OPTIMIZATION OF THE PHASE ADVANCE BETWEEN RHIC INTERACTION POINTS*

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Abstract

We consider a scenario of having two identical Interaction Points (IPs) in the Relativistic Heavy Ion Collider (RHIC). The strengths of beam-beam resonances strongly depend on the phase advance between these two IPs and therefore certain phase advances could improve beam lifetime and luminosity. We compute the dynamic aperture (DA) as function of the phase advance between these IPs to find the optimum settings. The beam-beam interaction is treated in the weak-strong approximation and a non-linear model of the lattice is used. For the current RHIC proton working point (0.69,0.685) [1] the design lattice is found to have the optimum phase advance. However this is not the case for other working points.

INTRODUCTION

The beam-beam interaction is a severe limit for the RHIC proton-proton luminosity. A 50% emittance growth has been observed after 2 hours of beam collisions with a bunch intensity of 1.7×10^{11} protons (see Fig. 1). The luminosity lifetime could in principle be improved by reducing the strength of the relevant beam-beam resonances. In this work we focus on the horizontal and vertical phase advances between the two IPs as the parameters to minimize resonance strengths. Assuming two identical interaction points the beam-beam interaction drives the resonance (j,k) with a strength given by

$$f_{(j,k)} \propto \frac{1+e^{i2\pi(j\Delta\phi_x+k\Delta\phi_y)}}{1-e^{i2\pi(jQ_x+kQ_y)}}\ , \qquad (1)$$

where $\phi_{x,y}$ are the horizontal and vertical phase advances and $Q_{x,y}$ are the horizontal and vertical tunes. From Eq. (1) one can deduce that for given tunes:

- The strength is maximum if

$$j\Delta\phi_x + k\Delta\phi_y = N, \quad N \text{ any integer} \qquad (2)$$

- The strength is zero if

$$j\Delta\phi_x + k\Delta\phi_y = N/2, \quad N \text{ odd integer} \qquad (3)$$

The above equations predict lines in the horizontal and vertical phase advance plane where the resonances are either maximum or zero, thus rendering resonance diagrams similar to those of the working point. In the following we discuss the means to vary the phase advances and compute the dynamic aperture (DA) for different settings.

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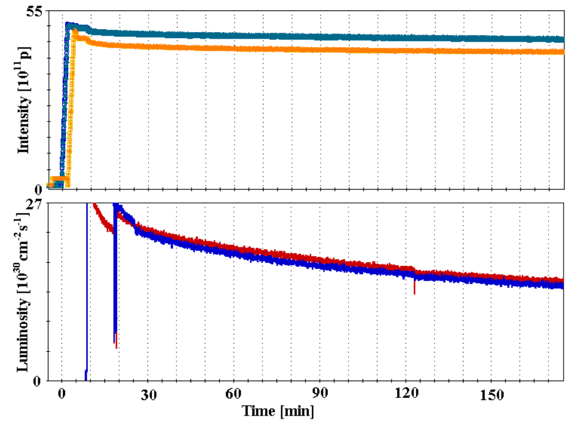

Figure 1: Luminosity decay for a store with 28 bunches. Note that the beam intensity is almost unchanged over the store length.

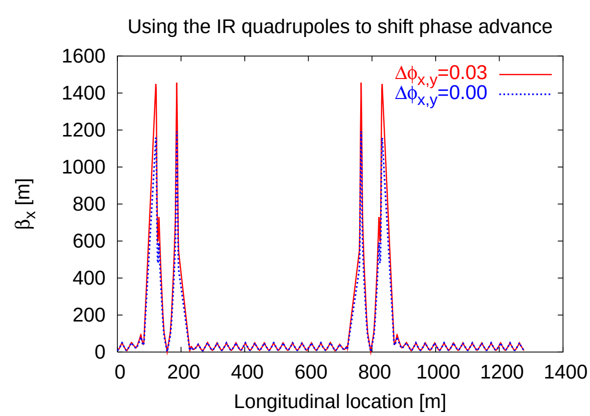

Figure 2: Optics for two phase advance configurations using the IR quadrupoles.

MEANS TO VARY $\Delta\phi_{X,Y}$

We have studied four different ways to vary the phase advances between the two IPs. We separate them in cases that would need new hardware and those that don't.
Do not need new hardware:

1. **Using IR quadrupoles:** The IR quadrupoles have independent power supplies that could be used to modify the phase advances. However this yields large changes in the betatron functions in the triplets, enhancing the large non-linearities present in these areas (see Fig. 2).

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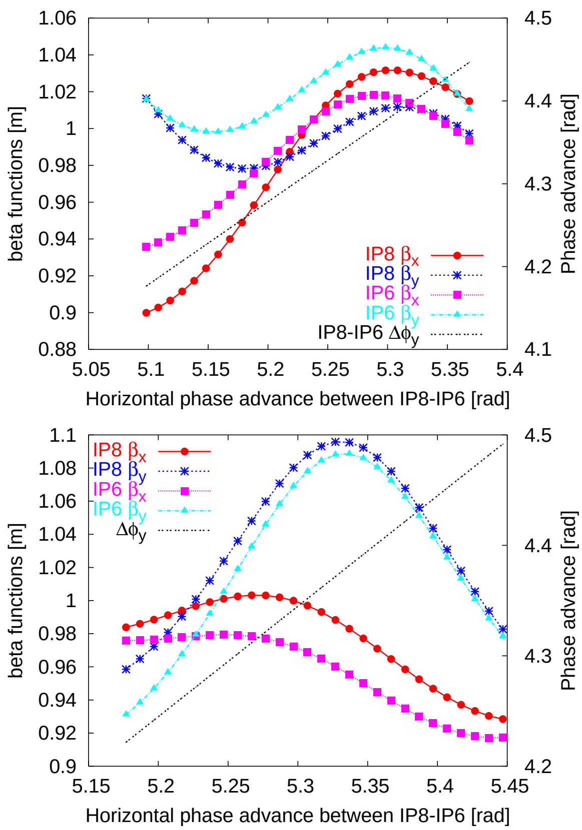

Figure 3: Twiss functions at the IP versus horizontal phase advance for tunes $(Q_x, Q_y) = (0.225, 0.235)$ (top), and tunes $(Q_x, Q_y) = (0.69, 0.685)$ (bottom).

2. **Using the γ_t-jump quadrupoles:** These quadrupoles are used to change the lattice γ_t rapidly while the beam crosses the transition energy, and are not used during stores. These quadrupoles are mainly placed at focusing locations and therefore the effect on the vertical phase advance is very limited.

Need new hardware:

3. **Using all arc quadrupoles in between the IPs:** This technique needs two new independent power supplies, and changes the lattice functions at the IPs, slightly stronger for the RHIC proton working point (0.69, 0.685) than for the traditional RHIC working point (0.225, 0.235) (see Fig. 3).

4. **Using 8 independent arc quadrupoles:** This is the most precise way to control the phase advances and beta functions since it provides enough degrees of freedom.

We further discuss only cases 3 and 4, which require new hardware.

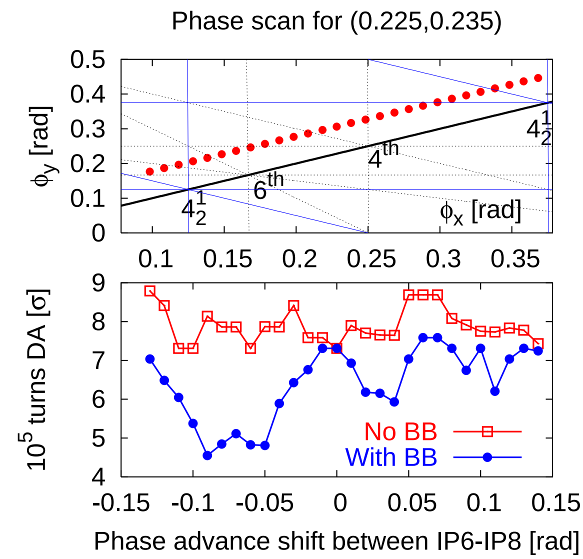

Figure 4: DA for RHIC tunes $(Q_x, Q_y) = (0.225, 0.235)$, using all arc quadrupoles to vary the horizontal phase advance between the two IPs (bottom). The top plot shows the working point in the phase advance diagram.

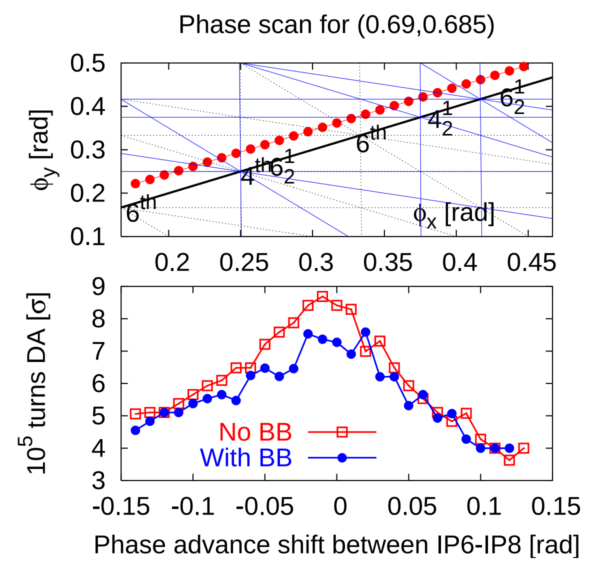

Figure 5: DA for the working point (0.69,0.685) using all arc quadrupoles. The top plot shows the working point in the phase advance diagram.

DA CALCULATIONS

We compute the DA for cases 3 and 4 using a complete non-linear model of the accelerator [2]. The DA is defined in this work as the minimum unstable transverse amplitude found along five angles of the transverse plane for 10^5 turns. The beam-beam interaction is introduced using the weak-strong approximation. The SixTrack [3, 4] tracking code has been used for all the simulations.

The results for case 3, when using all arc quadrupoles to

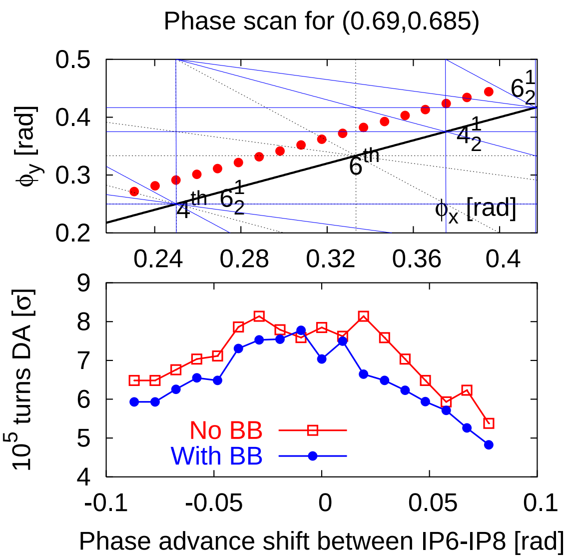

Figure 6: DA for the working point (0.69,0.685) using 8 independent arc quadrupoles. The top plot shows the location on the horizontal and vertical phase advance .

change the phase advances, and the RHIC working point $(Q_x, Q_y) = (0.225, 0.235)$ are shown in Fig. 4. The top plot shows the used horizontal and vertical settings in the phase advance diagram together with the resonance lines as described above. The blue lines represent the locations with zero resonance strength and the black lines those with maximum strength for a particular resonance. The bottom plot shows the computed DA for the different settings for two cases: with beam-beam interaction and without beam-beam interaction. The phase advances with minimum DA in the beam-beam case correspond to crossings with maximum fourth and sixth order resonance strength. While the maximum DA is found at a fourth order resonance with zero strength. This result shows a large influence of the phase advance on the beam stability in the presence of beam-beam.

The results for case 3, using again all arc quadrupoles, and the RHIC proton working point $(Q_x, Q_y) = (0.690, 0.685)$ are shown in Fig. 5. A different behavior is observed for this working point. Both DAs, with and without beam-beam interaction, decrease as we move away from the central point. The DA is not dominated by the beam-beam interaction.

Initially we assumed that the lattice perturbations were the cause of this behavior and a more refined optics matching was needed. For case 4, we used 8 arc quadrupoles to match the optics (lattice functions β and α for both the horizontal and vertical plane, not the dispersion) in the IR. The results for this case are shown in Fig. 6. The decrease of the DA is still observed, therefore the non-linearities of the lattice have to be enhanced by moving the phase advances. This point is confirmed by computing relevant lattice resonance terms. They are shown in Fig. 7 having a minimum in the center of the graph and thus confirming the hypothe-

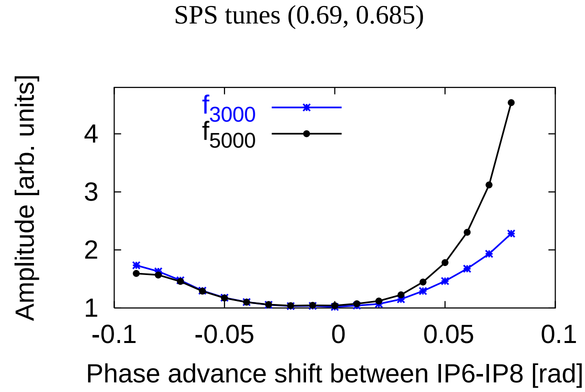

Figure 7: Strengths of two lattice resonances as a function of the horizontal phase advance shift between the two IPs.

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CONCLUSIONS

Four different ways of varying the phase advance between two IPs have been studied to mitigate beam-beam effects during RHIC stores. Configurations that do not require the installation of new hardware either distort the lattice functions or are ineffective.

Computations of the dynamic apertures for the working point (0.225, 0.235) show that the optimum setting of the phase advances between the IPs is not the initial one. Furthermore, a clear correlation between the resonances of the two kinds (maximizing and vanishing resonances) in the phase diagram and the dynamic aperture has been observed.

At the RHIC proton working point (0.690,0.685), changes in the phase advance between the IPs lead to stronger lattice resonances that shadow possible reductions of the beam-beam resonance strengths. No improvement of the dynamic aperture has been found for this working point.

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