RHIC BPM SYSTEM MODIFICATIONS AND PERFORMANCE

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Abstract

The RHIC beam position monitor (BPM) system provides independent average orbit and turn-by-turn (TBT) position measurements. In each ring, there are 162 measurement locations per plane (horizontal and vertical) for a total of 648 BPM planes in the RHIC machine. During 2003 and 2004 shutdowns, BPM processing electronics were moved from the RHIC tunnel to controls alcoves to reduce radiation impact, and the analog signal paths of several dozen modules were modified to eliminate gain-switching relays and improve signal stability. This paper presents results of improved system performance, including stability for interaction region beam-based alignment efforts. We also summarize performance of recently-added DSP profile scan capability, and improved million-turn TBT acquisition channels for 10 Hz triplet vibration, nonlinear dynamics, and echo studies.

INTRODUCTION

The RHIC BPM system [1, 2, 3] consists of 160 23-cm cryogenic striplines per plane per ring. 72 dual-plane BPMs are distributed through the interaction regions (IRs), and 176 single-plane BPMs are located at each arc $\beta_{\max}$. Signals are cabled through 6 dB reflection attenuators and 20 MHz lowpass filters to analog/digital integrated front ends (IFEs). Each IFE contains independent electronics boards for two measurement planes, including active 20 and 40 dB gain stages, 16-bit digitizers for 1 μm resolution over a $\pm$32 mm measurement range, and Motorola 56301 fixed-point digital signal processors (DSPs) for data reduction and acquisition control. Arc IFEs are in tunnel alcoves for radiation protection, while IR IFEs are located in equipment buildings.

Each IFE calculates digitizer status, digitized raw signals, and beam position once per turn for the first bunch after the abort gap. Upon receipt of a beam-synchronous trigger, up to 1024 turns are streamed to a local DSP buffer, then passed along IEEE1394 (firewire) to VME memory and the RHIC control system. Upon receipt of a separate trigger, TBT positions are averaged over 10,000 turns to provide an average orbit measurement. Each IFE can acquire simultaneous 1024-turn TBT and average orbit information. Details of RHIC BPM electrodes and acquisition electronics are available elsewhere [1, 2].

There are 20 dedicated BPM VME crates and controls front-end computers (FECs) distributed around the RHIC rings. Several console-level servers collect and correlate TBT and average orbit data from all BPMs, and handle both orbit logging and orbit delivery to application programs.

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RADIATION AND RELIABILITY

During previous RHIC runs, unexpectedly high numbers of BPM IFE digital boards failed. These were initially remotely resettable, but progressively deteriorated to nonresettable failures over 1–2 week timescales. The dominant radiation-driven failure mode for BPM IFEs in the RHIC tunnel was radiation damage of the Motorola 56301 DSP, particularly failure of the core memory. The process of spare DSP procurement and surface-mount replacement is expensive and both manpower- and spare-intensive.

During an earlier shutdown, 118 BPM IFEs (three alcoves) were moved from their locations above the cryostats to equipment alcoves. These showed a 95% reduction in DSP hang rate, and had no radiation-induced DSP failures through the following runs [3]. During the FY04 summer shutdown, 284 BPM IFEs (with 568 cables in 9 alcoves) were also moved from locations above the RHIC arc cryostats to equipment alcoves in the RHIC tunnel. To date there have been no further DSP radiation-induced failures during the RHIC FY05 run.

To track detailed BPM reliability and injection performance, 1024 turns of injection data at all BPMs are saved for the first bunch of every physics fill. Fig. 1 shows histograms of peak to peak values for several hundred RHIC

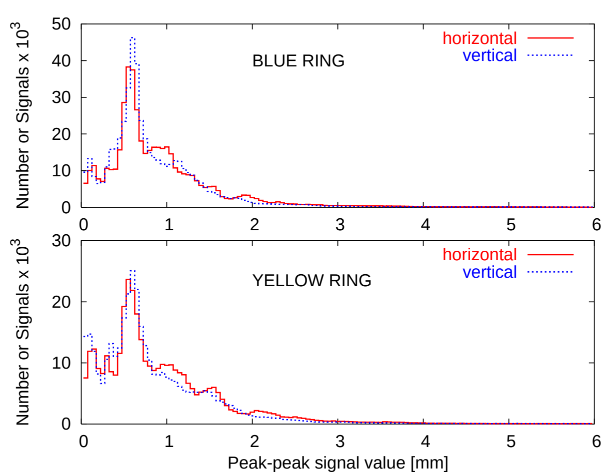

Figure 1: Histogram of RHIC BPM injection peak-to-peak signal values during the FY05 polarized proton run. Average injection quality has improved by a factor of two over previous runs [4].

fills. Good injection consistently gives 0.6 mm peak-to-peak values, consistent with AGS extraction jitter; these oscillations are removed with injection dampers. About 2–3% of BPM injection readings are faulty, indicated by very large or near-zero peak-peak signal values. This failure rate is reduced by a factor of five over previous runs [4].

GAIN RELAY MODIFICATIONS

The IFE electronics have a total of 15 gold-plated high-frequency DPDT analog relays [5]. Seven are in the signal path: a calibration signal relay, and three per signal path for switchable 0 dB, 20 dB, and 40 dB active gain stages. Six additional relays are in the calibration signal path for switchable attenuations. While attempting to diagnose radiation-induced hardware failures and system performance problems, diagnosis reproducibility problems were traced to contact instabilities in these relays due to organic membrane buildup and lack of routine contact cycling during RHIC operations. These relays contain gold-plated contacts but are not hermitically sealed.

For the FY05 run, 56 planes of BPM electronics in two service buildings were modified to remove these relays, and matched 50 ohm coaxial jumpers were installed in their place. A 3 dB fixed gain stage was included to maintain reasonable dynamic range for Cu-Cu and polarized proton operations. These modifications were made for interaction region BPMs in the low-beta areas around the large RHIC experiments STAR and PHENIX to assess modification stability. Initial beam-based alignment studies on both modified and unmodified BPMs show that offsets of BPMs without relays are stable to 100-200 μm, the accuracy of the measurement, while similar BPMs with relays produced unreproducible errors of over 1 mm [6]. Plans are underway to modify additional modules during the upcoming RHIC shutdown.

DSP TIMING SCANS

The RHIC BPM system contains over 1200 signal paths (two per BPM plane) to verify, and over 600 BPM channels must also be timed properly. This task is particularly onerous when moving from self-trigger to dead-reckoned timing, as each of these timings must be set within 1 ns of the beam peak to produce a meaningful signal. A LabView VI was previously used to for timing scans, but one scan for 12 BPMs would take up to five minutes, and tests of one RHIC ring would take over one shift.

In April 2005, the DSP code resident in BPM IFEs was modified to permit acquisition of longitudinal beam profiles by locally scanning timing registers. Two parameters specify start delay and scan width in ns, and on-board programmable delay generators are used to generate timings.

Fig. 2 shows a scan profile for two BPMs for the new code, showing profiles of the first two bunches in RHIC separated by a nominal bunch spacing of 105 ns. Each point represents an average digitizer value at that timing over 10,000 consecutive turns. These profiles are acquired simultaneously for all RHIC BPMs in the course of one minute. Analysis code is being developed to automatically set all BPM timings from this data in both dead-reckoned and self-triggered acquisition modes.

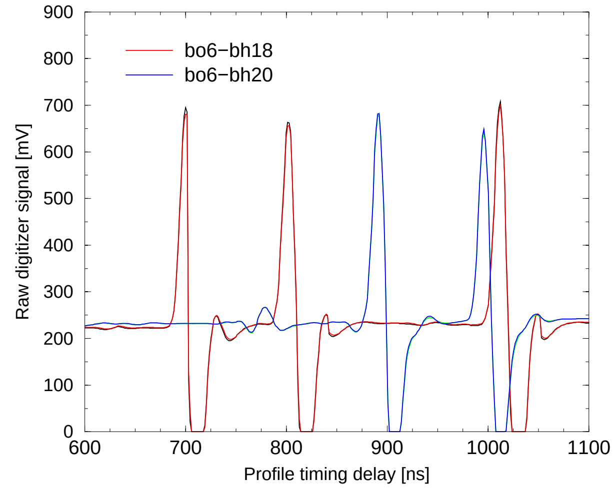

Figure 2: Profile timing scans for BPMs bo6-bh18 and bo6-bh20, with 105 ns bunch spacing. The vertical axis is digitizer voltage from each BPM stripline.

MILLION TURN PERFORMANCE

Ten BPM modules at RHIC have had 512 Mb SDRAM PCI mezzanine carrier (PMC) memory cards installed, interfacing Motorola 56301 DSP built-in PCI interface. Four of these in the RHIC blue ring were modified in late April 2003 [7], while the remaining six (four in yellow, two in 2 o'clock blue DX horizontal BPMs) were modified through 2005. Million-turn acquisition has the same TBT noise levels (about 50-75 μm) as normal 1024-turn TBT acquisition.

The million-turn BPMs have been used to observe and study well-established beam oscillations in RHIC at frequencies of about 10–14 Hz. The power spectrum for a million-turn acquisition at store energies is shown in Fig. 3, showing clear peaks at 9.8 Hz and 10.3Hz, and a substantial 60 Hz component that appears in other beam measurements. 256 kturn measurements have be acquired about every 30 seconds to correlate to possible cryogenic-driven triplet vibration sources [8]. Million-turn BPMs have also been used during electron cooling solenoid beam-based alignment experiments to attempt to improve signal to noise; here a 1 Hz modulation is applied to an alignment quadrupole, and the beam response at 1 Hz is measured [9].

CONCLUSIONS

The RHIC BPM system has demonstrated substantially improved performance and stability in 2005 compared to previous RHIC runs. All BPM electronics have been moved from the RHIC tunnel to limit radiation upsets and

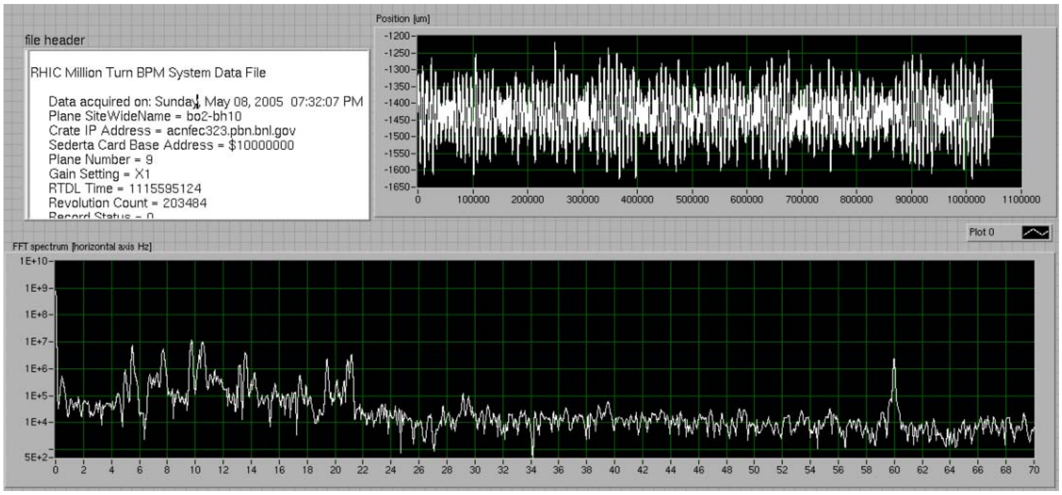

Figure 3: Million-turn acquisition and spectrum for the RHIC blue ring horizontal BPM bo2-bh10 at storage energy, showing 100 μm IR triplet vibration components and 60 Hz oscillations [8].

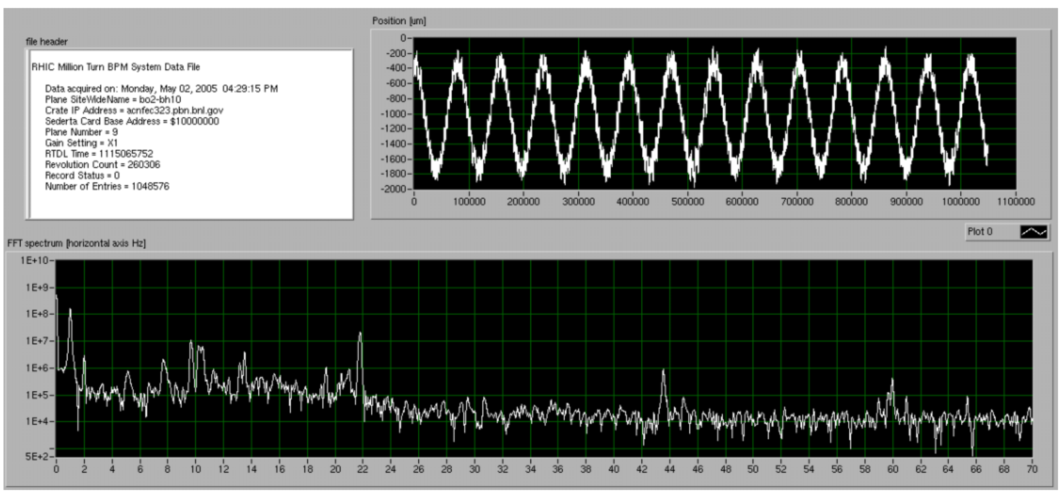

Figure 4: Million-turn acquisition and spectrum during blue ring electron cooling studies at injection where a nearby quadrupole is being driven at 1 Hz [9]. 22 Hz power in the spectrum comes from coherent synchrotron motion near transition energy.

radiation-induced DSP failures. A test sample of BPM electronics had their gain relays removed; beam-based alignment and operational experience demonstrate an order of magnitude improvement in readout stability. Fast DSP code for signal path validation and global timing has been implemented and tested, allowing full routine timing and signal tests for all BPMs. Ten BPM modules have million-turn capability, and are being routinely used for 11 Hz modulation feedback calibration, electron cooling beam-based alignment, and transition instability studies.

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