EXPERIMENTAL EFFECTS OF ORBIT ON POLARIZATION LOSS IN RHIC *

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Abstract

We are performing several experiments during the RHIC ramp to better understand the impact of orbit errors on the polarization at our current working point. These will be conducted by exciting specified orbit harmonics during the final two large intrinsic resonance crossing in RHIC during the 250 GeV polarized proton ramp. The resultant polarization response will then be measured.

EFFECT OF ORBIT ON POLARIZATION LOSS

The dominant mechanism for loss of vertical polarization during acceleration of protons in a ring such as the RHIC and AGS are via the accumulation of magnetic kicks due to propagation through a quadrupole vertically off-center. This can be due to either betatron oscillations (called intrinsic resonances) or due to misalignment and orbit errors (called imperfection resonances). These kicks can add coherently while crossing particular energies since the natural spin precession is a function of energy. In RHIC depolarization is avoided during these resonance crossings using two so-called snakes which achieve a full spin rotation per turn to keep the spin precession rate energy independent. However polarization loss is still possible via the snake resonance mechanism [1]. Snake resonances are strongly dependent on the machine tune as well as the strength of the overlapping effects of the imperfection and intrinsic resonances.

EXCITATION OF SINGULAR IMPERFECTION RESONANCE

Asside from the tune and the strength of the intrinsic resonance. Imperfection spin resonances can impact the amount of losses caused by the higher order snake resonances. In order to better understand how the strength of the imperfection resonance strength impacts polarization loss we identified corrector settings which would yield an isolated bump in the imperfection strength of 0.1 at a targeted resonance location. This change in the impefection resonance structure would not cause any other change out to several units of $G\gamma$ around the resonance of interest. Here G is the anomalous g-factor and γ is the relativistic gamma. Fig. 1) shows an example of how this bump in resonance strength would look. To accomplish this we translated the DEPOL algorithm[2] which calculates the imperfection resonance strength into a Matlab function usable in the Matlab accelerator toolbox[3]. We then developed another function to calculate a spin response matrix, relating imaginary and real imperfection resonance strength to the differential corrector strength. Then using an SVD minimization routine we developed a function to find the best corrector settings in order to achieve a desired resonance strength at a targeted $G\gamma$ value while being flat out to some user defined $G\gamma$ range. With this set of vertical corrector

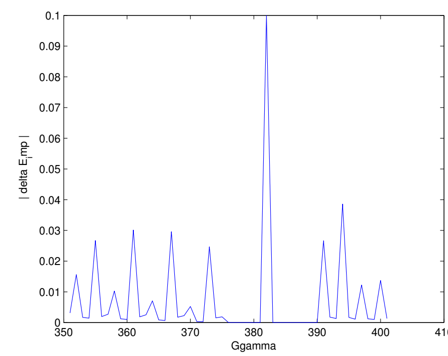

Figure 1: Exciting isolated imperfection resonance bump at $G\gamma = 381$. Here the effect is to add 0.1 to the existing imperfection resonance at $G\gamma = 381$ while doing nothing out several units of $G\gamma$ on either side. The flat structure around the targeted resonance permits the RHIC magnets time to ramp up during the resonance crossing and back down with out effecting any of the other resonance strengths.

strengths we could now scale them up and down uniformly to achieve an arbitrary imperfection resonance bump. We developed two sets of these correctors for each targeted resonance to bump the real and imaginary parts of the resonance. For this experiment however we only tested the real corrector sets for $G\gamma = 381$ and 423 near the strong intrinsic resonances $411 - \nu$ and $393 + \nu$. Ultimately we hope to be able to exert a targeted control over the strength of the imperfection resonances near each strong intrinsic resonance crossing, so that we have a collection of real and imaginary knobs targeting several resonances around each strong intrinsic resonance. Our plan is to first excite it and achieve a determined polarization loss and later to use it to suppress the imperfection resonance strength and thus improve polarization transmission.

EXPERIMENT

During the 2012 polarized proton run in RHIC we performed two experiments. The first was performed at injection energy to calibrate the orbit response to our corrector set. During the second experiment we tested our corrector

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sets in the yellow ring at $G\gamma = 381$ and in the blue ring at $G\gamma = 423$ trying to excite an imperfection resonance strength of 0.2 in each.

Orbit Control Set-Up

For this experiment we also developed a set of matlab functions to implement the pre-calculated corrector strength bumps. These functions permitted the corrector settings to ramp up at the time of each resonance crossing and then back down. We first tested the matlab scripts ability to turn on and off correctors based on our calculations and compared how the orbit responded to what the model predicted. At injection energy we excited what would be a 0.05 imperfection resonance at $G\gamma = 45$. The orbit was severely distorted yielding an rms vertical orbit of 2.5 mm. However as can be see in Fig. 2, our model looked fairly similar to what we measured using the beam position monitors (BPMs). During our next experiment we accelerated the beams in both rings with our corrections applied to the yellow ring for $G\gamma = 381$ at RHIC stone gg381 (a fixed time location on the ramp) and in the blue ring for $G\gamma = 423$ at RHIC stone gg422. The orbit results are plotted in Fig. 3 and 4. In the yellow ring we achieved 0.371 mm rms orbit distortion, compared with model prediction of 0.489 mm rms and the orbit seemed to respond as predicted by the model. However in the blue ring the situation was worse; the rms orbit distortion were comparable but the phase was visibly shifted.

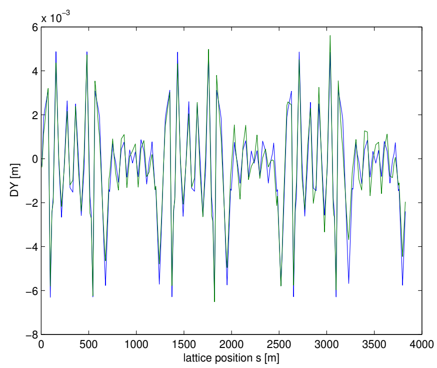

Figure 2: (Blue) model orbit response (Green) measured orbit response at injection in RHIC yellow ring.

Polarization Measurement

Before the RHIC acceleration ramp we performed three polarization profile measurements at injection for each ring. Then right at full energy (before collision) we performed over five profile measurments for each ring. We compared these to measurements made for the prior four stores at injection and right at full energy. A comparison for the blue and yellow measurements are shown in Fig. 5 and Fig. 6. For both rings there appears to be a detectable polarization loss which seem probably caused by the excitation of the imperfection resonances.

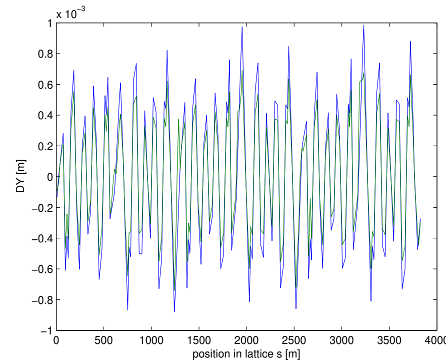

Figure 3: (blue) model orbit response (green) measured orbit response at stone gg381 in RHIC yellow ring.

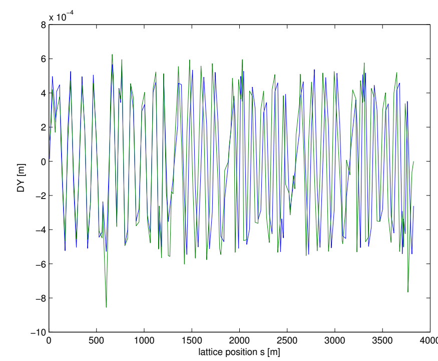

Figure 4: (blue) model orbit response (green) measured orbit response at stone gg422 in RHIC blue ring.

COMPARISON WITH SPIN TRACKING

6D tracking results using the newly developed version of UAL-SPINK [4] which runs on the NVIDA graphical processing unit (GPU) generated profiles for crossing the $411 - \nu$ resonance which appear consistent with our experimental results (see Fig. 7). This tracking consisted of 32760 particles distributed using a a Gaussian distribution with rms sigma consistent with 3.33 $\pi mm - mrad$ normalized with a cut off at 2 sigma. In the longitudinal plane we used 3 nsec rms bunch length also cut off at 2 sigma. The acceleration rate was approximately 8 times the nominal RHIC acceleration rate. Our tracking results showed no significant polarization loss below 0.12 imperfection resonance strength while crossing this resonances. We are still in the process of completing tracking work for the $393 + \nu$ resonance crossing but at this point the polarization losses due to imperfection resonances appear comparable. That is at 0.24 imperfection resonance we see a relative 20% loss in polarization.

CONCLUSION

In the yellow ring the results of the application of an isolated imperfection resonances appear consistent with what our tracking models predicted. We expected to see a reduc-

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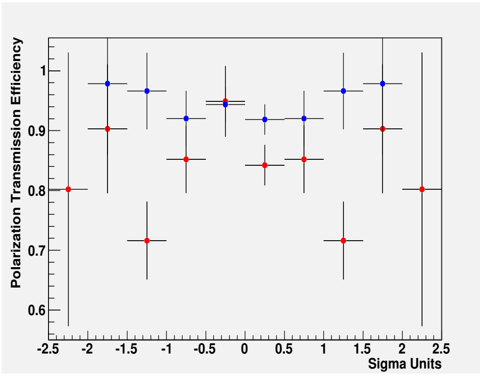

Figure 5: The polarization response of the Yellow ring due to excitement of a real 0.2 imperfection resonance at $G\gamma = 381$ (red). This plot comprises the average of five measurements taken at full energy divided by three taken at injection energy. The xaxis is in beam size sigma units. This is compared with the average efficiency from the previous four stores (blue). The data represents a ratio of the final polarization to the initial polarization at each sigma.

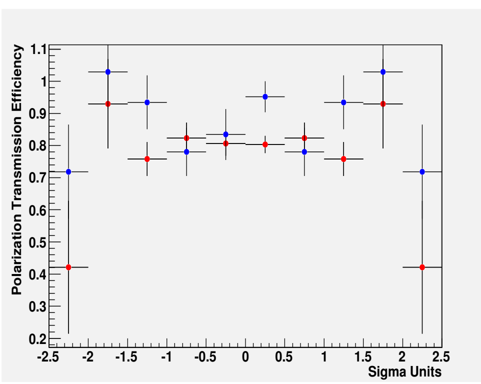

Figure 6: Polarization response of the blue ring due to excitement of a real 0.2 imperfection resonance at $G\gamma = 423$ (red). This plot comprises the average of five measurements taken at full energy divided by three taken at injection energy. The xaxis is in beam size sigma units. This is compared with the average efficiency from the previous four stores (blue). The data represents a ratio of the final polarization to the initial polarization at each sigma.

tion across the profile of about 20%. The same appears to be true for the blue ring however statistics for each measuremet seems worse than in the yellow ring. Indeed the baseline transmission efficiency in the blue ring is about 5-10% worse than yellow ring. Another issue could be related to the faulty optics we used in the blue ring which yielded a 0.03 tune difference from the measured. Our plan for succeeding RHIC polarized proton runs is to eventually commission a set of imperfection resonance tuning knobs around each strong intrinsic resonances. In this way the operators will be able to modify and hopefully suppress the imperfection resonance strength at each important resonance crossing. These knobs will give control over both the real and imaginary part of the resonance and function like the harmonic orbit correction knobs used the tune the AGS polarization.

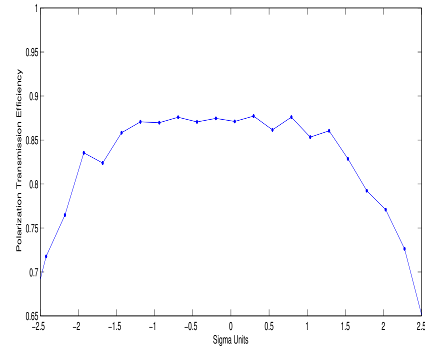

Figure 7: Simulated polarization response of the blue ring due to excitation of a real 0.24 imperfection resonance at $G\gamma = 381$. This results was generated from 32760 particles distributed using a Gaussian with a sigma consistent with 3.33 $\pi mm - mmrad$ cut off at 2 sigma for both transverse planes. The longitudinal assumed a 3 nsec rms bunch length match to the bucket. The acceleration rate was $d\gamma/dt = 8.55/sec$.

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