HELIUM FLOW INDUCED ORBIT JITTER AT RHIC *

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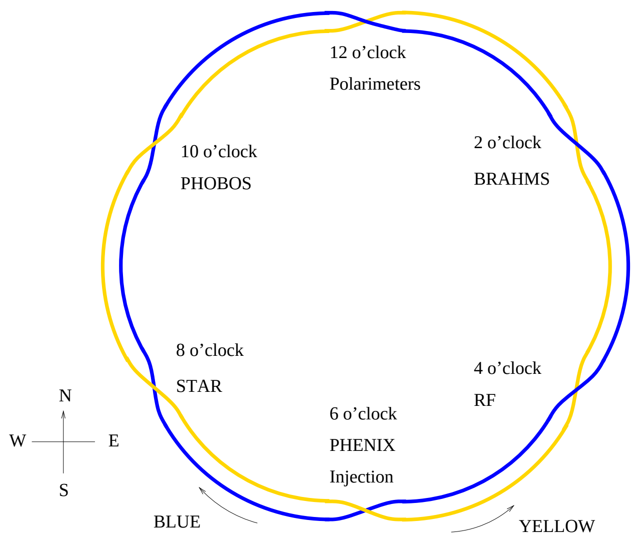

Figure 1: Schematic overview of the RHIC colliderr with its six interaction regions.

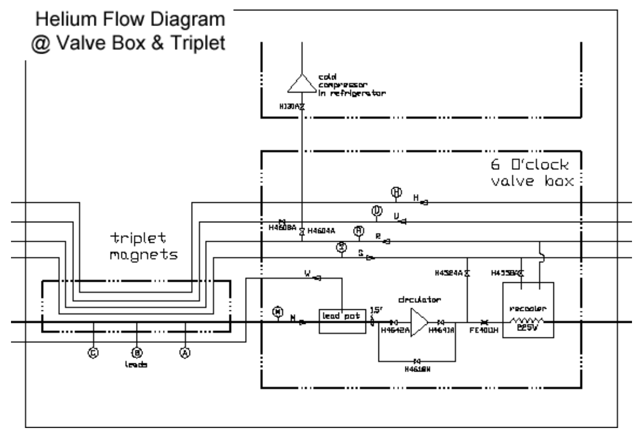

Figure 2: Flow diagram of the RHIC triplet cryostat and the associated valve box at the 6 o'clock location.

Abstract

Horizontal beam orbit jitter at frequencies around 10 Hz has been observed in RHIC for several years. The distinct frequencies of this jitter have been found at superconducting low-beta quadrupole triplets around the ring, where they coincide with mechanical modes of the cold masses. Recently, we have identified liquid helium flow as the driving force of these oscillations.

INTRODUCTION

THe Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory consists of two superconducting storage rings which intersect at six interaction points around the $3.8\,\mathrm{km}$ circumference of the machine, as schematically shown in Figure 1. Horizontal orbit jitter at frequencies around $10\,\mathrm{Hz}$ can be detected in both rings during regular machine operations [1]. The amplitude of this oscillation scales with the square root of the horizontal β-function at any location around the ring, indicating multiple sources. Given a normalized 6σ emittance of $\epsilon = 10\pi\,\mathrm{mm\,mrad}$ of the $250\,\mathrm{GeV}$ proton beam, the orbit jitter amplitude corresponds to roughly $5\ldots 10$ percent of the rms beam size. Mechanical vibrations of the superconducting low-β quadrupole triplets at the six interaction regions was identified as the source of the observed beam orbit jitter [1].

A finite-element analysis of the triplet assembly revealed that the observed beam jitter frequencies around $10\,\mathrm{Hz}$ are very close to the lowest mechanical eigenmodes of the triplet [2]. Given the fact that the effect of cooling the cold masses down to liquid helium temperature was not taken into account in this analysis, the small discrepancy between calculated and measured frequencies is no surprise, and it is very likely that the observed beam jitter frequencies are indeed eigenfrequencies of the triplet assembly. Therefore, an excitation force at practically any frequency around $10\,\mathrm{Hz}$ would cause mechanical vibrations of the triplets at their eigenfrequencies, and in turn lead to beam jitter at the observed frequencies.

To investigate the excitation force causing the triplets to vibrate at their eigenfrequencies, experiments were performed involving the cryo system. These experiments indicate that helium pressure oscillations my be the root cause of the observed beam jitter.

HELIUM PRESSURE MEASUREMENTS

To investigate the possible origin of the observed triplet magnet vibrations, helium pressures in the RHIC cryogenic system were monitored. Figure 2 shows a schematic flow diagram of one RHIC triplet cryostat and its associated valve box. Each triplet cryostat contains five helium transfer lines, supply (S), return (R), utility (U), thermal shield (H), and magnet (M) lines. At an operating temperature of

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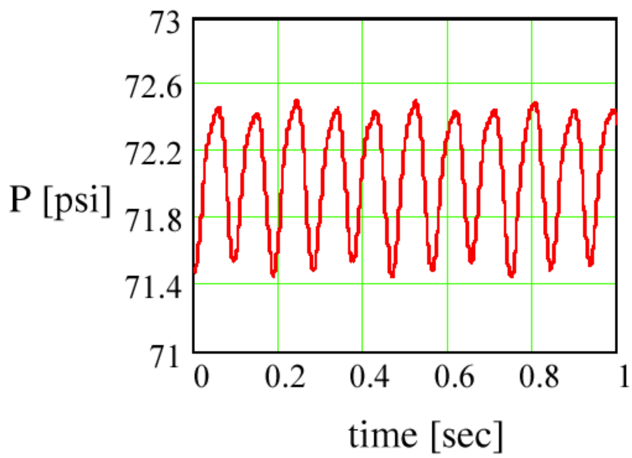

Figure 3: Measured helium pressure P in the magnet line "M" vs. time. The frequency of the obeserved pressure oscillation is $10.7\,\mathrm{Hz}$.

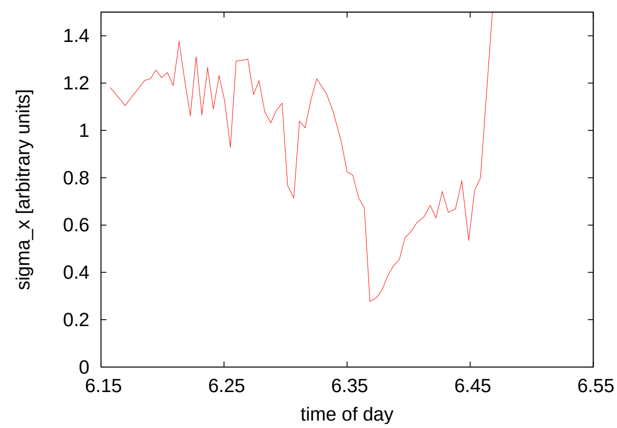

Figure 4: Measured horizontal rms beam jitter in the frequency range from $8.5\,\mathrm{Hz}$ to $14.5\,\mathrm{Hz}$ when the helium circulators in both rings were turned off.

$4.5\,\mathrm{K}$ the helium pressure in the magnet line is about $5\,\mathrm{bar}$. The pressure drop in the magnet cooling loop is about $0.25\ldots0.5\,\mathrm{bar}$, and the mass flow rate is $100\dot{1}50\,\mathrm{g/sec}$. To maintain the closed loop flow, a mechanical circulating compressor is used in each ring, located at the 6 o'clock valve boxes. A mechanical cold expander is installed in the refrigerator for pressure reduction in the recooler. Three power lead ports for each ring are extended out locally at each triplet cryostat. To monitor helium pressures, pressure transducers were installed in the five helium transfer lines (S, R, U, H, M) at the 6 o'clock valve box and at the six power lead ports of the 6 o'clock triplet. Pressure measurements performed during the FY04 RHIC run showed a $10.7\,\mathrm{Hz}$ oscillation in the "M"-line and a slow oscillation with a period of about $10\,\mathrm{seconds}$ in the "U" line, while the other three lines were very stable [3]. Figure 3 shows the measured pressure during $1\,\mathrm{second}$ in the "M"-line. This oscillation is caused by the mechanical circulating compressor, and vanishes when this circulator is turned off.

OBSERVATIONS WITH BEAM

To study the effect of the helium circulator on the beam jitter, a dedicated experiment was performed in April 2004 during which both circulators were turned off while beam jitter in the "BLUE" RHIC ring was observed with the million-turn beam position monitor. This experiment was conducted under "store" conditions when the observed beam orbit vibration amplitudes are largest due to the β squeeze at the interaction points which results in large β-functions at the vibrating low-β quadrupole triplets. 256k turns were recorded every $30\,\mathrm{seconds}$ for about 30 minutes, during which the circulators were turned off and subsequently turned back on after a few minutes. The horizontal rms beam jitter amplitude $\sigma_x(8.5\,\mathrm{Hz}\ldots14.5\,\mathrm{Hz})$ in the frequency range from $8.5\,\mathrm{Hz}$ to $14.5\,\mathrm{Hz}$ was determined by integrating over the power density spectrum $P(\omega)$ of the turn-by-turn BPM data,

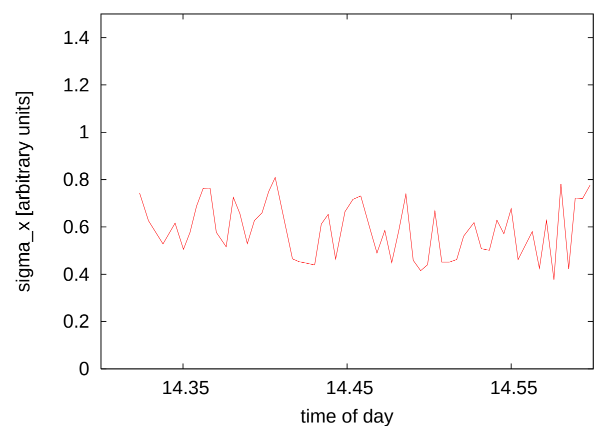

Figure 5: Example of measured horizontal rms beam jitter in the frequency range from $8.5\,\mathrm{Hz}$ to $14.5\,\mathrm{Hz}$ during regular beam operations in FY05.

$$\sigma_x(8.5\,\mathrm{Hz}\ldots14.5\,\mathrm{Hz}) = \sqrt{\int_{2\pi\cdot8.5\,\mathrm{Hz}}^{2\pi\cdot14.5\,\mathrm{Hz}} P(\omega)\,\mathrm{d}\omega}. \quad (1)$$

As depicted in Figure 4, the rms beam jitter amplitude in this frequency band dropped by a factor of five when the helium circulators in both were turned off, and increased again when the circulators were turned on.

To ensure that the observed beam jitter amplitude variation is indeed correlated with circulator operations and not just a natural fluctuation, million-turn BPM data were again taken during regular operations in FY05. Data were processed in the same way as during the dedicated experiment described above. Figure 5 shows a typical example of horizontal rms beam jitter amplitudes during about $30\,\mathrm{minutes}$.

During regular beam operations, the rms jitter amplitude is rather stable and shows peak-to-peak variations of

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only about 20 percent around the average value, which is far less than the reduction observed when the circulators were turned off during the dedicated experiment (Figure 4). The mean rms jitter amplitude during regular operations is about a factor two smaller than at the beginning and the end of the dedicated experiment. This may be explained by the fact that the average helium pressure in the "M"-line was reduced from $4.7\,\mathrm{atm}$ in FY04 to $4.0\,\mathrm{atm}$ in FY05.

DISCUSSION

The data presented in this paper strongly point at the cryogenic system ass the root cause of the observed beam jitter. However, more experiments are required to confirm this. It is currently planned to increase the helium pressure in the "M"-line from the present $4.0\,\mathrm{atm}$ to the FY04 value of $4.7\,\mathrm{atm}$ to check whether this influences the beam jitter amplitude. Furthermore, we are planning to repeat the measurement of beam jitter amplitude vs. circulator on/off to gain more confidence that the effect shown in Figure 4 is more than just a coincidence. Monitoring and frequent logging of cryo parameters such as helium pressure, circulator rpms and helium mass flow rate during this dedicated experiment is expected to contribute to an enhanced understanding of the observed effects.

REFERENCES

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