RHIC 10 HZ GLOBAL ORBIT FEEDBACK SYSTEM*

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Abstract

Vibrations of the cryogenic triplet magnets at the Relativistic Heavy Ion Collider (RHIC) are suspected to be causing the horizontal beam perturbations observed at frequencies around 10 Hz. Several solutions to counteract the effect have been considered in the past, including a local beam feedback system at each of the two experimental areas [1], reinforcing the magnet base support assembly, and a mechanical servo feedback system [2]. However, the local feedback system was insufficient because perturbation amplitudes outside the experimental areas were still problematic, and the mechanical solutions are very expensive. A global 10 Hz orbit feedback system consisting of 36 beam position monitors (BPMs) and 12 small dedicated dipole corrector magnets in each of the two 3.8 km circumference counter-rotating rings has been developed and commissioned in February 2011. A description of the system architecture and results with beam will be discussed.

DESCRIPTION OF ARCHITECTURE

The RHIC 10 Hz global orbit feedback system consists of the following main components:

- 72 (36 for each ring) standard RHIC BPM Integrated Front End (IFE) electronic modules [3] with new daughter card for ~10 kHz position data distribution.
- Dedicated 1 gigabit BPM data distribution network using off-the-shelf Netgear Ethernet switches [4].
- 6 Xilinx Virtex-5 based data processing modules with on-board power PC running vxWorks operating system as control system front end computer.
- 24 Kepco Model BOP-36-12M (+/- 36 V, +/- 12 A) magnet power supplies (12 for each ring).
- 24 small corrector magnets (12 in each ring) [5].
- 6 Modicon programmable logic controllers (PLCs) for Kepco power supply on/off control.

Block diagrams are shown in Fig. 1 and 2. Each ML-510 receives data from all 72 BPMs every 8 beam revolutions (~103 microseconds), and uses a matrix and control loop filter to generate the power supply setpoints for each of the 4 local corrector magnets (2 for each ring).

One ML-510 processing module, four power supplies, and related control equipment are located in each of 6 service buildings around the RHIC complex (Fig. 3). The BPM IFE modules are located in the same service buildings as well as in alcoves in the tunnel.

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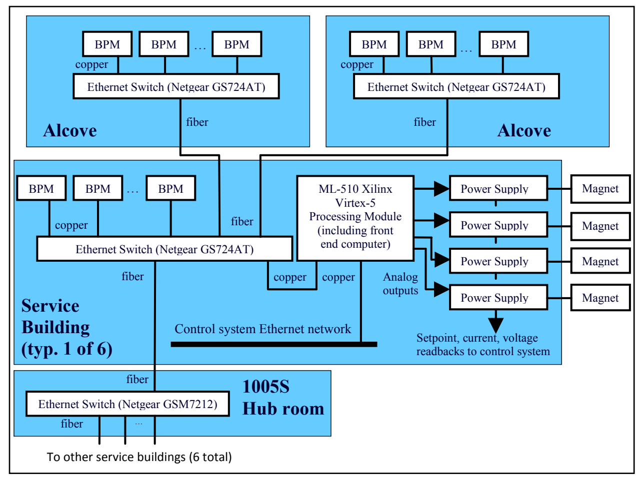

Figure 1: Hardware block diagram.

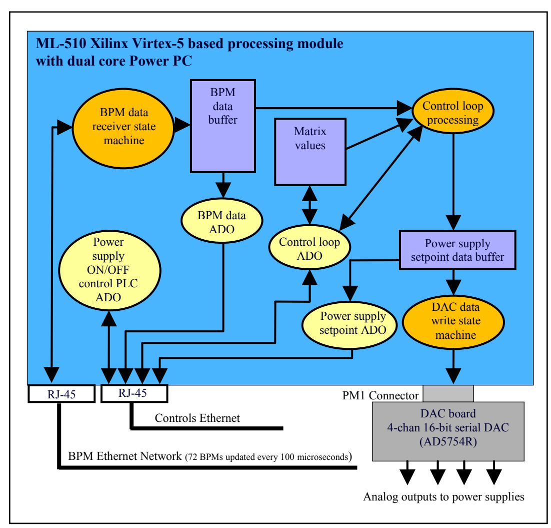

Figure 2: Software/firmware block diagram.

DESIGN DETAILS

BPM Daughter Card

A daughter card was designed for the standard RHIC BPM IFE module (Fig. 4) to distribute position data via a dedicated 1 gigabit Ethernet network. An Altera Arria GX EP1AGX35 gate array is used to calculate the position for a single selected bunch every turn, average 8 consecutive turns, and send the 8-turn average to the ML-510 processing modules located in the 6 service buildings.

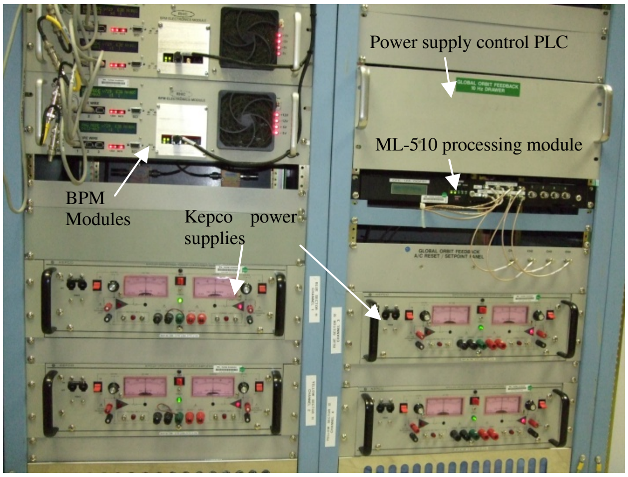

Figure 3: Typical equipment rack layout (1012A) showing BPM modules with Ethernet connection for BPM position data distribution, power supply control PLC panel, Kepco power supplies, and Xilinx Virtex-5 ML-510 processing and analog output module.

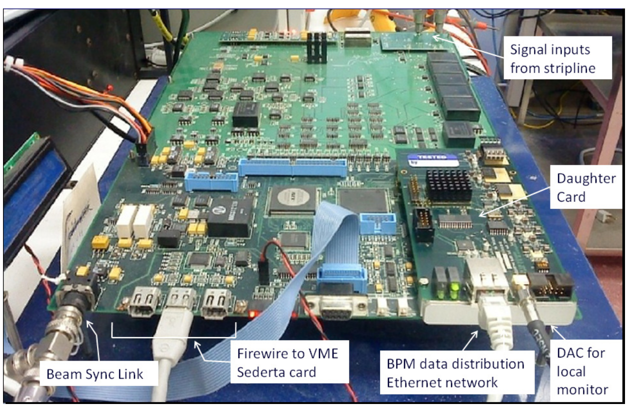

Figure 4: RHIC BPM hardware board with daughter card.

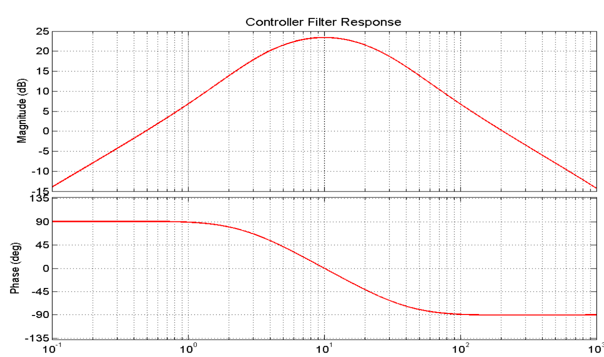

Figure 5: Control loop filter response.

BPM Data Distribution Network [4]

The standard Ethernet low level packet structure was selected for distributing BPM data in order to allow off-the-shelf network switch hardware to be used. After evaluation of several network switches, Netgear models GS724AT (24 RJ-45 connections, with 4 SFP ports) and GSM7212 (12 SFP ports) 1 gigabit switches were selected for their low latency performance (~2 microseconds). The BPM daughter cards connect to the local network switch via RJ-45 CAT-6 cables, and fiber optic cables are used to interconnect the network switches between alcoves and service buildings (Fig. 1). The service buildings are interconnected in a star configuration through a main hub room in building 1005S.

ML-510 Software/Firmware

The software/firmware block diagram for the ML-510 processing module is provided in figure 2. The on-board Xilinx Virtex-5 has a dual core Power PC 440, one of which is running the vxWorks real-time operating system and RHIC accelerator device object (ADO) software for interfacing with the higher level control system via the controls Ethernet network. The other Power PC is unused. The remaining software blocks shown in the diagram are implemented in VHDL gate array code.

Each ML-510 generates setpoints for 4 local magnet power supplies (2 per ring). A 36 x 1 matrix calculations is performed every 103 microseconds to calculate each power supply setpoint using up to 36 BPM measurements per ring. The SVD matrix output value [6] is processed by the control loop filter with the frequency and phase response shown in Fig. 5. This filter has proven very effective in correcting frequencies around 10 Hz while ignoring slow orbit shifts as occur during application of slow orbit feedback [7] and actions such as removal of separation bumps to bring beams into collision.

The corrector magnet power supply setpoints are generated by an AD475R +/-10V 16-bit DAC (Fig. 6). SMA connectors interface to the Kepco power supplies.

Corrector Magnets [5]

Each magnet coil pair is wired in parallel, and in series with a 7-turn reverse coil installed on the magnet in the other ring. The reverse coil is used to counteract the fringe field affects on the other beam. Figures 7 and 8 show a typical magnet installation in the RHIC tunnel. Twenty four magnets are installed in total, 12 in each ring, and are located near each of the triplet magnets that are driving the 10 Hz perturbations.

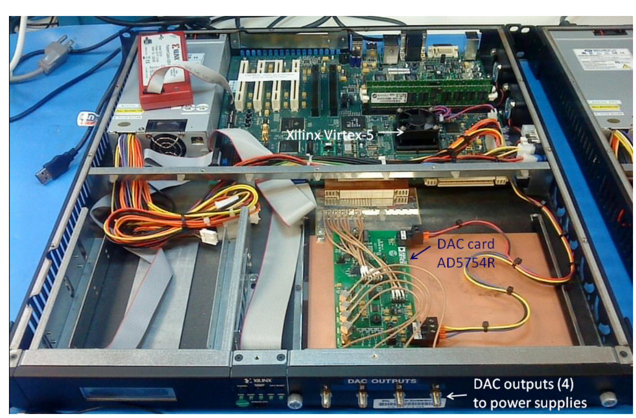

Figure 6: ML-510 processing module with DAC card.

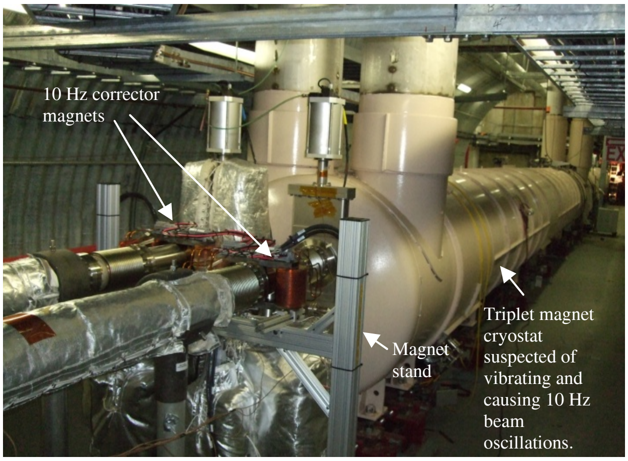

Figure 7: Typical installation of 10 Hz corrector magnets.

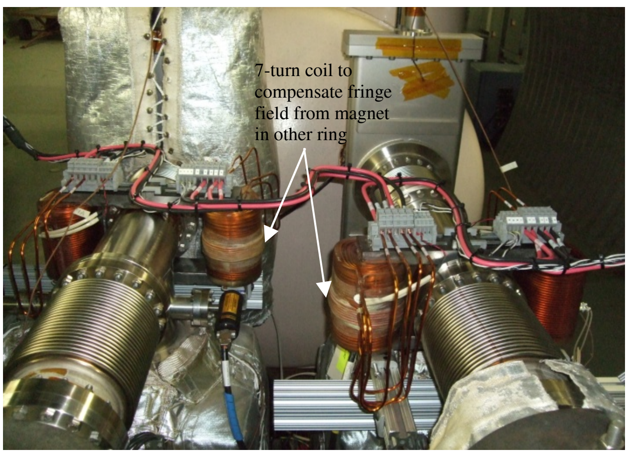

Figure 8: Corrector magnets in sector 12.

RESULTS WITH BEAM

The 10 Hz global orbit feedback system has recently been commissioned and has routinely been turned on during normal physics stores since Feb. 19, 2011.

Position data for a single BPM are shown in Fig. 9, comparing 10 Hz feedback off vs. on. The perturbations are dramatically reduced from about 3000 to about 250 microns peak-peak. Reductions of the same order are evident at all BPMs used for 10 Hz orbit feedback.

The amplitude variations noted when the feedback is off are due to the beating of several frequencies around 10 Hz as the different triplet magnets vibrate at slightly different frequencies [8].

The effect on the experimental collision rates and beam loss rates is shown in Fig. 10. The 10 Hz feedback clearly improves the collision rates and decreases beam loss rates.

Although luminosity lifetime is also expected to improve, additional studies are required in order to prove this expectation. Ideally a store with 10 Hz feedback on would be compared to a store with 10 Hz feedback off, but continuously changing beam conditions make this comparison very challenging.

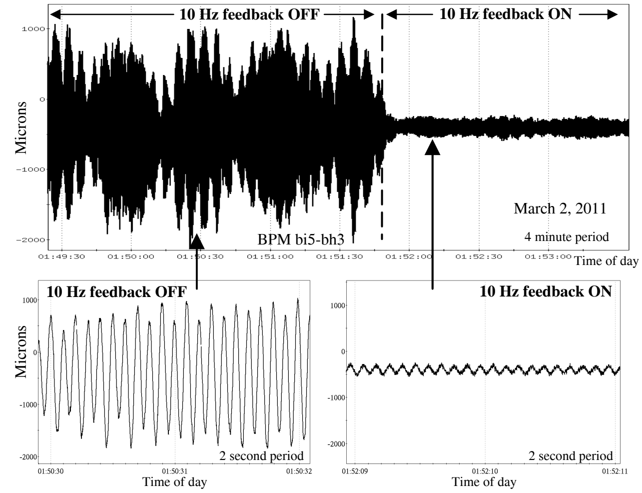

Figure 9: Typical BPM measurement with 10 Hz feedback OFF vs. ON (1000 data points per second).

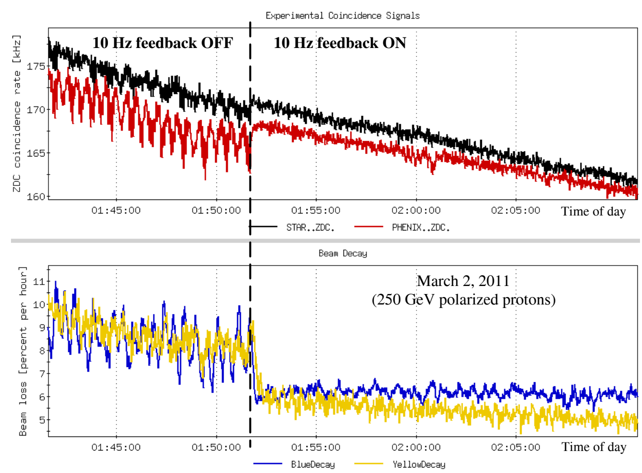

Figure 10: Effect on experimental collision rates and beam loss rates with 10 Hz feedback OFF vs. ON.

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