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DISCLAIMER

RECENT TRIPLET VIBRATION STUDIES IN RHIC*

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Abstract

We report on recent developments for mitigating vibrations of the quadrupole magnets near the interaction regions of the Relativistic Heavy Ion Collider (RHIC). High precision accelerometers, geophones, and a laser vibrometer were installed around one of the two interaction points to characterize the frequencies of the mechanical motion. In addition actuators were mounted directly on the quadrupole cryostats. Using as input the locally measured motion, dynamic damping of the mechanical vibrations has been demonstrated. In this report we present these measurements and measurements of the beam response. Future options for compensating the vibrations are discussed.

INTRODUCTION

RHIC consists of two 3.8 km long counter-rotating superconducting accelerators [1] with six symmetrically located interaction regions. As shown in Fig. 1, three super-conducting quadrupole magnets, forming a “triplet”, labelled Q1, Q2, and Q3 are located on either side of the interaction region for a total of 72 such magnets per accelerator. Previous studies [2] have shown that the flow of liquid Helium in the cryogenic systems caused low frequency vibrations of the magnets, that each triplet vibrated at multiple unique frequencies and that the influence of the triplet vibrations on the beam trajectories was predominantly on the horizontal beam orbits. Mitigation techniques have included mechanical decoupling of the cryogenic lines, orbit feedback designed to zero the difference in beam positions [3] at the interaction points (IPs) and passive stiffener designs.

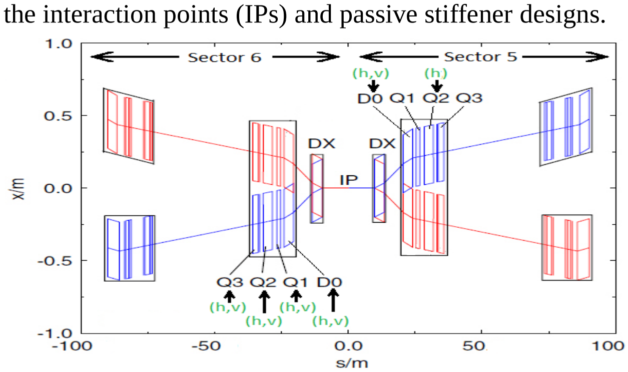

Figure 1: Layout of an interaction region showing triplet quadrupoles (Q1-Q3), D0 dipoles, and common DX magnets on each side of the IP. Also shown are the locations of new motion sensors for detection of horizontal (h) and vertical (v) vibrations.

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For many years it appeared that the triplet vibrations had little if any impact on collider performance. During run-8 however an attempt to operate with betatron tunes near integer was abandoned due to excessive detector backgrounds correlated with closed orbit distortions induced by the vibrating triplets [4]. In run-9, during operation with high-energy polarized protons, beam measurements showed that not only the beam orbits but also the betatron tunes were significantly modulated at frequencies near ~10 Hz [5]. These observations have renewed interest in mitigation techniques. In this report developments since run-8 are presented.

INSTRUMENTATION

Superconducting magnets for one of the two circulating beams were equipped with motion sensing geophones for detection of horizontal (h) and vertical (v) vibrations in two of the cryostats closest to one of the two IPs (see Fig 1). To accomplish this, a holder block, potted with both a horizontal and a vertical geophone, was installed on the top of the cold mass of each magnet at the axial location of the posts on each end of each magnet as shown in Fig. 2. Horizontal vibration measurements were made with 375 Ω SM-6 geophones (Sensor, the Netherlands) while vertical measurements were made with 4000 Ω GS-11D geophones (Geospace Technologies, Houston TX). Both these geophones had a natural frequency of 4.5 Hz and sensitivities of 28.8 V/m/s horizontally and 32 V/m/s vertically.

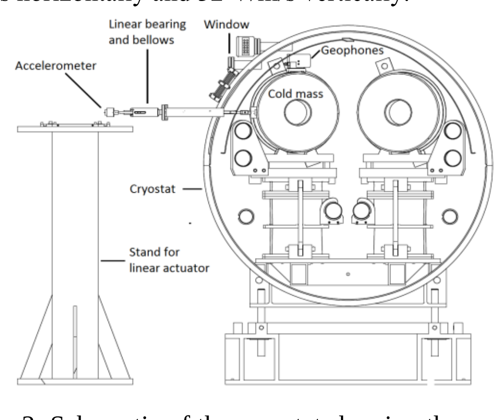

Figure 2: Schematic of the cryostat showing the mounting of the geophones and the connection to the cold-mass.

In addition, a laser vibrometer system was also set up as a backup in case the geophones were to malfunction when cooled to 4.5 K. Each geophone block was equipped with a reflector and a glass port was installed on the cryostats at each geophone station for laser access.

Data were acquired using a 16-bit National Instruments DAQCard 6036E ADC controlled by LabView software. All geophones were tested and calibrated at 77K in liquid nitrogen before installation to test whether these nominally room temperature devices would operate properly at cryogenic temperatures. Liquid nitrogen testing was chosen since most changes due to contraction would take place by 77K and testing in liquid helium would have been more costly. Several geophones were initially tested in liquid helium to verify proper operation before switching to nitrogen.

The raw time domain data files were processed by LabView software performing fast Fourier transforms (FFTs) to generate power density spectra and integrated spectra, which provided vibration displacements in nanometer range. Data sampling rate was 1.6 kS/s (625 µs sampling interval), so each spectrum represents data taken over a time period of 143.5 s.

Two external accelerometers (Model 731A with P31 preamps by Wilcoxon Research, Geithersburg, Maryland) were also installed on each end of the Q2 magnet in sector 6. As shown in Fig. 2, these were mechanically connected to the cold mass through thin-walled stainless steel tubes, appropriate coupling links, linear bearings and a balanced bellows arrangement. Similar mechanical connections with additional external links were used to attach two electromechanical linear actuators mounted securely on stands fastened to the tunnel floor as illustrated in Fig. 3.

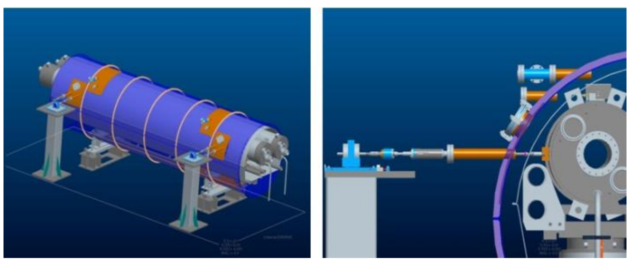

Figure 3: Schematic views of the 4 m long cryostat section showing the supports for the linear actuators.

VIBRATION ANALYSIS RESULTS

An example of vibration spectra is shown in Fig. 4, which were generated with horizontal data measured at the sector 6 Q3 triplet quadrupole during 4.5 K operation (without beam) with a stable supercritical helium flow rate of 125.602 g/s. At this location, data were also taken with the laser vibrometer system. The resolution in the frequency domain was 0.0977 Hz. The voltage resolution for the time domain vibration signals was 0.153 mV and 0.0153 mV for the geophone and laser, respectively.

The agreement between the geophone and laser measurements in the range of 5 - 50 Hz was very good, with the smallest discrepancy in the 6 to 20 Hz range of most interest being less than 7%. From 2 to 6 Hz the relative error increased to as much as 10%. Major peaks in the displacement spectrum were observed at the following frequencies: 5.2. 5.7, 6.3, 6.9, 8.5, 10.6, and 12.4 Hz, with the largest amplitude of 375 nm at 6.9Hz. These amplitudes are typical of the triplet quadrupoles, whereas the D0 dipoles exhibited larger displacements of about 1200 nm at 6.7 Hz in sector 6 and about 1600 nm at 7.4 Hz in sector 5.

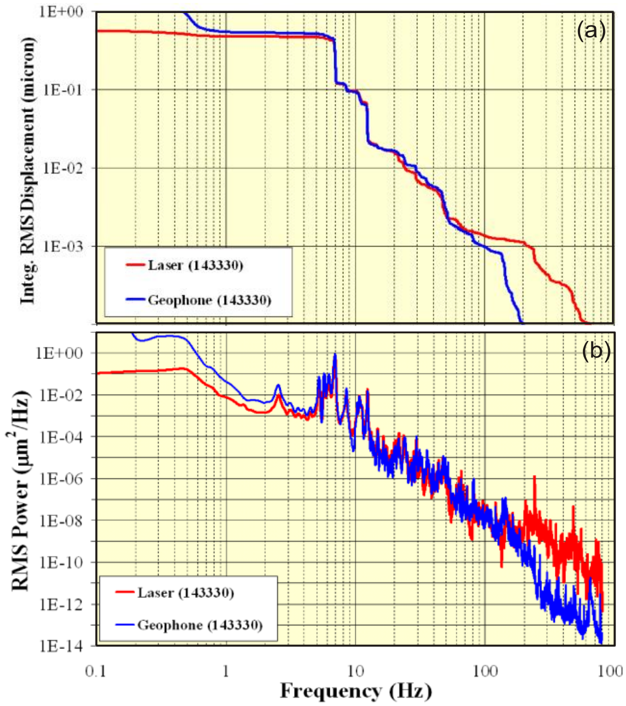

Figure 4: Integrated rms horizontal displacement (a) and rms power spectra (b) measured at a triplet quadrupole in sector 6 using a geophone and a laser vibrometer.

BEAM RESULTS

During run-9 select geophones and beam position monitor (BPM) data were logged through the control system with MADCs sampling at a 720 Hz rate. Shown in Fig. 5 are FFTs of the measurements from the geophone mounted on the Q2 magnet in sector 5 along with simultaneously acquired horizontal beam positions. These data demonstrate conclusively that the observed perturbations to the beam orbits are a direct result of the triplet vibrations. Moreover the high precision of both sets of data reveal that large amplitude quadrupole excitation frequencies were present in the beam trajectories.

Of note are excitations (of considerably lower amplitude than the dominant response near ~ 10.4 Hz) detected in the beam position measurements at frequencies not observed at this Q2 quadrupole. These are suspected to be due to vibrations of triplets located elsewhere in the accelerator.

During run-9 a dedicated study was performed with intentionally driven excitations of the Q2 magnet in sector 6. Shown in Fig. 6 are the deflection angles reconstructed from geophone measurements as a function of the voltage applied equally to the two actuators for three different frequencies of excitation including the at that time dominant frequency of the beam response of ~ 10.3 Hz. FFTs of the BPM data acquired simultaneously showed relatively good agreement. Extrapolation of each curve in Fig. 6a to the intercept gives an estimate of the required corrector strength that would be needed to compensate the natural motion of the beam at these frequencies.

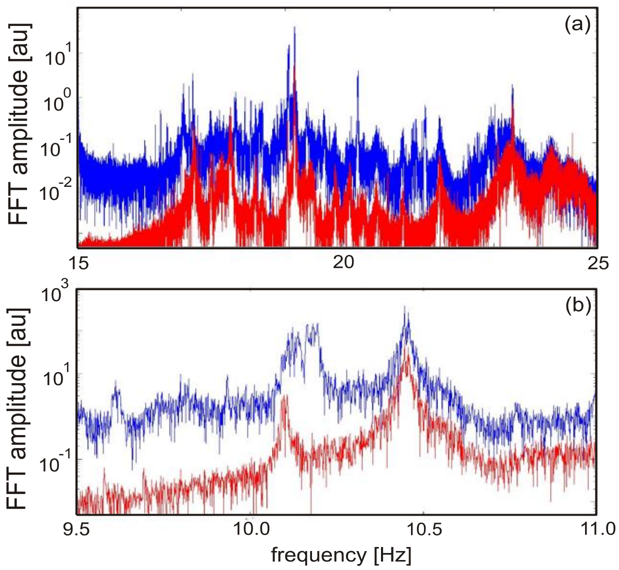

Figure 5: FFTs of horizontal beam position (blue) and geophone measurements on Q2 in sector 5 (red) acquired simultaneously over a relatively wide frequency range (a) and with an expanded view around the dominant frequencies experienced by the beam (b).

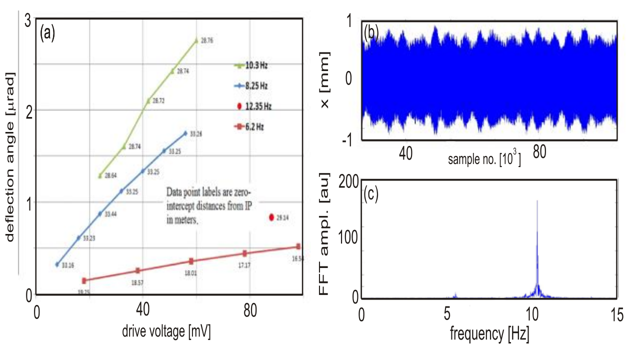

Figure 6: Deflection angle inferred from geophone measurements while driving the two actuators (a), BPM data (b), and BPM FFT (c) with 10.3 Hz / 60 mV drive.

DYNAMIC DAMPING RESULTS

Active damping of one of the quadruples was demonstrated using integrated signals from two accelerometers to drive two linear actuators connected to each end of the cold mass (see Figs. 2 and 3). This configuration provides forces proportional and opposite to the velocities of both ends of the cold mass. The result of the damping using an analogue feedback is illustrated in Fig. 7. The curves show FFTs of the motion of the center of the magnet derived from both accelerometers. If such an active damping systems were to be adopted, a digital feedback loop would be used for even better performance

LOCAL ORBIT FEEDBACK

Figure 8 illustrates a possible arrangement where the motions of the magnets are continuously sensed using precise displacement gauges; for example, accelerometers with appropriate integrators. The signals from the gauges would be combined in two linear networks to drive small corrector dipoles at either end of the cryostat. With this design trajectory compensation both in position and angle are achieved so that the orbit outside of each cryostat remains unaffected by the motions of the magnets within.

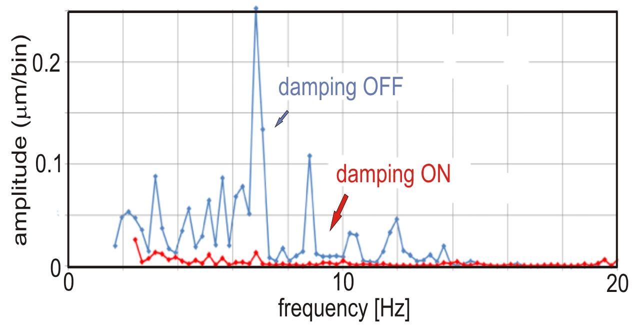

Figure 7: Demonstration of dynamic damping of locally detected mechanical motion.

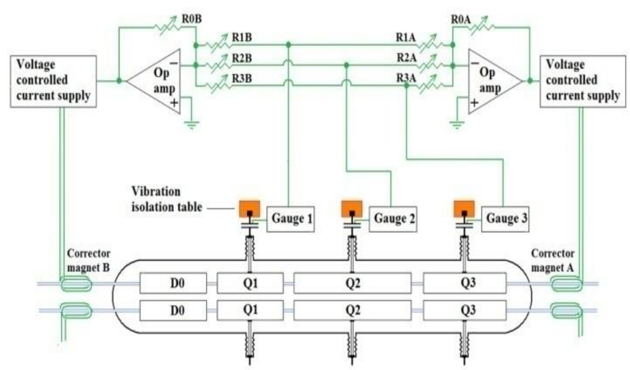

Figure 8: Schematic arrangement for local orbit feedback.

SUMMARY

Precision motion sensors and actuators were installed directly on cryostats near one interaction region. Data obtained evidenced a rich spectrum of frequencies which were shown to be directly correlated with the beam motion. Methods of compensation were presented including dynamic damping, which was successfully demonstrated using the new installations, and local orbit feedback. A less expensive approach namely global orbit feedback [6] tailored to damp trajectory oscillations near ~10 Hz is also in a prototyping phase.

REFERENCES

[1] T. Roser, Proc. of EPAC08, p. 3723 (2008).
[2] C. Montag et al, Nucl. Instr. Meth. A 564, 26-31 (2006).
[3] C. Montag et al, Proc. of PAC05, p. 3298 (2005).
[4] C. Montag et al, Proc. of EPAC08, p. 2563 (2008).
[5] M. Minty et al, these proceedings (2010).
[6] R. Michnoff et al, to be published.