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Status of Fast IR Orbit Feedback at RHIC

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DISCLAIMER

STATUS OF FAST IR ORBIT FEEDBACK AT RHIC

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Abstract

To compensate modulated beam-beam offsets caused by mechanical vibrations of IR triplet quadrupoles at frequencies around 10 Hz, a fast IR orbit feedback system has been developed. We report design considerations and recent status of the system.

INTRODUCTION

Beams at the Relativistic Heavy Ion Collider (RHIC) jitter in the horizontal plane at frequencies around 10 Hz. This oscillation is caused by mechanical vibrations of the superconducting low-β quadrupole triplets in the interaction regions (IRs). Beam jitter frequencies coincide with mechanical eigenmodes of the triplets that are driven by helium flow [1]. The modulated beam-beam offset caused by the orbit oscillation is likely to cause emittance growth, thus limiting the attainable luminosity in the machine. To compensate this modulated offset, a fast IR orbit feedback is currently being developed.

Beam position monitors (BPMs) in the DX separator dipoles (see Figure 1) on each side of each IP are being used to determine the position of each beam at the IP. To keep the system as simple as possible, it was decided to correct the relative offset of the two beams at the IP by applying orbit bumps to the "blue" RHIC beam only. Based on the four DX BPM signals BL, BR, YL, and YR, the required correction signal is derived as

$$\delta = \frac{BL+BR}{2} - \frac{YL+YR}{2}, \qquad (1)$$

as schematically shown in Figure 2.

During preliminary test in FY05, it was atttempted to use regular RHIC dipole correctors to provide the required orbit correction [2]. However, the large inductance of these magnets resulted in a bandwidth of only 20 Hz. While this bandwidth may have been sufficient to compensate orbit jitter around 10 Hz, it resulted in unwanted amplification at higher frequencies, in particular at the 60 Hz line frequency.

To overcome the bandwidth limitation, additional warm air coil dipoles were installed in the focal points of the low-β triplets, as schematically depicted in Figure 3. These dipole correctors provide a closed 180 degree orbit bump across the IP. Due to the anti-symmetric IR optics the kick angles required on the two sides of an IP are different. This difference is reflected in the number of turns per coil, so that both magnets can be connected in series to a single power supply.

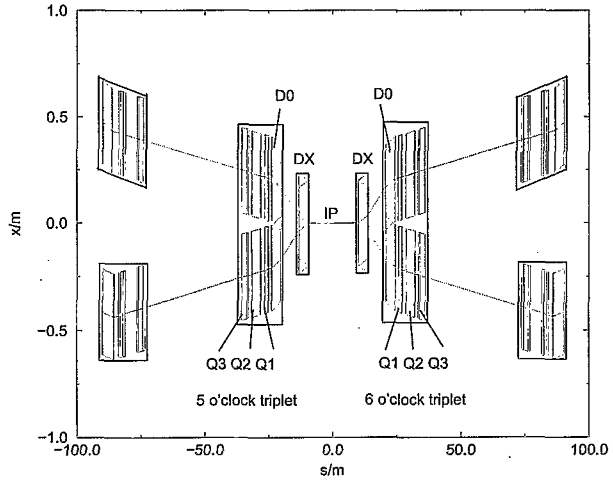

Figure 1: Schematic view of a RHIC interaction region. The BPMs used for the orbit feedback system are installed at the DX separator dipoles, and are therefore common to both beams.

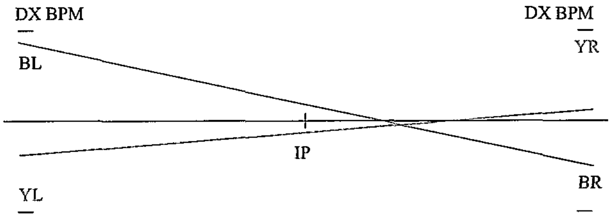

Figure 2: Derivation of the relative offset of the two beams at the IP from BPM measurements taken at the DX separator dipoles.

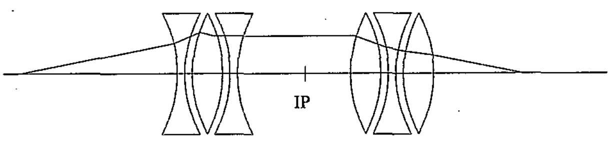

Figure 3: Location of the warm dipole correctors in the focal points of the superconducting low-β triplets. Note that the anti-symmetric optics requires different bending angles at the two correctors.

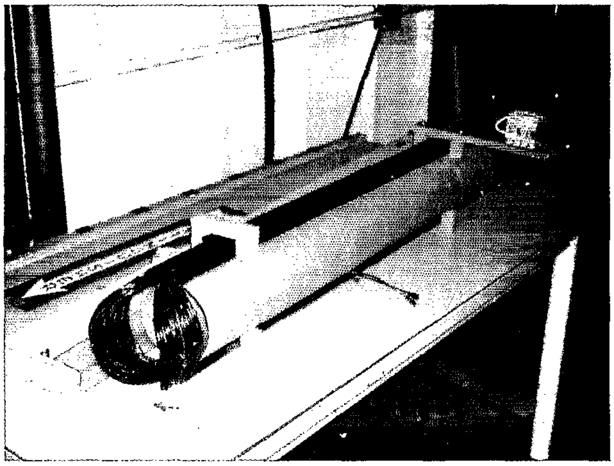

Figure 4: Photo of a correction coil during testing.

MAGNETS

The warm corrector coils are made of #8 wire wound directly on the beam pipe. Each magnet is 1 m long and consists two halves with $2 \cdot 36$ resp. $2 \cdot 49$ turns each. At a nominal current of 4.7 A these magnets are capable of providing an orbit offset of 50 μm at the IP at full beam energy - twice as much as necessary according to beam position measurements. With magnet inductances of 7 mH for the weaker of the two corrector coils with 72 turns, and 10 mH for the 98 turn magnet, the voltage required to provide a 50 μm oscillating orbit bump at $f = 10$ Hz is about 5 A when the magnets are connected in series. The magnets are connected to a KEPCO 12 A, 36 V power supply.

The shielding effect due to eddy currents in the beam pipe has been measured on a test bench (Figure 4). For this purpose, a pickup coil was inserted into the magnet while the magnet was powered at different frequencies, with and without a stainless steel beam pipe. The obtained transfer function (Figure 5) shows a pole at 48 Hz, which needs to be included in the feedback loop design.

BEAM POSITION MONITORS

The BPM electronics for this system are a modified version of the RHIC tune measurement and injection damper BPM signal conditioning electronics [3, 4]. These electronics provide a low pass filtered signal. Additional gain has been provided at the final output stage in order to measure the small 10 Hz beam jitter amplitudes. AC coupling was incorporated to prevent output signal saturation when the beam is not centered in the beam pipe. Normalization of the difference signal with respect to the sum is achieved by an auto gain circuit.

FEEDBACK ALGORITHM

The four DX BPM signals are electronically combined according to Equation (1) to derive the relative beam offset δ at the IP. The resulting signal is digitized at 37.8 kHz, and processed by a PENTEK DSP board. The DSP provides loop compensation with digital filters and sends the correction signal to the KEPCO power supply. Figure 6 depicts the open loop gain of the system as simulated by MatLab.

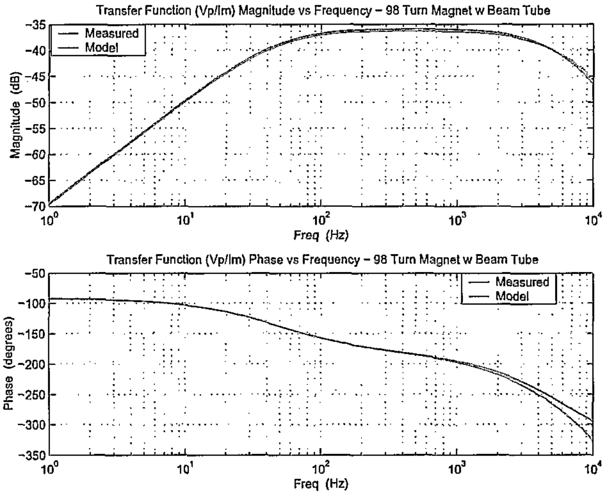

Figure 5: Measured magnetic field derivative of the correction coils vs. frequency, amplitude (top) and phase(bottom).

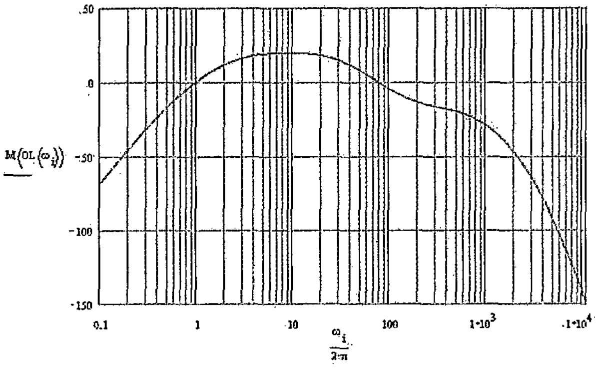

Figure 6: Open loop gain.

TEST RESULTS

The 10 Hz varies in amplitude and is mixed with other frequencies. Since data could only be taken with the system either on or off, this variation required averaging the data taken in the two states. To analyze the results of running the system, FFTs of the correction signal were averaged with the system in each of these two states. The FFTs were each a fixed length of one second, and the starting point of each FFT was walked through the data with an advance of 6.944 msec at each step. This produced averaging over twenty cycles of the 10 Hz and produced 144 spectra each for the two

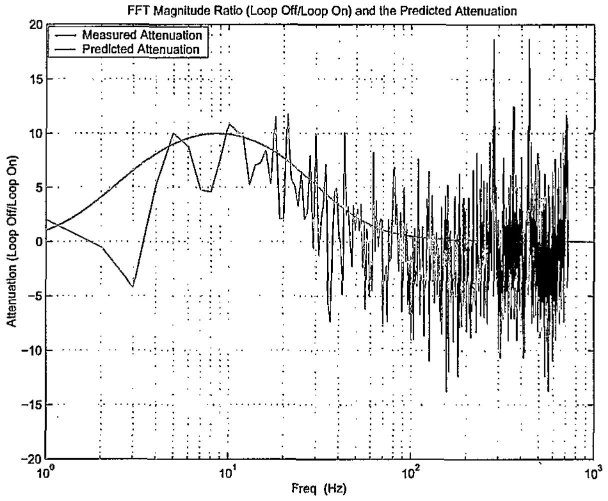

Figure 7: Measured IP orbit offset reduction.

system states. The average for each system state was computed by summing the magnitude of each frequency bin over the 144 spectra and dividing by the number of spectra. This produced average spectra for the on and off states. The ratio of the average spectrum's attenuation (Loop Off/Loop On) is plotted in Figure 7 along with the predicted attenuation from the feedback control system analysis. There is good agreement between the predicted attenuation and the measured attenuation.

CONCLUSION

The A/D converters of the PENTEK DSP board cause a time delay of 16 sampling periods. This results in a significant phase shift, even though the sampling rate is very high compared to the intended bandwidth of the system. This phase shift limits the use of low pass filtering in the feedback loop, which would be necessary to remove high frequency noise from the BPM signals. To overcome this limitation, it is planned to replace the existing PENTEK DSP boards with a type that uses A/D converters that do not cause severe time delays.

ACKNOWLEDGEMENTS

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