

Observation of Mechanical Triplet Vibrations in RHIC*

C. Montag, M. Brennan, J. Butler, R. Bonati, P. Koello, BNL, Upton, NY 11973, USA

Abstract

Mechanical vibrations of the RHIC IR triplets has been identified as the dominant source of horizontal orbit jitter in the frequency domain below 20 Hz. Results of detailed measurements are reported to characterize these effects.

1 INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) is designed and built to collide ions from protons to fully stripped gold at energies up to 250 GeV for protons and 100 GeV/nucleon for heavy ions. The two 3.8 km long superconducting storage rings (“Blue” and “Yellow”) of RHIC intersect at six equidistantly-distributed locations around the machine circumference, as shown in Figure 1. The nomenclature of these interaction regions (IRs) resem-

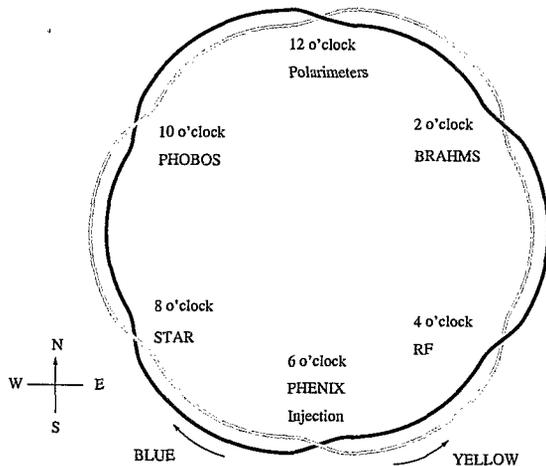


Figure 1: RHIC schematic overview

bles a clock, with “12 o'clock” referring to the northernmost IR. Within each of these IRs, the superconducting low- β quadrupole triplet on the right – as seen from the center of the RHIC rings – bears the same number as the IR itself, while the left triplet is named after the arc to its left. For example, in the 6 o'clock interaction region, the right triplet is called the 6 o'clock triplet, while the left one is referred to as the 5 o'clock triplet. Four out of six IRs are equipped with detectors: BRAHMS (2 o'clock), PHENIX (6 o'clock), STAR (8 o'clock), and PHOBOS (10 o'clock). The 12 o'clock interaction region is occupied by polarimeters, while the RF cavities reside at 4 o'clock. However, all six IRs are equipped with identical magnets.

During the 2001 RHIC run, purely horizontal orbit jitter with frequencies around 10 Hz was detected in both

rings [1]. This oscillation can be observed at all BPMs around the rings regardless of betatron phase, indicating distributed sources. At storage energy the amplitude of this vibration corresponds to 5...10 percent of the rms beam size at a nominal 6σ normalized emittance of 10π mm mrad. A spectral analysis of this orbit jitter revealed that spectra in both beams are almost identical, Figure 2. Therefore this effect was likely to be caused by single or multiple common vibration sources.

As already mentioned earlier, the two RHIC rings share

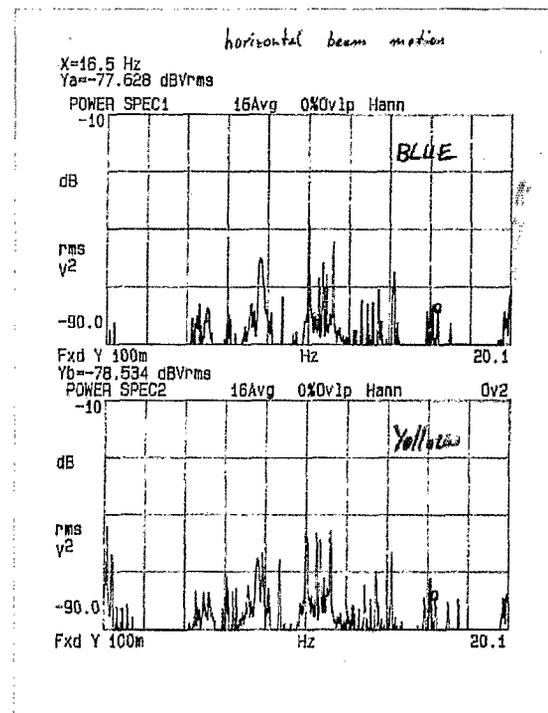


Figure 2: Simultaneously measured horizontal orbit vibration spectra in the BLUE (top) and YELLOW (bottom) RHIC rings.

only very few common magnetic elements in the IRs, while the D0 dipoles and the entire arcs are completely independent, Figure 3. The observed horizontal orbit oscillation could therefore be caused by power supply ripple on the DX dipoles, or by mechanical vibration of the triplet quadrupoles, which share a common cryostat for both rings though the actual magnets are mechanically independent. During a maintenance day in October 2001, vibration measurements were performed at all RHIC triplet cryostats to determine the sources of the orbit jitter.

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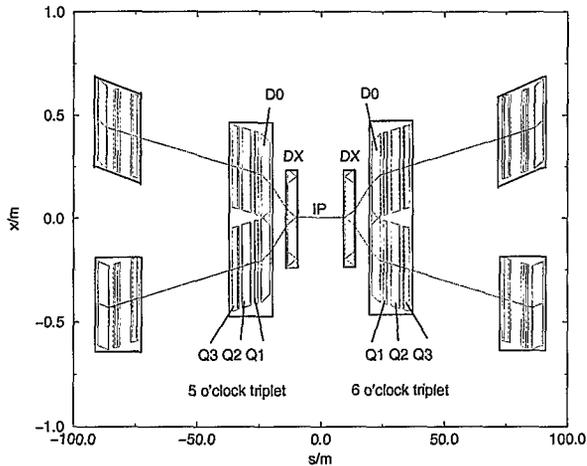


Figure 3: Schematic view of a RHIC interaction region lattice. Both beams collide head-on at the interaction point (IP) and are separated by the DX dipoles. Both orbits are bent back to an almost parallel direction by the D0 dipoles. Strong focusing is provided by superconducting triplets consisting of the quadrupoles Q1, Q2, and Q3.

2 VIBRATION MEASUREMENTS

Vibration measurements were performed on the outside of all RHIC cryostats, using a 3-axis accelerometer. This sensor was connected to a spectrum analyzer to study vibration characteristics in all three directions. Each triplet showed one or two dominant lines around 10 Hz in the horizontal direction, while few exhibited significant lines in the vertical plane. The dominant frequency lines detected in the horizontal plane clearly explain almost all dominant lines present in the horizontal beam jitter spectrum. As an example, Figure 4 shows the acceleration spectrum of horizontal motion of the 4 o'clock triplet, together with the spectrum of horizontal beam orbit vibration. The two peaks at 10.14 Hz and 16.50 Hz can be clearly identified in the beam jitter spectrum. Table 1 summarizes all major peaks within the beam jitter spectrum (Figure 2), together with the triplet at which these lines could be identified in the vibration spectrum of the cryostat, and the amplitude of the cryostat vibration. As this table shows, 13 out of 14 dominating frequencies in the horizontal beam jitter spectrum can be explained by mechanical motion of specific triplets.

3 MECHANICAL CONSIDERATIONS

Each triplet cryostat contains eight cold masses: two cold masses for the two D0 dipoles, and two for each pair of quadrupoles Q1, Q2, and Q3. Each of these cold masses is suspended on two posts, which for mechanical considerations can be regarded as springs, as schematically shown in Figure 5. The connection between the cold masses is stiff only in the longitudinal direction, while it is designed to allow independent transverse motion [2]. Therefore, coupled

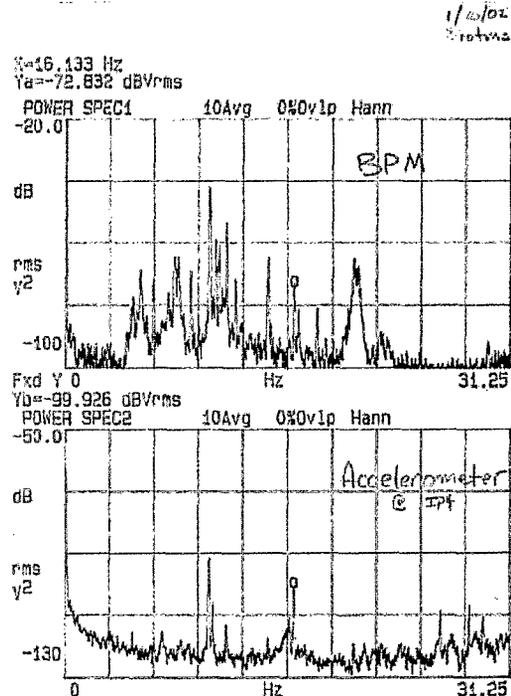


Figure 4: Simultaneously measured beam orbit vibration spectra in the YELLOW RHIC ring (top) and the 4 o'clock triplet acceleration (bottom).

motion of the cold masses is neglected.

The configuration with two posts allows for two oscillation

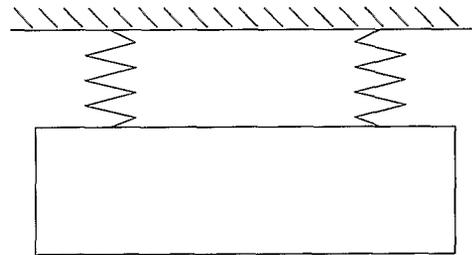


Figure 5: Mechanical model of a quadrupole cold mass suspended on two posts, indicated as springs here.

tion modes for each cold mass, a dipole mode with resonance frequency $f_d = \sqrt{2D/m}$, and a quadrupole mode with resonance frequency $f_q = \sqrt{2Ds^2/\Theta}$. Here, D denotes the spring constant of the posts, m the mass of the cold mass, s the distance from the center of the cold mass to the location of the post, and Θ the moment of inertia of the cold mass. Approximating the cold mass as a solid cylinder with length L and radius R , its moment of inertia can be calculated as

$$\Theta = \frac{mR^2}{4} + \frac{mL^2}{12}. \quad (1)$$

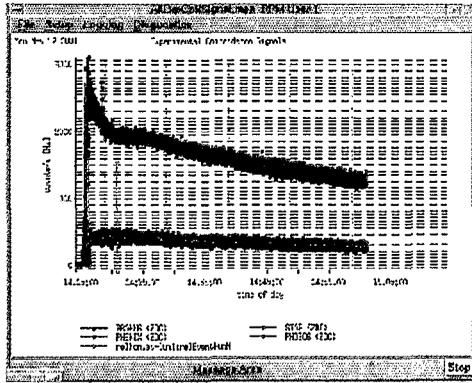


Figure 7: Luminosity during the first 45 minutes into a store.

IR triplet quadrupoles. A possible explanation of these vibrations is an oscillating helium pressure wave in the downward-angled leads of the triplets [4]. When liquid helium reaches the warm end of the lead, it quickly warms up and changes into its gaseous phase, leading to a greatly increased volume. This helium gas pushes the liquid helium back until an equilibrium is reached. The helium gas is subsequently pumped away, leaving room for liquid helium, which flows back to the warm end of the lead, where the whole process repeats. The resulting pressure wave oscillation could introduce sufficient force to the cold mass to cause the observed vibration. The mechanical resonance frequency of the cold mass on its two posts is also near 10 Hz, and this could further enhance the effect.

This scenario is consistent with the observation that the mechanical triplet vibration could no longer be detected during the shutdown after the machine had been warmed up. A more direct test of this hypothesis could be performed by increasing the helium flow in the leads such that the entire lead is eventually cooled to liquid helium temperature, avoiding the reflection of liquid helium. However, this test cannot be performed easily, because the helium flow is determined by fixed orifices.

If this model explains the observed triplet vibrations, an increased helium flow in the leads will eliminate it entirely. Other possible remedies include installation of an active feedback system to stabilize orbit jitter at the IPs. However, such a system would have to rely on the common beam position monitors near the IPs, which are currently not reliable enough for this purpose [5].

Simulation studies are being performed to investigate possible emittance growth caused by beam centroid motion at the interaction points during beam collisions, and associated beam-beam driven tune modulation. This work is still in progress, as well as vibration measurements on the cold masses of one sample triplet.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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