FAST IR ORBIT FEEDBACK AT RHIC *

C. Montag, R. Michnoff, T. Satogata, C. Schultheiss, A. Marusic, T. Roser,
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

Mechanical low-β triplet vibrations lead to horizontal jitter of RHIC beams at frequencies around 10 Hz. The resulting beam offsets at the interaction points are considered detrimental to RHIC luminosity performance. To stabilize beam orbits at the interaction points, installation of a fast orbit feedback is foreseen. A prototype of this system is being developed and tested. Recent results will be presented.

INTRODUCTION

Horizontal beam jitter at frequencies around 10 Hz has been observed at the Relativistic Heavy Ion Collider (RHIC) for several years [1]. The source of these oscillations has been identified as mechanical vibrations of the superconducting low-β triplets at the six interaction regions. The resulting modulated transverse offsets of the two beams at the interaction points is potentially detrimental to RHIC luminosity performance, since it may lead to emittance growth. Presently, the rms beam jitter amplitude is about 5 – 10 percent of the horizontal rms beam size, assuming the RHIC design emittance of $\epsilon_n = 10\pi\,\mathrm{mm\,mrad}$. After the RHIC-II luminosity upgrade, this relative rms beam jitter amplitude will increase for two reasons. First of all, the reduced transverse beam emittance will result in a smaller beam size, while the absolute beam jitter amplitude will be unchanged. Secondly, reduced β-functions at the interaction points result in larger β-functions at the low-β triplets, in turn leading to increased absolute beam jitter amplitudes caused by vibrations of these triplet quadrupoles. Since mechanical stiffening of the triplet supports turned out to be unfeasible, implementation of a fast orbit feedback in the interaction regions (IRs) is being attempted.

If a single source of a particular beam jitter frequency can be identified, the resulting time-dependent orbit distortion at any location around the ring can be determined from measured beam positions at two beam position monitors (BPMs) anywhere in the ring. However, this approach fails if multiple sources produce the same (or very similar) jitter frequency. It is therefore preferable to determine the beam position at each IP locally. In the case of RHIC, the preferred BPMs are located at the DX separator dipoles, in-between the two low-β triplets, as schematically shown in Figure 1. In this case, there is only a drift space from one of these BPMs through the IP to the other. The orbit between the two BPMs at each IP is therefore just a straight line; the offset $\Delta x_{\rm IP}$ and angle $\Delta x'_{\rm IP}$ of the orbit at the IP can therefore easily be calculated from the two BPM measurements $\Delta x_{\rm BPM\,1}$ and $\Delta x_{\rm BPM\,2}$ and the distance $s_{\rm BPM\,1} - s_{\rm BPM\,2}$ between the two BPMs as

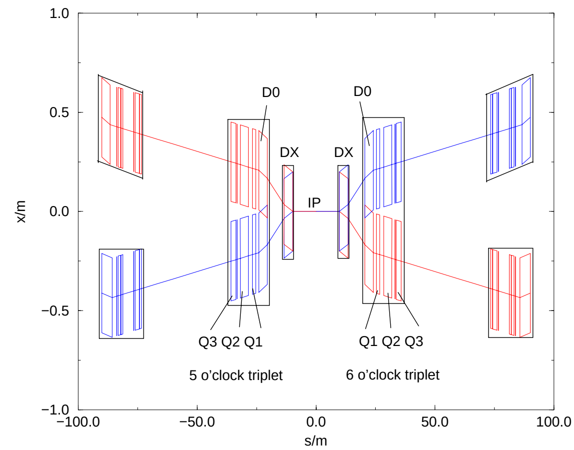

Figure 1: Schematic view of a RHIC interaction region. The BPMs used for the orbit feedback system are installed at the DX separator dipoles, and are therefore common to both beams.

$$\Delta x_{\rm IP} = \frac{1}{2}(\Delta x_{\rm BPM\,1} + \Delta x_{\rm BPM\,2}), \quad (1)$$

$$\Delta x'_{\rm IP} = \frac{1}{s_{\rm BPM\,1} - s_{\rm BPM\,2}}(\Delta x_{\rm BPM\,1} + \Delta x_{\rm BPM\,2}).$$

Offset and angle at the IP can then be corrected by a combination of a symmetric and an asymmetric 4-bump across the IP. Correcting offset and angle at the IP is equivalent to correcting the orbit at both DX BPMs simultaneously. In other words, the combination of symmetric and asymmetric 4-bump can alternatively be described as a combination of two 3-bumps, each of them correcting the beam offset at one of the DX BPMs.

The fact that the two BPMs are located on either side of the IP, with only a drift space in-between, has some important consequences. Due to multiple sources of the orbit jitter, the rms beam jitter amplitude scales with the square root of the local β-function everywhere in the ring. The orbit motion at the two DX BPMs is therefore highly correlated; for a vanishing β-function at the IP they would be in perfect anti-correlation. To suppress beam jitter at the IP by a factor k, the corresponding jitter at each of the two BPMs must be suppressed by the same factor k. Any additional noise Δx_n introduced by the feedback to any one

* Work performed under the auspices of the U.S. Department of Energy

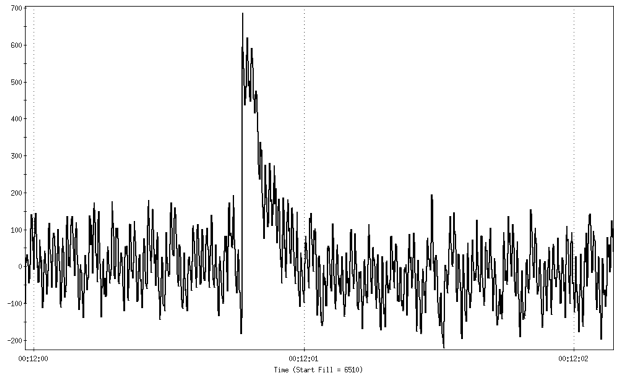

Figure 2: Signal shift due to auto gain bit change.

of the two BPMs translates to additional orbit movement by $\Delta x_n/2$ at the interaction point. A good signal-to-noise ratio is therefore mandatory, which is particularly challenging because the DX BPMs are common to both beams.

For this first test, compensation of beam orbit jitter at a single DX BPM in the “BLUE” RHIC ring was attempted. The measured horizontal beam position signal from the DX BPM is sent to a digital signal processor that calculates the required correction signal and feeds it into three power supplies of the three horizontal corrector magnets that form the appropiate 3-bump to correct the beam position.

BEAM POSITION MONITORING

The BPM electronics provides a $300\,\mathrm{Hz}$ low pass filtered A.C. coupled position signal to the Digital Signal Processor (DSP) module where the feedback control algorithm resides. The DSP control output is provided as a bump position to the three waveform generator modules to provide a closed 3-bump at the DX BPM ring location. Each waveform generator power supply control output adds the required bump setting to the normally calculated set-point.

The BPM electronics for this system are a modified version of the RHIC tune measurement and injection damper BPM signal conditioning electronics [2, 3]. Additional gain has been provided at the final output stage in order to measure the small $10\,\mathrm{Hz}$ beam jitter amplitudes. A.C. coupling was incorporated to prevent output signal saturation when the beam is not centered in the beam pipe.

An auto gain circuit is used to normalize the difference with respect to the sum, thus providing a difference signal that is independent of beam current. This caused difficulties when the A.C. coupling was added. The A.C. coupling capacitor in combination with the resistor to ground for the next stage buffer created a time constant of about $200\,\mathrm{msec}$. When the auto gain varied by a single bit, a noticeable change in the difference signal was detected (Figure 2). The circuit was reworked including the addition of A.C. coupling to the auto gain input to limit this false signal shift. Figure 3 shows $10\,\mathrm{Hz}$ beam oscillations as detected by the DX BPM.

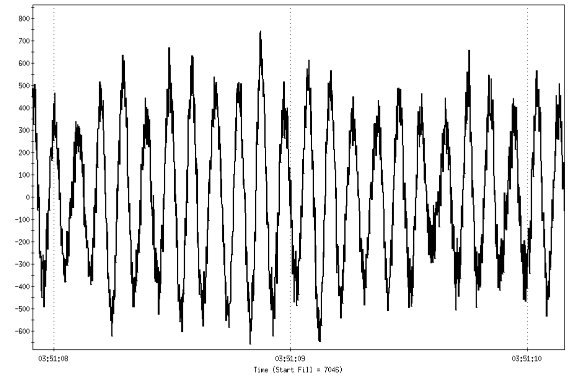

Figure 3: $10\,\mathrm{Hz}$ beam oscillations as detected by the DX BPM.

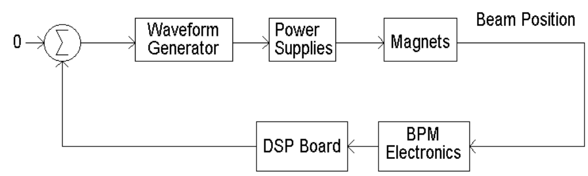

Figure 4: Hardware block diagram.

FEEDBACK ALGORITHM

Two feedback algorithms are being considered. The first algorithm would detect the amplitude and phase of the frequencies to be corrected. This information would drive sine-wave generators that would be summed together to produce the final signal to drive the magnet power supplies. This method would provide individual weighting of the various frequencies; hence the relative correction of each frequency could be controlled. The required bandwidth of the loop would be determined by the rate of change of the amplitude of the individual frequencies. Since the amplitudes change slowly the bandwidth of the loop would be less than that of a position loop. This method has proved to be difficult to implement since the amplitude of each frequency is always positive and does not provide direction information for the loop. Various methods to derive the direction information are being investigated.

The second algorithm is a simple position loop. The position of the beam is measured with a BPM and corrections are sent to the magnet power supplies to cancel the oscillations.

These two algorithms can be implemented with the same hardware since the method of processing the BPM beam position information is the only difference. Figure 4 shows a block diagram of the hardware.

The BPM electronics provides a signal that is proportional to the beam position. This signal is digitized on the DSP board at $720\,\mathrm{Hz}$. This is the frequency that the set-points are sent to the power supplies and provides synchronization between the set-points and the corrections. The

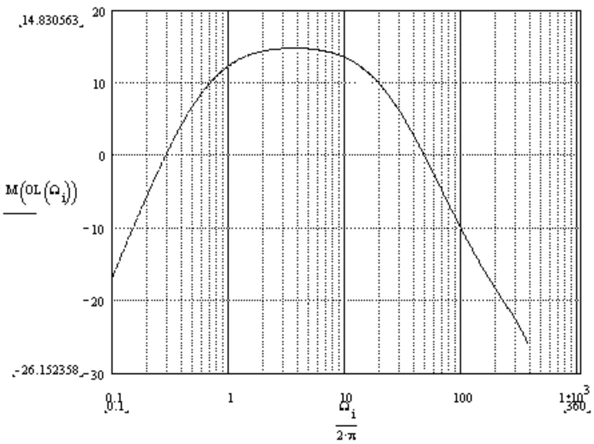

Figure 5: Open-loop response of the position loop.

DSP board performs a Goertzel algorithm [4] that supplies a spectrum of the beam position in real-time. Since the algorithm provides a new spectrum for each new data point it can support the $720\,\mathrm{Hz}$ correction rate. The DSP provides loop compensation with digital filters and sends the corrections to the waveform generators in the form of millimeters of beam position at the location of the BPM. The waveform generators convert this beam position to current set-points for the three power supplies that generate the bump.

The frequencies to be corrected range between approximately $5\,\mathrm{Hz}$ and $20\,\mathrm{Hz}$. The loop is A.C. coupled to insure that the steering for collisions at the IP is not affected. These considerations drive the frequency response of the position loop. Figure 5 shows the open-loop frequency response for this loop.

The open-loop response shows a region of flat gain around $4\,\mathrm{Hz}$; ideally this should be around $10\,\mathrm{Hz}$. The roll-off is caused by $20\,\mathrm{Hz}$ set-point filters in the power supplies. These filters will be moved to a higher frequency to provide a flatter response above $10\,\mathrm{Hz}$.

The position loop was simulated with the MatLab model shown in Figure 6. White noise was included in the model with a signal-to-noise ratio of $40\,\mathrm{dB}$. The simulation also included a beam position offset to test the effect of the A.C. coupling. The simulation shows a reduction of the disturbances by a factor of 5.

The software to implement the position loop is presently being written. The system will be tested in RHIC before the end of this year's run.

CONCLUSION

During first tests with beam, the response of the DX BPM to a signal input at the waveform generators was measured in the frequency range of interest, from $3\,\mathrm{Hz}$ to $20\,\mathrm{Hz}$. Based on these data, the feedback algorithm will be adjusted if necessary, and we expect to be able to close the feedback loop in the near future.

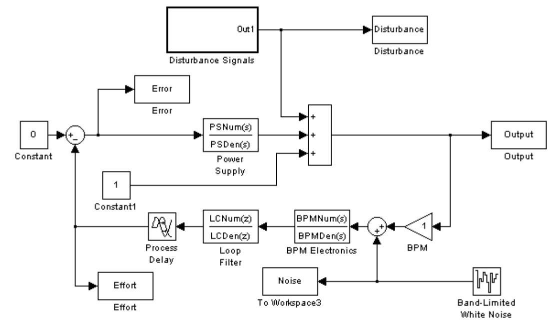

Figure 6: Position loop MatLab model.

REFERENCES

[1] C. Montag, M. Breannan, J. Butler, R. Bonati, P. Koello, “Measurements of Mechanical Triplet Vibrations at RHIC”, Proc. EPAC 2002

[2] A. Drees, R. Michnoff, M. Brennan, J. DeLong, “ARTUS: The Tune Measurement System at RHIC”, Proc. BIW 2000

[3] A. Drees, R. Michnoff, M. Wilinski, C. Montag, P. Cameron, “RHIC Transverse Injection Damping”, Proc. PAC 2003

[4] E. Jacobsen, R. Lyons, IEEE Signal Processing Magazine, vol. 20, issue 2, pp. 74 – 80, March 2003