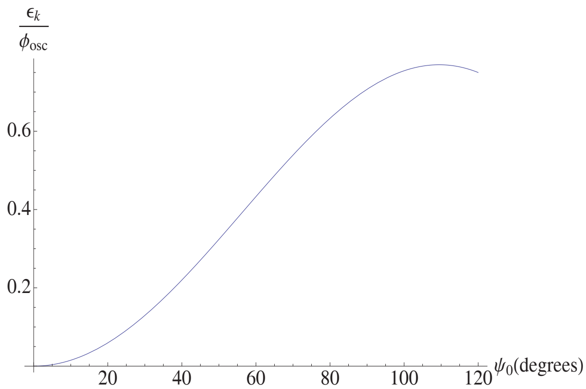


Figure 3: The 5 ac dipole design spin flipper strength as a function of the DC spin rotator strength in units of the ac dipole strength $\phi_{osc}$

rent in AC dipole #2 but opposite polarity. Similarly, AC dipole #5, AC dipole #4 and AC dipole #3, can be powered to form another closed orbital bump. The phases between the currents in AC diple #2 and AC dipole #4 are chosen to fullfill $180° - \psi_0$. The effective spin resonance strength of this design $\epsilon_k$ then becomes

$$\epsilon_k = 2\phi_{osc} \sin\psi_0 \sin\frac{\psi_0}{2}, \tag{1}$$

where $\phi_{osc}$ is the amplitude of the spin rotation of AC dipole #2 or #4 and $\psi_0$ is the amount of spin rotation of each DC spin rotator. Fig. 3 shows the spin flipper strength as a function of the strength of the DC spin rotator. With the spin rotator strength of the two AC dipole design, the effective spin resonance strength would only be 13.5% of the resonance strength of the spin flipper with two AC dipole. In order to increase the effective spin resonance strength, the amount of the spin rotation of each spin rotator is increased to 45° for the new design.

A set of spin trackings with RHIC polarized proton lattice was carried out to explore the spin flipper parameter space. For all spin tracking studies in this paper, all ac dipoles were first ramped to their amplitudes in 1000 turns at a fixed tune of 0.49. Their tune was then swpet to 0.51 in 48000 turns. Fig. 4 shows the simulation results of spin flipping a single on-momentum particle with different ac dipole strength. The particle was on an ellipse of $7\pi$ mm-mrad emittance for all the cases. Clearly, only partial spin flip is achieved if the spin flipper is not strong enough. For the current $45^o$ DC spin rotator strength, 120 Gauss-m ac dipole is required for full spin flip. This can also be achieved for 100 Gauss-m ac dipole by running DC spin rotator to 60°.

## IMPACT OF SYNCHROTRON OSCILLATION ON SPIN FLIPING

Even though in the presence of full Siberian snakes, spin tune in principle should be energy dependent, momentum

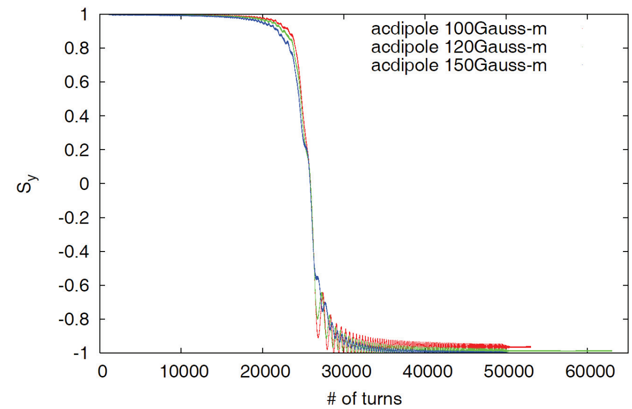


Figure 4: The plot shows the vertical spin component as function of orbital revolution for different ac dipole strength. An on momentum particle was launched at an emittance of $7\pi$ mm-mrad. The red dot data set shows the spin flipping with ac dipole strength of 100 Gauss-m, green dot data set is for ac dipole strength of 120 Gauss-m and blue dot data set corresponds to the ac dipole strength of 150 Gauss-m

spread in a beam can still result in non-zero spin tune spread $\delta Q_s$ due to the difference of dispersion function slope at the two snakes [3, 4] $\Delta D\prime$, i.e.

$$\delta Q_s = \frac{G\gamma}{\pi}\Delta D\prime \frac{\Delta p}{p}, \tag{2}$$

where $G = 1.793$ is the proton anomolous g-factor and $\gamma$ is the Lorentz factor. In RHIC, this local dispersion slope difference between the two snakes is about 0.15, i.e. 0.002 spin tune spread for a beam with momentum spread of 0.001.

For a spin flipper with a strength of a few units of $10^{-4}$, if the spin flipping time, during which the spin flipper tune is adiabatically swept across the spin tune, is much longer than the synchrotron period, particle then crosses this resonance multiple times and can result in polarization loss. Fig. 5 shows a on momentum single particle spin flipping vs. particle with a momentum spread of 0.0005 and 0.001, respectively. In both cases, the ac dipole strength was 120 Gauss-m and DC spin rotators were set to 45° spin rotation. All calculations were done with the RHIC 28 MHz RF system for acceleration [5]. The harmonic number is 360 and RF voltage in one turn is 300 kV. The expected synchrotron frequency is about 43 Hz.

One way to mitigate this problem is to match the dispersion slope at the two snakes. Unfortunately, this is not possible with the current RHIC lattice, which is designed to be anti-symmetric across each IP. However, in the current RHIC polarized proton run, a new RF system of 9MHz has been recently commissioned for accelerating polarized protons. With this system, the synchrotron frequency is reduced to about 8 Hz. Fig. 6 shows the results of an off momentum single particle tracking with 9MHz RF system and with 28 MHz RF system, respectively. For both cases,

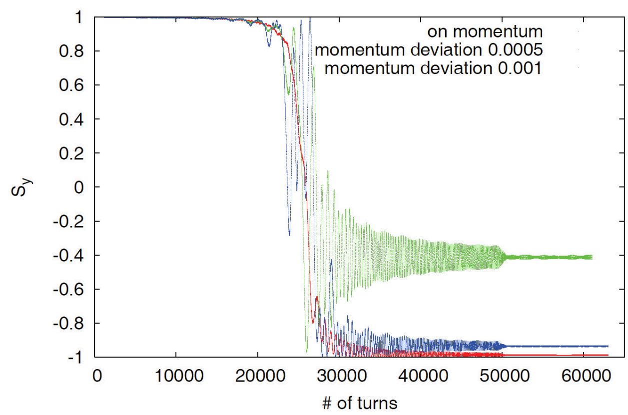


Figure 5: Vertical component of spin vector as a function of number of turns for a single particle with different momentum spread. Red is for the on momentum case. Blue and green are for off momentum of 0.0005 and 0.001, respectively. The particle was launched from $2.5\pi$ mm-mrad emittance for all the cases.

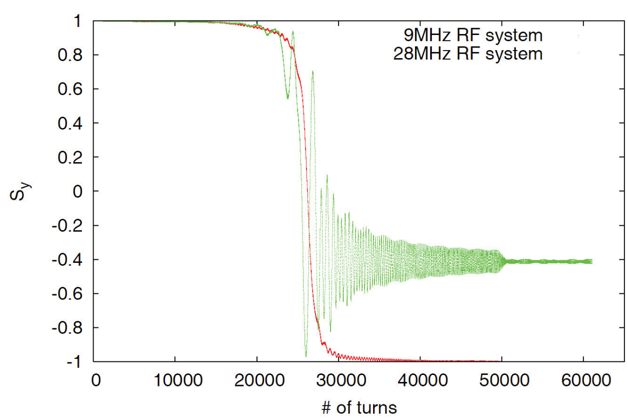


Figure 6: Vertical component of spin vector as a function of number of turns for a single off-momentum particle of 0.0005 under 28MHz RF system (green) and 9MHzRF system (red). AC dipole strength was set to 120 Gauss-m for both case.

the momentum devation of the particle is 0.0005 and the spin flipper was set to the same configuration as in Fig. 5. Evidentally, the multiple resonance crossing was significantly reduced with 9MHz system and full spin flipping can be achieved.

## CONCLUSION

The spin tracking studies confirmed that the new design with 5 ac dipoles should work if the ac dipole driven vertical coherent betatron oscillation can be localized within the spin flipper. This requires a careful adjustment of all the ac dipole currents and phases to ensure the closure of the two vertical ac dipole bumps. Due to the lack of beam time, we haven't had chance to take any measurements with beam.

The spin tracking with off momentum particles also shows the impact of synchrotron oscillation on spin flipping. The spin tune spread due to the asymmetry of the dispersion slope at the two snakes can cause multiple resonance crossing during the spin flipping and result in polarization loss. Since it is extremely difficult to match the dispersion slope at the two snakes due to the intrinsic property of the RHIC lattice, one practical way to mitigate the problem is to use the 9MHz RF system which reduces synchrotron tune significantly.

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