RECENT DEVELOPMENT ON BEAM-BASED ALIGNMENT IN RHIC*

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Abstract

During the 2012 polarized proton and heavy ion runs, we continued the efforts on beam-based alignment (BBA) of quadrupoles in RHIC. A complete set of BBA data of triplet quadrupoles in all interaction regions (IRs) of RHIC was obtained. In addition, the measurement procedures and data analysis algorithm were improved and corresponding codes were developed. Here we report on the results of BBA measurements, analysis, and corrections. The BBA accuracy limitations are also discussed. As a continuing effort, we also present application code that is under development for future BBA operations in RHIC.

ISSUES WITH BBA IN RHIC

The standard BBA technique [1, 2] in storage rings involves calculating the RMS beam-orbit difference between two states: nominal and slightly modified magnet strength of the quadrupole under investigation with varying beam-to-quadrupole offsets. The center of the quadrupole is indicated by the orbit position, read from the beam position monitor (BPM) located near the quadrupole, at which the RMS beam-orbit difference reaches a minimum when a series of beam-to-quadrupole offsets are produced by a local orbit bump. Therefore, in order to perform BBA measurement, a quadrupole has to have (1) independent control of the power supply; and (2) a nearby BPM with capability of the plane in question.

The measureable quadrupole magnets in both rings can be identified by RHIC design [3]:

1. Only quadrupoles Q1 - Q9 can be controlled independently;
2. In each triplet, quadrupoles Q1 and Q3 have associated BPMs, but Q2 does not;
3. Quadrupoles Q1, Q3, Q4, Q7 and Q8 are associated with dual-plane BPMs;
4. Quadrupoles Q5, Q6 and Q9 are associated with single-plane BPMs;
5. Quadrupoles Q1, Q2, and Q3 allow for independent power supply control;
6. None of Q4, Q5, or Q6 quadrupoles have independent control;
7. However, it is possible to perform BBA on the associate BPMs using trim-quadrupoles TQ4, TQ5, TQ6, which are independently controlled;
8. Not all Q7, Q8, and Q9 quadrupoles have independent control. It varies by IRs and rings.

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In RHIC, there are 222 quadrupoles (111 in each ring) that can be measured, but BBA measurement is difficult in RHIC for the following reasons:

1. There is limited number of dipole correctors, especially in IRs. For example, in order to make measurements on the triplet magnets, one needs to use the BBA bump (3-corrector bump) that includes not only the triplet quadrupoles but also 3-4 additional quadrupoles, 2 DX magnets and 2 D0 magnets.
2. The effects of Q1, Q2, Q3 quadropoles are equally strong and they cannot be decoupled.
3. There are unknown errors in alignment of magnets relating to each other;
4. Beam angles at the quadrupoles cannot be measured because beam positions and angles at the first corrector of the BBA bump are unknown;
5. The ring is very large and Signal to noise ratio is low. When all the BPMs in all the arcs are used, the level of noise in some BPMs can outweigh the signal.

PRE-2012 MEASUREMENTS AND RESULTS

Limited raw data were collected during the 2010 and 2011 runs due to excessive beam loss, noise and a limited analysis algorithm. During the 2012 run, all the pre-2012 data were re-evaluated and re-analyzed. 77 sets in total (44 sets in the Blue ring, 33 sets in the Yellow ring) were identified to be useful and were utilized to aid the 2012 BBA activities. The error bars of the processed BBA results were found to be 267 μm and 171 μm in the Blue and Yellow rings, respectively. Data from 2010 and 2011 runs are shown in figures 1 and 2. Further details on the pre-2012 runs can be found in references [4, 5].

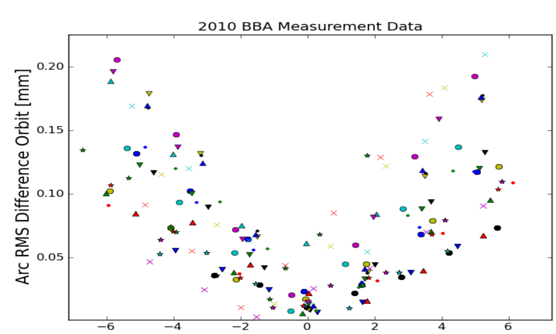

Figure 1: Superimposed BBA measurement data obtained during RHIC 2010 run.

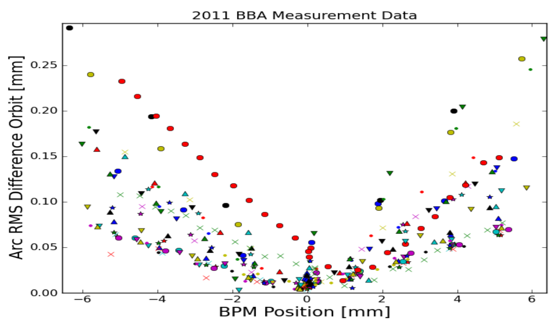

Figure 2: Superimposed BBA measurement data obtained during RHIC 2011 run.

IMPROVEMENTS MADE DURING 2012

A major effort was made in the 2012 run to overcome the challenges faced by BBA in RHIC. It was determined, after careful study of the previous two years of measurement data, that an unconventional measurement procedure in which the quadrupole magnet strength is modulated only once between two identical bump scans could result in higher signal to noise ratio while spending approximately equal time for data collection. As an example, figures 3 and 4 compare the currents of the same power supplies (bo7-th2, bi8-qf3) with conventional procedures used before the 2012 run and with the unconventional procedure used in 2012 run.

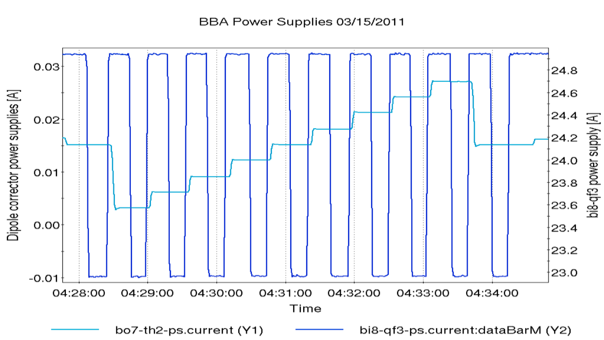

Figure 3: The power supply currents of a quadrupole (bi8-qf3) and a dipole corrector (bo7-th2) during BBA measurement with the typical procedure used before RHIC 2012 run.

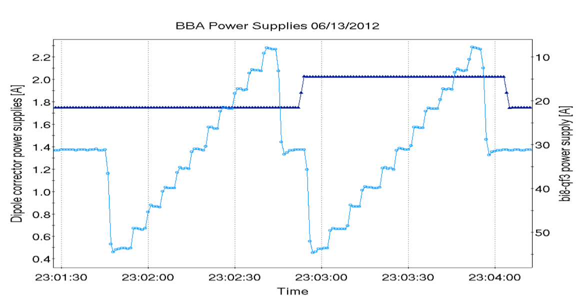

Figure 4: The power supply currents of the same quadrupole and the same dipole corrector as in Figure 3 during BBA measurement with the untypical procedure used during the RHIC 2012 run.

During RHIC 2010 and 2011 run, a set of bash, gnuplot, and perl scripts were used for measurement and analysis. The orbit bumps had to be built manually after looking up the proper coefficients for each power supply involved. This was very time consuming and error prone. One of the major efforts during the 2012 run was consolidating measurement and analysis into two easy-to-use and dependable scripts.

The data acquisition code and data analysis code were completely rewritten for RHIC 2012 run. Python was chosen for a number of reasons including readability, integration of matplotlib, and the ability to use modules already developed for interacting with a newly created bump manager for RHIC. The new bump manager allows the user to simply supply the parameters for a bump without having to construct bump coefficients manually.

Figure 5 shows the new data analysis algorithm developed during the 2012 run based on the physical model.

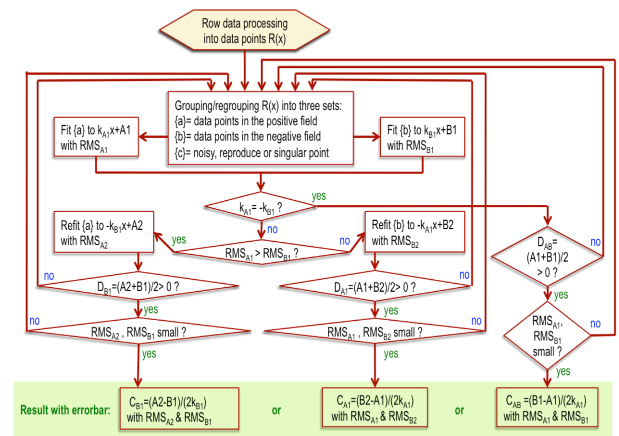

Figure 5: The new data analysis algorithm based on the physical model.

2012 MEASUREMENTS AND RESULTS

During RHIC 2012 run, 128 sets useful raw data were collected in total (60 sets in Blue ring, 68 sets in Yellow ring). Measurements in all Q1 and Q3 quadrupoles in both horizontal and vertical directions were completed. Data from RHIC 2012 run are shown in figure 6. The average error bar was 138 μm. Further details can be found in [6].

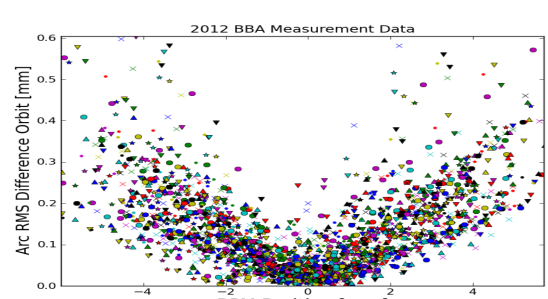

Figure 6: Superimposed BBA measurement data obtained during RHIC 2012 run.

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The improved measurement procedure and the analysis have been highly successful. Figures 7 and 8 show results before and after the BBA corrections during RHIC 2012 run in Blue and Yellow ring, respectively.

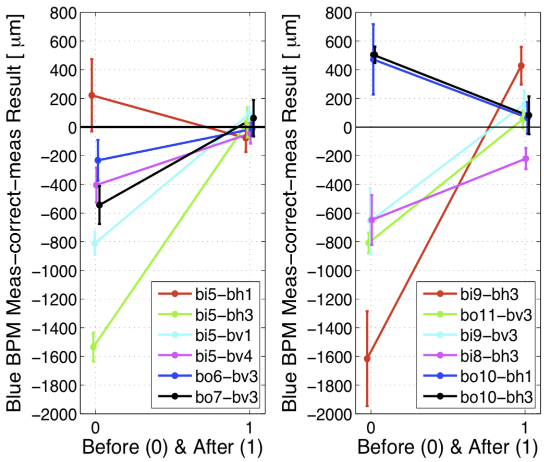

Figure 7: Measurement results before and after the BBA corrections in the Blue ring during RHIC 2012 run.

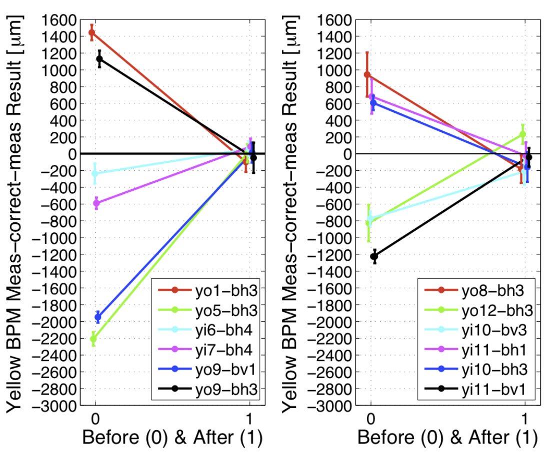

Figure 8: Measurement results before and after the BBA corrections in the Yellow ring during RHIC 2012 run.

The accuracy limitation of BBA on RHIC is about 0.1 mm because of the following factors:

1. BPM accuracy is temperature dependent. Each $\Delta 10^{\circ}$F temperature change results in ~Δ1ns change in trigger time which adds an uncertainty of ~ +/-0.1mm to ~1mm in BPM reading. BPM resolution is ~0.01mm at a constant temperature;
2. Quadrupole physical misalignment relative to each other is ~ +/-0.06mm;
3. BPM position with respect to the outside fiducials is ~ +/-0.13mm;
4. Unknown beam positions and angles at the first corrector (beam angle at the triplet). It was estimated to have an effect ~ +/-0.1mm;
5. Repeatability under the same machine settings is found by experiment to be ~ +/-0.1mm.

Significant improvements in usability and reliability of the BBA codes has been achieved by:

1. Incorporating a bump manager;
2. Rewriting the initial code with explicit emphasis on error handling, modularity, and usability;
3. Designing measurement, analysis, and offset correction scripts in parallel;
4. Adapting measurement techniques based on knowledge from previous measurements.

A stand-alone GUI application is under development. It handles measurement, monitoring and analysis in one application. It is capable of accessing the RHIC BBA database for faster, safer, more accurate measurements and data storage. In addition, the application can be used to view or analyze the measured data from previous runs.

SUMMARY

Now RHIC BBA generally produces reliable results. It takes 3-4 min for each set of measurement with good accuracy/resolution. Measurements at Q1 & Q3 have been completed in both rings (24H, 24V each ring). BPM at TQ4 has been completed in Blue IR 6, 8, 12; in Yellow IR 2, 6, 8, 10, 12, and we have confirmed some of the large offsets. The results are generally good. Offset corrections have been installed on all the BPMs measured.

All the existing measurement data in the RHIC BBA history (after BPM offset fix in 2010) have been revisited. All the useful data have been identified and re-analyzed with the 2012 analysis program. All the useful results were utilized in BBA activities during RHIC run 2012.

BBA codes have been significant improved during RHIC run 2012 to increase the usability and reliability. In addition, a stand-alone GUI application is currently under development for future BBA operations in RHIC.

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