RHIC SPIN FLIPPER COMMISSIONING

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Abstract

An ac dipole with horizontally oriented oscillating magnetic field (spin flipper) was installed in RHIC to reverse the spin direction in the presence of two full Siberian snakes, thereby reducing the systematic errors for the spin physics experiments in RHIC. With two full snakes, the spin vector completes one full precession around the vertical direction in two revolutions, and the spin depolarization resonances due to the machine imperfections and betatron oscillations are eliminated. Since the spin flipper provides an oscillating horizontal dipole field, a "spin resonance" can occur if the spin flipper frequency is placed in the neighborhood of the spin precession frequency [1, 2, 3]. By slowly sweeping the spin flipper frequency across the spin precession frequency, a full spin flip can be achieved. This paper reports the results of the RHIC spin flipper commissioned during the RHIC 2002 polarized proton run. By running the spin flipper at a slightly different configuration, one can also measure the spin precession tune.

1 INTRODUCTION

Like any other magnets, the spin motion through an ac dipole also obeys the Thomas-BMT equation

$$\frac{d\vec{S}}{dt} = \frac{e}{\gamma m}(1 + G\gamma)\vec{S} \times \vec{B}(t), \qquad (1)$$

where $\vec{S}$ is the spin vector in the particle rest frame, G is the anomalous gyro-magnetic g-factor and γmc^2 is the moving particle energy. $\vec{B}(t)$ is the magnetic field of the ac dipole

$$B(t) = B_o cos(2\pi f_m t + \chi) \qquad (2)$$

where B_o is the amplitude of the oscillating magnetic field, f_m is the oscillation frequency and χ is the arbitrary phase of the ac dipole oscillating magnetic field.

In a perfect planar circular accelerator, the beam's spin vector precesses around vertical direction. With the ac dipole in the machine, the spin vector gets kicked away from the vertical direction every time it passes through the ac dipole. In the frame which rotates at the same oscillation frequency of f_m, the two-component spinor equation then becomes

$$\frac{d\psi_K}{d\theta} = -\frac{i}{2}(\vec{\sigma} \cdot \vec{n})\psi_K \qquad (3)$$

where

$$\vec{n} = G\gamma \hat{e}_3 - B_o \hat{e}_1. \qquad (4)$$

Here, $\hat{e}_1$ is the unit vectors pointing radially outward and the unit vector $\hat{e}_3$ points up along the transverse axis. Compare this with spinor equation of an intrinsic spin resonance [4]; the effect of the ac dipole on the spin motion is equivalent to a spin resonance located at

$$\nu_s = \nu_m = \frac{f_m}{f_{rev}}, \qquad (5)$$

where ν_s is the spin precession tune and f_{rev} is the beam revolution frequency. The strength of this ac-dipole-induced spin resonance is given by

$$\epsilon_K = \frac{1 + G\gamma}{4\pi} \frac{B_o L}{B\rho} \qquad (6)$$

where L is the length of the ac dipole and $B\rho$ is the magnetic rigidity.

According to the Frossart-Stora formula, the beam polarization after crossing through a spin resonance is

$$P_f = \left(2e^{-\pi|\epsilon_K|^2/2\alpha} - 1\right) P_0 \qquad (7)$$

where P_f and P_0 are the beam polarization after and before the resonance. $\alpha = \frac{d\Delta\nu_m}{d\theta}$ is the resonance crossing rate. To achieve a 99.999% spin flip, the following condition has to be satisfied

$$\alpha \leq 0.13|\epsilon_K|^2 \qquad (8)$$

2 SPIN FLIPPING IN RHIC

2.1 RHIC spin setup

To eliminate the spin depolarization resonances along the acceleration, two pairs of Siberian snakes were installed in RHIC [5]. In each ring, the two snakes are placed on opposite sides of ring. Each snake consists of four superconducting helical dipole magnets and rotates the spin vector by $180°$ around an axis. This axis lies in the horizontal plane and is called the snake axis. The spin precession tune is given by

$$\nu_s = \frac{1}{\pi}|\psi_1 - \psi_2| \qquad (9)$$

where ψ_i is the angle between the axis of the i_{th} snake and the longitudinal direction. In general, the axes of the two snakes are configured to be $\pm 45°$ away from the longitudinal direction for the RHIC polarized proton run and the nominal spin precession tune is $\frac{1}{2}$. In order to rotate the spin vector by 180°, the two outer helical magnets are powered with same current with opposite polarities. Similarly the two inner helical magnets are powered with equal but opposite currents.

The RHIC beam polarization was measured with the CNI(Compton Nuclear Interaction) polarimeter located at the IP12 region [6]. It measures the left-right asymmetry of the recoil carbon. A typical measurement acquires 2 million events to reach a 2% statistical error bar.

2.2 RHIC spin flip

To induce a full spin flip in RHIC, one can sweep the artificial spin resonance across the spin precession frequency. In order to cross over the resonance, one needs to detune the snake axis to move the spin precession tune away from $\frac{1}{2}$.

The RHIC spin flipper is located at the interaction region of IP4 and is common to both beams. Since each Siberian snake in RHIC is energized with two independent power supplies, the control of the spin precession tune in the two rings is independent of each other. Thus, one should in principle be able to achieve spin flipping in one ring without impacting the beam polarization in the other ring.

Two spin flips were tried in the Blue ring at the end of a typical polarized proton store. We first ramped the both snakes in the blue ring to the settings which correspond to $\nu_s = 0.48$. Table 1 lists the snake inner and outer currents set values and read-backs. We then ramped the ac

Table 1: Blue Siberian Snake Current Setting

magnet	set current[A]	current rck[A]
bo3 snake outer	106.11	105.75
bo3 snake inner	325.06	324.07
bi9 snake outer	106.11	106.40
bi9 snake inner	325.06	324.88

dipole magnetic field amplitude from zero to 100 gauss-m in 6000 revolution turns with the resonant frequency fixed at $0.47 f_{rev}$. Here, f_{rev} is the particle's revolution frequency around the ring. The ac dipole frequency was then swept from $0.47 f_{rev}$ to $0.49 f_{rev}$ in 200,000 revolution turns. The ac dipole was gradually turned off at a fixed frequency of $0.49 f_{rev}$ during 6000 turns. With the ac dipole maximum field of 100 gauss-m and the resonance crossing rate

$$\alpha = \frac{d\Delta\nu_m}{d\theta} = \frac{0.02}{200000 \times 2\pi} = 1.6 \times 10^{-8}, \quad (10)$$

the expected spin flip is

$$\frac{P_f}{P_0} = -1.0. \quad (11)$$

Fig. 1 shows the measured asymmetry before and after the spin flipping. The average spin flipping efficiency η is defined as

$$P_i = P_0 \eta^i \quad (12)$$

where P_0 is the beam polarization before the spin flipping and P_i is the beam polarization after the ith spin flipping.
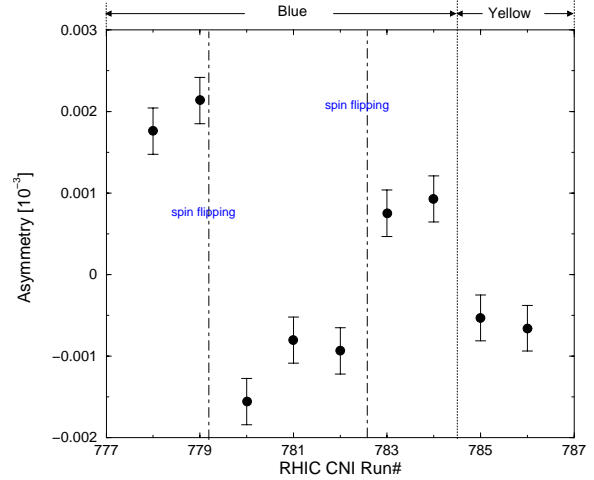

Figure 1: This plot shows the measured beam asymmetry before and after the spin flipping in RHIC. The averaged asymmetry in blue was measured as 0.00195 ± 0.0002 After the 1st spin flipping, the asymmetry was measured as 0.0011 ± 0.000164. The asymmetry was 0.00084 ± 0.0002 after the 2nd spin flipping. The data point of RHIC CNI run 785 and 786 correspond to the measured asymmetry in the yellow ring after the 2nd spin flipping in blue.

In this case, two spin flippings were performed and the average spin flipping efficiency was measured as.

$$\eta = 0.66. \quad (13)$$

The fact that we did not reach full spin flip can be either due to the spin precession tune was not 0.48 as we expected or due to the spread of spin precession tune among the different particles in the bunch. Further study is needed to investigate the amount of the spin tune spread in RHIC. However, due to the lack of time, we did not have chance to improve the spin flipping efficiency.

The asymmetry in yellow was also measured as before the spin flippings in blue as 0.0015 ± 0.0003 However, the fact that we measured the yellow asymmetry as -0.00075 ± 0.0002 after the 2nd spin flipping in blue as shown in Fig. 1 indicated that the spin tune in the yellow ring is not $\frac{1}{2}$. Otherwise, the spin flipping in blue should not have done any harm to the beam polarization even though the ac dipole affects both beams. This is also consistent with the two spin flipping attempts in the yellow ring in which no spin flipping except depolarization was observed even though the same procedure as the blue one was followed.

3 CONCLUSION

A short study of using the RHIC vertical ac dipole as a spin flipper was performed at the end of the RHIC 2002 polarized proton run. A partial spin flip was obtained in the RHIC blue ring at the storage energy. However, due to the time limitation, we did not get chance to investigate

the cause and improve the spin flip efficiency. However, no spin flipping was obtained in the yellow ring.

4 ACKNOWLEDGEMENT

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