Vibration Measurement of the PHENIX Central Magnet Poles

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Abstract

This report describes the vibration measurement test of the PHENIX experiment. It covers the test equipment, set-up, testing conditions, analysis of the measurement data, and expected impact to the central detector upgrade project.

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-	July 11, 2007	RJ Ponchione	Initial release.
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1. Introduction

The PHENIX vertex detector will be mounted to a pair of rails that span between the two poles of the central magnet. During the design of the detector there was concern about the vibration environment that existed on these rails. The central magnets are very large, powerful water cooled magnets and there was the possibility that the operation of the magnets would induce significant vibrations into the support rails. In addition the PHENIX experiment hall has rotating machinery for pumping and cooling that could generate vibrations. Since no existing vibration measurements were available it was decided that the most prudent course of action would be to perform a direct measurement of the vibrations present on the rails.

The measurements were successful at collecting sufficient data to conclude that the vibration levels on the support rails would not adversely affect the performance of the vertex detector.

Vibration Level Threshold	1*E-8 g^2/Hz
Accelerometer Noise Floor	1*E-11 g^2/Hz
Peak Measured Vibration	1.2*E-9 g^2/Hz

2. Experiment Description

- Accelerometer – Kistler, model 8632C5 (3)
- Amplifier – Kistler, type 5134
- Signal Processor – Spectral Dynamics, SigLab model 20-42
- System Control/Data Storage – IBM T43p Laptop w/ Adaptec 1460D SCSI card
- Data Acquisition Software – SIGLAB v. 3.28

3. Vibration Level Threshold

The vibration threshold is a vibration level below which there would little or no impact on the central detector.

The threshold value was calculated using Miles' equation. Miles' equation transforms an input level of random vibration to an output response for a lightly damped 1 DOF system. While the detector clearly has many DOF, it was assumed that conservative use of Miles' equation would be sufficient to set a threshold level of vibration.

Standard formulation of Miles' equation:

$$G_{rms} = \sqrt{\frac{\pi}{2} \cdot f_n \cdot Q \cdot PSD_{input}}$$

Where:

G_{rms} = RMS acceleration response in g's

f_n = natural frequency of the system

Q = the amplification factor = ½*ζ; where ζ is the critical damping ratio

PSD_{input} = the input power spectral density in g^2/Hz.

This equation is converted to calculate peak amplitude by using a 3σ range where; peak g = 3*G_{rms}*3*ω^2*δ. Where δ is the peak amplitude, and ω = 2*π*f. The notation ASD (Acceleration Spectral Density) is now used instead of the more general PSD (Power Spectral Density).

This results in:

$$\delta^2 = \frac{9 \cdot ASD_{input} \cdot Q}{32 \cdot \pi^3 \cdot f_n^{\ 3}}$$

If the peak amplitude is known and the desired output is the ASD_{input} then the equation can be rearranged to:

$$ASD_{input} = \frac{32 \cdot \delta^2 \cdot \pi^3 \cdot f_n^{\ 3}}{9 \cdot Q}$$

This equation has units of $(m/s^2)^2$/Hz, to convert to g^2/Hz it is divided by g^2, yielding:

$$ASD_{input} = \frac{32 \cdot \delta^2 \cdot \pi^3 \cdot f_n^{\ 3}}{9 \cdot Q \cdot g^2} \qquad \text{where } g = 9.81 \text{ m/s}^2$$

Two cases were assessed to establish the threshold value. The first case represented large amplitude, low frequency rigid body motion of the entire detector, and the second represented low amplitude, high frequency oscillation of a single stave.

Case 1:
f_n = 25 Hz
Q = 100
δ = 100 μm
This results in a ASD_{input} of 1.8 E-6 g^2/Hz

Case 2:
f_n = 100 Hz
Q = 100
δ = 1 µm
This results in a ASD_{input} of 1.14 E-8 g^2/Hz

The selected Q value of 100 is equal to 0.5% of critical damping. This is a fairly conservative damping value for a structure. Rule of thumb damping values for welded structures are 2-3%.

The lower value of the two cases was chosen for the threshold value, and rounded to 1.0 E-8 g^2/Hz.

4. Accelerometer Noise Floor

To measure the noise floor of the accelerometer and data acquisition system, the accelerometer was isolated as much as possible and tested. The accelerometer was isolated by mounting it to a block of steel placed on top of a soft piece of foam. This was then located on an air-isolated optical table. To minimize acoustic input the accelerometer was covered with a plastic container.

The data acquisition system was then set up identically to the experiment set-up, using 100 samples taken at 1 Hz averaged to create the data set.

Figure 1 shows the resulting data set. The accelerometer noise above 20 Hz was less than 1.0 E-11, or two orders of magnitude below the threshold level. Therefore the accelerometers were sensitive enough to measure vibration levels that would be of interest.

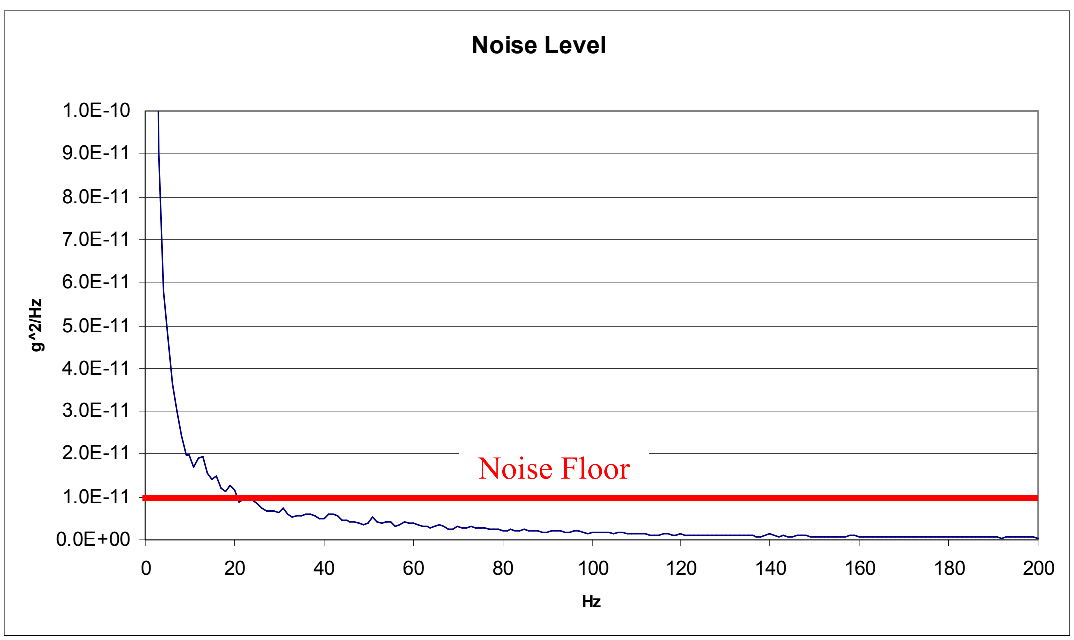

Figure 1: Accelerometer Noise Floor

5. PHENIX Data Collection

5.1 Equipment Setup

To obtain 3 axes of measurement, 3 accelerometers were epoxied to 3 sides of an aluminum block. Each accelerometer was then connected to the amplifier with 10' of coaxial cable. Each amplifier channel was then connected to the signal processor with 100' of coaxial cable. The signal processor was connected to the laptop using a SCSI cable.

The accelerometer block was mounted to one of the aluminum brackets that support the aluminum rails that span between the two magnet poles. These rails will support the central detector. The amplifiers were located about 8' away and strapped down to part of the magnet support structure. The peak strength of the magnetic fields between the magnets is 1 Tesla, the strength of the magnetic field at the amplifier is estimated to be around 100 Gauss. The signal processor and laptop were located on a table just outside of the plug door of the PHENIX vault.

Installation of the accelerometers was straightforward and did not impact the operational state of the experiment. Figure 2 shows the central detector area with the West carriage rolled back. Figure 3 shows the installation of the accelerometer block on the central magnet south pole. Due to the availability of mounting points the orientation of the accelerometer block was changed between the North and South poles. Figure 4 shows its position on the central magnet South pole, and figure 5 shows its position on the central magnet North pole.

5.2 Measurement Coordinate System

The vibration measurements use the standard coordinate system for PHENIX.

- X axis – in the horizontal plane perpendicular to the beam line
- Y axis – in the vertical plane perpendicular to the beam line
- Z axis – aligned with the beam line

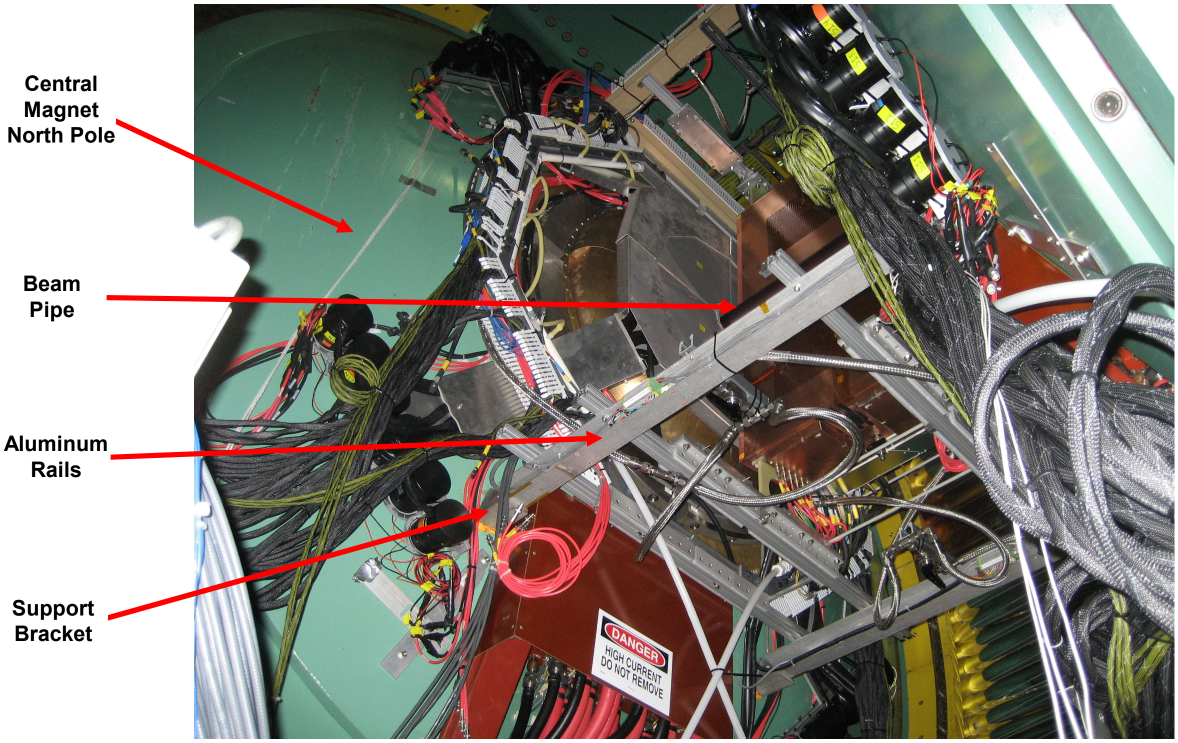

Figure 2: PHENIX Experiment Central Area

Figure 3: Installation of Accelerometer Block

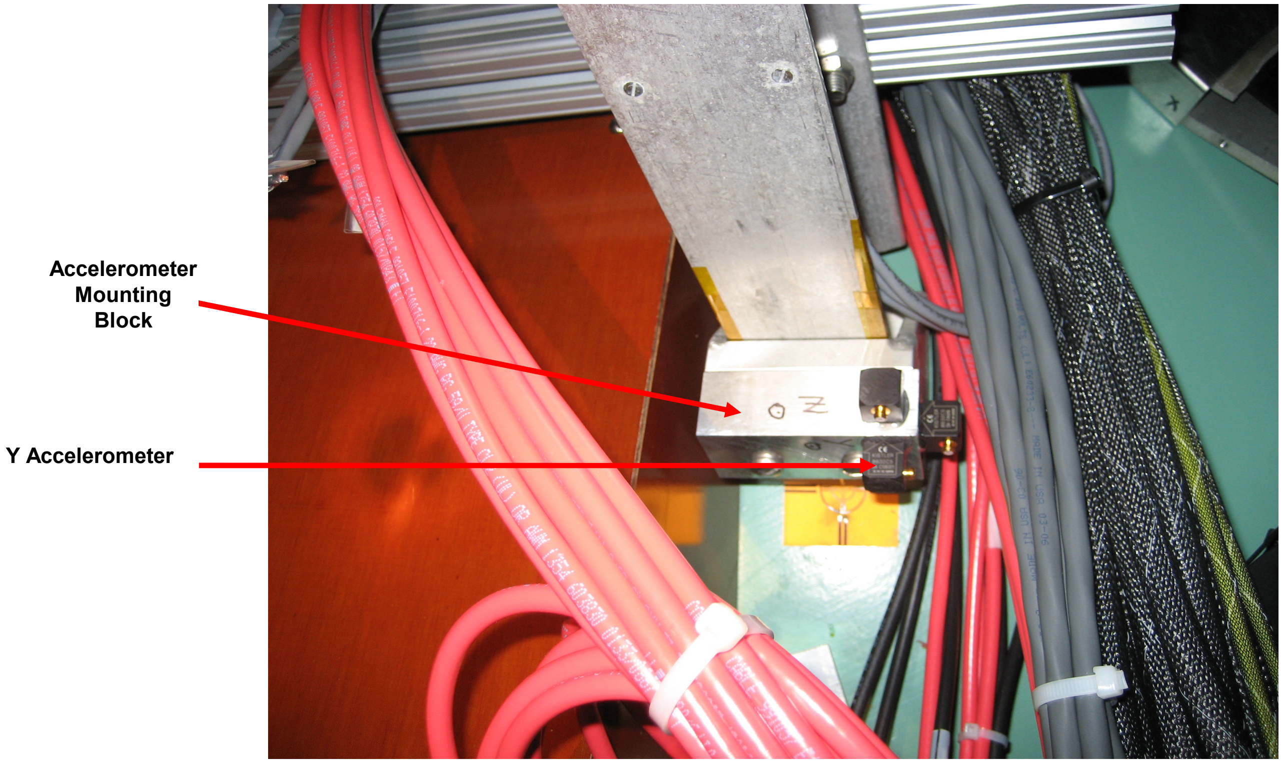

Figure 4: Accelerometer Block Mounted on Central Magnet South Pole

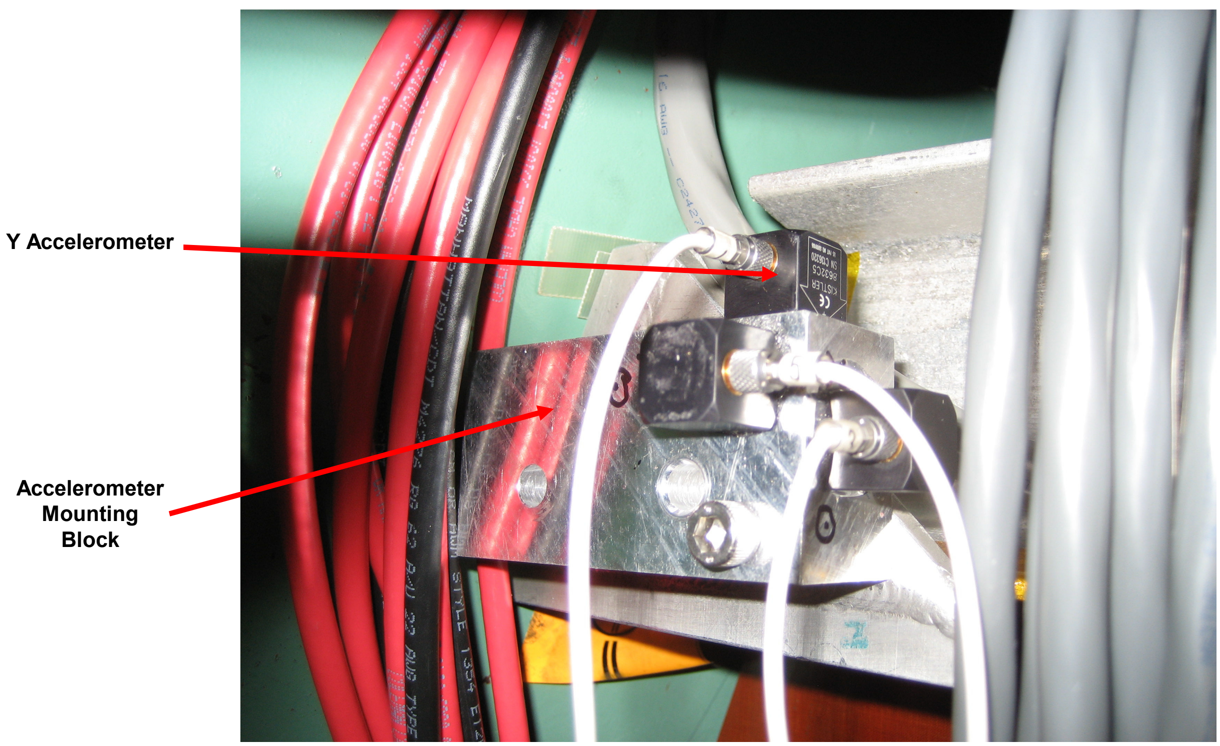

Figure 5: Accelerometer Block Mounted on Central Magnet North Pole

5.3 PHENIX Experiment State

Vibration measurements were made with the PHENIX experiment in as close to a fully operational state as possible. While this was achieved for the measurements on the central magnet South pole, the measurements on the central magnet North pole were made with the system not fully in its operational configuration.

The measurement test was performed on 5/23/07 during a scheduled mid-run maintenance day. This ensured that all of the systems within the PHENIX experiment were operating.

For the measurements on the central magnet South pole the system was completely in its operational state except that the beam was not active, and it is not expected that the beam will contribute to the vibration environment. Once the measurement equipment was in place, the carriage was closed and the magnets turned on. Measurements were taken after the carriage was closed before the magnets started ramping up, during magnet ramp up and with the magnets fully powered.

Due to logistical constraints the configuration on the central magnet North pole was not as close to the operational state. During the measurements on the North pole, the West carriage was open, the magnets were not on, and work was being performed on the electronic racks located in the vicinity of the measurement. However the following analysis of the data shows that this configuration yielded sufficient data for the purposes of this test.

All of the data sets taken consist of 100 samples taken at approximately 1 Hz that were averaged to create a single set. This brought the noise floor well below the region of interest.

5.4 Data Acquisition System Problems

During the test it was observed that there was a strong spike at 60 Hz on channel 3 of the data acquisition system. During the measurements made on the central magnet South pole, the focus was primarily on whether there would be significant changes as the magnets ramped up and the spike was thought to be a valid measurement. While making measurements on the central magnet North pole it was speculated that the spike could be electrical noise rather than an actual signal. To test this, the cables for channels 1 and 3 were switched at their connection to the accelerometers. This switched the channels that were used for measuring the Y and Z axes. It was observed at the time that the spike stayed on channel 3. This was accepted as confirmation that the spike was simply noise on channel 3 and was not a valid signal. What was not noticed during the test was that the other components of the signal also changed. When the Y accelerometer was moved to channel 1 there were spikes in the signal that were not present when it was connected to channel 3, and conversely there were signal spikes in the Z accelerometer that went away when it was switched between channel 1 and channel 3. The signal that was observed on the central magnet North pole was relatively small. It is suspected that the scaling level used during the real time viewing of the signal was not sufficient to resolve these spikes from the noise floor and they went unnoticed during the test. It was not until the data was analyzed in depth did they become apparent.

Based on these observations, and inspection of the rest of the data, it has been concluded that the data acquisition system channel 3 was malfunctioning during the entire test and that it did not record any valid data. Due to the swap of the cables during the test on the central magnet North pole, data on each of the 3 axes was successfully acquired. However on the central magnet South pole no valid data was acquired for the Z axis. In spite of this lost of data it is believed that the data acquired is sufficient for the design of the central vertex detector. All three axes on the central magnet North pole showed vibration levels of approximately the same value, so it is reasonable to assume that the Z vibrations of the central magnet South pole are also of similar value to those measured in X and Y.

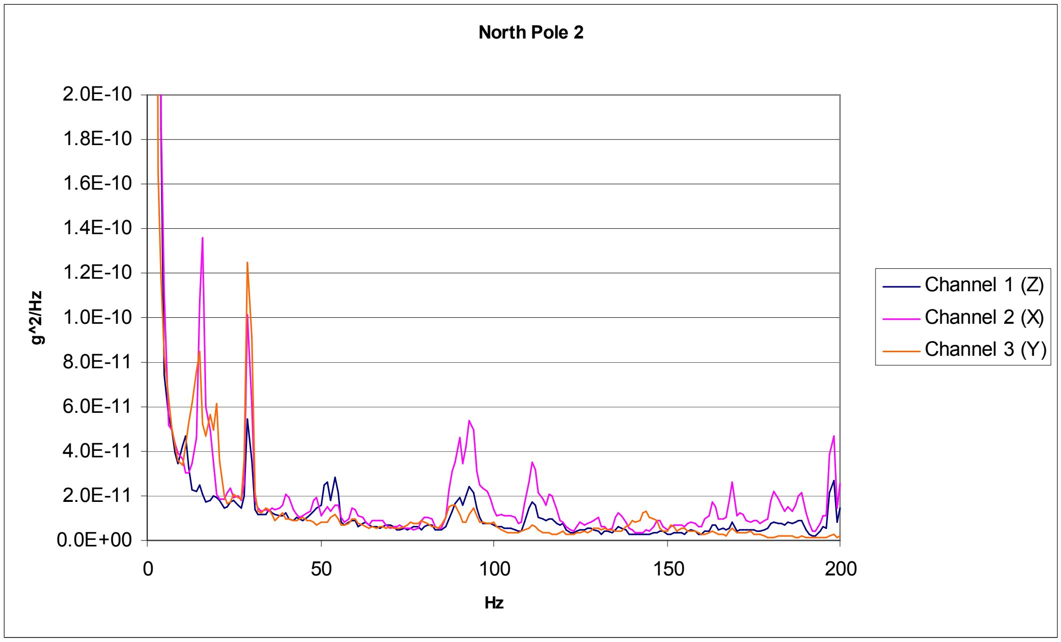

Figure 6 : Initial Measurements on the Central Magnet North Pole

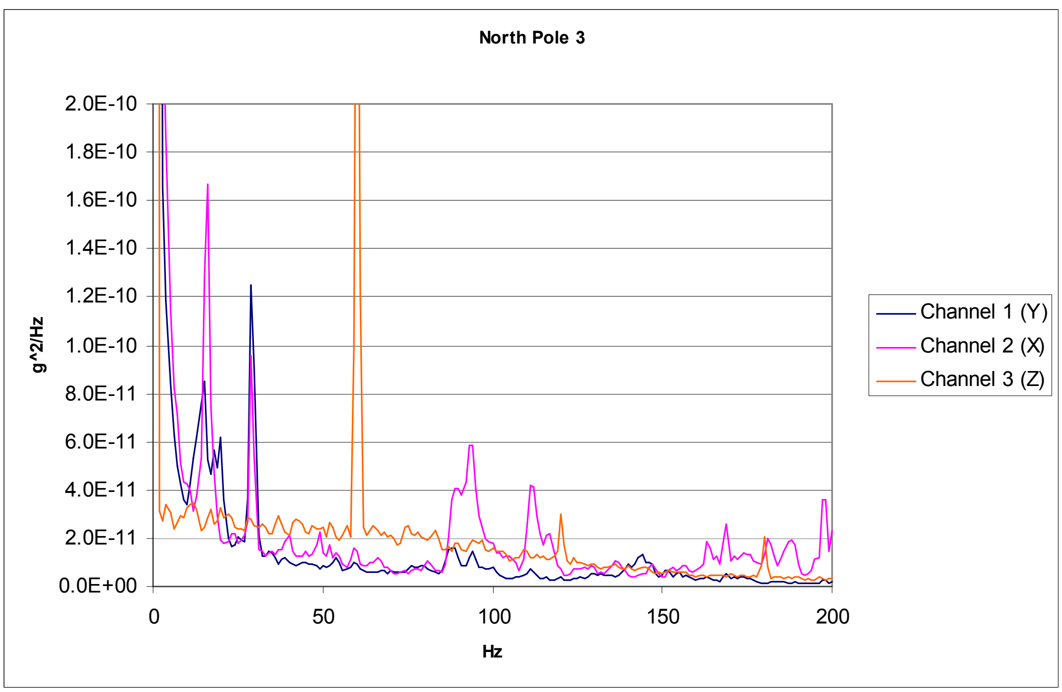

Figure 7: Measurements after Cable Switch

6. Data Analysis

6.1 Central Magnet South Pole

The graphs in the following section typically only show data for two directions of measurement. This is due to the problems with the data acquisition system mentioned in the previous section. The axes measured with the faulty channel have been removed from the graphs presented.

6.1.1 Before Magnet Start Up

Figure 8 shows the vibrations measured in the X and Y axes before the magnets were ramped up. There is a clear spike at 90 Hz in the Y axis, and smaller spikes around 140 Hz in both axes. It is suspected that these vibrations are somehow related to the magnet's cooling system. There are also spikes at 30 Hz as would be expected from rotating machinery. These are fairly small but that is not surprising given the size of the magnets and the absence of any large rotating machinery in the immediate vicinity.

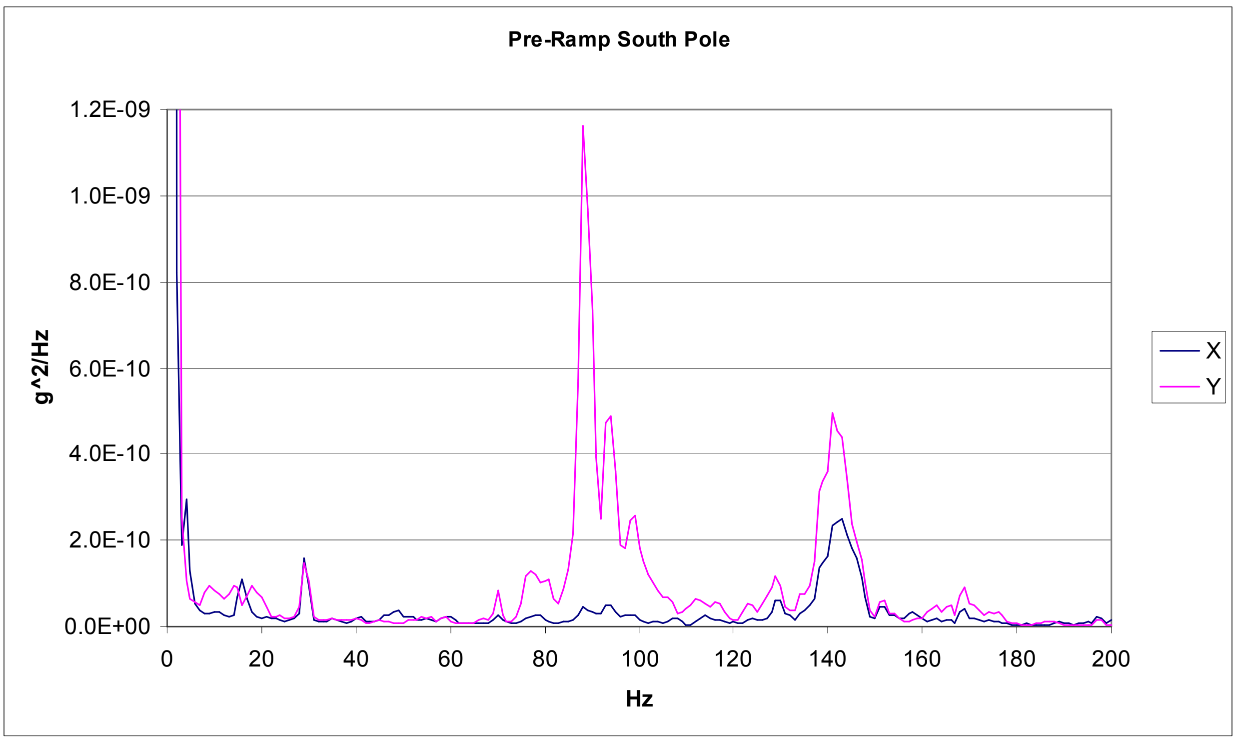

Figure 8: Measurement before Magnet Start-Up

6.1.2 Magnet Fully Energized

The data set in figure 9 was taken after the magnets were fully energized. The general profile of the response is very similar to that of the magnet before it was energized, however the vibration level is lower with the magnets on then with them off. The general expectation was that the vibration level would increase when the magnets were energized. However upon investigation there is really no basis for this expectation. The magnetic field is very stable, and there are no additional sources of vibration.

Several data sets were taken during the ramp up period, and the peak amplitudes from those sets ranged between the peak amplitudes from the un-energized and fully energized states.

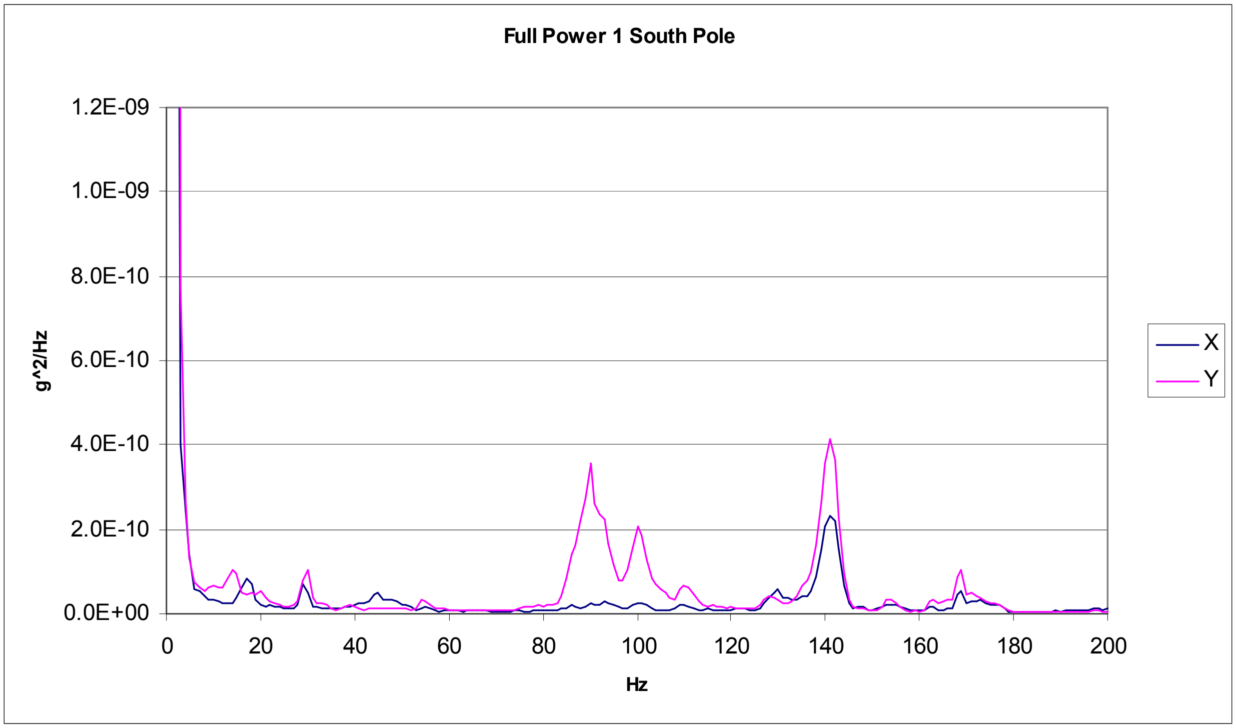

Figure 9: Measurement after Magnet Power-Up

6.2 Central Magnet North Pole

Due to logistical reasons it was not possible to energize the magnet during the test on the North pole of the central magnet. It was expected that the vibration levels on the North pole would be lower than those on the South pole since the North pole structure is securely anchored into the concrete floor of the facility, while the South pole structure sits on a movable carriage.

As can been seen from the graph this assumption proved to hold true. The problem with the data acquisition system was detected during the measurements on the North pole. The channels used for two of the accelerometers were switched in an attempt to troubleshoot the problem. This enabled the capture of valid data from all three axes from the North pole magnet. Figure 10 is a composite of two runs that covered all three axes. The vibration levels on the North pole are significantly lower than those on the South pole. The peak in vibration levels around 90 Hz can still be seen although it is much smaller. The higher frequency peak seems to have moved from around 140 Hz to 120 Hz and is also reduced. The small signal at 30 Hz still exists and appears to be about the same magnitude.

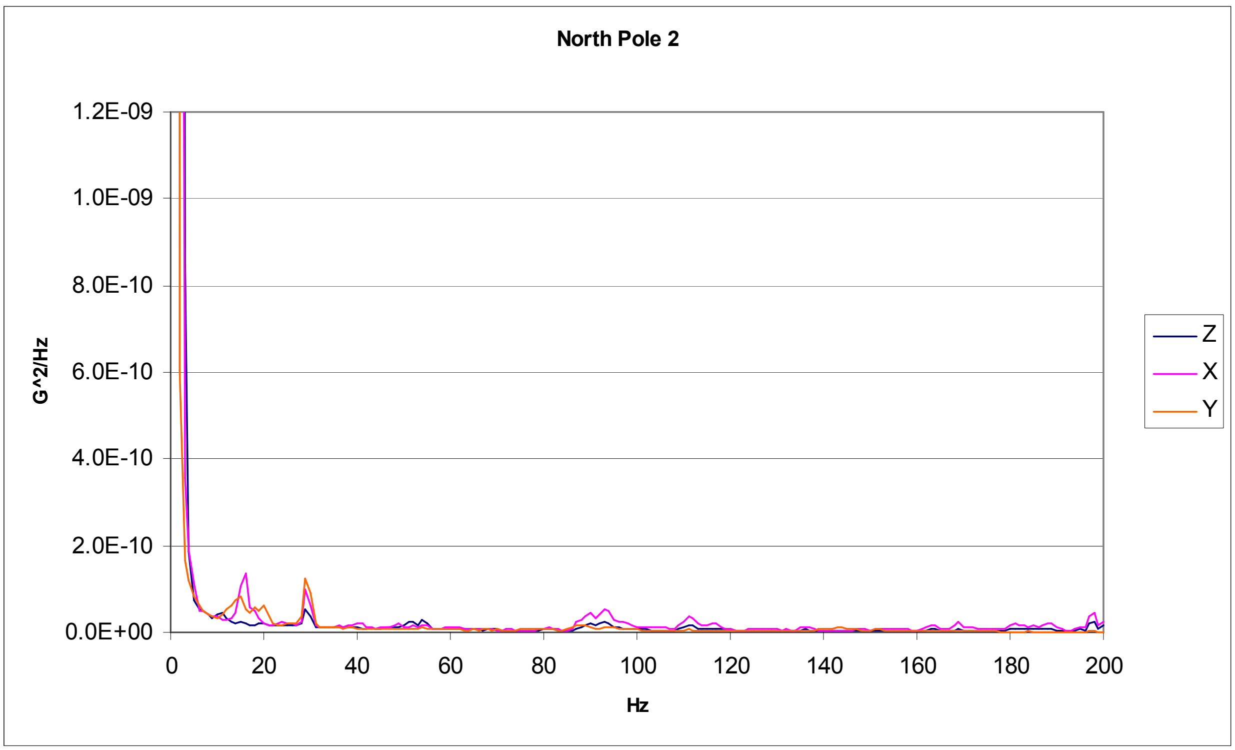

Figure 10: Measurement of Central Magnet North Pole

7. Implications for Central Detector Upgrade

The goal for this test was to measure the vibrations levels on the central detector mounting points so that that informed decisions could be made during the design of the central detector. A comparison of the vibration levels measured and the threshold levels calculated shows that the peak vibration levels are 10X lower than the threshold values.

Vibration Level Threshold	1*E-8 g^2/Hz
Accelerometer Noise Floor	1*E-11 g^2/Hz
Peak Measured Vibration	1.2*E-9 g^2/Hz

If the vibrations measured had exceeded the threshold value, the design would have been carefully considered so that none of the modes in the system matched up with frequencies that had high vibration levels. The final system response would have been simulated by applying the measured PSD as a load in a Finite Element Model of the system and calculating the response.

Since the differential between the measured value and the threshold value is so large it is considered unnecessary to perform the FEM response analysis. It is also expected that the vibrations that exist will have no significant impact on the performance of the central detector.

8. Conclusions

The vibration test was performed using equipment that was sensitive enough and under conditions that were close enough to operational conditions to detect vibration levels that might adversely affect the performance of the vertex detector. The vibration levels that were detected during the test were low enough that a simplified calculation was sufficient to determine that the vibrations present will not degrade the performance of the vertex detector.