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RHIC HEAVY ION OPERATION WITH NEAR-INTEGER WORKING POINT

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Abstract

The interplay of space charge and beam-beam effects limits the beam lifetime at low energies at the Relativistic Heavy Ion Collider (RHIC). To improve the beam lifetime, a near-integer working point (0.09/0.085) was tested at fixed energy and during acceleration. In the demonstration experiments and following operation at 13.5 GeV, we observed the benefit of the near-integer working point on beam lifetime, however, also its complication on beam conditions. This article presents the experimental results of operation with a near-integer working point.

QUEST OF NEW WORKING POINT AT RHIC

Near-integer working point provides a larger tune space for heavy ion beam with non-negligible space charge and beam-beam effects [1]. RHIC has been operated at tunes of (0.235, 0.225) for many years for high energy heavy ion program after some attempts at other working points [2]. However, lifetime of ion beam was limited at and below injection energy (9.8 GeV/nucleon) at these tunes. It was demonstrated that beam loss with collision was lower with tunes below 0.1 at and below injection energy [3], where luminosity drops significantly with beam energy. During Beam Energy Scan I and II [4], where beams collide with energy below, at and slightly above injection energy, it is beneficial to find out whether beam can be accelerated and if beam lifetime is better with these near-integer tunes. Therefore, working point (0.09, 0.085) was proposed for beam acceleration from injection energy to 13.5 GeV and also for beam collision at 13.5 GeV.

Near-integer working point also provides high stable polarization in addition to potential better lifetime for polarized proton beam with stronger beam-beam force [5]. Polarized proton beam has been operated with working point at (0.695,0.685) for one beam and (0.685, 0.695) for the other, which are between third order resonance (2/3) and a Snake resonance (7/10). The dynamic aperture of the beam with horizontal tune closer to 2/3 is visibly smaller than the other beam. During the attempt of working point at (0.96,0.95), beam was accelerated to top energy with a tune (0.89) further away from integer to avoid orbit and optics distortion. However, the near-integer working point for polarized proton was abandoned due to high background at the experiments [6]. Therefore, demonstration of beam acceleration and collision at near-integer tunes in RHIC will be beneficial for high energy polarized proton operation as well.

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DEMONSTRATION AND OPERATION OF 13.5 GEV/NUCLEON AU BEAM WITH TUNES AT (0.09, 0.085)

The new working point was first successfully demonstrated for 13.5 GeV/nucleon beam in a beam study. This study first setup the beam at injection energy (9.8 GeV/nucleon) with the new working point. Then the beam was accelerated up to 13.5 GeV/nucleon with tunes kept constant by tune feedback, orbit controlled by slow global orbit feedback. Beam collision was afterwards established at 13.5 GeV/nucleon beam energy.

The new working point was later adopted for beam operation at 13.5 GeV/nucleon for a week. The experimental results presented in this paper are from this time period. With the new working point, beam intensity was limited due to beam loss in the arc during beam acceleration. For later operation at 13.5 GeV/nucleon, the working point was reverted back to (0.235, 0.225). In the following, we will present the operational experience with tunes at (0.09, 0.085) and comparison of beam conditions at these two different working points.

Orbit, Tune Control and Beam Loss During Beam Acceleration with Tunes at (0.09, 0.085)

During beam acceleration, tune feedback was engaged to keep the tunes constant (Fig. 1). However, tune variations were observed during acceleration with the deviation of the vertical tunes (0.02) larger than those of horizontal tunes (0.01).

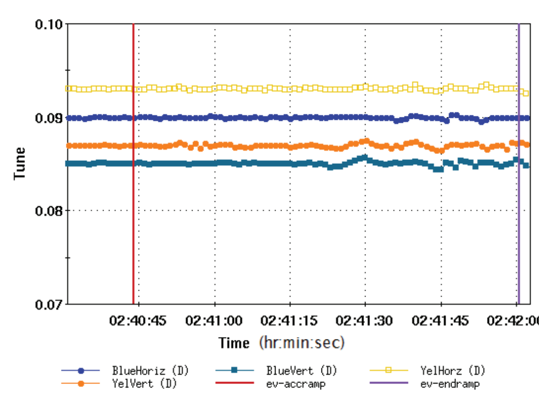

Figure 1: Measured tunes of 'Blue' and 'Yellow' beam during beam acceleration. The acceleration started at the first vertical line, ended at the second vertical line.

With slow global orbit feedback (1 Hz) engaged to control the orbit during beam acceleration, the orbit RMS were found to be less than 0.5 mm for both beams (Fig. 2). Xmean

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(Ymean) is the average of all horizontal (vertical) arc beam position monitor (BPM) readings. Xrms (Yrms) is the root mean square of all horizontal (vertical) arc beam position monitor readings.

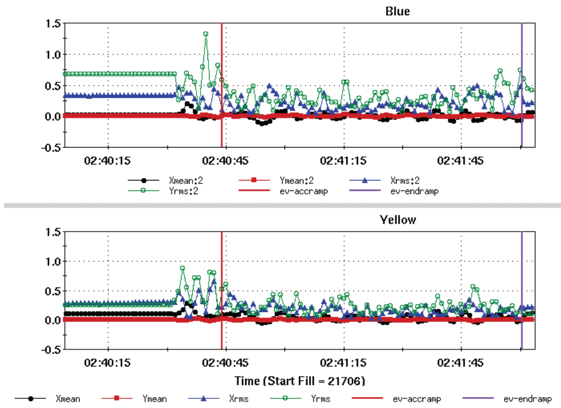

Figure 2: Beam orbit statistics, Xmean, Ymean, Xrms, Yrms, of both beams during beam acceleration with global orbit feedback engaged.

The 10 Hz global orbit feedback was engaged to combat triplet vibration induced beam motion. Before acceleration started, the 10 Hz feedback damped peak-to-peak oscillation amplitude by a factor of 3-5 (Fig. 3). During beam acceleration, the damping effect was reduced due to interference with the slow global orbit feedback, which stopped right after the system being turned off when beams were brought into collisions.

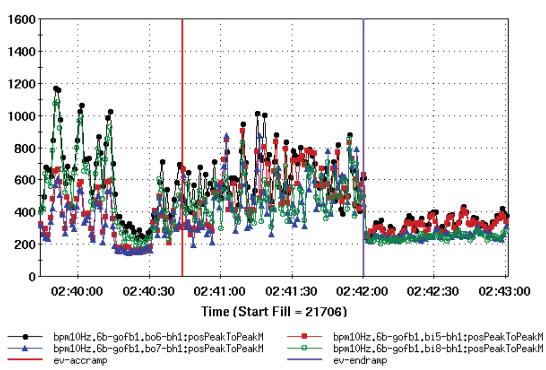

Figure 3: Peak-to-peak oscillation amplitude measured by fast BPMs during beam acceleration with 10 Hz feedback system engaged. The four selected BPMs are the ones near the two experimental areas.

Beam loss of both beams during beam acceleration with near-integer tunes are shown in Fig. 4. The first peak of beam loss of both beam was associated with the magnet persistent current 'snap-back' [7] where most de-bunched beam lost on limiting apertures. The second and third peaks in Yellow beam only, which happened in the middle of arcs, were not well understood. These losses limited the ion beam intensity and led to the switch of tunes.

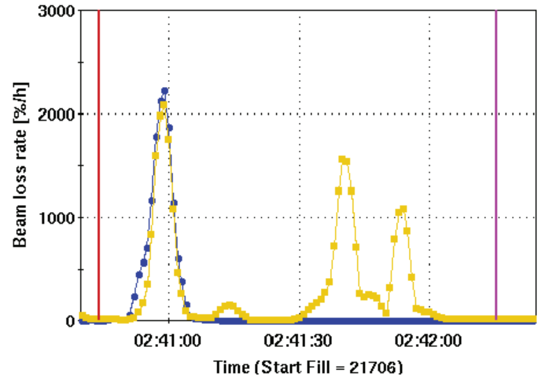

Figure 4: Beam loss of both beams during beam acceleration with near-integer tunes.

Beam Loss, Background Control and Emittance Evolution with Collisions

With larger tune space at the new working point (0.09, 0.085), beam loss when beams in collision (Fig. 5) was observed to be less than that at working point of (0.235, 0.225) (Fig. 6). The difference was most pronounced right after beams were brought into collisions.

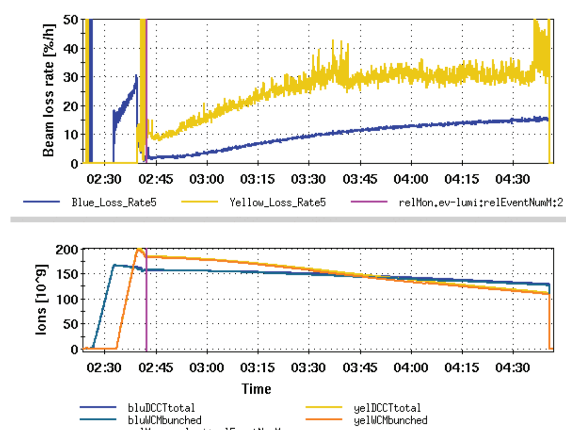

Figure 5: Upper plot: beam loss rate with beam collision at 13.5 GeV/nucleon with working point of (0.09, 0.085). Lower plot: beam intensity in the two RHIC accelerators.

For Au beam at 13.5 GeV/nucleon, the 10 Hz feedback worked well even at the near-integer tunes. The background at the experiment (STAR) was under control with 10 Hz feedback engaged and collimators employed.

With beams in collision, the beam transverse emittance, shown in Fig. 7, were measured by Ionization Profile Monitors (IPMs). With near-integer tunes, the Blue horizontal emittance kept increasing over the course of a physics store; the Yellow vertical emittance reached a plateau due to physical aperture limit.

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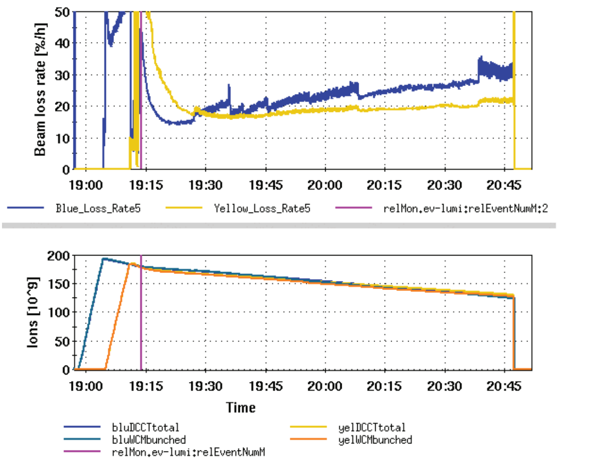

Figure 6: Upper plot: beam loss rate with beam collision at 13.5 GeV/nucleon with working point of (0.235, 0.225). Lower plot: beam intensity in the two RHIC accelerators.

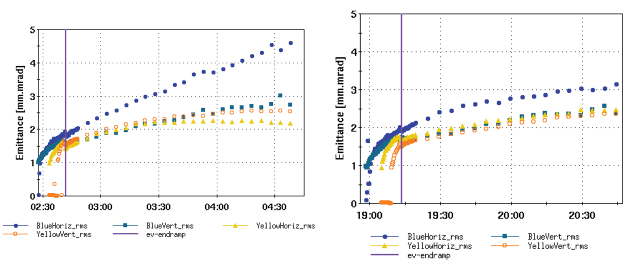

Figure 7: The measured beam transverse emittance of both beams, on the left was with (0.09, 0.085) tunes, on the right was with (0.235, 0.225) tunes.

BEAM OPTICS MEASUREMENT WITH TUNES AT (0.09, 0.085)

With a given distributed quadrupole errors, the relative errors of $\beta-$functions have a strong dependence on the fractional tunes. Near-integer tunes would enhance relative $\beta-$function errors. The optics errors were measured and shown in Fig. 8.

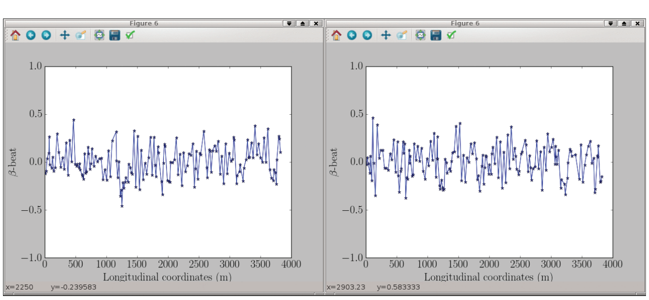

Figure 8: The measured relative errors of $\beta-$functions, the horizontal plane on the left and the vertical plane on the right with working point (0.09, 0.085).

IMPROVEMENT OF ORBIT CONTROL

The orbit control was improved after upgrade of corrector power supply control from 12 to 16 bit. The corrector power supply bit resolution drops with beam energy [8]. With near-integer working point, orbit distortion was further enhanced. To improve orbit control at near-integer tunes, upgrade of corrector power supply control was proposed and implemented fully before RHIC operation in 2019. The orbits, before and after the upgrade, are shown in Fig. 9 for comparison with beams at the same energy and working point of (0.09, 0.085).

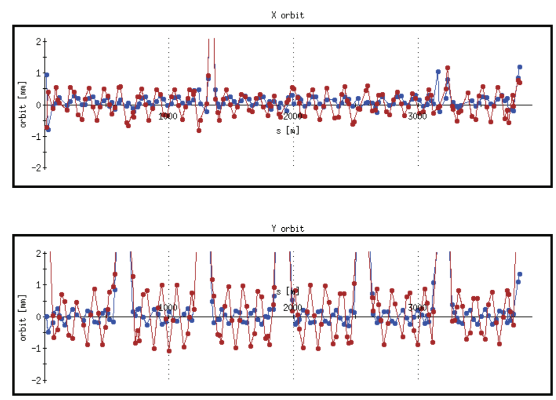

Figure 9: Upper plot: red is horizontal orbit before corrector power supply control upgrade, blue is after upgrade. Lower plot: red is vertical orbit before corrector power supply control upgrade, blue is after upgrade.

SUMMARY

RHIC Au-Au collision at 13.5 GeV/nucleon was operated with near-integer working point (0.09, 0.085) for part of the time in 2018. Orbit and tune during beam acceleration were controlled by feedback systems. Beam loss of Yellow beam during beam acceleration was not well understood. Background was under control with 10 Hz feedback engaged. Blue horizontal emittance with near-integer tunes grew faster, however others are the same as those with tunes at (0.235, 0.225). Orbit control was improved later in 2019 with upgrade of corrector power supply control bit resolution. The operation of Au at near-integer tune demonstrated a path for polarized proton beam operating at near-integer tunes for high stable polarization.

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