DYNAMIC APERTURE EVALUATION FOR THE RHIC 2009 POLARIZED PROTON RUNS*

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Abstract

In this article we numerically evaluate the dynamic apertures of the proposed lattices for the coming Relativistic Heavy Ion Collider (RHIC) 2009 polarized proton (pp) 100 GeV and 250 GeV runs. One goal of this study is to find out the appropriate β^* for the coming 2009 pp runs. Another goal is to check the effect of second order chromaticity correction in the RHIC pp runs.

INTRODUCTION

To further increase the luminosity in the RHIC polarized proton run, we can reduce β^* functions at the interaction points and increase the bunch intensity. In the previous pp runs, the β^*s at IP6 and IP8 were about 0.9 m at store. $\beta^* =$ 0.7 m at store was achieved in the 2008 beam experiment. The bunch intensity has reached 1.7×10^{11} in the Blue ring in the 2008 pp run.

Reducing β^* requires a large physical aperture in the interaction region. And a lower β^* increases the sextupole correction strengths. Higher order chromaticities also are increased. To achieve acceptable beam dynamic aperture, both nonlinear chromaticity and sextupole resonance driving terms have to be well compensated.

The beam-beam tune spread is proportional to the bunch intensity. In the current RHIC pp run, the working points are constrained between 2/3 and 7/10. Current non-colliding working points for the Blue and Yellow rings are set to (28.685, 29.695) and (28.695, 29.685). With bunch intensity 2.0×10^{11} or above, there will not be enough tune space to hold the beam-beam tune spread [1, 2].

In the following, we first go through the lattice and beam parameters of the proposed lattices for the RHIC 2009 pp runs. Then we calculate the 10^6 turn dynamic apertures with different β^*, bunch intensity and transverse beam emittance.

BEAM AND OPTICS PARAMETERS

For all the proposed RHIC run 09 lattices, the non-colliding tunes are set to (28.685, 29.695) and (28.695, 29.685). The magnetic nonlinearities in the interaction regions (IRs) are installed in these lattices. The linear chromaticities are corrected to 1. The second order chromaticities can be corrected with 8 chromatic sextupole families [3]. Second order chromaticities can be corrected with the 8 sextupole families with the Harmon module and with a 4-knob method [4]. All the studies are based on the Blue ring lattices.

For the 100 GeV RHIC pp run, we will calculate the dynamic apertures for the three lattices with β^* =0.9 m, 0.7 m, and 0.5 m. For the 250 GeV RHIC pp run, we will check the two lattices with β^* =0.7 m and 0.5 m. The βs at other symmetric points IP10, IP12, IP2, IP4 are set to 5m. Table 1 lists the optics and beam parameters of the proposed lattices for the RHIC 2009 100 GeV and 250 GeV runs.

Second order chromaticities can be corrected with the 8 sextupole families with the Harmon module and with a 4-knob method [4]. From the simulation study, we learn that the 4-knob method does reduce the unbalance in the correction strengths among the sextupole families and avoids the reversal of sextupole polarities. Therefore, it yields a larger dynamic aperture than the Harmon module for the low β^* RHIC 2009 run pp lattices.

DYNAMIC APERTURE CALCULATION

In this section, we calculate the 10^6 turn dynamic apertures for the above lattices. The dynamic apertures are searched in the 6 angles from 15° to 75° with a step size of 15° in the $(x/\sigma, y/\sigma)$ space. The initial transverse momenta of the particles are set to 0. We calculate the dynamic apertures for the relative off-momentum deviation $\delta = 0.0007$ and 0.0005 for the 100 GeV and 250 GeV lattices respectively. In the following the dynamic apertures are given in the unit of $\sigma = \sqrt{\frac{\epsilon_n \beta^*}{6\gamma}}$, which differs with particle energy, β^*, and beam emittance. ϵ_n is normalized 95% transverse emittance.

The 100 GeV lattices

Table 1 shows the dynamic apertures for the proposed RHIC 2009 100 GeV pp lattices. From Table 1, for the proposed 100 GeV lattices with the working point (28.685, 29.695), without second order chromaticity correction, the minimum dynamic apertures are 4.9 σ, 4.1 σ, 2.9 σ for the lattices with $\beta^* = 0.9$ m, 0.7 m, and 0.5 m. For the working point (28.695, 29.685), the minimum dynamic apertures are 4.7 σ, 3.6 σ, and 3.6 σ for the lattices with $\beta^* = 0.9$ m, 0.7 m, and 0.5 m. There are a large reduction in the minimum dynamic aperture with the $\beta^* = 0.5$ m lattice for the working point (28.685, 29.695). For the working point (28.695, 29.685), the minimum dynamic apertures for the

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Table 1: Calculated 10^6 turn dynamic apertures for the proposed RHIC 2009 100 GeV pp lattices. Here bunch intensity $N_p = 1.8 \times 10^{11}$, beam emittance 20π mm.mrad, relative momentum deviation 0.0007.

Working point	β^*	$\xi^{(2)}$ correction	Min. DA
Above Diagonal :			
(28.685, 29.695)	0.9	No	4.9
(28.685, 29.695)	0.9	Yes / Harmon	3.6
(28.685, 29.695)	0.9	Yes / 4-knob	4.5
(28.685, 29.695)	0.7	No	4.1
(28.685, 29.695)	0.7	Yes / Harmon	3.5
(28.685, 29.695)	0.7	Yes / 4-knob	4.1
(28.685, 29.695)	0.5	No	2.9
(28.685, 29.695)	0.5	Yes / Harmon	3.4
(28.685, 29.695)	0.5	Yes / 4-knob	3.5
Below Diagonal :			
(28.695, 29.685)	0.9	No	4.7
(28.695, 29.685)	0.9	Yes / Harmon	4.3
(28.695, 29.685)	0.9	Yes / 4-knob	4.2
(28.695, 29.685)	0.7	No	3.6
(28.695, 29.685)	0.7	Yes / Harmon	3.6
(28.695, 29.685)	0.7	Yes / 4-knob	3.8
(28.695, 29.685)	0.5	No	3.6
(28.695, 29.685)	0.5	Yes / Harmon	3.6
(28.695, 29.685)	0.5	Yes / 4-knob	3.6

lattices with $\beta^* = 0.7$ m and $\beta^* = 0.5$ m both are about 3.6 σ.

Then we check the dynamic aperture changes with the second order chromaticity corrections. The Harmon module and the 4-knob method both are used to do the corrections. According to Table 1, for the 100 GeV lattices with the working point (28.685, 29.695), the 4-knob method yields larger minimum dynamic apertures than the Harmon module. From Table 1, the second order chromaticity corrections improve the minimum dynamic apertures for the lattices with $\beta^* = 0.5$ m, but reduces the minimum dynamic apertures for the lattices with $\beta^* = 0.9$ m. Also from Table 1, for the lattices with the working point (28.695, 29.685), the minimum dynamic apertures have small changes with second order chromaticity correction for the lattices with $\beta^* = 0.7$ m and 0.5 m. While for the lattices with $\beta^* = 0.9$ m, the second order chromaticity correction reduces the minimum dynamic aperture.

The 250 GeV lattices

Table 2 shows the dynamic apertures for the proposed RHIC 2009 250 GeV pp lattices. From Table 2, for the proposed 250 GeV lattices with the working point (28.685, 29.695), without second order chromaticity correction, the minimum dynamic apertures are 4.9 σ for both lattices with β^* =0.7 m and 0.5 m. While for the working point (28.695, 29.685), the minimum dynamic apertures for the lattices with β^* =0.7 m and 0.5 m are 5.4 σ and 4.9 σ. From Table 1 and Table 2, with the same $\beta^* = 0.7$ m, without second order chromaticity correction, the 250 GeV lattices yield 1 σ more than the 100 GeV lattices.

Table 2: Calculated 10^6 turn dynamic apertures for the proposed RHIC 2009 250 GeV pp lattices. Here bunch intensity $N_p = 1.8 \times 10^{11}$, beam emittance 20π mm.mrad, relative momentum deviation 0.0005.

Working point	β^*	$\xi^{(2)}$ correction	Min. DA
Above Digonal			
(28.685, 29.695)	0.7	No	4.9
(28.685, 29.695)	0.7	Yes / Harmon	3.9
(28.685, 29.695)	0.7	Yes / 4-knob	6.0
(28.685, 29.695)	0.5	No	4.9
(28.685, 29.695)	0.5	Yes / Harmon	4.1
(28.685, 29.695)	0.5	Yes / 4-knob	4.8
Below Digonal			
(28.695, 29.685)	0.7	No	5.4
(28.695, 29.685)	0.7	Yes / Harmon	4.8
(28.695, 29.685)	0.7	Yes / 4-knob	6.8
(28.695, 29.685)	0.5	No	4.9
(28.695, 29.685)	0.5	Yes / Harmon	5.5
(28.695, 29.685)	0.5	Yes / 4-knob	4.9

From Table 2, for the proposed 250 GeV lattices with $\beta^* = 0.7$ m, the second order chromaticity corrections from the 4-knob method increase the minimum dynamic aperture by more than 1 σ, comparing to those without correction. However, the second order chromaticity corrections from the Harmon reduces the minimum dynamic apertures.

For the lattices with $\beta^* = 0.5$ m, the minimum dynamic apertures with the second order chromaticity corrections from 4-knob method are comparable to that without correction. The correction strengths from the Harmon require the polarity reversal of family SDPO. However, all the power supplies of RHIC sextupoles are monopolar.

Scan in bunch intensity

In this section we calculate the dynamic apertures in scans of bunch intensity and transverse beam emittance. The starting optics and beam parameters are $\beta^* = 0.7$m, bunch intensity is $N_p = 1.7 \times 10^{11}$, beam emittance 20π mm.mrad. The relative momentum deviation are 0.0007 and 0.0005 for 100 GeV and 250 GeV lattices respectively. The second order chromaticities are corrected with the 4-knob method.

Table 3 lists the calculated 10^6 turn dynamic apertures in the scan of bunch intensity. From Table 3, for the 100 GeV lattice, there is no clear trend in the minimum dynamic apertures when we scan the bunch intensity from $N_p = 1.4 \times 10^{11}$ to 2.0×10^{11}. For the 250 GeV lattice, we observe reduction in the minimum dynamic aperture for the cases with $N_p = 2.0 \times 10^{11}$.

Table 3: Calculated 10^6 turn dynamic apertures in the scan of bunch intensity. Here $\beta^* = 0.7$m, bunch intensity 1.7×10^{11}, relative momentum deviation are 0.0007 and 0.0005 for 100 GeV and 250 GeV lattices respectively.

working point	Bunch intensity	Minimum DA
100 GeV:		
(28.685, 29.695)	1.4×10^{11}	4.1
(28.685, 29.695)	1.7×10^{11}	4.1
(28.685, 29.695)	2.0×10^{11}	3.9
(28.695, 29.685)	1.4×10^{11}	3.5
(28.695, 29.685)	1.7×10^{11}	3.8
(28.695, 29.685)	2.0×10^{11}	3.8
250 GeV:		
(28.685, 29.695)	1.4×10^{11}	6.1
(28.685, 29.695)	1.7×10^{11}	6.1
(28.685, 29.695)	2.0×10^{11}	5.7
(28.695, 29.685)	1.4×10^{11}	7.1
(28.695, 29.685)	1.7×10^{11}	6.9
(28.695, 29.685)	2.0×10^{11}	6.2

Scan in beam emittance

Table 4 lists the calculated 10^6 turn dynamic apertures in the scan of beam emittance. From Table 4, there is no clear trend in the minimum dynamic apertures when we scan the beam emittance from 14π mm.mrad to 20π mm.mrad. The differences in the minimum dynamic apertures are less than 0.3 σ.

$\beta = 7.5$m at non-colliding IPs

In all the above simulations, the βs at the other non-collisional IPs are set to 5 m. For the coming RHIC 250 GeV pp run, we may set $\beta = 7.5$ m at these points. Table 5 compares the dynamic apertures for the 250 GeV lattices with different βs at the non-collisional IPs. The β^* at IP6 and IP8 are 0.7 m or 0.5 m. The second order chromaticities are corrected to below 500 with the 4-knob method in all cases. Form Table 4, for the working point (28.685, 29.695), the lattices with β =7.5 m give higher minimum dynamic apertures. For the working point (28.695, 29.685), the lattices with β =7.5 m do not.

SUMMARY

We evaluated the dynamic apertures with the proposed RHIC lattices for the 2009 polarized proton runs. The 100 GeV lattices with β^* =0.9 m, 0.7 m, and 0.5 m, and the 250 GeV lattices with β^* =0.7 m and 0.5 m are checked. For each lattice, second order chromaticities are corrected with the Harmon module and the 4-knob method. We also calculated the 10^6 turn dynamic apertures in the scans of β^* at IPs, bunch intensity and transverse beam emittance. For 250 GeV lattices, we checked the dynamic apertures with the lattices with $\beta = 7.5$m at non-colliding IPs.

Table 4: Calculated 10^6 turn dynamic apertures in the scan of beam emittance. Here β^*=0.7 m, bunch intensity 1.7×10^{11}, relative momentum deviation are 0.0007 and 0.0005 for 100 GeV and 250 GeV lattices respectively.

working point	emittance	Minimum DA
100 GeV:		
(28.685, 29.695)	14π	4.1
(28.685, 29.695)	17π	4.3
(28.685, 29.695)	20π	4.1
(28.695, 29.685)	14π	3.8
(28.695, 29.685)	17π	3.8
(28.695, 29.685)	20π	3.8
250 GeV:		
(28.685, 29.695)	14π	6.3
(28.685, 29.695)	17π	6.4
(28.685, 29.695)	20π	6.1
(28.695, 29.685)	14π	6.6
(28.695, 29.685)	17π	6.8
(28.695, 29.685)	20π	6.9

Table 5: Calculated 10^6 turn dynamic apertures for the 250 GeV lattices with different β functions at the non-collisional IPs. Bunch intensity 1.8×10^{11}, beam emittance 20π, relative momentum deviation are 0.0005.

working point	$\beta*$	βs at other IPs	Min. DA
(28.685, 29.695)	0.7 m	5.0 m	6.0
(28.685, 29.695)	0.7 m	7.5 m	6.1
(28.685, 29.695)	0.5 m	5.0 m	4.8
(28.685, 29.695)	0.5 m	7.5 m	5.6
(28.695, 29.685)	0.7 m	5.0 m	6.8
(28.695, 29.685)	0.7 m	7.5 m	6.5
(28.695, 29.685)	0.5 m	5.0 m	4.9
(28.695, 29.685)	0.5 m	7.5 m	4.9

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