DYNAMIC APERTURE EVALUATION AT THE CURRENT WORKING POINT FOR RHIC POLARIZED PROTON OPERATION*

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Abstract

With the updated multipole magnet field errors in the interaction regions (IRs), detailed dynamic aperture studies are carried out around the current RHIC polarized proton (pp) working point. The beam parameters and β^*s are similar to those proposed for the next pp run. The effects on the dynamic apertures from nonlinear corrections, such as multipole field error correction in the IRs, second order chromaticity correction and horizontal third order resonance correction are evaluated. The sextupole components in the arc dipoles and the observed tune ripples are also considered.

INTRODUCTION

At the current working point for the RHIC polarization proton (pp) operation, the fractional tunes are constraint between $2/3$ and 0.7. The vertical faction tune 0.7 will impact both the luminosity lifetime and the polarization. And when the horizontal tune is close to $2/3$, the beam lifetime is affected by the third order betatron resonance.

To further increase the luminosity, we can increase the bunch intensity N_b and reduce the β^*. At 100 GeV, assuming $N_b = 2.0 \times 10^{11}$, $\beta^* = 0.9$ m at two collision points IP6 and IP8 and and the normalized transverse rms emittance $\epsilon_{rms,norm} = 2.5 \times 10^{-6}$ m.rad, the total beam-beam tune shift is 0.02. Therefore, the non-collisional horizontal tune should be larger than $0.666 + 0.02 = 0.686$. According to Ref. [1], to increase the tune space to accommodate the beam-beam tune spread and to get higher luminosity, both nonlinear chromaticities and horizontal third order resonance have to be corrected.

There are a total of 144 sextupole magnets in the 6 arcs of each RHIC ring. In previous RHIC pp runs, they were sorted into two families, one focusing and one defocussing, which allowed only first order chromaticity correction. In the 2007 Au run, the number of arc sextupole power supplies were doubled from 12 to 24. S. Tepikian proposed a 8-family scheme to compensate the second and third order chromaticities [2]. In the scheme, each outer or inner arc has 4 sextupole families, and all outer or inner arcs have the same sextupole strength patterns. An online nonlinear chromaticity correction based on off-momentum tune response matrix was proposed in Ref. [3].

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In the 2006 RHIC pp run, the correction of the horizontal third order resonance $3Q_x$ was tested at injection, where 12 sextupole families were used [4, 5]. The key point for this correction scheme is to measure the driving term h_{30000} of the $3Q_x$ resonance. The technique of measuring h_{30000} with an AC dipole is still under evaluation [6]. In Ref. [7], 12 local sextupole correctors in the interaction regions (IRs) are suggested for the $3Q_x$ resonance correction. The merit of using IR sextupole correctors is to separate the nonlinear chromaticity correction and third order resonance $3Q_x$ correction. In the following, we will use the arc sextupole families for the second order chromaticity correction and use the IR sextupoles for the $3Q_x$ correction.

To further increase the luminosity, we plan to increase the bunch intensity to 2.0×10^{11}, and reduce the β^* down to 0.9 m. There will be two collision points, IP6 and IP8. The β^*s at the other IPs are 5 m. The first order chromaticities are set to 2.0 before tracking, for both the 2-family and 8-family chromaticity correction schemes.

In this article, using the updated magnetic multipole field errors in the interaction regions, dynamic apertures are calculated in the tune range around the current pp working point. The effects on the dynamic apertures from nonlinear corrections, such as multipole field error correction in the IRs, second order chromaticity correction and horizontal third order resonance correction are evaluated. The sextupole components in the arc dipoles and the observed tune ripples are also considered.

TUNE FOOTPRINT CALCULATION

In this section, the tune footprints are calculated below and above 0.7 to check the available tune space to accommodate the beam-beam tune spread. The 4-D Tracking of on-momentum particle is performed with SixTrack. The tunes are calculated with the 10^3 turn-by-turn tracking data, using the modified Fast Fourier transformation (FFT) techniques. The 2-family chromaticity correction scheme is used here.

Tune space below 0.7

Fig. 1 shows the tune footprints for the two working points $(Q_x, Q_y) = (28.685, 29.695)$ and $(Q_x, Q_y) = (28.695, 29.685)$. From Fig. 1, with the beam-beam interactions on or off, the footprint with IR multipole correction is smaller than that without IR multipole correction.

With the beam-beam interactions, for working point $(Q_x, Q_y) = (28.685, 29.695)$, the beam-beam interactions

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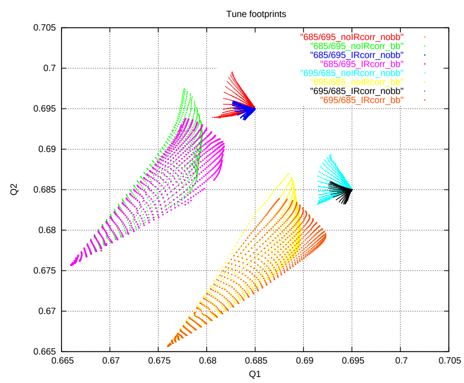

Figure 1: Below 0.7: The tune footprints with and without IR multipoles corrections for on-momentum particles up to $6\sigma_0$.

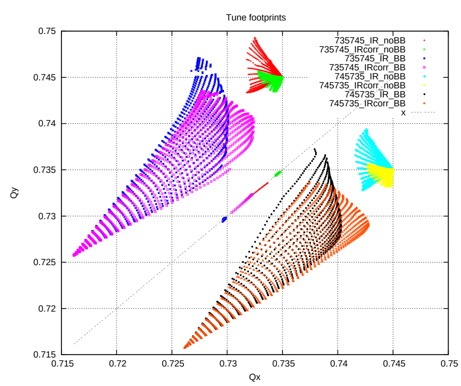

Figure 2: Above 0.7: The tune footprints with and without IR multipoles corrections for on-momentum particles up to $6\sigma_0$. The tune spots on the diagonal are due to the failure in tune searching.

push the horizontal tune of the beam center to the horizontal third order resonance at $Q_x = 28.666$. And for the working point $(Q_x, Q_y) = (28.695, 29.685)$, the beam-beam interactions push the vertical tune of the beam center to the vertical third order resonance at $Q_y = 29.666$.

Tune space above 0.7

Limited by the resonances at 0.7 and 0.75, and considering the beam-beam tune shift 0.02, two working points $(28.735, 29.745)$ and $(28.745, 29.735)$ are used for tune footprint calculation above 0.7. Fig. 2 shows the tune footprints for these two working points. From Fig. 2, the IR multipole correction does help single particle's short-term stability above 0.7, too.

Without the beam-beam interactions, for the working point $(28.735, 29.745)$, the vertical tunes for large amplitude particles are close to the vertical fourth order resonance at $Q_y = 29.75$. For the working point $(28.745, 29.735)$, the horizontal tunes for large amplitude particles are close to the horizontal fourth order resonance at $Q_x = 28.75$.

DYNAMIC APERTURE CALCULATION

In this section, the dynamic apertures calculations are presented for the tune range around the current pp working point [8]. The tracking is performed to 10^5 turns. The 6-D tracking code SixTrack is used. The initial relative energy deviation is 0.0007. The beam-beam interactions are calculated with the weak-strong model. For each tune spot, the dynamic apertures are searched in five angles in the normalized coordinate frame. For comparison, in the following we only show the minimum dynamic apertures among these five angles. The dynamic apertures are given in units of design rms beam size σ_0. To speed up the dynamic aperture search, a binary searching method is used.

Effect of nonlinear corrections

As we mentioned earlier, we are able to locally correct the sextupole, quadrupole and skew sextupole multipole field errors in IR6 and IR8. Comparing the DAs with and without IR multipole correction, we conclude that the local IR multipole corrections do improve the dynamic apertures slightly along the diagonal in the tune space.

Then we check the effect of the nonlinear chromaticity correction and $3Q_x$ correction. The strengths for the nonlinear chromaticities are calculated with MADX. Based on our simulation study, there is no significant change in the dynamic apertures along the diagonal below in the tune space between $2/3$ and 0.7 with and without nonlinear chromaticity correction.

The horizontal third order resonance $3Q_x$ is corrected with the 12 local sextupole correctors in the interaction regions although by now only 4 sextupole correctors have their power supplies. From our simulation study, the $3Q_x$ correction does increase the dynamic apertures when the horizontal tune is close to $2/3$.

Effect of tune ripples and b_2 *in arc dipoles*

Tune ripples were observed in RHIC operation and may reduce the beam dynamic aperture. In the following simulation, the observed tune ripples are artificially introduced by modulated quadrupoles at IP6. In the 10^5 turn DA calculation, no clear dynamic aperture reduction due to the tune ripples is observed. Larger turn numbers may be needed to see their effect. Also the sextupole components in arc dipoles are inlcuded in the simulation study. There is no clear change in the dynamic apertures with and without these sextupole components.

Fig. 3 and Fig. 4 show the dynamic apertures calculated with and without nonlinear chromaticity correction. In both plots, the $3Q_x$ corrections, tune ripples, and sextupole components in arc dipoles are included.

Tune scan above 0.7

Fig. 5 shows the dynamic apertures in the tune scan above 0.7 in the tune space. The chromaticities are corrected with the 2-family sextupole scheme. From Fig. 5,

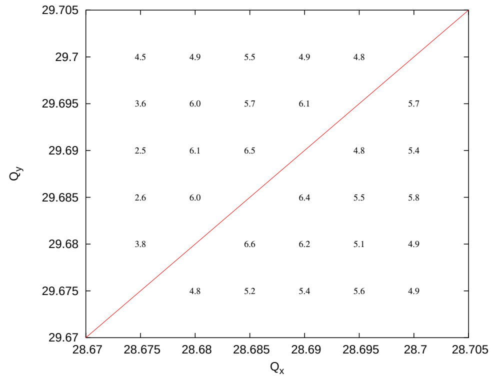

Figure 3: DAs in the tune scan under condition of (IRerrcorr + BB + b2 + 2fam).

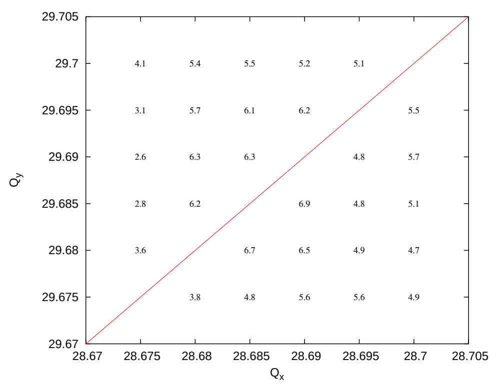

Figure 4: DAs in the tune scan under condition of (IRerrcorr + BB + b2 + 8fam).

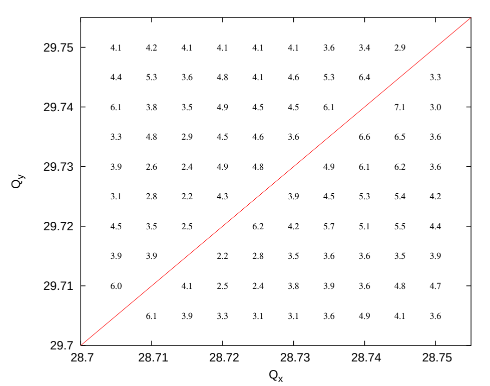

Figure 5: DAs in the tune scan above 0.7 under condition of (IRerrcorr + BB + b2 +2fam).

the dynamic apertures reaches its maximum when the uncollisional horizontal tune Q_x is close to 0.745. When the non-collisional horizontal tune is around 0.72, the dynamic aperture reduction is seen.

CONCLUSION

Detailed 10^5-turn 6-D dynamic apertures have been calculated around the current RHIC polarization proton working point. The initial relative momentum deviation is 0.0007. The model includes the updated IR multipole field errors and their corrections, the sextupole components in the arc dipoles, and tune ripples. The second order chromaticities and the horizontal $3Q_x$ resonance can be effectively corrected before tracking. Based on the dynamic aperture calculations, we conclude:

- With the beam-beam interactions at IP6 and IP8, where we have $\beta^* = 0.9$m, and a bunch intensity $N_b = 2.0 \times 10^{11}$, the dynamic aperture at good tune spots is about $6\sigma_0$.
- The dynamic apertures of particles with the same momentum deviation 0.0007 are not affected by the nonlinear chromaticity correction.
- A correction of the $3Q_x$ resonance driving term h_{3000} leads to an increase in the dynamic aperture for tune spots above the diagonal.
- There is only a small effect of the inclusion of sextupole field errors in the arc dipoles on the dynamic aperture.
- There is only a small effect of tune ripple on the dynamic aperture up to 10^5 turns.
- Between 0.667 and 0.7 in the tune diagram, the tune space is tight to accommodate the beam-beam tune spread of 0.02 with $N_b = 2.0 \times 10^{11}$.
- Between 0.7 and 0.75 in the tune diagram, the maximum dynamic aperture is reached when the noncollisional tunes are chosen to be near 0.745. The non-collisional tunes should not be smaller than 0.72.

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