OPERATIONAL EXPERIENCE WITH A NEAR-INTEGER WORKING POINT AT RHIC *

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Abstract

During the RHIC polarized proton run in FY 2006 it became evident that the luminosity performance is limited by the beam-beam effect. With a working point between 2/3 and 7/10, and the necessity to mirror the tunes of the two RHIC rings at the diagonal, the beam with a horizontal tune closest to 2/3 showed poor lifetime. To overcome this limitation, a near-integer working point has been proposed. Tracking studies performed at both working points showed a larger dynamic aperture near the integer tune than above 2/3. In Run-8, this new working point was commissioned in one ring of RHIC, while the other ring was operated at the same working point as in Run-6.

In this paper we report the commissioning process and operational experience with this new working point.

INTRODUCTION

A number of working points have been used or tested in RHIC (Fig. 1). The design tunes $(Q_x, Q_y) = (.19, .18)$ were chosen because the dynamic aperture was found to be large at these tunes. However, during commissioning it was found that larger tune deviations on the energy ramp could be tolerated at the higher tunes (.235,.225). These are still used for heavy ions. Since the beam-beam parameter in proton operation is about three times larger than in heavy ion operation, tunes were investigated in simulation and experiments that could accomodate a larger tune spread [1]. In 2004 the new tunes (.695,.685) were used in proton operation [2]. These tunes were also used in the Sp$\bar{p}$S, and are mirrored to the LHC tunes.

During RHIC polarized proton operations in Run-6 the working points of both the "Blue" and the "Yellow" ring were placed between 2/3 and 7/10. To avoid detrimental effects due to coherent beam-beam interaction [3], the two working points were mirrored across the $Q_x = Q_y$ diagonal, thus resulting in fractional tunes of $(Q_x, Q_y) = (.685, .695)$ in one ring, and $(.695, .685)$ in the other.

With the third-order resonance being stronger in the horizontal plane than in the vertical, the lifetime of the beam with the horizontal tune closest to 2/3 was significantly worse than that of the other beam. Fig. 2 shows a typical RHIC store with the "Blue" working point at $(.685, .695)$, and the "Yellow" tunes at $(.695, .685.)$ In this case, the horizontal tune in the "Blue" ring is closer to 2/3 than in the "Yellow" ring, and as a consequence the "Blue" lifetime suffers.

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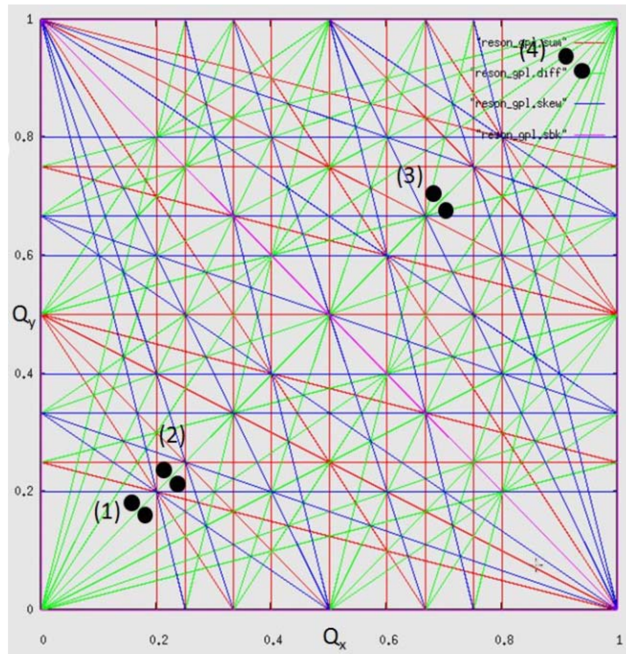

Figure 1: Tune diagram with resosances up to order 5, and working points considered or used in RHIC: (1) design tunes, (2) current tunes for heavy ions, (3) current tunes for polarized protons, (4) near integer working point tested for heavy ions.

To overcome this limitation, a new near-integer working point was proposed and studied in extensive simulations [4]. These studies showed a significant increase of the dynamic aperture for tunes around (.96,.95). However, the mirrored working point (.95,.96) was found to have a slightly smaller dynamic aperture than the one at (.695,.685). Based on these results it was therefore decided to operate at totally different working points in the two rings, namely (.96,.95) in the "Blue" ring, and (.695,.685) in "Yellow". This configuration also has the additional advantage of avoiding coherent beam-beam effects altogether due to the large tune separation between the two rings.

OPERATIONAL CHALLENGES

Operating any storage ring at near-integer tunes is very challenging. With the closed-orbit distortion $\Delta z(s)$ at any azimuthal position s as a result of dipole errors $\delta(t)$ around

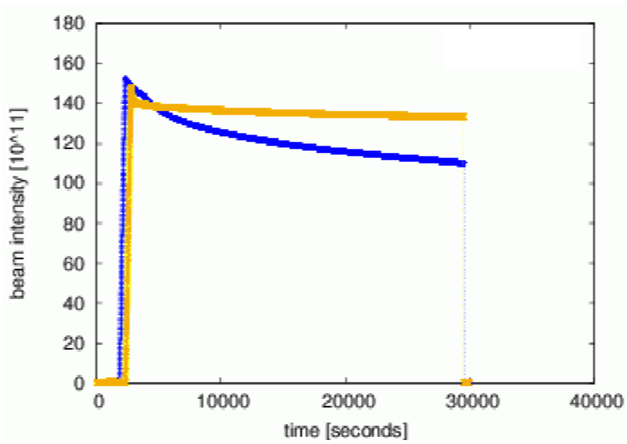

Figure 2: Beam intensities during a typical store in Run-6, with the "Blue" working point above the diagonal at (.685,.695), and the "Yellow" tunes below, at (.695,.685).

the ring being

$$\Delta z(s) = \oint \frac{\sqrt{\beta(s)\beta(t)}}{2\sin(\pi Q_z)}\delta(t) \cdot \cdot \cos(|\phi(s) - \phi(t)| - \pi Q_z)\,\mathrm{d}t, \quad (1)$$

the denominator vanishes at integer tunes Q_z, resulting in large closed-orbit distortions Δz. Control of the vertical orbit on the ramp is especially important to preserve polarization, with the goal being $\sqrt{\langle(\Delta z(s))^2\rangle} < 0.5\,\mathrm{mm}$. Additionally, the β-beat for a given distribution of quadrupole errors $k(t)$ around the machine has a strong dependence on the tune,

$$\frac{\Delta\beta_z(s)}{\beta_z(s)} = \oint \frac{\beta(t)}{2\sin(2\pi Q_z)}\Delta k(t) \cdot \cdot \cos(2|\phi(s) - \phi(t)| - 2\pi Q_z)\,\mathrm{d}t. \quad (2)$$

As in the case of closed-orbit distortions, the denominator vanishes at integer tunes Q_z, thus resulting in enhanced β-beat.

While the tunes at store energy are determined by the need for the largest possible dynamic aperture in collision, tunes on the ramp can be chosen more freely. Ramping at tunes further away from the integer allows for some unavoidable tune excursions during the ramp. However, one has to ensure that no strong depolarizing resonances are crossed when moving from the ramp tunes to the store working point of (.96,.95). Based on these considerations ramp tunes around $.89$ were chosen. The denominator in the expression for the closed-orbit distortion (Eq. 1) for the ramp working point is roughly three times larger than for the store tunes, while the β-beat (Eq. 2) is a factor 2.5 smaller at $.89$ than at $.96$.

Taking the derivative of the closed-orbit distortion $\Delta x(s)$ with respect to the tune Q (Eq. 1), we can calculate the sensitivity of closed-orbit distortions to unintended tune changes as

$$\frac{\mathrm{d}}{\mathrm{d}Q}\Delta z(s) \propto \frac{1}{\sin^2(\pi Q)}. \quad (3)$$

At the ramp tune $Q = .89$, this sensitivity is therefore roughly 7 times smaller than at the store working point $Q = .96$. Likewise, we can compute the sensitivity of the β-beat to tune variations as

$$\frac{\mathrm{d}}{\mathrm{d}Q}\frac{\Delta\beta(s)}{\beta(s)} \propto \frac{1}{\sin^2(2\pi Q)}, \quad (4)$$

which at the ramp tune is about 7 times smaller than at the store working point.

MACHINE PERFORMANCE

At the beginning of the Run-8 RHIC polarized protons run, the "Blue" beam was injected at tunes around .89. These tunes were kept constant on the ramp towards 100 GeV; at the very end a tune swing towards the store working point $(.96, .95)$ was introduced. Fig. 3 shows the "Blue" beam intensity and the measured tunes during a 37-bunch ramp in this configuration. The tunes on the ramp are controlled through the "RampEditor" (Fig. 4), where tune setpoints are defined at a number of "stepstones" along the ramp. As a comparison of the setpoints in the RampEditor and the corresponding tune measurements shows, setpoints and measurements are in good agreement, indicating that the machine model describes the real accelerator rather well even at near-integer tunes.

Orbit cntrol and correction also worked very well, with

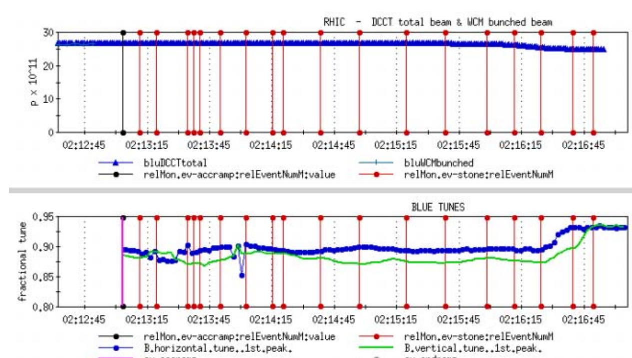

Figure 3: Beam intensity (upper) and measured tunes (lower) during a 37-bunch ramp. The vertical lines indicate the "stepstones" along the ramp.

the vertical rms orbit being corrected below the $\Delta y_{\mathrm{rms}} = 0.5\,\mathrm{mm}$ level required for good polarization transmission on the ramp, see Fig. 5.

When colliding beams were provided for detector setup at the PHENIX and STAR experiment, both detectors reported high background rates from the "Blue" beam. These backgrounds fluctuated on a time scale of typically 30 seconds. Beam decay rates were observed to fluctuate

	Time	Stepstone	Gamma	TuneX	TuneY	ChromX	ChromY
1	0.0	injection	25.379	27.9207	28.8264	4.6	1.5
2	8.0	t8	25.443	27.9197	28.8223	7.5	2.6
3	16.0	snapback	25.893	27.9234	28.8276	9.5	2.2
4	31.0	t31	28.956	27.9330	28.8436	10.3	3.2
5	34.0	t34	29.974	27.9323	28.8473	10.0	2.7
6	37.0	t37	31.128	27.9304	28.8507	9.9	2.7
7	46.5	gg64	35.697	27.9248	28.8578	9.1	1.2
8	59.0	t59	43.743	27.9190	28.8663	10.6	1.7
9	71.7	gg98	54.383	27.9157	28.8740	10.2	2.3
10	76.9	gg106	59.403	27.9162	28.8795	10.0	2.7
11	95.0	t95	79.735	27.9026	28.8743	9.6	2.8
12	113.6	gg179	99.562	27.8911	28.8518	10.0	3.1
13	136.0	flattop	106.813	27.8854	28.8580	8.0	2.7
14	155.0	t155	106.813	27.8854	28.8580	8.0	2.7
15	175.0	t175	106.813	27.8854	28.8620	6.6	2.5
16	188.0	t188	106.813	27.8844	28.8530	6.0	1.8
17	201.0	beta0p9	106.813	27.8844	28.8530	6.5	1.9
18	216.0	uncogged	106.813	27.9204	28.8780	6.5	2.1
19	226.0	store	106.813	27.9209	28.9125	5.0	0.5

Figure 4: Tune and chromaticity setpoints on the ramp. The "stepstones" correspond to the vertical lines in Fig. 3.

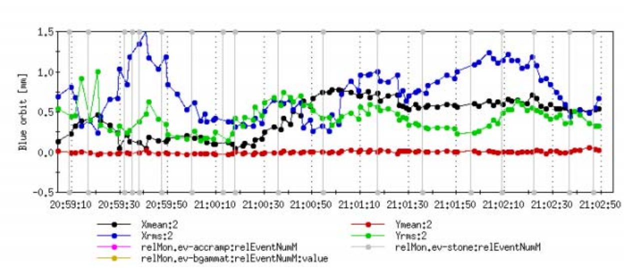

Figure 5: Orbit statistics on the "Blue" ramp. Horizontal and vertical mean orbit excursions $\langle \Delta x \rangle$ and $\langle \Delta y \rangle$ are indicated in blue and red, respectively, while the black and green symbols show the horizontal and vertical rms values $\langle (\Delta x)^2 \rangle$ and $\langle (\Delta y)^2 \rangle$.

on a similar time scale, and were found to be in perfect correlation with the detector background. These beam losses are caused by horizontal orbit jitter at frequencies around 10 Hz, resulting from mechanical vibrations of the low-β triplets in the six interacton regions of RHIC driven by the cryogenic flow [5]. As Fig. 6 shows, the amplitude of this orbit jitter fluctuates on a time scale of roughly 30 seconds; both the beam decay and the detector background correlate almost perfectly with the orbit jitter amplitude.

The IR orbit feedback installed at both PHENIX and STAR is only capable of reducing the relative beam-beam offset at the two interaction points, while it leaves the orbit angle at the IP, as well as the orbit outside these two interaction regions, unaffected. Therefore, the large orbit jitter amplitudes of up to 7 mm in the low-β triplets at these two experiments could not be reduced. When several attempts at reducing the resulting detector background by means of collimation failed, the near-integer working point was abandoned, and the machine was set-up in the Run-6 configuration instead.

SUMMARY

Operational use of the near-integer working point in regular RHIC operations was prevented by the increased amplitude of the 10 Hz orbit jitter, which resulted in unacceptably high background levels in the detectors.

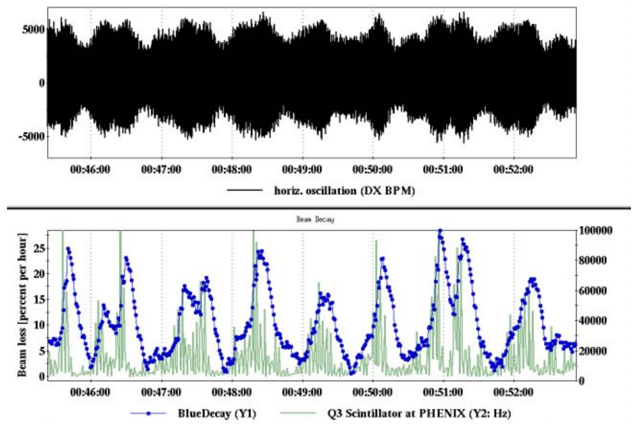

Figure 6: Horizontal orbit position (top graph), and resulting beam decay (lower graph, blue line) and correlated detector background at PHENIX (lower graph, green).

Several schemes to eliminate the 10 Hz orbit oscillation are currently under consideration, both beam-based and mechanical. A global orbit feedback system is being developed to stabilize orbit positions not only at the interaction points, but around the entire circumference of the machine. An active mechanical damping system where the positions of the cold masses are continuously measured and mechanically corrected is under development [6]. Furthermore, two passive mechanical methods are being studied. The first one aims at forcing the three individual cold masses in each triplet to move as one single solid object, which would reduce the effect on the beam orbit by a factor 5 for the same vibration amplitude [7]. The second approach aims at increasing the mechancial resonance frequency of the magnet supports by stiffening.

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