RHIC POLARIZED PROTON OPERATION AND HIGHLIGHTS*

H.Huang†, L. Ahrens, I.G. Alekseev, E. Aschenauer, G. Atoian, M. Bai, A. Bazilevsky, M. Blaskiewicz, J.M. Brennan, K.A. Brown, D. Bruno, R. Connolly, A. Dion, T. D'Ottavio, K.A. Drees, W. Fischer, C.J. Gardner, J.W. Glenn, X. Gu, M. Harvey, T. Hayes, L. Hoff, R.L. Hulsart, J.S. Laster,, C, Liu, Y. Luo, W.W. MacKay, Y. Makdisi, G.J. Marr, A. Marusic, F. Meot, K. Mernick, R.J. Michnoff, M.G. Minty, C. Montag, J. Morris, S. Nemesure, A. Poblaguev, V. Ptitsyn, V. Ranjbar, G. Robert-Demolaize, T. Roser, B. Schmidke, V. Schoefer, F. Severino, D. Smirnov, K. Smith, D. Steski, D. Svirida, S. Tepikian, D. Trbojevic, N. Tsoupas, J.E. Tuozzolo, G. Wang, M. Wilinski, K. Yip, A. Zaltsman, A. Zelenski, K. Zeno, S.Y. Zhang , BNL, Upton, NY 11973-5000, USA

Abstract

RHIC operation as a polarized proton collider presents unique challenges since both luminosity and spin polarization are important. Many improvements and modifications have been made since the last polarized proton operation in 2009. A 9 MHz rf system was completed that improved the longitudinal match at injection. To preserve polarization on the ramp, a new working point was chosen with the vertical tune near a third order resonance. The newly realized orbit and tune feedback systems are essential for polarization preservation. To calibrate the polarization measurement at 250 GeV, polarized protons were accelerated up to 250GeV and decelerated back to 100GeV. A vertical realignment of RHIC was conducted before the run to reduce magnet misalignment. A record peak luminosity was achieved with higher polarization at 250 GeV in this run.

INTRODUCTION

The spin physics program in the Relativistic Heavy Ion Collider (RHIC) calls for highly polarized proton beams with high luminosity. Acceleration of polarized proton beams to high energy in circular accelerators is difficult due to numerous depolarizing resonances. The RHIC spin program uses two Siberian snakes [1] in each ring to accelerate polarized protons to various energies as high as 250 GeV.

With two snakes in each ring, the spin tune to the first order is 1/2 and energy independent. Thus, all imperfection, intrinsic and coupling resonance conditions can be avoided. However, when the spin resonance strength is large, a new class of spin-depolarizing resonances can become important. These resonances, due to coherent higher-order spin-perturbing kicks, are called snake resonances [2] and are located at

$$\Delta\nu_y = \frac{k \pm \nu_{sp}}{n}, \qquad (1)$$

where $\Delta\nu_y$ is the fractional part of vertical betatron tune, n and k are integers, and n is called the Snake resonance order. There are two kinds of snake resonances, even order resonances (n=even integer) and odd order resonances (n=odd integer). With the two snakes configuration in RHIC, the even order snake resonances are suppressed with no closed orbit errors, but will appear when the intrinsic resonance overlaps an imperfection resonance. The orbit and tune feedback systems are very important to suppress the resonance strength and to keep ν_y away from the resonance conditions.

The β^* of the two major experiments is set to 0.65m. The working point is around (28.685, 29.673) for both rings. Dynamic aperture simulation shows better dynamic aperture for a working point below the $(\nu_y - \nu_x = 0)$ diagonal line. The transition energy was lowered by 0.5 unit by using gamma jump quads such that the injection energy is further away from the transition energy. Polarization is measured by two fast relative p-carbon polarimeters in each ring. The absolute polarization measurement is provided by the polarized hydrogen jet target [3].

ORBIT AND TUNE CONTROL

The tune, coupling and orbit feedback systems were on for all ramps. As a result the reproducibility of a ramp was not an issue. Thus the 24 hours orbit variation observed in the past has been avoided. Orbit feedback on every ramp allowed for smaller y_{rms} which in turn resulted in smaller imperfection resonance strength. The ramp efficiency was improved to 99% with high bunch intensity of 1.8×10^{11}, due to the tune and orbit control on the ramp and 9MHz rf system. With the orbit feedback, the vertical rms closed orbit error was less than 0.1mm (see Fig. 8 in [4]), much better than the 0.5mm last run and well within the specification value of 0.3 mm to maintain polarization on the energy ramp. A new vertical realigment was done before the run and the misalignments as large as 2mm were eliminated. With the reversal of the BPM offsets, both RHIC rings are flatter than before. With correct BPM offset and vertical realignment, this rms orbit error is indeed small. However, there are still additional hidden orbit errors due to misalignment between BPMs and magnet centers. The alignment between magnets and BPMs will be important to achieve smaller orbit errors, which will require exten-

* Work performed under contract No. DE-AC02-98CH10886 with the auspices of the DoE of United States and support of RIKEN of Japan.
† huanghai@bnl.gov

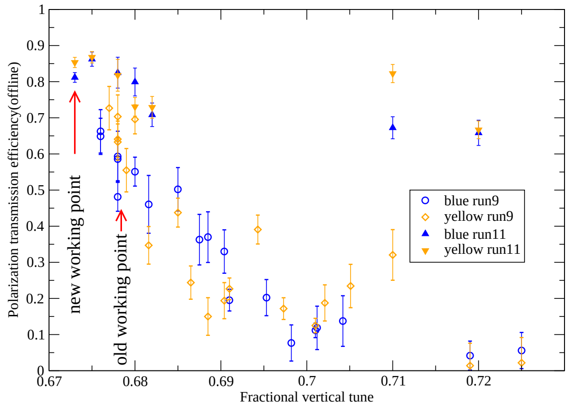

Figure 1: The polarization transmission efficiency on the energy ramp as a function of ν_y. The open points are from run9 and the solid ones are from run11. The efficiency is improved in run11 and is about 85% at the new working point.

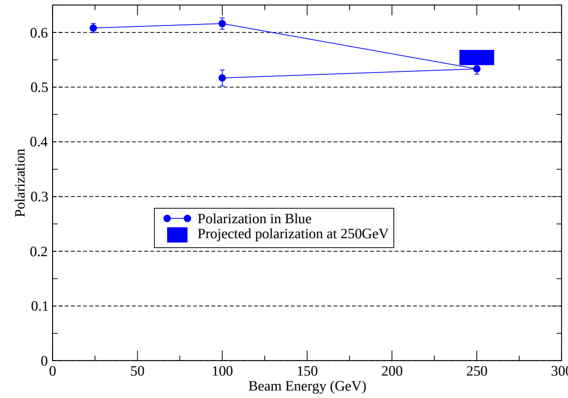

Figure 2: The polarization at various energies in RHIC blue ring. The projected 250GeV polarization is also shown as a band indicating error bars.

sive beam based alignment. The tune feedback kept the betatron tune at the desired values, which made it possible to push the tune closer to 2/3 resonance [4]. There are three strong intrinsic resonances on the ramp. The vertical tune is pushed down in this region to be away from the 7/10 and 11/16 snake resonances (see Fig. 6 in Ref. [4]). The tune and orbit feedback resulted in a higher polarization transmission efficiency than in previous run. This improvement is visible in Fig. 1.

UP-DOWN RAMP

To calibrate the analyzing power of RHIC polarimeters, the polarized hydrogen jet target runs at store with both beams [3]. Due to the low event rate, it has large error bars for individual stores (5-8%). It's known that there is very little polarization loss between injection and 100 GeV. An alternative calibration method is to measure the asymmetry at 100 GeV followed by ramping up to 250 GeV and back down to 100 GeV and then to measure the asymmetry again at 100 GeV. In this experiment, orbit, tune, coupling and chromaticity feedback systems were all on, which provided "identical" acceleration and deceleration ramps [4]. The polarization loss on the up ramp would be just half of the total polarization loss measured at the finishing energy, 100GeV. The polarization measurements are summarized in Fig. 2. The projected polarization after the up ramp is reasonably close to the measured values at 250GeV. This experiment shows that the polarization loss on the up ramp is about 10-15%.

POLARIZATION LOSS

With the new working point and feedback system on, the residual polarization loss in RHIC does not change for small changes of snake current, vertical and horizontal tune, vertical chromaticity. This indicates we are not losing polarization due to being close to an edge in one of these parameters.

Polarization loss from intrinsic resonances depends on the betatron amplitude. This results in a polarization loss increasing with betatron amplitude and the creation of a polarization profile correlated with the beam intensity profile. Assuming polarization profile is a Gaussian, the polarization of hypothetical zero emittance particles P_0 can be estimated from the average polarization <P> over the whole beam measured by polarimeter at injection and at beginning of the store [5]. The maximum possible polarization P_{max} in RHIC should be less than the source polarization 80% after taking into account the spin mismatch at AGS and RHIC injection (different for blue and yellow rings). The Table 1 shows that the polarization of hypothetical zero emittance particles P_0 is close to the maximum possible polarization P_{max}, even at 250GeV. This means that the polarization loss observed are mainly due to polarization profiles developed during the ramp.

Table 1: Projected Polarization

Energy	<P>	P_0	P_{max}
inj. Blue	65.7±0.3	76.6±0.4	76.1
inj. Yellow	66.4±0.3	77.3±0.4	78.7
250GeV Blue	52.2±0.3	71.5±0.4	76.1
250GeV Yellow	54.5±0.3	73.3± 0.4	78.7

There are still some polarization loss during the store. The continuous polarization measurements done by jet for a few long stores with same conditions were segmented to four pieces in each of the long stores and then combined. They showed about 10% relative polarization loss over the eight hour store as shown in Fig. 3. The plan is to change the working point at store so that it is further away from the depolarizing resonance conditions. The beam energy at store will also be scanned in a small range to optimize the polarization at store.

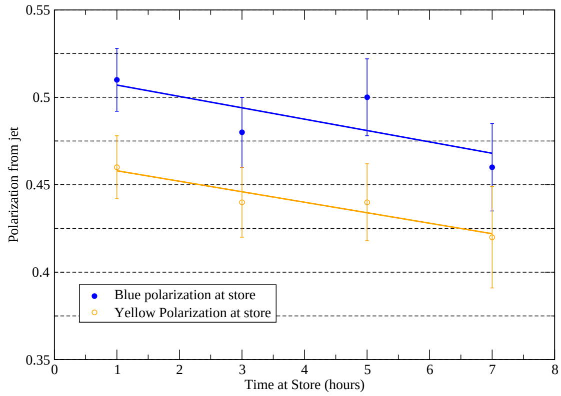

Figure 3: The polarization measured by the jet averaged over several long stores in both rings as a function of time.

9MHz RF SYSTEM

Several factors prevented increasing the bunch intensity in the past. First, we frequently observed magnet quenches when dumping beam with bunch intensity above 1.1×10^{11} at 250GeV. The beam dump system has been upgraded to accommodate a higher bunch intensity. Secondly, the electron cloud effect is stronger with a higher bunch intensity. It is desired to have shorter bunches at store for higher luminosity within the vertex region of the experimental detectors. However, short bunches during the ramp enhance the electron cloud effect, which results in lower luminosity due to transverse emittance growth and instability. In the past, a long bunch was generated by a mismatch between the bunch (AGS) and the bucket (RHIC, 28MHz). A longer bunch was obtained at the cost of a large longitudinal emittance. The 9MHz cavity is a cavity common to both rings. Due to its design, it can have a much lower voltage to match the beam coming from AGS. With the 9MHz cavity, the bunch length remains long on the ramp without blowing up the longitudinal emittance at injection. A longer bunch helps mitigate the electron cloud effect on the ramp. At the same time, the longitudinal emittance is preserved such that rebucketing with the 197MHz cavities at store is possible.

10Hz ORBIT FEEDBACK

Vibrations of the cryogenic triplet magnets are suspected to be the cause of the closed orbit oscillations at frequencies close to 10 Hz. They reach several millimeters in the focusing triplets. This gives rise to modulated beam-beam jitter at the interaction point (IP) which can lead to emittance growth and luminosity loss for sufficiently large beam-beam offsets. Several solutions to counteract the effect have been considered in the past, including reinforcing the magnet base support assembly, a mechanical servo feedback system, and a local beam feedback system at each of the two experimental IPs. The global orbit feedback is the better solution in both expense and performance. The 10Hz orbit oscillations are greatly reduced and the oscillations in the collision rate are also eliminated [6] (Fig. 4).

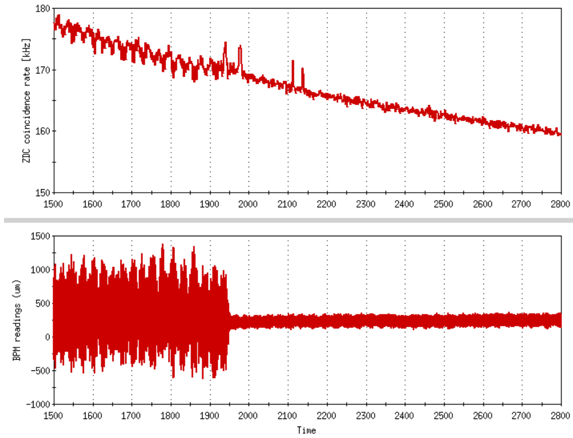

Figure 4: Collision rate with and without 10Hz orbit feedback as a function of time. Top: collision rate. Bottom: BPM signals with feedback off($<$1950) and on($>$1950).

CONCLUSION

With many upgrades and improvements, the bunch intensity has reached $1.8{\times}10^{11}$ /bunch. The peak luminosity was $1.5{\times}10^{32}$ cm^{-2}s^{-1} and the average polarization over the whole run was 48% as measured by the jet [3]. Considering the polarization profile, the polarization for double spin experiement is higher as 53%. The peak luminosity record was attained through higher beam intensities primarily and smaller β^* secondarily. Thirdly, beam-based control of the orbits, tunes, and coupling removed diurnal and long-term variations allowing improved reproducibility during the energy ramp. The higher polarization during this run comes from several improvements. First we have a much better orbit control on the ramp. Secondly, the horizontal jump quads in the AGS improved input polarization for RHIC. Thirdly, the vertical tune was pushed further away from the 7/10 snake resonance on the ramp.

To further understand the spin dynamics in RHIC, new spin simulation with the real magnet fields is underway. Further polarization gain will require a polarized source upgrade; control emittance in the whole accelerator chain; and more coupling control on the ramp and at store.

REFERENCES

[1] Ya.S. Derbenev and A.M. Kondratenko, Part. Accel. **8**, 115 (1978).

[2] S.Y. Lee and S. Tepikian, Phys. Rev. Lett. **56**, 1635 (1986).

[3] Y. Makdisi, *et. al.*, in *Proc. of PAC07*, p. 4671.

[4] M. Minty, *et al.*, “Precision Beam Instrumentation and Feedback-Based Beam Control at RHIC”, these proceedings.

[5] W. Fischer and A. Bazilevsky, C-A/AP Notes 430 (2011).

[6] R. Michnoff, *et al.*, ”RHIC 10 Hz Global Orbit Feedback System”, Proc. of PAC11, New York (2011).