RHIC BEAM-BASED SEXTUPOLE POLARITY VERIFICATION*

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Abstract

This article presents a beam-based method to check RHIC arc sextupole polarities using local horizontal orbit three-bumps at injection energy. We use 11 bumps in each arc, each covering two SFs (focusing sextupoles) and one SD (defocusing sextupole). If there are no wrong sextupole polarities, the tune shifts from bump to bump and the tune shift patterns from arc to arc should be similar. Wrong sextupole polarities can be easily identified from mismatched signs or amplitudes of tune shifts from bump to bump and/or from arc to arc. Tune shifts in both planes during this study were tracked with a high-resolution baseband tunemeter (BBQ) system. This method was successfully used to the sextupole polarity check in RHIC Blue and Yellow rings in the RHIC 2006 and 2007 runs

PRINCIPLE

General Solution

In the simple case where a single sextupole is covered by a local horizontal orbit bump, the horizontal and vertical tune shifts are:

$$\left\{ \begin{array}{rcl} \Delta Q_x & = & \frac{1}{4\pi}\beta_x(k_2L)\Delta x_{co}, \\ \Delta Q_y & = & -\frac{1}{4\pi}\beta_y(k_2L)\Delta x_{co} \end{array} \right. , \qquad (1)$$

where (β_x, β_y) are the horizontal and vertical beta functions at the sextupole, (k_2L) is the integrated sextupole strength, and Δx_{co} is the horizontal orbit change due to the bump. If Δx_{co} is positive in Eq. 1, the sign of (k_2L), or the sextupole polarity, is only decided by the signs of the tune shifts. For simplicity, in the following, we call a sextupole with positive polarity $k_2 > 0$ an SF sextupole, and call a sextupole with negative polarity $k_2 < 0$ an SD sextupole. The most general method is only useful when there is a single sextupole in the horizontal three-bump.

RHIC Sextupole Locations

Each ring of RHIC consists of six arcs and 144 sextupoles. Each arc has 11 periodic FODO cells. There are 12 SFs and 12 SDs in each arc. The phase advance per FODO cell is about 85° in each plane. There are one SF sextupole and one horizontal dipole corrector close to each arc focusing quadrupole, and one SD sextupole and one vertical dipole corrector close to each arc defocusing quadrupole in the regular arc FODO lattice. There are no horizontal dipole correctors close to defocusing quadrupoles, or vertical dipole correctors close to focusing quadrupoles. One defocusing SD sextupole in each arc is located outside of the standard FODO cell arc.

Fig. 1 shows the horizontal dipole correctors and sextupoles in the first arc of RHIC ring. With the general solution mentioned above, 144 local three-bumps are required to cover all 144 sextupoles in each RHIC ring. However, for the RHIC rings, it is not possible to create a horizontal orbit three-bump to only cover one sextupole in the RHIC arcs. These individual sextupole-based local horizontal three bumps always cover two to four sextupoles. The tune shifts are therefore different for these bumps even if the closed orbit bumps at the sextupoles are the same size. This complication makes it difficult to identify individual sextupole polarity problems by simply looking at the tune shift patterns during data acquisition.

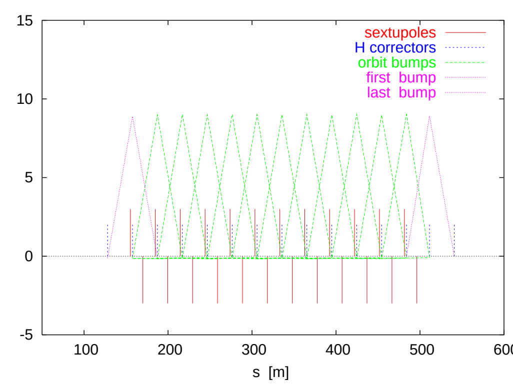

Figure 1: Corrector based bumps in the first arc.

Solution with Multiple Sextupoles per Bump

Considering the periodic FODO optics in the arcs, we construct 13 horizontal local bumps with horizontal dipole correctors in each arc. These bumps are corrector based, instead of the sextupole based bumps mentioned above. Fig. 1 shows the 13 three bumps in the RHIC blue ring 6-7 o'clock arc. The amplitudes of these bumps are same. Each of center 11 horizontal bumps covers one SF and two SD sextupoles, while the first bump covers one SD and one SF and the last bump covers only one SD.

For the center 11 bumps, considering the repetitive optics and bumps, if there is no wrong sextupole polarity, the tune shifts from individual bumps should be same. Wrong ploarity sextupoles can be identified by the anomalous tune shifts from bumps which cover them. The tune shift patterns from arc to arc also should be same if there is no

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wrong sextupole polarity at all. The two end bumps are not in the periodic arc FODO lattice, their setup are slightly different than the center 11 horizontal three-bumps. The tune shifts from them can be compared to the model predications.

We set the kicking strengths for the first dipole correctors of each bumps same. The strengths for the following other two dipole correctors are given by

$$\left\{ \begin{array}{rcl} \frac{\theta_2}{\theta_1} & = & -\sqrt{\frac{\beta_1}{\beta_2}} \frac{\sin(\phi_3 - \phi_1)}{\sin(\phi_3 - \phi_2)} \\ \frac{\theta_3}{\theta_1} & = & -\sqrt{\frac{\beta_1}{\beta_3}} \frac{\sin(\phi_2 - \phi_1)}{\sin(\phi_2 - \phi_3)} \end{array} \right. , \tag{2}$$

where θ_i, $i = 1, 2, 3$, is the kicking strength for ith dipole corrector. β_i is the betatron amplitude function, and ϕ_i is the horizontal phase advance from the optics starting point.

Previous measurements of RHIC injection lattice optics indicate that injection arc optics are regular at the level of 5-10%. Closure of bumps constructed using the above equations with model beta function and tunes also confirm this regularity. With constant bump amplitude, tune shifts from each of the 11 center bumps should match, and should match comparable patterns produced in the other five arcs. Outliers immediately indicate isolated problem sextupoles. Systematic sextupole wiring errors can be found by comparing measurements to a model – tune shifts from all bumps are compared to a model that includes sextupole feed-down, and potential errors can be simulated by reversing or zeroing selected sextupoles until the modified model matches the measurements.

Based on the offline simulation, there are some rules for quick identifying wrong sextupole polarities in the center 11 arc FODO horizontal bumps:

- If there are no wrong sextupole polarities, the tune shifts from bump to bump and the tune shift patterns from arc to arc should be similar. Wrong sextupole polarities can be easily identified from mismatched signs or amplitudes of tune shifts from bump to bump and/or from arc to arc.

- If one SF sextupole has a wrong polarity, it will only affect the tune shifts of the bump which covers this SF sextupole since one SF is only covered once by one bump. If one SD sextupole has a wrong polarity, it will only affect the tune shifts of two adjacent bumps since one SD is only covered by two adjacent bumps.

- From the RHIC optics model, if there are no wrong sextupole polarities, horizontal and vertical tune shifts from each bump should be positive.

- If the horizontal tune shift from one bump is negative and the vertical tune shift from this bump is excessively positive, there is a possibility that the SF in this bump has a wrong polarity. The name of the suspicious SF can be easily identified since each bump only covers one SF.

- If the vertical tune shifts from two adjacent bumps are negative or close to zero and the horizontal tune shift from these bumps are excessively positive, there is a possibility that the SD covered by these two bumps has a wrong polarity.

BEAM EXPERIMENT IN RHIC

Beam Experiment and Results

In RHIC run_06, the above method was used to check all chromaticity sextupole polarities in RHIC during the Accelerator Physics beam experiment period of March 22, 2006, starting at 14:50. The machine ramp and stone were pp30::injection. The rings were decoupled at injection, and the tunes were separated to avoid coupling interference in tune measurements. Scripts were written to adjust consecutive three-bumps with +5 mm amplitudes through the arcs in each ring while monitoring and logging the tunes with the BBQ tunemeter system and orbits in all BPMs. Each bump took 25–30 seconds; the total data acquisition time for both rings was under two hours. The blue ring was scanned first, and then the yellow ring. The scripts record timestamps for each bump, and these records were later used to correlate bumps to logged BBQ tunemeter strip chart data.

Fig. 2 shows BBQ tunemeter data acquired during the scan of the blue ring. This data includes tests of the bumps, and proceeds in groups from arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. There are two anomalies at 15:02 and 15:09 — these are the result of bumps that were not removed before the next bump was applied, and are not due to mis-wired sextupoles. Comparison of data in this figure to simulation indicates that all chromaticity sextupoles in the RHIC blue ring are wired correctly. A zoom of this data showing the details of tune response in correctly wired chromaticity sextupoles is shown in Fig. 3.

Fig. 4 shows BBQ tunemeter data acquired during the scan of the yellow ring. This data also includes tests of the bumps, and proceeds in groups from arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. This data is significantly harder to interpret from 16:08 to 16:18, when control system problems interfered with the three-bump script operation. This data was removed, and remaining yellow measurements were manually compared to the script logs and simulations. This comparison indicated that one sextupole, yo4-sxd9, had a reversed polarity. Once understood, this is fairly easy to see in data in Fig. 4 at 16:19:33, where the vertical tune clearly moves in the wrong direction. The wiring for this sextupole was corrected on April 4, 2006, and the correct polarity was confirmed with this method on April 12.

Both BBQ measurements show base tunes that gradually increase with time. This tune shift is about 0.002 up in both planes over about one hour, inconsistent with tune drift from persistent currents. This is likely due to some sort of systematic drift in the BBQ data, or feed-down ef-

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fects of slow orbit drifts.

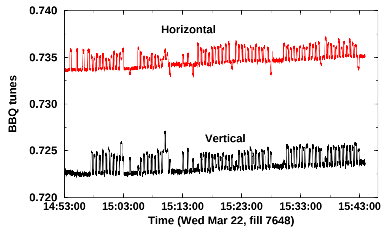

Figure 2: Blue BBQ tunemeter data acquired for scans of blue ring bumps in arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. Anomalies at 15:02 and 15:09 are the result of bumps not being removed, and are not due to mis-wired sextupoles.

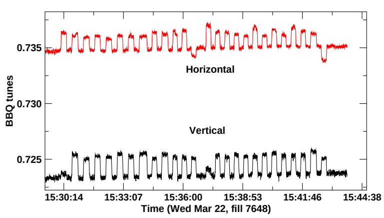

Figure 3: A zoom of the blue BBQ tunemeter data acquired for scans of blue ring bumps in arcs 6/7, and 8/9 o'clock, showing detailed bump configurations for correctly wired chromaticity sextupoles.

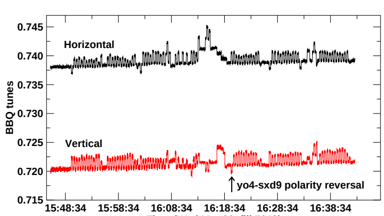

Figure 4: Yellow BBQ tunemeter data acquired for scans of yellow ring bumps in arcs 10/11, 12/1, 2/3, 4/5, 6/7, and 8/9 o'clock. The bump at 16:19 indicates a polarity reversal of chromaticity sextupole yo4-sxd9.

During the beam study, horizontal orbit motion due to in the arcs was also noted when bumps were applied. For constant frequency, the momentum shift due to a fractional closed orbit length change $\Delta C/C$ is $\delta = \gamma_T^2 \, \Delta C/C$. Observed orbit motion outside of the bump in regular arcs of RHIC was 0.5 mm, corresponding to a fractional energy change of $\delta = 2.5 \times 10^{-4}$ and a fractional closed orbit length change of $\Delta C/C = 5 \times 10^{-6}$. This is completely consistent with the +5 mm horizontal bumps used along three-bumps that have 30 m between correctors in the RHIC arcs. The horizontal orbit motion from this effect in other chromaticity sextupoles is 10% of the bump size; this effect can be neglected when determining sextupole polarities, but should be included for measurement of optics from this data.

In RHIC run_07, the number of the arc sextupole power supplies had been be doubled from 12 to 24 to allow nonlinear chromaticity correction. In previous runs, all SFs or all SDs in one arc were powered by one sextupole power supply. And in the operation, two-family chromaticity correction scheme was adopted for the first order chromaticity correction. During the shutdown between run_06 and run_07, the sextupole magnets were rewired. In each arc, there are four sextupole families, two SFs and two SDs. In the eight-family chromaticity correction scheme, all outter and inner arcs have the same sextupole family patterns, which gives totally 8 sextupole families per ring [1, 2]. To check the sextupole polarities, we adopted two-family chromaticity correction scheme, that is, all the four SF or SD sextupole families had the same strengths. The sextupole check for Blue ring was done on Feb 23, 2007. And the sextupole parity check for Yellow ring was taken on March 14, 2007. For each ring, the data taking time was less than 1 hour. And no wrong polarity was found.

CONCLUSIONS

We have presented a beam-based method to check RHIC chromaticity sextupole polarities using local horizontal orbit three-bumps. This method was successfully used to check all sextupoles in RHIC run_06. All blue chromaticity sextupoles had correct polarities verified; in the yellow ring, a single sextupole, yo4-sxd9, was found to be reversed. The wiring for this sextupole was corrected on April 4 2006, and the corrected polarity was confirmed during another beam study on April 12 2006. This method was also used in the startup of RHIC run_07 and no wrong polarity was found.

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