AGS POLARIZED PROTON OPERATION EXPERIENCE IN RHIC RUN17*

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Abstract

The imperfection and vertical intrinsic depolarizing resonancesin the Brookhaven AGS have been overcome by the two partial Siberian snakes in the Alternating Gradient Synchrotron (AGS). The relatively weak but numerous horizontal resonances are overcome by a pair of horizontal tune jump quads. 70% proton polarization has been achieved for 2.1E11 bunch intensity. Further gain can come from maintaining smaller transverse emittance with same beam intensity. The main efforts now are to reduce the transverse emittance in the AGS and Booster, as well as robust jump quads timing generation scheme. This paper summarizes the operation results in the injectors.

INTRODUCTION

AGS has been running as polarized proton injector for Relativistic Heavy Ion Collider (RHIC) with dual partial snakes [1] and two horizontal tune jump quads [2] since 2011. The dual partial snakes overcome the vertical intrinsic and imperfection depolarizing resonances in the AGS. The introduction of partial snakes generates horizontal intrinsic resonances. They are generally weak but could cause accumulated polarization loss if left uncorrected [3]. A modest horizontal tune jump system has been used to overcome these weak but numerous resonances while maintaining the transverse emittances. A relative gain of 10-15% polarization has been achieved with the tune jump system. The general layout of polarized proton apparatus of RHIC injectors are shown in Fig. 1. The upgrade of polarized proton source provided more intensity for the injectors. We can also get more intensity through injectors. The intrinsic depolarizing resonance strength is proportional to the square root of emittance. The further gain in polarization while raising intensity will come from the control of emittance growth.

BOOSTER EMITTANCE CONTROL

Polarized H^- beam is strip-injected into the AGS Booster at kinetic energy of 200MeV. Typically, beam will pass the stripping foil a few hundreds turns and the multiple scattering through the stripping foil causes emittance growth. The growth can be reduced by reducing the beta functions at the foil. This has been achieved by setting Booster tune slightly above 4.5. The tunes are rapidly

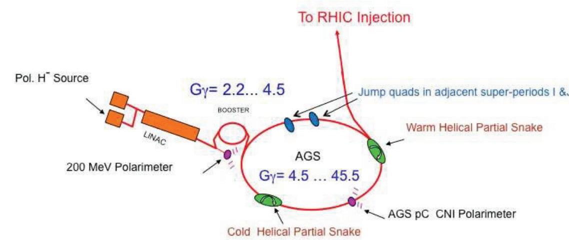

Figure 1: The general layout of polarized proton apparatus in the injectors of RHIC.

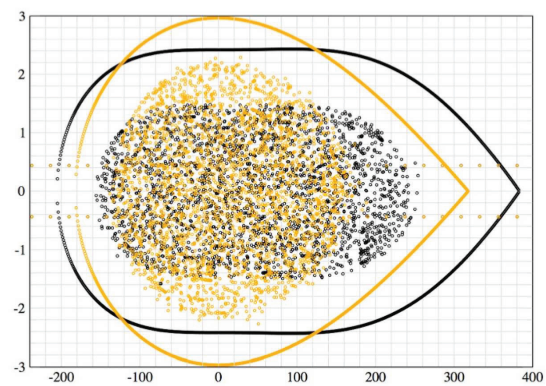

Figure 2: The bucket and bunch shape for one harmonic (h=1) and dual harmonics (h=1 and 2) in the AGS Booster. The black (darker) line and dots are for dual harmonics, and the orange (lighter) line and dots are for single harmonics. It is clear that the bunch is flatter in the case of dual harmonics.

ramped up before beam is bunched, so that there is enough tune space for the beam to deal with space charge force which tends to lower the tune. The low energy combined with high intensity generates strong space charge effect when beam is bunched. The space charge effect is proportional to the peak beam current. So adding second harmonic to operate the RF system with dual harmonics will reduce the peak current, hence reduce the space charge effect.

Simulations have been done to make sure this idea works for the Booster [4]. The results are shown in Figs. [2-3]. With Booster input current increased by almost a factor of 2, space charge force becomes important. The solution is to use dual RF harmonics (h=1 and 2) in the Booster. The reduction of peak current is about 25-30%.

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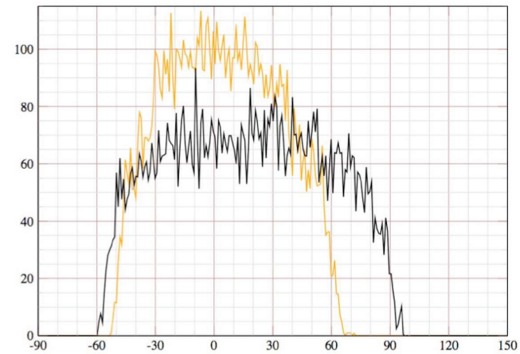

Figure 3: The beam distributions for one harmonic (h=1) and dual harmonics (h=1 and 2) in the AGS Booster. The black (darker) line is for dual harmonics, and the orange (lighter) line is for single harmonics. The peak current is reduced by about 30% with dual harmonics.

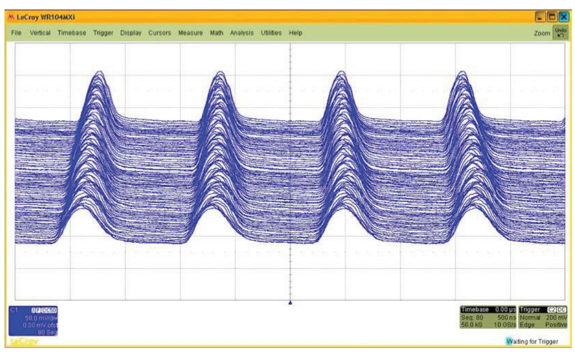

Figure 4: The mountain range Booster bunch with single RF harmonic.

The dual RF harmonics scheme was used since run15. The peak current reduction resulted in brighter beam out of Booster. Figs. 4-5 depict the bunch shapes in the Booster with the two RF harmonic settings, which show the bunch shape is flatter in the case of dual harmonics. The scope picture of beam intensity is shown in Fig. 6. After Booster scraping, more beam get through the scraping, indicating brighter beam.

AGS EMITTANCE

In run15, the polarization was maintained at similar level as run13 but at higher intensity. The emittance out of AGS is smaller due to heavier scraping in the Booster and dual harmonic operation in the Booster. The smaller emittance helped us to maintain polarization with higher intensity. Table 1 shows the emittance measured at various locations along the injector chain. These emittances are measured with different devices and each has its own systematic errors. The linac emittance shows no dependence on beam intensity. The Booster to AGS (BtA) emittance measurement was done with multiwire scanner and was done without Booster scraping, which showed larger emittance due to

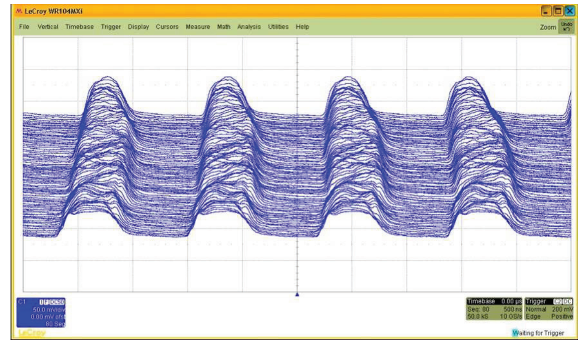

Figure 5: The mountain range Booster bunch with dual RF harmonics. Compared with bunch shapes in Fig. 4, the bunch shape is flatter, corresponding to less peak current.

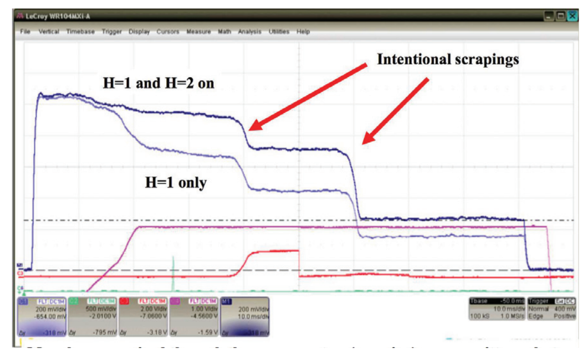

Figure 6: The scope picture for single and dual harmonic cases. The beam intensity as function of time is shown for the two cases. There are two intentional scrapings along the energy ramp. The settings are fixed for the two cases. More beam survives with dual harmonics. The emittance is defined by the scraping and more intensity passes the scraping aperture. This indicates brighter beam at the end of Booster acceleration.

stripping foil and possible space charge effect in the early ramp. The AGS Ion Profile Monitor (IPM) measurement was with 2×10^{11} intensity at extraction. With Booster scraping in place, the vertical emittance is smaller than shown in the table. The difference in the values suggests vertical emittance growth on the AGS ramp. There are two possible sources: the vertical emittance growth at AGS injection and along AGS ramp. To confirm the growth at injection, we need turn-by-turn(TBT) emittance information at injection. Electron collecting IPM have been installed in AGS which is capable of TBT emittance measurement [5]. The injection TBT emittance information showed little mismatch at injection.

The space charge tune shift at AGS injection is estimated to be around 0.2 for polarized proton beam. This is a significant tune shift and transverse emittance growth is quite likely. Longer bunch with less peak current will be helpful. To reduce the peak current, lower RF harmonic (h=6 instead of 8) has been used in run17 operation. In addition, dual harmonics (h=6 and 12) have also been used in AGS,

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Table 1: Measured Emittance Along the Injector Chain

Location	Hori. Emit.	Vert. Emit.
Linac	5.5±1.0	6.0±1.0
BtA	9.2±0.9	7.1±1.0
AGS extraction	10±1.0	12±1.0

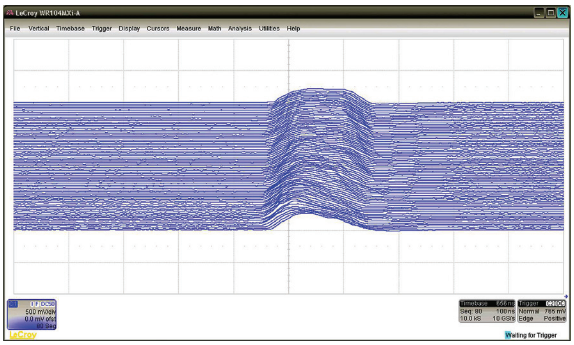

Figure 7: The mountain range of AGS bunch with dual RF harmonics for the first 10ms near AGS injection. The bunch shape is flatter, corresponding to less peak current.

based on the success in the Booster. The dual harmonics was used from injection (2.4GeV) up to around 4GeV, as the dual harmonic RF cavity is only possible before peak RF voltage is reached. The resulted flatter bunch is shown in Fig. 7. With the dual harmonics setup, the transverse emittance is smaller and such setup has been used for run17 polarized proton operation.

JUMP QUAD TIMING

In run15, the horizontal tune jump quadrupoles became inneffective from time to time. Many factors can change the jump quadrupole timing, such as AGS main magnet field drift, radial change, and betatron tune change. The required timing accuracy is below $100\mu s$, which is challenging. It is critical that the multiple tune jumps happen at

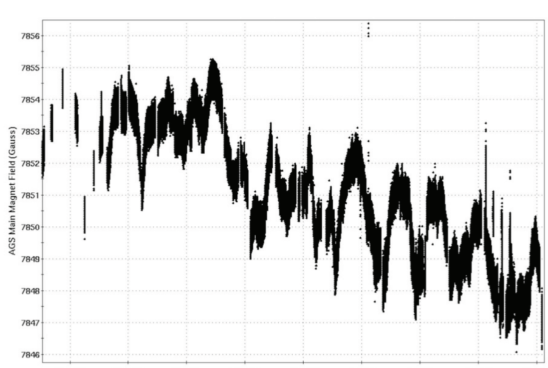

Figure 8: The AGS main magnet field at 549ms on the ramp over several months. Due to the ambient temperature change, the field changes about 9 Gauss peak to peak over several months. This is about 0.1% change.

the right energies. The horizontal tune jump amplitude of 0.04 is equivalent to about 8 Gauss magnetic field change. It was noticed that the AGS main magnet field measurement drifted over five months operations. The drifts seem to be correlated with the room temperature and cooling water temperature. The AGS main magnet regulation circuitry was modified to reduce the temperature impact. Nevertheless, the B field variation is still observed as shown in Fig. 8. So this is likely not the source of the timing drifting.

On the other hand, even if the main magnet field drifts over time, a new jump quad timing based on new energy information (from revolution frequency, beam radius) should compensate the effect. At the beginning of the operation of horizontal tune jump, the timing was derived from betatron tune, main magnet field and beam radius along the ramp. Due to the errors of the last two quantities, the derived tune jump timing could have errors, too. With partial snake magnets in the AGS, the spin will flip sign when $G\gamma$ encounters an integer. If we measure the polarization on the ramp, the spin flip information can be used to determine the energies of these spin flips. Consequently, the jump quad timing can be derived from these spin flips. In the past, a sophisticated combination of spin flips and B field/radius measurements were used. But it was not good enough to find beneficial jump quad timings after main magnet drifts. This year, the jump quad timing derivation was modified. Only spin flip information was used to derive jump quad timing. The results are very robust: they show consistent beneficial jump quad timing files while the magnet drift is still present. These results may suggest that the main magnet drift could be just a measurement issue.

CONCLUSIONS

Proton polarization have been maintained at 70% level with bunch intensity 2.1E11 at extraction by dual partial snakes and horizontal tune jump quadrupoles. The transverse emittance is smaller for the same AGS late intensity thanks to heavier Booster scraping and dual harmonics in the Booster and early part of AGS acceleration. The heavy Booster scraping is possible due to more Booster input intensity. Smaller emittances are the results of these new schemes. The newly installed electron collecting IPM provided valuable emittance information on the ramp and TBT at injection. These improvements are critical for emittance preservation along the ramp. In the coming years, further polarization gain is expected to come from emittance preservation and higher source polarization.

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