GLOBAL AND LOCAL COUPLING COMPENSATION IN RHIC USING AC DIPOLES *

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Abstract

Compensation of transverse coupling during the RHIC energy ramp has been proven to be non-trivial and tedious. The lack of accurate knowledge of the coupling sources has initiated several efforts to develop fast techniques using turn-by-turn BPM data to identify and compensate these sources. This paper aims to summarize the beam experiments performed to measure the coupling matrix and resonance driving terms with the aid of RHIC ac dipoles at injection energy.

INTRODUCTION

RHIC operates close to the difference coupling resonance $Q_x = 28.685$, $Q_y = 29.695$ at top energy. This region helps maximize the available “tune space” and avoid any overlap with lattice and spin resonances. It is favorable to operate near the difference resonance to alleviate beam-beam effects and maximize the dynamic aperture. The ability to operate near the difference resonance depends on minimizing the ΔQ_{min}. Therefore, it is important to identify the coupling sources in RHIC and compensate them with available skew quadrupoles, both locally and globally. RHIC has the following relevant sources of transverse coupling:

- Rolls in the triplet and arc quadrupoles (-$k_1\theta$)
- Skew quadrupole errors in the interaction region (IR) (-k_1^s) and experimental solenoids
- Sextupole feed-down to skew quadrupole field at the chromaticity sextupoles and at all the dipoles due to vertical closed orbit offsets (-$k_2 y$)

The major sources of the coupling are expected from triplet rolls where the β functions are also the largest. This paper aims at localizing uncompensated coupling errors in the RHIC lattice using the techniques described in Ref. [1, 3] and compensate first the local sources using IR skew quadrupoles and residual coupling with global families.

LOCAL COUPLING

RHIC is uniquely equipped with two AC dipoles to excite coherent betatron oscillations in transverse planes which are routinely used to measure RHIC optics [2]. Coupling observables ($|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ or equivalently $f_{\substack{1001\\1010}}$) described in Ref. [1] are calculated from 1024 turn-by-turn coherent oscillations driven by AC dipoles and recorded at BPMs along the ring. Baseline measurements of $f_{\substack{1001\\1010}}$ and $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ at nominal operation were presented in Ref. [4]. Significant number of coupling sources were evident in the yellow ring from baseline measurements. Detailed measurements of $f_{\substack{1001\\1010}}$ and $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ at RHIC during the 2005 Cu-Cu run follows.

Baseline Measurements

Nominal injection requires compensation via global skew families to be able to operate near the difference resonance. To capture the effects of natural skew error sources without external compensation, data sets were taken with the global skew families turned off. The coupling terms without the global families are shown in Fig. 1 Despite several missing and faulty BPMs, positive or negative slopes in $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ in the arcs are clearly evident. This is somewhat counter intuitive to the original assumption that the coupling sources are mainly confined to IR regions. Possible reasons for the slopes can be attributed to

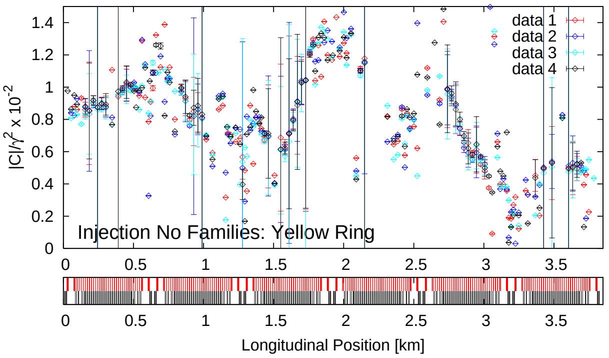

Figure 1: Baseline injection measurements of $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ without global skew quadrupole families plotted as a function of longitudinal position along the yellow ring. A representation of the lattice (dipoles in black and quadrupoles in red) is shown in the bottom graph.

- A systematic roll of quadrupoles (or skew quadrupole component in dipole ends) in an entire arc region.
- A systematic vertical orbit displacement in the arc sextupoles.

Fit Model to Measurements

A least squares type fitting routine was used to fit model to measured values using just arc quadrupole tilts (6-families), and IR skew quadrupoles as fitting variables. As seen in Fig. 2 the fit converges for the average value of the coupling terms, but the local features and the slopes is not

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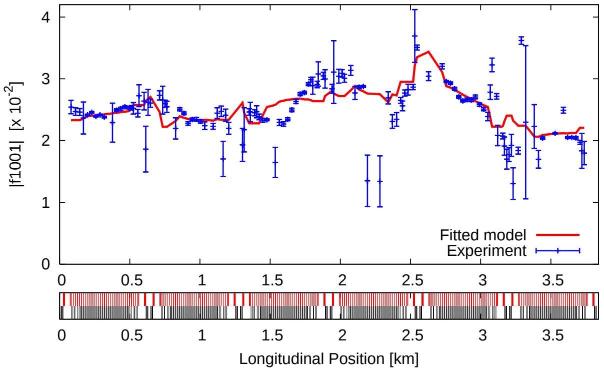

Figure 2: Least squares fit of model f_{1001} to measured f_{1001} values using individual IR skew correctors and 6-families of arc quadrupole tilts.

reproduced. Additional sources have to be systematically added to improve fit.

Effect of AC Dipoles

It was initially considered that ac dipoles could possibly result in spurious slopes due to a sufficiently large difference between the drive tune and the natural tune ($Q_x - Q_d > 0.005$). A tracking test for three different drive tunes with a fixed natural tune does not exhibit any slopes in the coupling terms. This test can be used to rule out ac dipoles as possible sources of these slopes.

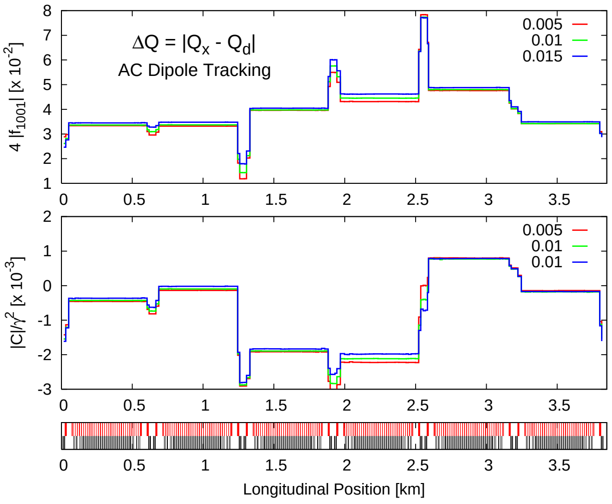

Figure 3: Coupling terms calculated via sixtrack tracking of the RHIC lattice with skew quadrupole errors in the IR regions. The drive tune was varied w.r.t to the natural tune.

Vertical Orbit Bump: 2.858 km

An experiment to investigate the effect of a vertical orbit bump on the behavior of the coupling terms was performed. A closed 3-bump was inserted in the middle of the arc between the IR-2 and IR-4 region of RHIC (2.858 km). AC dipole data with increasing amplitude of the orbit bump was taken and Fig. 4 shows $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ as a function of longitudinal position for increasing orbit bump.

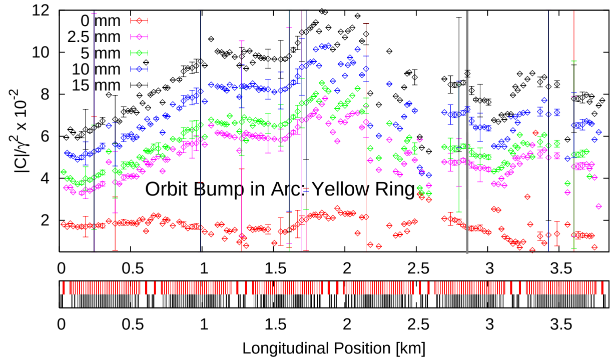

Figure 4: $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ (top) as a function the vertical orbit bump amplitude. The vertical bump was placed at 2.858 km (middle of the arc).

Although small excursions and slopes exist in the baseline measurements as shown in Fig. 1, the slope behavior becomes prominent with the introduction of the vertical orbit bump. Additionally, the increase in the bump amplitude only seems to increase the average value of the coupling terms without changing the behavior or the slope around the ring. The increase in the coupling can be attributed to the coupling induced by a vertical offset in the arc. However, the distinct slopes cannot be directly attributed to the sextupoles because the orbit recorded by the BPMs is usually centered and any small orbit displacements maybe random in nature. Also, the polarities of the chromaticity sextupoles are alternating, which would lead one to expect an oscillating behavior rather than a consistent slope. More simulations are underway too investigate the effect of vertical offsets in sextupoles as variables to fit to measured data. Also, the location of the slope is far from the location of the bump pointing to a more global effect than local.

A Possible Correction Strategy

Although the slope behavior is not well understood along with several missing or faulty BPMs, a correction strategy using IR correctors was explored. RHIC is equipped with 12 skew quadrupole correctors in the IRs with individual power supplies mainly to compensate tilts in the triplets. These 12 correctors can be approximately categorized into 3 families, 2 per IR in phase with each other and each of the 2 IRs being approximately π phase apart. The procedure involved a systematic scan of each correctors and simultaneous measurement of $4|f_{1001}|$ and $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$. The goal of the scan was to minimize all local excursions and also reduce the overall amplitude of the coupling terms. Any residual coupling will be further compensated with global skew families that yields the minimum f_{1001} for the minimum achievable ΔQ_{min}. Fig. 5 shows $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ and it's mean value as a function of corrector scan for two out of the five IR scans performed during Run 2005.

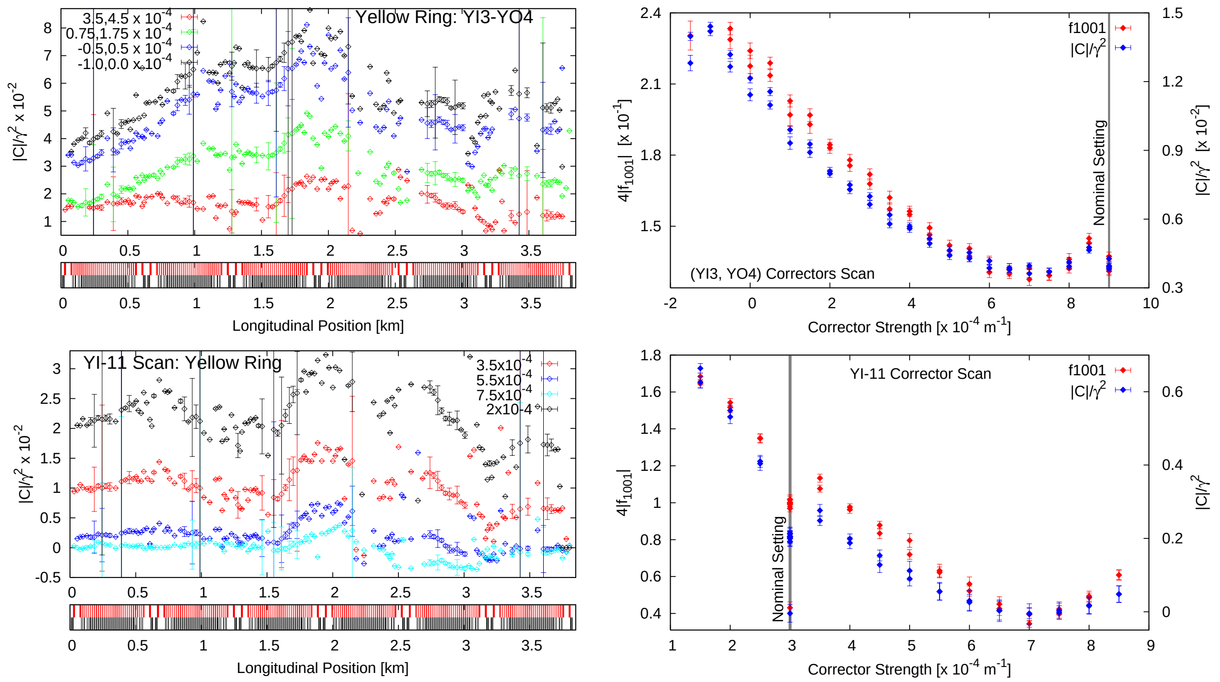

Figure 5: Left: $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ during IR scans of skew correctors from their nominal value as a function of longitudinal position. Right: The average value of $4f_{1001}$ and $|\overline{\mathbf{C}}|/\gamma^{\mathbf{2}}$ plotted as a function of the skew corrector strength. The error bars are calculated from the standard deviation of the coupling terms around the ring. Global families were turned off and the natural and drive tunes $Q_{x,y}$ and $Q^d_{x,y}$ were adjusted accordingly.

GLOBAL COUPLING & CORRECTION

Global coupling is routinely corrected at RHIC by minimizing ΔQ_{min} using skew families either by a manual tune scan, a skew quadrupole modulation technique [5], or at injection using N-turn maps [6]. Two families are enough to construct a unique coupling vector and minimize the closest tune approach. The RHIC coupling correction system consists of three families with a phase of 60° between them. Therefore, there exists an infinite number of settings for three families that minimize the closest tune approach. Assuming that the setting given by the vector (f_1, f_2, f_3) minimizes the tune split, then any other setting of the form $(f_1 - \Delta, f_2 + \Delta, f_3 + \Delta)$ with arbitrary Δ is also a local minimum of the tune split. Although different configurations all yield a minimum tune split, $|f_{1001}|$ varies significantly for each setting. The best setting should have the lowest values without large spikes. Simulations illustrating this effect was described in Ref. [4] and experiments with beam to probe the ΔQ_{min} space to find the optimum compensation of coupling terms are underway.

CONCLUSION

Detailed measurements of RDT's and **C** matrix elements were accomplished during the RHIC Run-2005. A systematic scan of IR skew correctors was performed for each individual IR as a possible strategy to minimize local excursions in the coupling terms. The nominal settings at injection can be improved using the information from these corrector scans to reduce the excursions and overall amplitude in the yellow ring. Appropriate extrapolation and possibly more experiments can help improve the settings at top energy. A consistent slope behavior was observed and the source of the slopes is under investigation using fitting techniques. A vertical orbit offset through arc sextupoles exhibits and amplification of the slopes. A technique using RDT's or **C** matrix to optimize the global family settings was also outlined with possible experiments during Run-2006.

ACKNOWLEDGMENTS

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