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Spin Flipping in RHIC *

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Abstract

At the Relativistic Heavy Ion Collider (RHIC), polarized protons will be accelerated and stored for spin physics experiments. Two full helical snakes will be used to eliminate the depolarization due to imperfection and intrinsic spin resonances. Since no resonances are crossed in RHIC, the beam polarization remains fixed through acceleration. However, in order to reduce systematic errors, the experiment often requires the polarization direction reversed. This paper presents a method of using an ac dipole to obtain a full spin flip in the presence of two full snakes [1]. A similar method of using an rf solenoid for spin flip was tested at IUCF [2, 3].

1 INTRODUCTION

In a perfect planar synchrotron with vertically oriented guiding magnetic field, the spin vector of a proton beam precesses about the vertical axis $G\gamma$ turns per revolution. Here, $G\gamma$ is the spin precession tune of proton, $G = (g-2)/2 = 1.7928474$ is the anomalous magnetic g-factor and γ is the relativistic Lorentz factor. In a real circular accelerator, the horizontal magnetic field that arises from the various sources like the vertical close orbit, the vertical betatron oscillation and etc kicks the spin vector away from precessing around the vertical axis. Normally, this perturbation is small. However, when the spin precession frequency coincides with the frequency at which the spin vector gets kicked by the horizontal magnetic field, the spin vector then gets bent away coherently and a spin resonance is encountered. In general, a spin resonance is located at

$$G\gamma = k + m\nu_z + n\nu_x + p\nu_{syn}. \quad (1)$$

where k, m, n and p are integers. ν_x and ν_z are the horizontal and vertical betatron tunes. ν_{syn} is the tune of the synchrotron oscillation.

Among all the spin resonances, the imperfection resonance at $G\gamma = k$ and the intrinsic spin resonance at $G\gamma = k + m\nu_z$ are the two most common and fundamental spin resonances in a circular accelerator. The imperfection spin resonance is due to the vertical closed orbit error, and its strength is proportional to the size of the closed orbit distortion. This resonance can be eliminated if the orbit is flattened. On the other hand, the intrinsic resonances comes from the vertical betatron motion and are determined by the size of the vertical betatron oscillation. The larger the betatron oscillation, the stronger the resonance.

In spite of the difference between the origin of the imperfection and intrinsic spin resonance, both resonances are proportional to the beam energy. The higher the beam energy, the stronger the spin resonance. The acceleration of polarized proton beam in RHIC from 25 GeV/c to 250 GeV/c crosses numerous spin resonances. Figure 1 shows the imperfection and intrinsic spin resonance strength as a function of the beam energy in RHIC. Because the RHIC lattice contains 3 super-periods and 27 effective FODO sells in each super-period, the imperfection spin resonances at $G\gamma = k \times 81$ and intrinsic spin resonances at $G\gamma = k \times 81 \pm (\nu_z - 12)$ with $k = 3, 5$ are strongly enhanced. $\nu_z - 12$ is because there are total 12 insertion regions in RHIC and the phase advance of each insertion region is π [4]. The spin resonances with k =even integers are weakened because the arrangement of the focusing and defocusing quadrupoles on either side of each interaction point is antisymmetric.

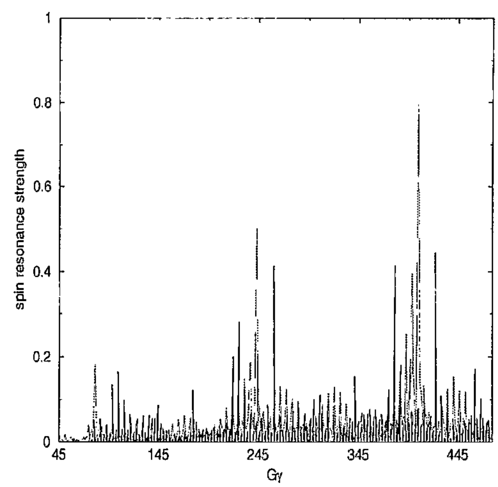

Figure 1: RHIC spin resonance spectrum. The black lines are the imperfection resonances and the red lines are the intrinsic resonances. Because of the superperiodicity structure, the important spin resonances are located at $G\gamma = 3 \times 81 + (\nu_z - 12)$ and $G\gamma = 5 \times 81 \pm t(\nu_z - 12)$.

In order to maintain the beam polarization through the acceleration in RHIC, two pairs of helical dipole snakes are installed in the two rings to deal with the spin resonances.

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A full helical snake consists of four twisted dipole magnets (helical dipoles) which rotates the spin vector by 180^o when the particle passes through the snake [4]. Therefore, the errors on the spin vector accumulated in the first half path along the ring is canceled out with the errors in the second half path around the ring and no spin resonance occurs. In the presence of the full snakes, the spin precession tune then becomes independent of the energy and is determined by the configuration of the snakes. In the case of RHIC, the spin precession tune is given by

$$\nu_s = \frac{1}{\pi}\Delta\phi, \tag{2}$$

where ν_s is the spin precession tune, $\Delta\phi$ is the angle between the two snakes' axis. In normal operation, the axes of the two helical snakes are perpendicular to each other and the nominal spin precession tune is 0.5.

2 SPIN FLIPPING IN THE PRESENCE OF FULL SNAKE

The spin vector can be flipped by a spin rotator to bend the spin vector by 180^o. It can also be reversed by slowly crossing a strong spin resonance based on the Froissart-Stora formula [5] as shown in Eq. 3

$$P_f = \left(2e^{-\pi|\epsilon_K|^2/2\alpha} - 1\right) P_i \tag{3}$$

where ϵ_K is the resonance strength, α is resonance crossing rate given by

$$\alpha = \frac{d(G\gamma - kP \mp m\nu_z)}{d\theta}, \tag{4}$$

and θ is the orbiting angle in the synchrotron.

Although in the presence of two full helical snakes, the spin precession tune is independent of beam energy and no spin resonance is crossed, the vertical ac dipole introduces an artificial spin resonance at the frequency which its magnetic field oscillate at. When the frequency of the ac dipole is swept through the spin precession frequency, the artificial spin resonance is crossed and the beam polarization after crossing this resonance is given by the Froissart-Stora formula in Eq. 3.

The strength of this artificial spin resonance is proportional to how strong the ac dipole magnetic field is. It is given by

$$\epsilon_K = \frac{1 + G\gamma}{4\pi}\frac{B_m L}{B\rho}, \tag{5}$$

where ϵ_K is the resonance strength, B_m is the ac dipole field oscillating amplitude [6]. $B\rho$ is the rigidity of the beam. To obtain a spin flip of 0.99, the upper limit of the ac dipole frequency sweeping rate is given by

$$\alpha \leq 0.2965|\epsilon_k|^2, \tag{6}$$

where ϵ_k is the resonance strength as shown in Eq. 5. For the RHIC spin flipper, the ac dipole field oscillating amplitude is 100 Gauss-m, the artificial spin resonance strength is 4.6×10^{-4}.

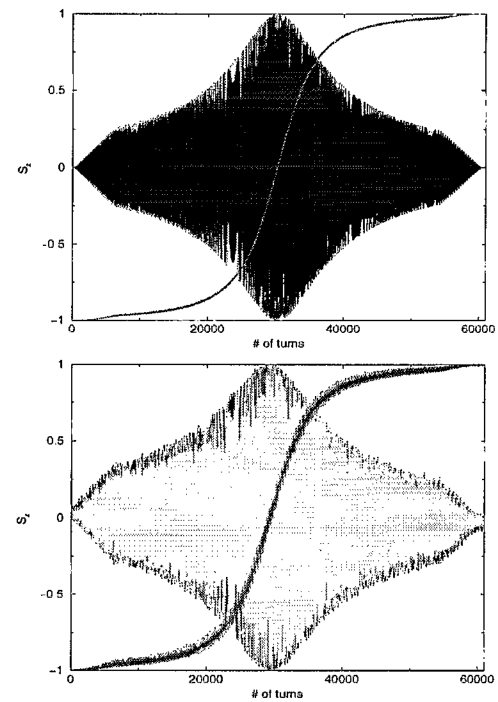

Figure 2: RHIC spin flip single particle simulation result. The top plot corresponds to the single particle at center. The lower plot is the spin tracking result with a particle at a ellipse of 20π mm-mrad. The red curve in both plots is the vertical projection of the spin vector while the blue and green curves are the horizontal and longitudinal projections. In both cases, a full spin flip is obtained.

In order to sweep the ac dipole frequency through the spin precession frequency, the spin precession tune needs to be tuned away from its nominal value 0.5. This can be achieved by adjusting the helical snakes' axis angle according to Eq. 2. Figure 2 shows the single particle spin tracking results at $G\gamma = 192$ using a $\beta^* = 10$ m RHIC lattice with rms 3 mm closed orbit distortion. Both the spin tracking of a particle with 0 mm-mrad emittance and of a particle at 20π mm-mrad ellipse show a full spin flip. In this case, the vertical ac dipole field oscillating amplitude gets slowly ramped to 100 Gauss-meter in 6000 turns and its tune is swept from 0.417 to 0.437 in 48000 turns. Two plots in Figure 3 are the vertical ac dipole field oscillating amplitude and tune as a function of revolution turn number. the The two snakes'axis are tuned to 38.43^o and -38.43^o.

3 CONCLUSION

A vertical ac dipole is scheduled to be installed in RHIC before this year's RHIC polarized proton run. The ac dipole

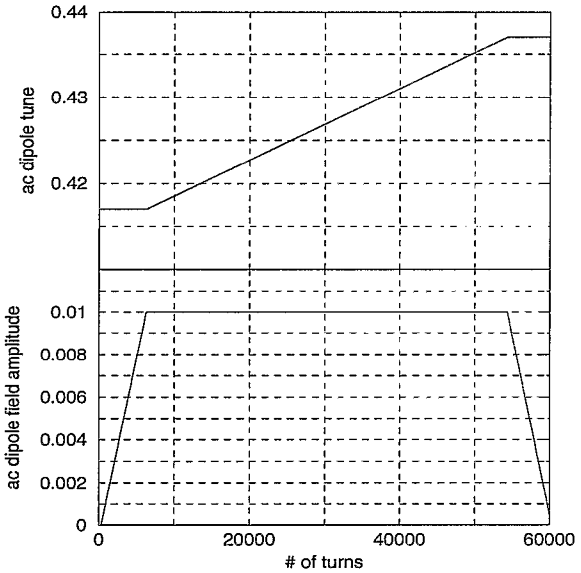

Figure 3: RHIC spin flipper field oscillating amplitude and frequency profile. The top plot is the ac dipole tune versus # of turns and the lower plot shows the ac dipole field amplitude as a function of time.

will be used as a spin flipper to reverse the spin vector of the stored polarized proton beam and change the polarized proton collision pattern which is required to reduce the systematic error of the polarized proton experiment. The numerical simulation shows a full spin flip can be induced by slowly sweeping the ac dipole frequency across the spin precession frequency.

4 REFERENCES

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