IMPLEMENTATION OF OPTICS CORRECTION ON THE RAMP IN RHIC*

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Abstract

In this report we describe and present experimental results from correction of the accelerator optics during acceleration and preparation for collisions at the Relativistic Heavy Ion Collider (RHIC) at BNL. Past experiences with beam optics correction at RHIC have concentrated on measurements and corrections at store beam energies. While well-corrected store beam optics is desirable for maximizing beam and polarization lifetime, well-corrected beam optics during the ramp is also desirable for example to reduce the strength of depolarizing resonances. With optics measurements on the ramp at every 2 or 4 seconds, corrections were computed for several fixed points on the ramp using a well-tested weighted Singular Value Decomposition algorithm. Successful implementation of correction on the second part of the ramp (rotator ramp), together with some observations on the first part of the ramp (the energy ramp) will be presented.

INTRODUCTION

Analysis of depolarizing resonances on the ramp and dynamic aperture study are part of the ramp optics design nowadays in RHIC [1]. Acceptable intrinsic resonance strength and dynamic aperture are ensured by design. With optics errors, both of these quantities are hard to predict. Most likely the machine performance in both aspects will degrade to some extent with optics errors. Therefore, it is desirable to correct the optics on the ramp for better polarization and intensity transmission efficiencies.

Besides continuous efforts for improving TbT (turn-by-turn) BPM data quality over the years [2], there are two developments in 2013 that make ramp optics correction feasible. One of the developments is the precision optics measurement based on ARTUS kicker [3] which is critical for ramp optics analysis. Firing the AC dipole for optics measurement is operational and robust at injection and store energies [4], however, it has not been demonstrated on the ramp during acceleration. Exciting the beam periodically with the ARTUS tune meter kicker has been done previously for the purpose of ramp chromaticity control, however, no successful effort has been applied to extract accurate linear optics information along the ramp. The other development is the successful demonstration of global optics corrections based on both the ARTUS kicker and the AC dipole [5, 6].

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RAMP OPTICS MEASUREMENT

By firing the ARTUS kicker every 2 or 4 seconds on the ramp, TbT BPM data of free betatron oscillations can be recorded in both planes [2]. The timing of the excitations in the two transverse planes is shifted by 510 turns to reduce coupling effects. Special care was taken to avoid interference between TbT and average orbit data taking. The option of 1k, 2k and 4k turns TbT orbit is available. The option of 1k is chosen for the ramp optics measurement since usually the oscillation lasts less than 500 turns due to decoherence. Examples of TbT BPM data are shown Fig. 1.

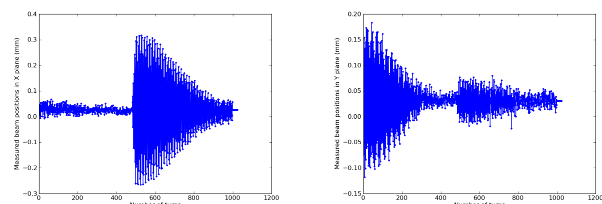

Figure 1: Turn by turn BPM positions in the horizontal (left) and the vertical (right) plane from ramp optics measurement, residual coupling (right) appears in the vertical plane where the horizontal oscillation starts.

As with usual optics analysis, beta functions and phase advances are determined for both planes from TbT BPM data. The analysis technique adopted by the author favors the data in the horizontal plane for better measurement resolution [3]. Therefore, the data in the vertical plane was shifted backwards by 500 turns (data after 500 turns being discarded) before windowed FFT being applied, which also reduces the impact of the residual coupling in the vertical plane after ∼500 turns.

The beta beats and phase errors at 289 s into the ramp are shown in Figs. 2 and 3. The whole ramp takes 320 s. Similar analyses were performed with data acquired every 4 seconds in the Blue ring and every 2 seconds for the Yellow ring. The overall trend of the optics errors is similar for both rings. As beam is being accelerated, the optics error decreases to its minmum in the middle of the ramp. Then the error goes up as beta stars are being squeezed.

RAMP OPTICS CORRECTION SCHEME

For the polarized proton program at RHIC in 2013, the ramp has two parts. The first one, during which the energy is ramped up and beta stars are squeezed, is called energy ramp. The second ramp, during which the rotator magnet ramps up, is called rotator ramp. There are 32 fixed points

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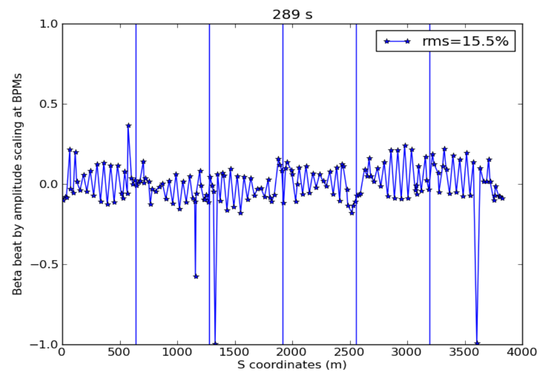

Figure 2: Beta beats at 289 s into ramp in the horizontal plane from ramp optics measurement.

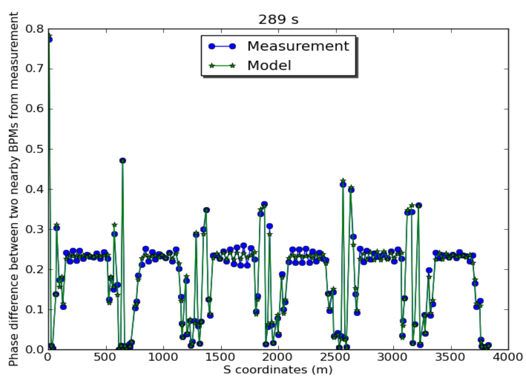

Figure 3: Phase errors at 289 s into ramp in the horizontal plane from ramp optics measurement.

(stepstones) for the energy ramp where magnet strengths are controllable for the energy ramp. The magnet strengths are interpolated between these stepstones. The rotator ramp has fewer stepstones since the optics is smoothier.

TbT orbits near stepstones are picked for optics analysis for the availability of optics models. Then corrections using the 72 trim quads are calculated based on the principle presented in [5]. Two scripts are designed for ramp optics correction. One of them goes through all the picked orbits for analyzing optics in both planes. The second one implements the corrections in RampEditor for all relevant stepstones. Due to the fact that the beam is not perfectly centered in quadrupoles, the closed orbit will vary with implementation of correction. Therefore, orbit feedback was turned on to keep the orbit stable. Besides that, tune feedback was used as well to avoid beam loss due to resonances. Chromaticity changes due to optics corrections were predicted by the online model (OptiCalc), which was then manually corrected before activation of corrections.

TEST ON ROTATOR RAMP

The concerns regarding ramp optics correction implementation are mostly related to the beam loss and beam emittance dilution. As a test, correction on a rotator ramp with fewer bunches (12 by 12) was attempted to study these effects. The test ramp was the same as a physics ramp except for the fewer bunches. The optics for the rotator ramp is considered as smooth regardless of the ramping of the rotators. Therefore, corrections calculated for the full energy were applied to all stepstones of the rotator ramp except the very first one. It means the correction strengths ramp up from the first to the second stepstone.

Beam loss of the test ramp and a physics ramp are shown in Fig. 4. The rising of beam loss around 1300 s in the Blue ring was due to other beam study. The oberservation is that the beam loss was slightly better for the test ramp during the rotator ramp and after beam collision. The IPM

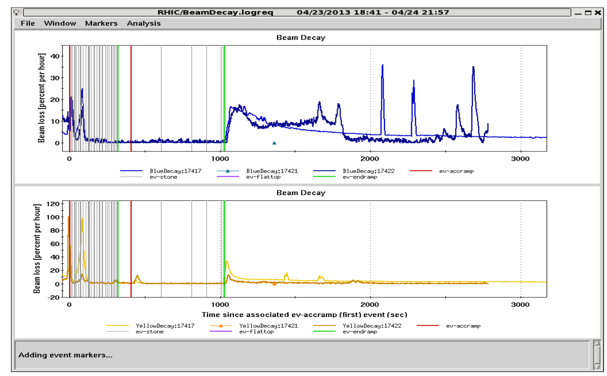

Figure 4: Comparison of beam loss between the test ramp and a physics ramp for both rings.

(Ionization Profile Monitor) reported emittance for the test ramp and a physics ramp are shown in Fig. 5. They are similar except for the large error bars due to fewer bunches. In addition, the calculated beam emittance inferred from beam collision signals are as good as in a good physics store.

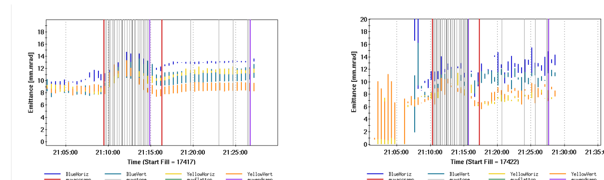

Figure 5: IPM measured emittance in a physics ramp (left) and the test ramp (right) for both rings.

The collision rate was expected to reach 1070 kHz at STAR by scaling beam intensities, which is $\sim$15% increase of luminosity.

The results of the test eliminate the concern of adverse effects of ramp optics corrections. Later on, the correction for the rotator ramp was implemented operationally for the physics program in the Yellow ring only due to other changes being made in the Blue ring. The rest of the program has been running with corrected optics without any complication.

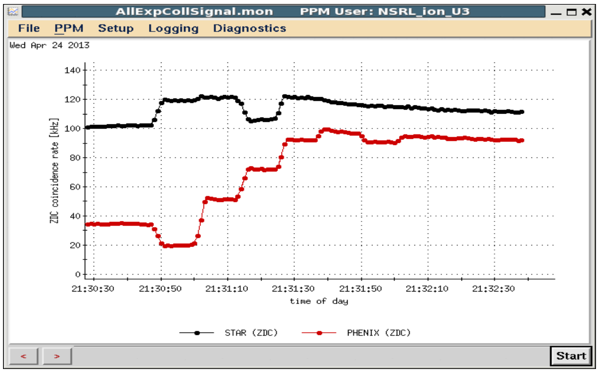

Figure 6: Beam collision signals in the test ramp for both experiments.

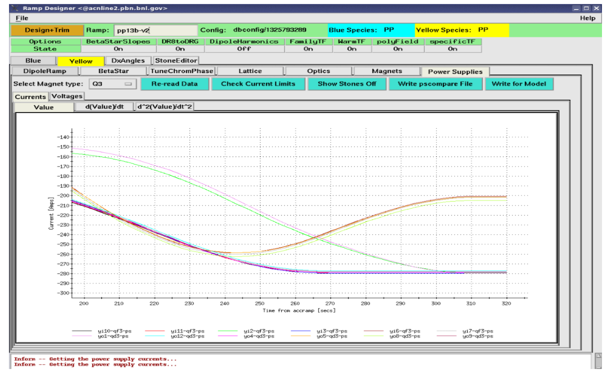

Figure 7: Current curves for selected magnets without ramp optics correction.

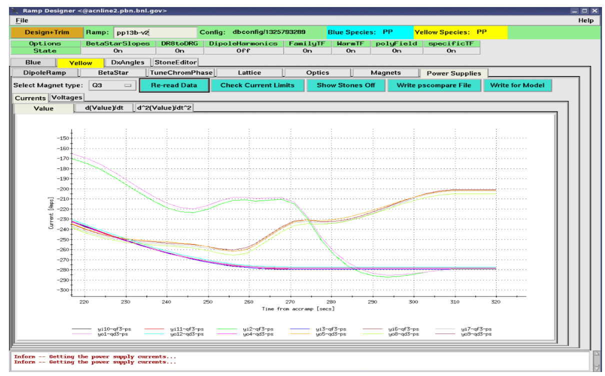

Figure 8: Current curves for selected magnets with ramp optics correction.

TEST ON ENERGY RAMP

Ramp optics correction for the energy ramp has been tested twice in 2013. We ran a 12 by 12 ramp for ramp optics measurement, ran a script to select the TBT orbit files near the stepstones and calculate optics corrections, ran script to send correction strengths to RampEditor and activated corrections. We were not able to ramp again for ramp optics measurement to verify the correction due to time limitations.

The problem encountered in the first attempt was that, each time a set of strengths were sent to a stepstone in RampEditor, the online model recalculated all relevant magnet strengths for the whole ramp which was too time-consuming. The solution was to send all correction strengths for a stepstone once, not separately. The other way around is to fix magnet strengths (anchoring) for the relevant stepstones so interpolation of magnet strengths will not occur after implementing correctons. The two ways are similar because changing strengths for a stepstone would anchor it as well. The problem encountered in the second attempt was that, anchoring stepstones changes the current curves for magnets dramatically, which caused magnets to exceed limits. The selected current curves before and after anchoring stepstones are shown in Figs. 7, 8. The ongoing effort is to change the RampManager code so that anchoring stepstones only fix the magnet strengths, but does not change the derivatives of the current curves.

SUMMARY

Precision analysis of the linear optics based on TbT BPM data by the ARTUS kicker opened out the possibility of ramp optics measurement at RHIC. Breakthrough of global optics correction added the critical piece for implementing ramp optics correction. Ramp optics correction for the rotator ramp has been implemented operationally at RHIC. Ramp optics correction for the energy ramp is in progress.

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