Snake Calibration in RHIC *

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Abstract

A proper understanding of the response of the spin orientation due to the currents in the four helices which make up each snake is necessary to control spin tune, avoid snake resonances and facilitate the operation of the RHIC spin flipper. The effect of the helical dipole snakes in RHIC is to rotate the spin orientation an angle μ about an axis at an angle ϕ in the horizontal plane. With two snakes the combined effect gives rise to a spin precession frequency which is determined by the μ and ϕ angles at each snake. Depolarization or spin flipping can occur when this spin tune is near an external driving frequency. We employed the RHIC spin flipper in this way to determine the spin tune and thus verify spin tune predictions based upon previous field measurements of the snake. We also considered the response of snake resonances locations to spin tune as another way of verifying spin tune predictions

1 HELICAL DIPOLE SNAKE CONFIGURATION

RHIC is equipped with four full Siberian snakes two for each ring (blue and yellow rings). They are situated on opposite sides of each ring and serve to avoid depolarizing resonances by introducing 180° spin rotation without an associated net orbit distortion. The helical dipole snakes are composed of four separate helical dipoles with a combined total length of 10.56 m [4]. The outer and inner two magnets are powered on the same power supply but with opposite polarity.

2 ESTABLISHING SPIN RESPONSE TO CURRENT INPUT

In a previous paper [1] we presented a technique of generating full field maps of the helical dipole snakes in RHIC. Using the OPERA and TOSCA [2] commercial software packages we reconstructed the full 3 dimensional fields from the multipole measurements taken along a fixed radius along the axis of the snake for various currents. Using these field maps the orbit and spin dynamics through each snake was determined employing the SNIG [5] integration program.

In this paper we have used these results to study the spin response of the input currents to the inner and outer helical pairs. It is convenient to parameterize the effects of the snake on the spin by using the angles μ and ϕ. As you can see in Figure 1 ϕ represents the angle from the longitudinal axis in the horizontal plane of the axis of rotation and μ represents the magnitude of the spin rotation about this "snake axis".

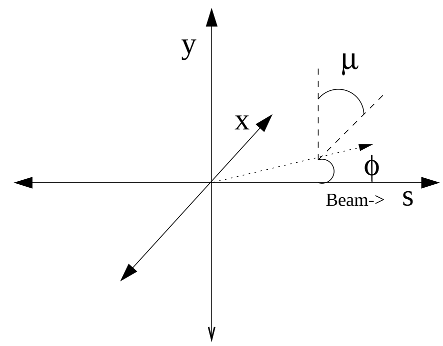

Figure 1: Rotation axis of the snake is ϕ and μ is the rotation angle.

From the values of μ and ϕ for each snake it is possible to evaluate the total spin tune ν_s of the machine. It is a well known result that ν_s can be given by Eq. 1

$$\cos\nu_s\pi = \cos\frac{\mu_2}{2}\cos\frac{\mu_1}{2}\cos G\gamma\pi - \sin\frac{\mu_2}{2}\sin\frac{\mu_1}{2}\cos(\phi_2-\phi_1) \qquad (1)$$

In order to keep the spin precession energy independent and thus avoid spin resonances it is necessary to keep our spin tune $\nu_s = 0.5$. From equation 1 it is easy to see that one way this can be accomplished is if the right side is made to vanish. Currently in RHIC the snakes have been configured to achieve this with $\phi_1 = -\phi_2 = \pi/4$ and $\mu_1 = \mu_2 = \pi$.

One of the major challenges has been identifying those settings which can achieve this $\mu = \pm\pi/4$ and $\phi = \pi$ desired snake configuration.

To simplify our predictions we generated μ and ϕ results over a range of input currents and using these constructed a fourth order polynomial fit which was implemented in a simple graphical TCL program. In figures 2 and 3 the residuals from the fit and the actual μ and ϕ values are shown for the snake HRD101(1st snake in blue ring) at $\gamma = 107.0922$. Since most of our data points were collected in the region of $\pm(300-330)$ A for the inner current and $\pm(90-120)$ A for the outer currents our largest residual values naturally occur well outside this range and reach a maximum of $\pm5^\circ$. Within the operating and detuning range used for the spin flipper commissioning the deviation is down to less than $\pm2^\circ$.

To achieve the desired $\mu = 180^\circ$ and $\phi = \pm45^\circ$ values the RHIC snakes were all powered to 325 A for the inner helices and 100 A on the outer helices. These figures were

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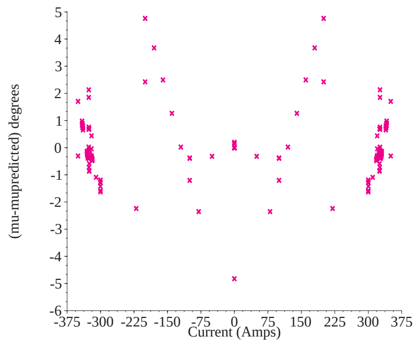

Figure 2: μ residuals for snake HRD101 at $\gamma = 107.0922$ versus inner current

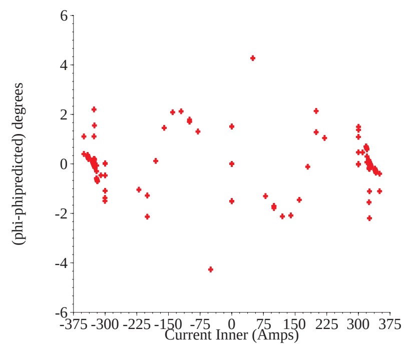

Figure 3: ϕ residuals for snake HRD101 at $\gamma = 107.0922$ versus inner current

based on the HRD101 blue snake multipole measurements. Since ramping the beam energy from b $\gamma = 25.9364$ to $\gamma = 107.0922$ only yielded a 0.01 change in spin tune the current settings were kept fixed throughout the acceleration ramp.

3 ROUGH SPIN TUNE MEASUREMENTS IN RHIC

The process of commissioning the RHIC spin flipper as well provides an estimate of the spin tune. Commissioning of the spin flipper in RHIC is detailed in another paper by M.Bai et,al [3]. Briefly however the driving frequency of the AC dipole was swept through a range where the spin tune was believed to reside. Thus if a spin flip was observed then it was known that the spin tune must lie within the range of frequencies swept by the AC dipole.

Results showed that a partial spin flip (66%) was obtained in the Blue ring when the AC dipole was swept over a driving frequency from 0.47 to 0.49 and the snake was detuned to a predicted value of $\nu_s = 0.48$. These results indicate several possible explanations. Either the spin tune was not exactly 0.48 but on the edge of the 0.47 to 0.49 range or the spin tune distribution exceeded ± 0.01.

During this experiment it was noticed that partial spin flipping was observed in the yellow ring. This despite the fact that the currents powering the snake were fixed at inner current = 325 Amps and outer current = 100 Amps. Which by our calculations based on the HRD101 blue snake should have yielded a spin tune of 0.5. Clearly our spin tune distribution must have partially overlapped with the tunes in the range of 0.47 to 0.49.

If we consider in detail the field strengths of the HRD102 yellow snake however we find that at the 325 Amp and 100 Amp current settings will yield a $\mu = 179.956475$ and $\phi = -44.0853423$ at $\gamma = 107.0922$. This difference of about 1° can lead to ± 0.01 change in the spin tune which could account for the spin detuning observed in the yellow ring.

In addition to using the spin flipper it is possible to use snake resonance theory to help estimate the spin tune using the snake resonance condition [4]

$$\delta\nu_y = \frac{\nu_s \pm k}{n}. \tag{2}$$

Here n represents the snake resonance order and $\delta\nu_y$ the fractional part of the vertical betatron tune. In the betatron tune space used during the RHIC acceleration ramp tracking indicates that there should be two observable snake resonances, the strongest of which occurs at a betatron tune $\nu_y = 0.25$ [4]. Following from Eq. 2 the exact location of this resonance in betatron tune space should be dependent on the exact spin tune achieved by the snakes.

In Figs. 4 - 5 we can see a graph of the maximum vertical betatron tune during the acceleration ramp versus polarization transfer efficiency. Clearly in both the blue and yellow rings this snake resonance at $\nu_y = 0.25$ was observed whenever the tune crossed the 0.245 threshold setting a lower bound of 0.49 spin tune for both rings.

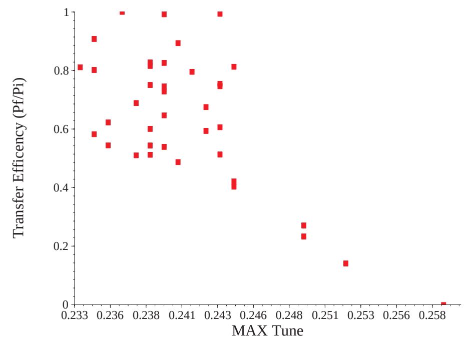

Figure 4: Maximum tune along acceleration ramp for Blue ring versus Polarization transfer efficiency (P_f/P_i)

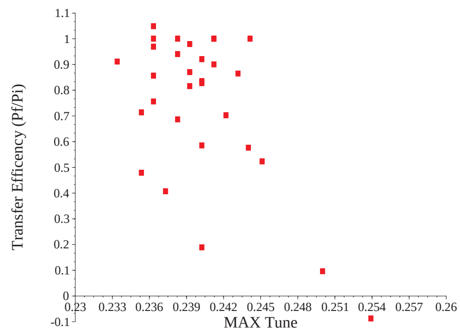

Figure 5: Maximum tune along acceleration ramp for Yellow ring versus Polarization transfer efficiency (P_f/P_i)

4 REFERENCES

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