OPTICS MEASUREMENTS AND CORRECTIONS AT RHIC

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Abstract

The further improvement of RHIC luminosity performance requires more precise understanding of the RHIC modeling. Hence, it is necessary to minimize the beta-beat, deviation of measured beta function from the calculated beta functions based on an model. The correction of beta-beat also opens up the possibility of exploring operating RHIC polarized protons at a working point near integer, a prefered choice for both luminosity as well as beam polarization. The segment-by-segment technique for reducing beta-beat demonstrated in the LHC operation for reducing the beta-beat was first tested in RHIC during its polarized proton operation in 2011 [2]. It was then fully implemented during the RHIC polarized proton operation in 2012. This paper reports the commissioning results. Future plan is also presented.

INTRODUCTION

The further improvement of RHIC luminosity as well as polarization performance involves a series efforts in using electron lens (eLens) [1] to compensate head-on beam-beam effects, further beta squeeze at IP, dynamics beta squeeze, near-integer working point etc. Many of these efforts require more precise optics modeling of RHIC. Hence, good optics measurement as well as optics correction to minimize beta beat, deviation of measured beta functions from the expected beta functions from the model, are necessary.

Optics measurement at RHIC has been routinely conducted by using an AC dipole to excite driven global betatron oscillation [3]. A total of 1024 turn by turn beam position data from all beam position monitors (BPM) are acquired. From there, a fit of the betatron signal [3] or the phase method, using SUSSIX [4] is used to calculate the linear optics, i.e. phase advance between bpms as well as beta functions at all bpms. The two methods were compared and good agreement was found [2]. Fig. 1 shows the measured beta beat of polarized protons at 255 GeV during the latest RHIC polarized proton operation in 2012. The store lattice was designed to yield 0.6 m beta functions at IP6 for STAR, IP8 for PHENIX and 2 m beta function at IP2. The measured horizontal beta beat shows about peak beta beat 20% through the whole ring. However, vertical beta beat shows large variations from sector to sector, and its peak beta beat varies from 30% down to less than 10% from sector to sector in Blue. In Yellow, the vertical beta beat reached as high as 70%. This indicates large localized gradient errosr at various IPs. Error bars on the beta beat measurement in this paper only reflect statistical errors. Systematic errors from bpms as well as other sources are not represented in this paper.

The segment by segment technique (SBST) was first introduced to RHIC in 2011 [2]. This technique was developed at LHC to correct beta beat [5]. It assumes that most of the beta beat is driven by the gradient errors from the quadrupoles at low beta IPs, and treats part of the ring as a beam line. It first matches the twiss parameters at the beginning of the beam line with the measured optics, and then propagates the phase advance along the beam line and compares it with the measured phase advance. If a large deviation is observed a local error source could be present. This technique was successfully demonstrated during the LHC commissioning.

For RHIC, few limitations had to be taken into account during the development of the segment by segment technique. The first limitation is that double plane BPMs are only available around the IPs, elsewhere single plane BPMs are installed. Second limitation is that limited number of independent power converters are available, meaning that the available number of correctors is limited [6]. Currently, only quadrupoles with independent power supplies in the interaction regions are included in the analysis, i.e. trim

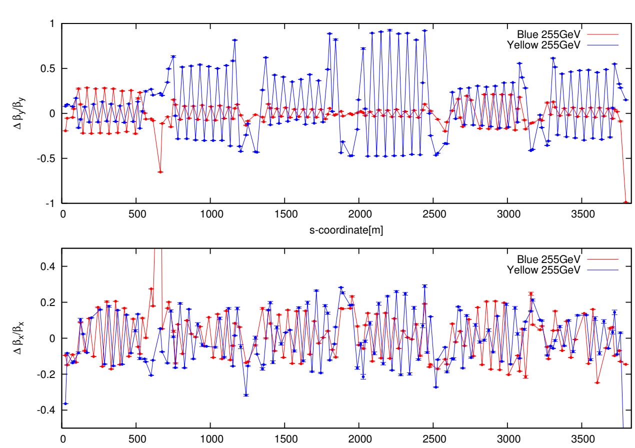

Figure 1: The top and bottom plots are the measured horizontal and vertical beta beat in the two accelerators of RHIC with polarized protons at a beam energy of 255 GeV, respectively.

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quadrupoles and triplets. Because the phase advance within a triplet is very small, only the quadrupole in the middle is used for SBST analysis.

OPTICS CORRECTION

Based on the measured linear optics shown in Fig. 1, a set of SBST analysis was performed to find local gradient errors at each IP. As an example, Fig. 2 shows the SBST analysis results of IP8. In Fig. 2, quadrupoles just

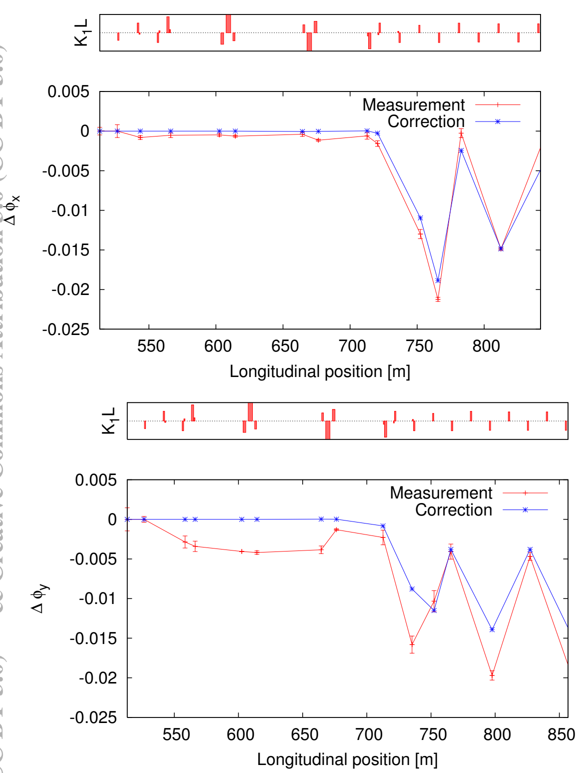

Figure 2: These plots show the SBST analysis results of IP8 horizontal and vertical, respectively. For each plot, the measured phase advance along the beam line is shown in red, and the calculated phase advance with local gradient errors in the model is shown in blue.

upstream of the large phase jump were adjusted to match the calculated phase advance with the measured phase advance. Due to RHIC nested power supply scheme, only quadrupoles with independent controls were chosen in the analysis. Fig. 2 shows a good agreement between the measurement and calculation. Similar analysis was performed for all IPs, and the final results are listed in Table 1.

These corrections were then implemented during the last day of polarized proton operation. Fig. 3 shows the measured beta beat before and after the corrections. It is clear that these corrections helped to reduce both horizontal and vertical beta beat. However the limited beam time excluded the chance to have another iteration of optics correction using SBST.

Optics measurements in the RHIC Yellow ring during its

Table 1: Tolerance of Beam Parameter for Polarized Beam Acceleration in RHIC

Quadrupole	sector	Design strength[1/m]	Trim value [1/m]
bi5-qd2	IP6	-0.1905	-9.525e-5
bo6-qf2	IP6	0.19055	-3.811e-5
bo7-qf2	IP8	0.19055	9.525e-5
bi8-qd2	IP8	-0.1905	-9.525e-5
bi9-qd2	IP10	-0.188121	-1.505e-4
bi1-qd2	IP2	-0.190252	-1.3318e-4
b02-qf2	IP2	0.190295	-1.3321e-4
bo11-tq5	IP12	-0.0121251	-2.425e-4
bo11-qf2	IP12	0.189437	-1.5155e-4
bi12-qd2	IP12	-0.188121	-1.505e-4

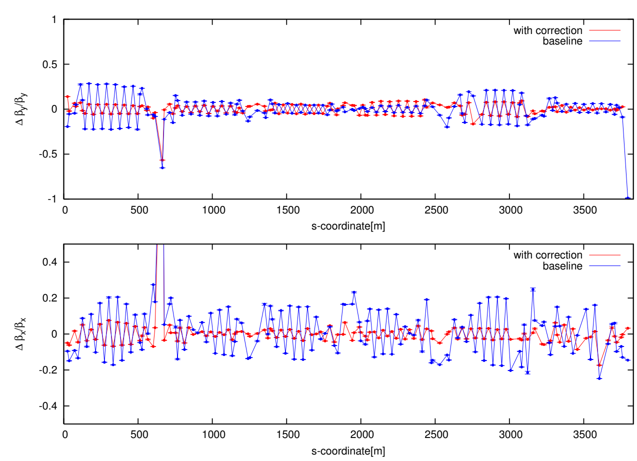

Figure 3: The plot shows the measured beta beat in the Blue ring after the correction in Table 1 was put in. Significant reduction in beta beat was achieved.

UU operation showed again a as large as 50% beta beat in the vertical plane of the Yellow ring at store, as shown in Fig. 5. Significant jump in the vertical beta beat indicates a large gradient error localized at IP6 and IP8. The abrupt jump of beta beat between IP6 and IP8 also suggest large localize errors. SBST analysis was then performed and yields a large number of corrections for yellow optics correction. Fig. 4 shows the SBST analysis results of IP8. Table 2 summarizes the calculated corrections. All corrections except yo5-tq4 were then applied to the Yellow ring and optics with the corrections was measured as shown in Fig. 5. yo5-tq4 power supply was running at its maximum current without correction. A significant reduction of Yellow vertical beta beat was achieved. However, horizontal beta beat was increased moderately. This indicates that more iterations are needed since SBST assumes that the machine optics is in reasonable agreement with model. Hence, more iterations is necessary in the case of excessive beta beat. Another issue encountered is that beta remained unchanged with the correction. This also indicates that a

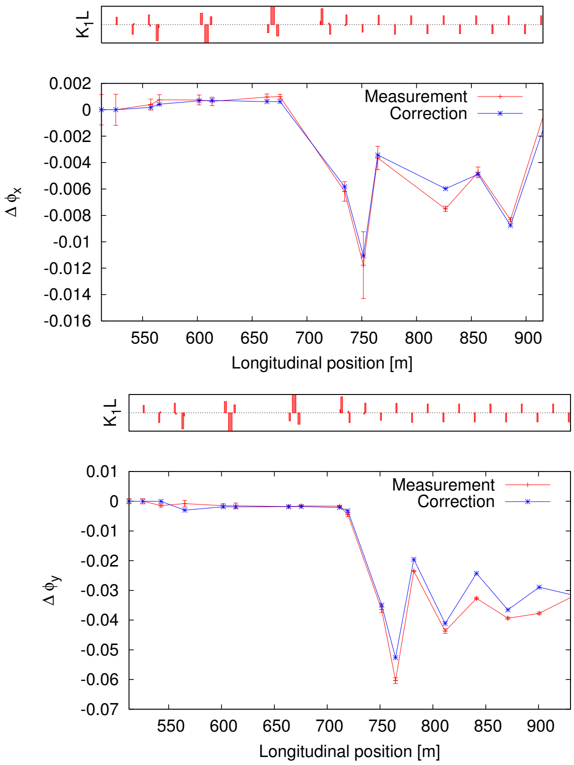

Figure 4: These plots show the SBST analysis results of Yellow IP8 horizontal and vertical, respectively.

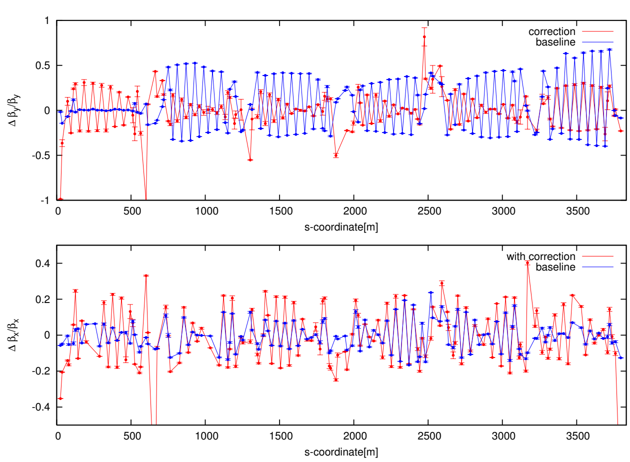

Figure 5: The plot shows the measured beta beat in the Yellow ring after the corrections in Table 2 were put in. Significant reduction in the vertical beta beat was achieved.

localized correction for beta function at IP as well as the location of beta waist is highly desired for RHIC operations.

CONCLUSION

The Segment By Segment Technique, successfully developed at LHC, has finally been fully implemented at RHIC. The experience of applying SBST for optics correction of RHIC store lattice of polarized protons as well as heavy ions has been quite successful. After corrections, local abrupt beta beam jump was significantly minimized and a factor of 3 global beta beat reduction was observed. However, it was observed that global beta beat reduction didn't necessarily improve the local beta function at interaction point. Hence, a set of local optics corrections for adjusting local beta function as well as beta waist location is necessary in combination with the global beta beat correction.

Table 2: Corrections in Yellow

Quadrupole	sector	Design strength[1/m]	Trim value [1/m]
yi6-qd2	IP6	-0.190395	-4.76e-05
yi6-tq5	IP6	-0.0158717	1.984e-4
yi6-tq6	IP6	-0.0122023	-1.83e-3
yo5-tq6	IP6	-0.012141	6.0705e-4
yo5-tq5	IP6	-0.0169043	-2.536e-3
yo5-tq4	IP6	-0.033423	3.344e-3
yi7-tq6	IP8	0.0122023	-7.6265e-05
yi7-qd2	IP8	-0.190395	-3.8079e-05
yo8-qf2	IP8	0.190589	3.812e-05
yo8-tq5	IP6	-0.0169043	-1.268e-3
yo9-tq4	IP10	-0.00892191	-1.11524e-4
yo9-qf2	IP10	0.188921	4.7230e-05
yi10-qd2	IP10	-0.189342	-4.73356e-05
yi10-tq5	IP10	0.00894271	1.11784e-5
yi11-tq5	IP12	0.00894271	6.70703e-05
yi11-qd2	IP12	-0.189342	-7.100e-05
yo12-qf2	IP12	0.188921	7.0845e-05
yo12-tq4	IP12	-0.00892191	-2.2305e-4
yo12-tq6	IP12	0.0049635	1.2409e-4
yo1-tq6	IP2	0.0049635	6.2044e-05
yo1-tq5	IP2	-0.00771896	-3.859e-05
yo1-qf2	IP2	0.188921	3.77842e-05
yi2-qd2	IP2	-0.189342	-3.7868e-05

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