RHIC BPM SYSTEM AVERAGE ORBIT CALCULATIONS*

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Abstract

RHIC beam position monitor (BPM) system average orbit was originally calculated by averaging positions of 10000 consecutive turns for a single selected bunch. Known perturbations in RHIC particle trajectories, with multiple frequencies around 10 Hz, contribute to observed average orbit fluctuations. In 2006, the number of turns for average orbit calculations was made programmable; this was used to explore averaging over single periods near 10 Hz. Although this has provided an average orbit signal quality improvement, an average over many periods would further improve the accuracy of the measured closed orbit. A new continuous average orbit calculation was developed just prior to the 2009 RHIC run and was made operational in March 2009. This paper discusses the new algorithm and performance with beam.

RHIC BPM SYSTEM OVERVIEW

The Relativistic Heavy Ion Collider (RHIC) BPM system [1][2] consists of 333 measurement planes in each of the two collider rings. The following two modes of operation are available:

- Turn-by-turn mode: 1024 position measurements are acquired for a single selected bunch with a programmable spacing between measurements from 1 to 4000 turns. An event on the RHIC beam synchronous event link [3] is used to trigger the acquisition. Higher level software is capable of correlating measurements from all BPMs in the same ring to the same turn.
- Average orbit mode: A single average orbit position for a selected bunch is returned from each BPM, with typical update rates of 2, 4 or 60 seconds. This mode is used for beam steering, orbit correction, etc. An event on the RHIC beam synchronous event link is also used to trigger average orbit measurements.

Although each mode is independent to allow simultaneous turn-by-turn and average orbit acquisitions, some parameters are common, including the selected bunch, gain settings, and timing trigger values.

One electronics board exists for each RHIC BPM plane, and contains a Freescale Inc. (previously Motorola) 56301 Digital Signal Processor (DSP), two Analog Devices AD677 100 ksamples/second analog to digital converters for turn-by-turn measurements at RHIC's 78 kHz revolution frequency, programmable delay timers, and associated analog and digital electronics.

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OLD AVERAGE ORBIT ISSUES

After discovering that 10 Hz beam perturbations [4] contribute to BPM average orbit variations, the average orbit algorithm was modified in 2006 to provide an average over a programmable number of turns, with a maximum of 10000 turns due to hardware limitations. Averaging 7800 turns, or approximately one 10 Hz period, was found to provide the best improvement in measurement quality. However, since the beam perturbations include multiple discrete frequencies around 10 Hz, averaging over 7800 turns never produces an accurate measurement of the closed orbit.

NEW AVERAGE ORBIT ALGORITHM

A new continuous average orbit calculation, shown in Fig. 1, was implemented in the RHIC BPM system for the 2009 RHIC run.

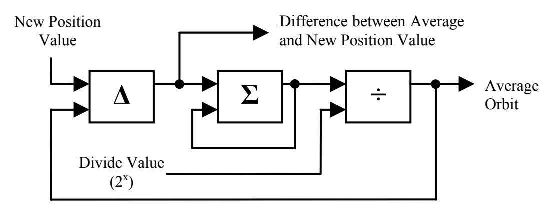

Figure 1: RHIC BPM continuous average orbit algorithm.

This algorithm [5] acts as a low pass filter where the response time is configured with the divide value. The divide value is programmed as a power of 2 to allow fast computation with a simple bitwise shift. The average orbit is computed by adding a percentage of each new position measurement, based on the divide value, to the average orbit position value. A step in beam position therefore requires several iterations of the calculation to settle to a new value.

This algorithm has previously been used successfully in the AGS transverse damper [6][7] and RHIC injection damper [8] systems. For a damping system, the desired feedback parameter is a turn-by-turn measurement that indicates the difference between the average orbit and the new turn position value, as shown in Fig. 1.

The average orbit from this calculation provides an accurate measurement of the closed orbit. The difference, sum, and divide calculations are performed sequentially in the on-board Freescale 56301 DSP using every sixth turn of position data. Although using every turn is more desirable, the required processing time cannot be sustained with the existing hardware. The feedback values into the difference and sum blocks are the results of the previously executed calculation.

RESULTS

The improvements in the quality of the BPM measurements using the new continuous average orbit calculation are dramatic in comparison with the 7800-turn average orbit that has been used in prior RHIC runs.

Fig. 2, which shows data from a single BPM for a physics store lasting approximately 8 hours, compares the 7800-turn average orbit position values with the continuous average orbit position values. Note that measurement variations are greater than 100 microns from the 7800-turn average and only about 10 microns from the continuous average.

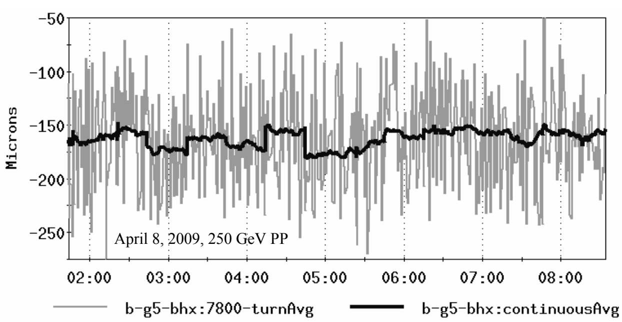

Figure 2: 7800-turn average vs. continuous average.

Shown in Fig. 3 is a zoom-in of the continuous average orbit position data shown in Fig. 2. The position steps that occur about every 30 minutes are a result of automatic orbit corrections. Step sizes of less than 15 microns are clearly detected. This resolution was never achievable with the old average orbit algorithm.

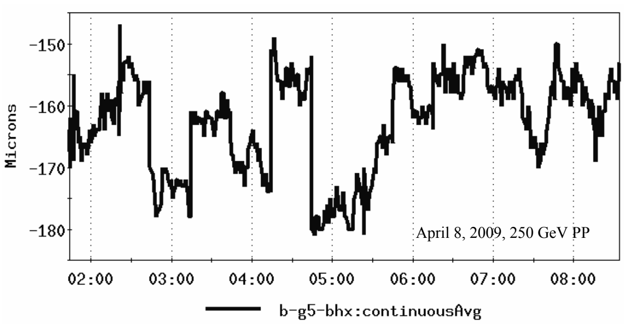

Figure 3: Zoom of Fig. 2 continuous average data.

Fig. 4 shows continuous average orbit data from another BPM for a different physics store also lasting approximately 8 hours. Again, the position steps that occur about every 30 minutes are a result of automatic orbit corrections.

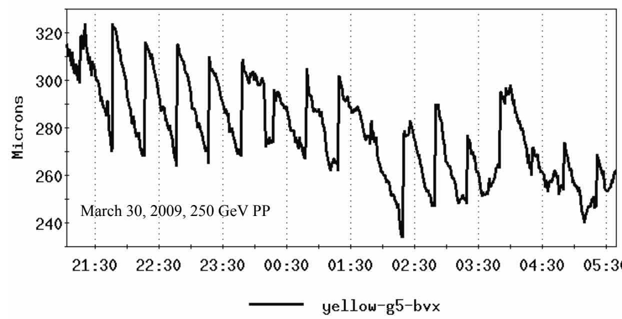

Figure 4: Continuous average orbit for a single BPM during an 8 hour RHIC store.

Note that the orbit correction steps are larger in Fig. 4 (a vertical plane) than in Fig. 3 (a horizontal plane). This is due to 24-hour periodic vertical beam pipe motion currently under investigation.

DIVIDE VALUE OPTIMIZATION

Studies were performed with beam to determine the optimal setting for the divide value by finding the fastest response time with acceptable measurement variations. Figure 5 compares the 7800-turn average with the continuous average as the beam was moved in 6 discrete steps spanning a total of 1 mm when the divide value was set to 2^{16}. Note that the continuous average calculation has a settling time of nearly one minute for each step. This delay is not acceptable for operational use during these and similar scans.

Figure 6 compares position data from another position scan with the divide value set to 2^{13}. This value has been deemed best for operation since it produces a reasonable settling time of a few seconds and low measurement variations.

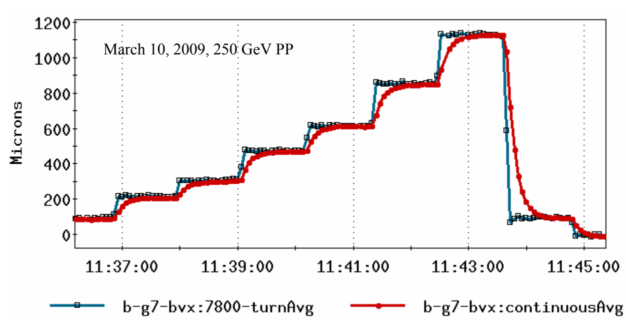

Figure 5: 7800-turn average orbit vs. continuous average orbit (divide value = 2^{16}) during beam position scan.

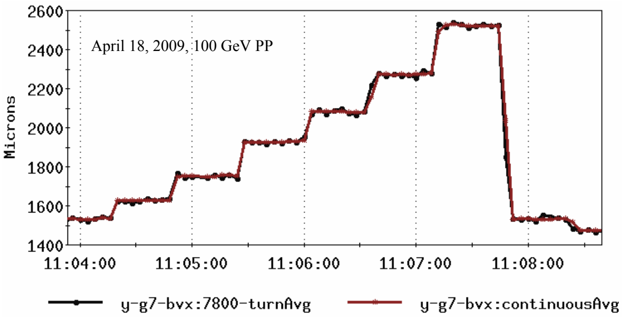

Figure 6: 7800-turn average orbit vs. continuous average orbit (divide value = 2^{13}) during beam position scan.

ANOTHER ADVANTAGE

Aside from producing much cleaner signals, another advantage to using the continuous average orbit calculation instead of the n-turn average is that continuous acquisition updates are possible at a faster rate, perhaps every second or less. The n-turn data acquisition and processing begins when the event trigger is received and requires greater than one second, where the continuous average orbit value can be delivered as soon as the event trigger is detected.

10 HZ ORBIT FEEDBACK

Additional work has been performed during the 2009 RHIC run to determine if continuous measurements can be generated from the RHIC BPM electronics that would be suitable for a future 10 Hz global orbit feedback system.

The difference signal from the average orbit calculation (Fig. 1) was analyzed and found to have excessive variations. Filtering was added to the difference signal as shown in Fig. 7, and was found to be very effective with a difference divide value of 2^3. A phase shift was noticed when the difference divide value was set to 2^5.

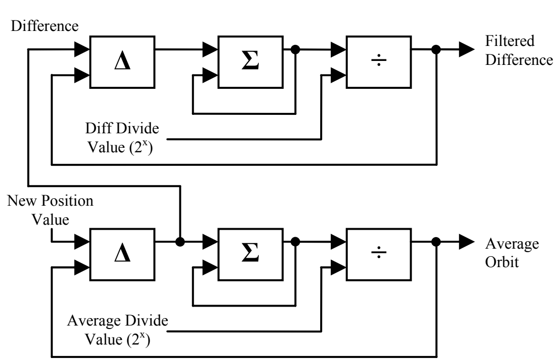

Figure 7: BPM continuous average orbit and filtered difference signal.

Fig. 8 compares the raw difference signal with the filtered difference signal for an approximately one second period. The 10 Hz orbit variations of greater than +/- 100 microns are visible in both signals, but the filtered difference provides a much cleaner signal. Therefore, with this significant signal quality improvement using the filtered difference signal, the existing RHIC BPM electronics are very likely adaptable for use in a future global orbit feedback system. A new daughter board design will be required to digitally deliver the position difference data at a continuous rate greater than 1 kHz.

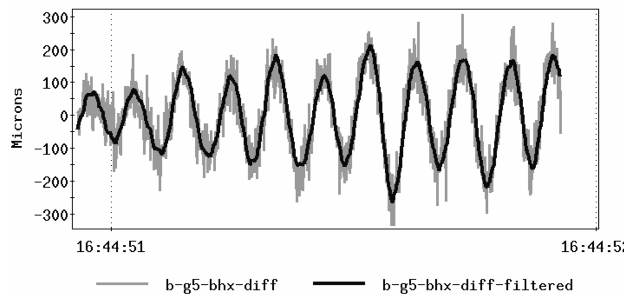

Figure 8: BPM Raw Difference vs. Filtered Difference.

TEMPERATURE ISSUES

Another contribution to RHIC BPM measurement variations was found to be building temperature changes of +/- 1 deg F. After extensive analysis, the major cause has been confirmed to be variations in the analog to digital converter (A/D) triggers based on temperature.

The RHIC BPM hardware provides a 20 picosecond per count configurable timing trigger delay for each of the two stripline signal inputs. Beam tests revealed that position measurement variations due to temperature could be significantly decreased, and almost eliminated by adjusting the relative timing between these triggers.

Precise setting of these timing values has proven to be a challenge; work is ongoing to develop automated methods for optimizing the timing trigger values.

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