SNAKE DEPOLARIZING RESONANCE STUDY IN RHIC*

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Abstract

Snake depolarizing resonances due to the imperfect cancellation of the accumulated perturbations on the spin precession between snakes were observed at the Relativistic Heavy Ion Collider (RHIC). During the RHIC 2005 and 2006 polarized proton runs, we mapped out the spectrum of odd order snake resonance at $Q_y = \frac{7}{10}$. Here, Q_y is the beam vertical betatron tune. We also studied the beam polarization after crossing the $\frac{7}{10}$th resonance as a function of resonance crossing rate. This paper reports the measured resonance spectrum as well as the results of resonance crossing.

INTRODUCTION

Siberian snake was first introduced to high energy accelerators in the 1970s by Derbenev and Kondratenko [1] to preserve the beam polarization through acceleration. It is a device designed to rotate the spin vector by 180° around an axis in the horizontal plane. This way the perturbation on the spin vector cancels out and the imperfection spin resonance at $G\gamma = k$ and intrinsic spin resonance at $G\gamma = kP + Q_y$ [2] are overcome. Here, $G\gamma$ is the spin tune, i.e. number of spin precessions one orbital revolution. $G = 1.7928474$ is the anomalous g-factor of proton, γ is the proton's Lorentz factor, k is an integer and P is the periodicity of the accelerator. Q_y is the vertical betatron tune, the vertical betatron oscillation in unit of orbital revolution frequency.

However, the vertical betatron oscillation can cause imperfect cancellation of the perturbations on the spin motion and result in polarization loss when

$$mQ_y = Q_s + k \tag{1}$$

where m and k are integers and m is the order of the snake resonance [2]. This is the so-called snake depolarizing resonances and was first described by Lee and Tepikian [3]. It was also observed experimentally at IUCF and RHIC [5, 4]. Depending on whether m is an even or odd number, a snake resonance is either an even order resonance or an odd order resonances.

For each of the two RHIC accelerators (Blue ring and Yellow Ring), the two snakes are separated by 180° and the corresponding spin tune is determined by

$$Q_s = \frac{|\phi_1 - \phi_2|}{\pi} \tag{2}$$

where $\phi_{1,2}$ are the snakes' spin rotation axes angle relative to the direction of the beam velocity. With the spin rotation axises of the two snakes perpendicular to each other, the spin tune is $\frac{1}{2}$. Another advantage of having two Siberian snakes instead of one is that this configuration provides additional cancellation when m is an even number. Hence, all the even order snake resonances are absent. However, the even order snake resonances reappear if the intrinsic resonance overlaps with an imperfection resonance. Fig. 1 shows the snake resonance spectrum with and without imperfection resonances for spin tune at $Q_s = 0.5$ and at $Q_s = 0.49$. Furthermore, it also splits the existing odd order resonances [2, 6]. All of this greatly reduces the available betatron tune space where polarization can be preserved.

The odd order snake resonances are directly derived from the intrinsic spin resonances, and the stronger the intrinsic resonance, the stronger the derived snake resonance. For an even order snake resonance, the resonance strength

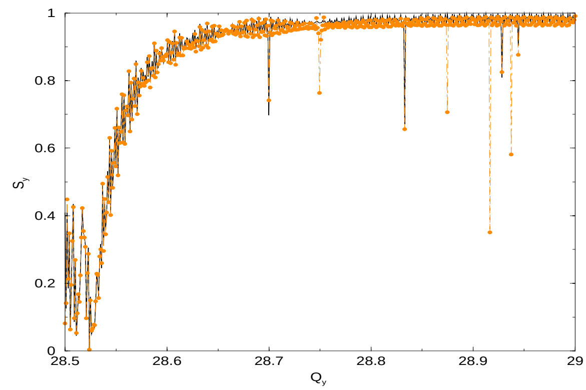

Figure 1: The two plots are the snake resonance spectrums with spin tune at $\frac{1}{2}$. The black line is with zero imperfection resonance and the yellow line is when the intrinsic resonance overlaps with an imperfection resonance. Both cases are obtained by single particle spin tracking of a simple lattice with two snakes separated by 180° azimuthally. The intrinsic resonance was treated as an distributed spin resonance between the two snakes in the simulation. The imperfection resonance was obtained by mis-tuning the snake settings.

* The work was performed under the US Department of Energy Contract No. DE-AC02-98CH1-886, and with support of RIKEN(Japan) and Renaissance Technologies Corp.(USA)

is also proportional to the size of the vertical closed orbit distortion. But because this type of resonance is due to the overlap of the imperfection resonance with the intrinsic resonance, it is very difficult to obtain the strength analytically.

Furthermore, unlike imperfection resonance and intrinsic resonance, which have well defined theoretical models on how polarization evolves when an isolated resonance is crossed [7], very little is known about how polarization behaves when a snake resonance is crossed. A dedicated study was carried out in RHIC to explore the even order snake resonance and the characteristics of resonance crossing.

STUDY OF THE ODD ORDER SNAKE RESONANCE AT $Q_Y = \frac{7}{10}$

The even order snake resonances $Q_y = \frac{1}{4}$ and $Q_y = \frac{3}{4}$ were successful observed experimentally by measuring the beam polarization as a function of vertical betatron tune at RHIC injection. However, it was very difficult to observe the odd order resonance at $Q_y = \frac{7}{10}$ at RHIC injection energy because the intrinsic spin resonance at injection is very weak [8].

In order to study the odd order resonance at $Q_y = \frac{7}{10}$, a mini energy ramp was introduced to accelerate polarized proton beam to a beam energy of $G\gamma = 63$ where a strong intrinsic resonance is located [8]. Both horizontal and vertical betatron tunes were kept away from the even order snake resonance at $Q_y = 0.75$ and the odd order snake resonance at $Q_y = 0.7$ to preserve the beam polarization during the acceleration.

In RHIC, the beam polarization is measured by the relative CNI polarimeter, which measures the asymmetry of the recoiled carbon from protons scattering off the carbon target [9, 10]. The beam polarization is the measured asymmetry normalized by the analyzing power, an energy dependent constant [12]. The analyzing power at this beam energy is interpolated from the analyzing power at RHIC injection energy measured in the AGS [13] and at 100 GeV in RHIC [12].

Fig. 2 shows the measured beam polarization as a function of the vertical betatron tunes. The significant lower polarization around $Q_y = 0.7$ confirms the snake resonance at $Q_y = \frac{7}{10}$. Even though $Q_y = \frac{10}{14} \sim 0.714$ is another odd order snake resonance, it is an higher order resonance and weak enough to be benign to the beam polarization.

To study the resonance crossing, polarized protons were first accelerated to $G\gamma = 63$ with vertical betatron tune around 0.692 and horizontal tune around 0.73. The vertical betatron tune was then ramped across 0.7 to 0.713 at various speeds and beam polarization was measured before and after the tune ramp as shown in Fig 3. The rate of resonance crossing is determined by the speed at which the RHIC quadrupole current gets ramped. Currently, the fastest ramp rate of RHIC quadrupole is $\frac{dQ_y}{dt} = 0.021$. Slowfactor is a constant which is proportional to the RHIC quadrupole ramping rate, i.e. slowfactor$\sim \frac{0.021}{\frac{dQ_y}{dt}}$. The higher the slowfactor, the slower the tune get swept and the slower the resonance is crossed. For the fast resonance ramping rate, the resonance was crossed multiple times to amplify the effect of the snake resonance.

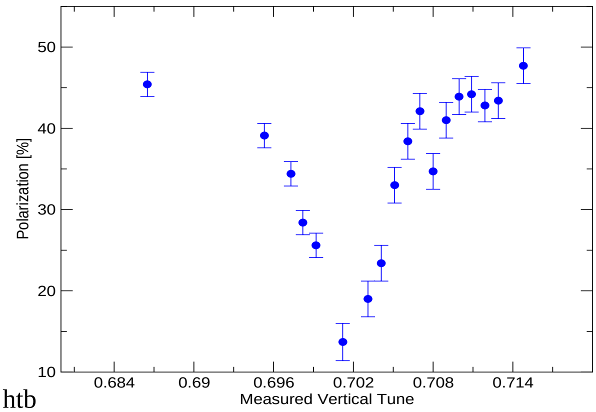

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Figure 2: This plot shows the measured beam polarization as a function of the vertical betatron tune. The depolarization around $Q_y = 0.7$ confirms the odd order snake resonance at $Q_y = \frac{7}{10}$.

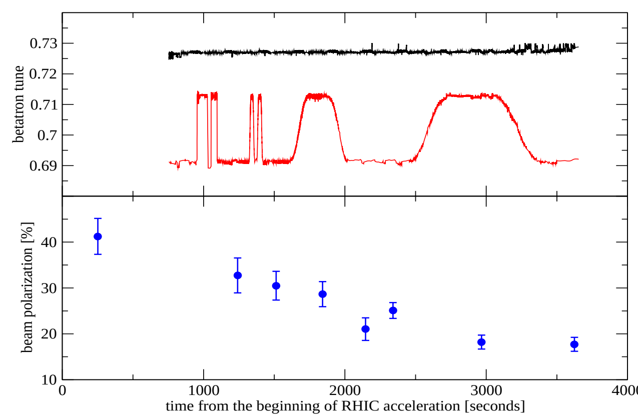

Figure 3: The top plot shows the measured betatron tune using the RHIC base band tunemeter [14] as a function of time. The black line is the horizontal betatron tune and red line is the vertial betatron tune. The horizontal tune was kept unchanged during the experiment and vertical tune was swept across 0.7 at various speeds. From the left to the right on the axis of time from the beginning of RHIC acceleration, the first two groups of vertical tune sweep located were done with a slow factor of 1 and 10, respectively. The third pair of tune sweep is with a slow factor of 100 and the slow factor of the last pair of tune sweep is 200 and 250, respectively. The bottom plot shows the beam polarization measured after each time the snake resonance was crossed.

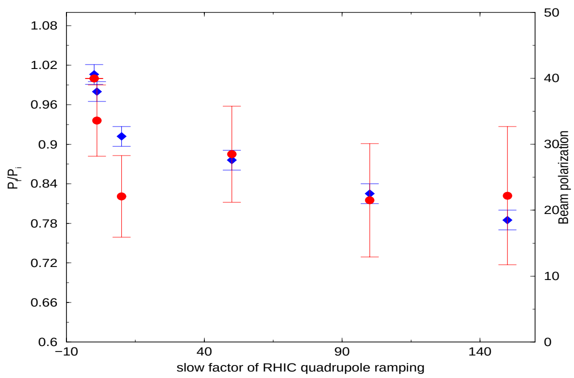

Figure 4: This plot shows the measured beam polarization after each resonance crossing as a function of the resonance crossing rate in units of RHIC qudrupole ramping slow factor. The higher the slowfactor, the longer it takes for the quadrupoles to ramp.

Fig. 4 shows the ratio of polarization before and after each resonance crossing. The data show little or no correlations between the amount of polarization loss and the resonance crossing rate, and suggest that snake resonance crossing does not follow the Froissart-Stora formula as isolated imperfection or intrinsic spin resonance do.

CONCLUSION

The even order snake resonance at $Q_y = \frac{7}{10}$ was experimentally observed in RHIC at a beam energy of $G\gamma = 63$ where a strong intrinsic spin resonance is located. A detailed study of beam polarization as function of resonance crossing rate was also carried out and the results show that unlike the imperfect resonances and intrinsic resonances, the snake resonance which is derived from the first order resonances does not follow the traditional Froissart-Stora formula.

ACKNOWLEDGEMENT

The authors would like to thank all the operation staff and AGS polarized proton staff for making this study possible.

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