LOCAL $3Q_y$ BETATRON RESONANCE CORRECTION IN THE 2012 RHIC 250 GeV RUN *

Y. Luo, C. Zimmer, W. Fischer, V. Schoefer, T. Roser, BNL, Upton, NY 11973, USA

Abstract

In this article we performed numerical simulations to correct the local vertical third order betatron resonance $3Q_y$ in the interaction regions in the Yellow ring for the 2012 RHIC 250 GeV polarized proton run. Considering the main sources of skew sextupoles are located in the interaction regions, we used local bump methods to minimize their contributions to the global $3Q_y$ resonance driving term. Two kinds of correction orbit bumps are tested and the dynamic apertures with these correction strengths are calculated and compared.

INTRODUCTION

To further increase the luminosity in the RHIC 250 GeV polarized proton (p-p) run, we planned to increase the proton bunch intensity. Increased bunch intensity will increase the beam-beam tune spread and beam-beam resonance driving terms (RDTs). In the 2012 run, the peak proton bunch intensity reached 1.7×10^{11} at the beginning of store.

Figure 1 shows the proton tune footprint with beam-beam in the current tune space between 2/3 and 7/10 with the proton bunch intensity 2.0×10^{11} and the transverse rms emittance 2.5 mm.mrad. There is not enough tune space between 2/3 and 7/10 to hold the beam-beam tune spread when the proton bunch intensity is bigger than 2.0×10^{11}.

To compensate the beam-beam tune spread and beam-beam resonance RDTs, we planned to install electron lenses in both rings for head-on beam-beam compensation [1]. In the RHIC p-p runs, we normally put the working points of both rings below the diagonal in the tune space to achieve a better beam lifetime. In this article, we correct the $3Q_y$ RDT with available interaction region (IR) skew sextupole correctors to mitigate the tune space limit.

RESONANCE DRIVING TERMS

The first order geometric RDTs caused by skew sextupoles are

$$h_{0030} = -\frac{1}{24}\sum_{i=1}^{N}(K_{2s}L)_i\beta_{y,i}^{3/2}e^{i3\mu_{y,i}}, \quad (1)$$

$$h_{0021} = +\frac{1}{8}\sum_{i=1}^{N}(K_{2s}L)_i\beta_{y,i}^{3/2}e^{i\mu_{y,i}}, \quad (2)$$

* This work was supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.

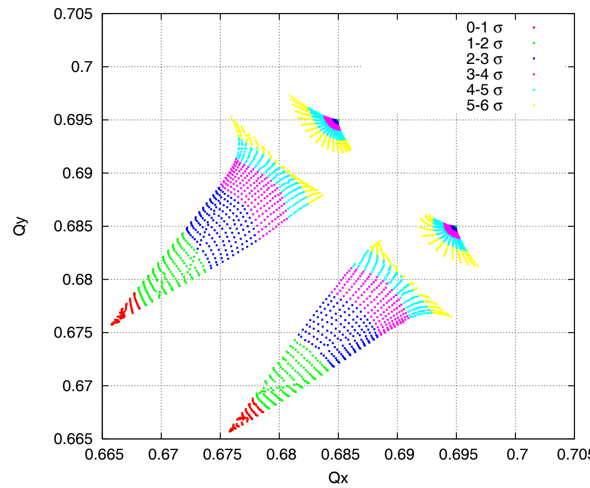

Figure 1: Tune footprint with bunch intensity 2.0×10^{11}.

$$h_{1110} = -\frac{1}{4}\sum_{i=1}^{N}(K_{2s}L)_i\beta_{x,i}\beta_{y,i}^{1/2}e^{i\mu_{y,i}}, \quad (3)$$

$$h_{2001} = -\frac{1}{8}\sum_{i=1}^{N}(K_{2s}L)_i\beta_{x,i}\beta_{y,i}^{1/2}e^{i(2\mu_{x,i}-\mu_{y,i})}, \quad (4)$$

$$h_{2010} = -\frac{1}{8}\sum_{i=1}^{N}(K_{2s}L)_i\beta_{x,i}\beta_{y,i}^{1/2}e^{i(2\mu_{x,i}+\mu_{y,i})}. \quad (5)$$

Here $(K_{2s}L)$ is the integrated strengths of skew sextupoles. The following betatron resonances will be driven:

$$3Q_y,\ \ Q_y,\ \ 2Q_x - Q_y,\ \ 2Q_x + Q_y. \quad (6)$$

Each driving term is a complex number. To correct the $3Q_y$ RDT h_{0030}, we need at least two orthogonal skew sextupoles or families. In RHIC, there is one skew sextupole corrector on either side of each IP and only the 4 correctors in the IR6 and IR8 have their own power supplies. The contributions from the 2 correctors in one IR have opposite contributions and only can be grouped into one family. And the contributions from IR6 and IR8 skew sextupole correctors can't form two orthogonal families for an effective global h_{0030} correction with current p-p run lattices.

SOURCES OF SKEW SEXTUPOLES

Considering that the β function is much larger in the IR than in the arc, the main sources of skew sextupoles to excite the $3Q_y$ resonance are located in the IR6 and I8. Based on the off-line IR nonlinear field model [2] and Eq. (1),

ISBN 978-3-95450-122-9

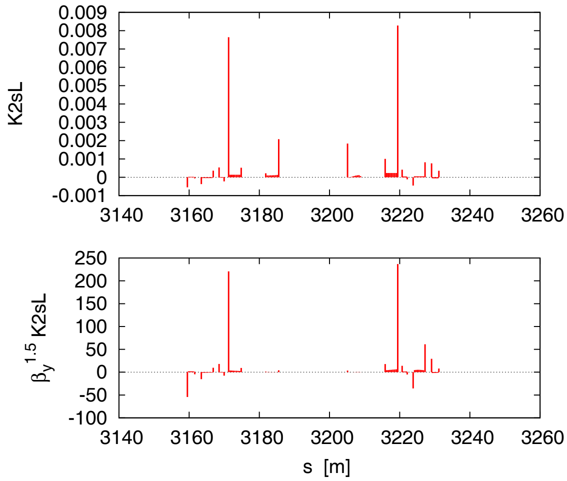

Figure 2: $K_{2s}L$ and $\beta_y^{1.5}K_{2s}L$ in IR8 in Yellow ring.

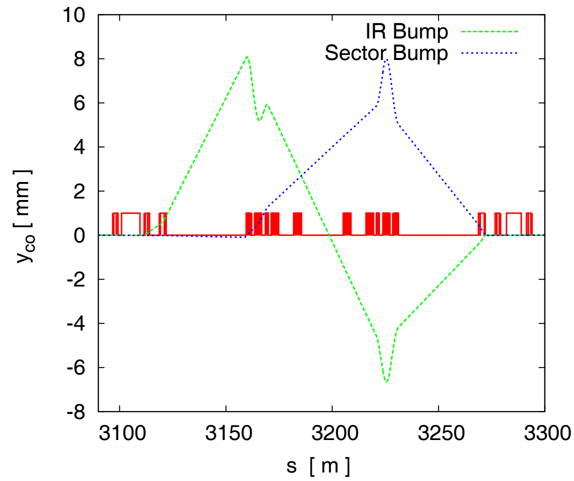

Figure 4: IR bump and sector bump in IR8 in Yellow ring.

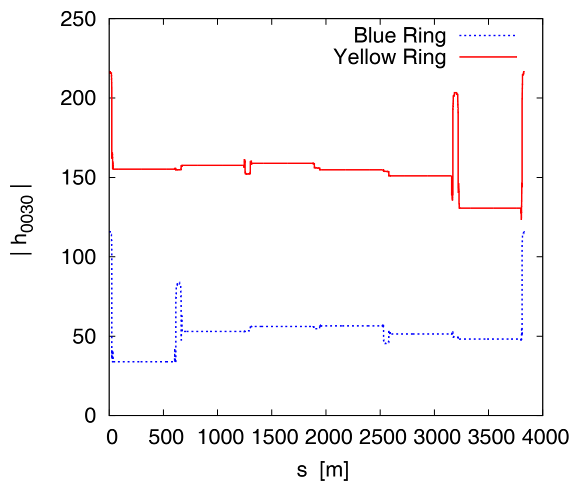

Figure 3: $3Q_y$ RDTs in the Blue and Yellow rings without correction.

Fig. 2 shows $K_{2s}L$ and $\beta_y^{1.5}K_{2s}L$ in the IR8 in the Yellow ring. In the off-line model, we split each actual magnet into 8 slices and insert the measured nonlinear field errors between slices and append errors on both ends of magnets. The main contribution to the $3Q_y$ resonance are from the D0 and triplets.

Figure 3 shows the $3Q_y$ RDT in the Blue and Yellow rings without any skew sextupole correction. The RDT varies along the ring. The sudden jumps of the RDT's absolute value hints the locations of skew sextupoles. The IR nonlinear field model predicts that $3Q_y$ RDT is bigger in the Yellow ring than that in the Blue ring. In the following, we will focus on the local $3Q_y$ correction in the Yellow ring.

LOCAL RESONANCE CORRECTIONS

Since the main sources of skew sextupoles are located in IR6 and IR8, in the following we use local correction methods to minimize their contribution to $3Q_y$ RDT. In RHIC we already developed an effective method - IR bump to correct the local nonlinear field errors in IRs [3]. IR bump can be an orbit bump covering the whole IR or one only covering one side of an IR. For simplicity, we name the latter as a sector bump. As an example, Fig. 4 shows the orbit bumps in the Yellow ring IR8.

For local skew sextupole correction or local $3Q_y$ correction on line, we generate local vertical orbit bumps. The tune shifts from the feed-down of the skew sextupoles due to the orbit bump are proportional to $\beta_x\beta_y^{1/2}$ in the horizontal plane and $\beta_y^{3/2}$ in the vertical plane. For the sector bump, we minimize the linear term of the vertical tune shift w.r.t. the orbit amplitude with the IR skew sextupole corrector that the bump covers. By doing this, we actually minimize $\sum \beta_y^{3/2}K_{2s}L$ in the sector which is their net contributions to the global h_{0030} RDT. For the IR bump, we simultaneously minimize the linear terms of the horizontal and vertical tune shifts w.r.t. the vertical orbit amplitude with the 2 skew sextupole correctors in the IR. By doing so, we actually minimize $\sum \beta_x\beta_y^{1/2}K_{2s}L$ and $\sum \beta_y^{3/2}K_{2s}L$ in the IR which are the net contributions to the global h_{0210},h_{2010}, and h_{0030} RDTs.

Figure 5 shows $3Q_y$ resonance driving terms in the Yellow ring without and with corrections from the IR bump and sector bump methods. Both the IR bump and sector bump methods reduce $|h_{0030}|$ along the ring. From Fig. 5, the sector bump method is more effective than the IR bump in reducing the global $|h_{0030}|$ and $|h_{0030}|$s at IP6 and IP8. However, the IR bump method reduces not only the RDT of $3Q_y$ resonance but also that of $2Q_x \pm Q_y$ resonances.

DYNAMIC APERTURE CALCULATIONS

In this section we calculate and compare the particle dynamic aperture with the above local $3Q_y$ resonance correction methods. In the dynamic aperture calculation [4], we track particles up to 10^6 turns in 10 phase angles in the

ISBN 978-3-95450-122-9

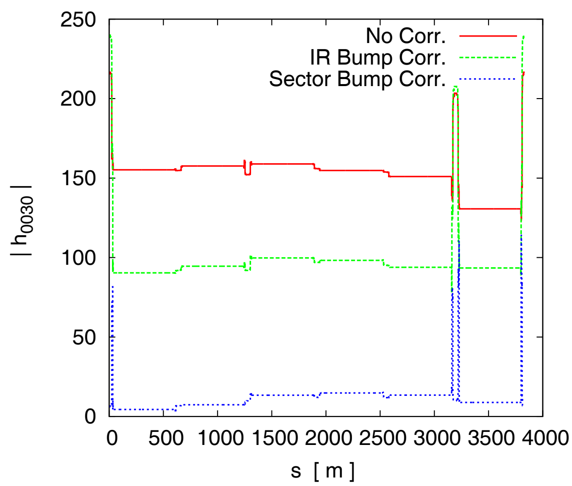

Figure 5: $|h_{0030}|$ with IR bump and sector bump methods.

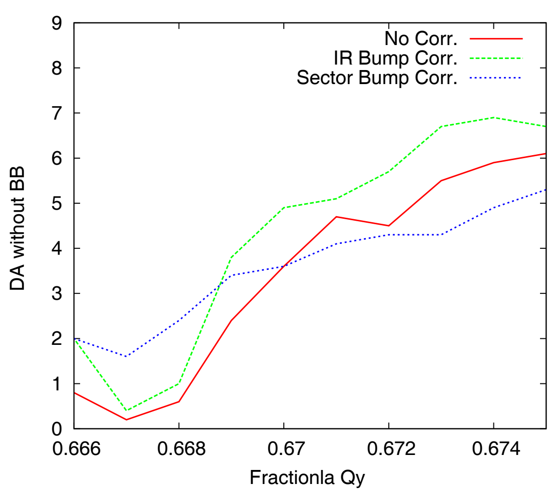

Figure 6: Comparison of dynamic aperture w/o skew sextupole corrections. Beam-beam effect is excluded.

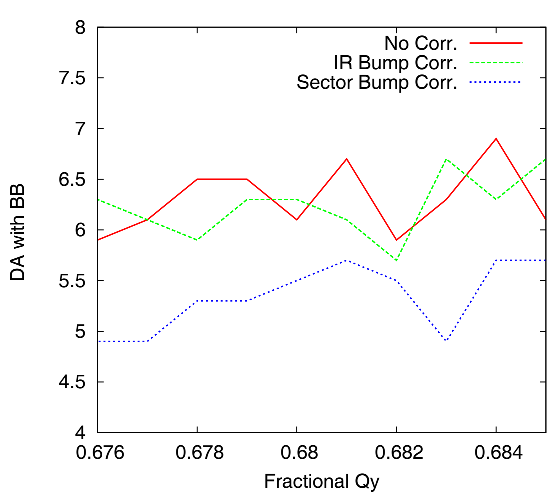

Figure 7: Comparison of dynamic aperture w/o skew sextupole corrections. Beam-beam effect is included.

first quadrant of (x,y) plane. The initial relative momentum deviation of the particles is 0.0005. Figure 6 shows the dynamic apertures without beam-beam interaction in a tune scan from (28.685, 29.675) to (28.676, 29.666) with a step size of 0.001. The horizontal axis is the fractional vertical tune. The skew sextupole correction strengths from the IR bump gives a bigger dynamic aperture than the sector bump when the vertical tune is above 0.669.

Figure 7 shows the dynamic aperture with beam-beam interaction in a tune scan from (28.695, 29.685) to (28.686, 29.676). The horizontal axis is the fractional vertical tune before beam-beam is turned on. The proton bunch intensity is 1.65×10^{11}. The transverse rms emittance is 15 mm.mrad. The beam-beam parameter is about -0.017. From Fig. 7, the correction strengths from the sector bump method gives a lower dynamic aperture than that without correction and that with the correction strengths from the IR bump method.

EXPERIMENTS

During the normal RHIC operation, the IR skew sextupole corrector strengths were installed based on the IR bump method. In a dedicated machine study during 2012 RHIC 250 GeV run we re-visited the sector bump method to focus on correcting only $3Q_y$ resonance in the Yellow ring. Experimentally we were able to minimize the linear dependence of the vertical tune shift with respective to the bump amplitude. However, the skew sextupole strengths from the sector bump method reduced the Yellow beam lifetime. We also noticed that the skew sextupole correction strengths were very different from IR bump and sector bump methods.

SUMMARY

In this article we performed numerical simulations to locally correct the vertical third order betatron resonance $3Q_y$ in the Yellow ring for the 2012 RHIC 250 GeV polarized proton run. We compared the IR bump and sector bump methods to locally correct the IR skew sextupole field errors. Simulation and experiment show that the correction strengths from the sector bump method reduces the beam lifetime with beam-beam. It is probably due to the fact that the sector bump method only focuses on $3Q_y$ resonance correction while the IR bump also corrects $2Qx \pm Q_y$ resonances. $2Q_x \pm Q_y$ resonances also cross (2/3,2/3) in the tune space.

REFERENCES

[1] Y. Luo, et al., Phys. Rev. ST Accel. Beams 15, 051004 (2012).

[2] J. Beebe-Wang, et al., in Proceedings of PAC'07, Albuquerque, USA, 2007.

[3] F. Pilat, Y. Luo, et al., in Proceedings of PAC'05, Knoxville, USA, 2005.

[4] Y. Luo, in Proceedings of IPAC'10, Kyoto, Japan, 2010.