Ambient Vibration Measurement for APS floor at Sectors 29, 26, 23, and 21

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1 Introduction

An intermediate energy X-ray beamline has recently been installed in Sector 29 of the Advanced Photon Source (APS). Beamline 29-ID-C,D specializes in angle-resolved photoemission spectroscopy (ARPES) and resonant soft x-ray scattering (RSXS). Ambient vibration levels caused by building and floor dynamics, air and water handling systems, and electro-mechanical equipment in this sector is important for scientists and engineers in the design of beamline equipment. To better understand noise levels in Sector 29 ambient vibration measurements were taken in horizontal and vertical directions on October 28th, 2011 and on November 1st, 2011. The APS storage ring was operating with 7-GeV ~102 mA (top-up/0+24x1) for user operation on October 28th, 2011, and was operating with 7-GeV ~102 mA (top-up/0+24x1) for machine studies on November 1st, 2011.

This report summarizes the measurements taken in the vertical direction and horizontal direction perpendicular to the beamline. These two directions are the most important to scientists and engineers. The ambient vibration levels in Sector 29 are compared to generic vibration criteria. The two groups of criteria used are the VC criteria and the NIST-A criterion [1]. The Sector 29 vibration measurements were then compared to nearby sectors to determine if the noise level in Sector 29 is typical or not. The results are verified by comparison of two separate data acquisition systems and the measurements in 2011 and earlier are compared to new measurements taken on March 14th, 2016 and March 24th, 2016.

2 Objectives

- Measure and report vibration levels at key points along the 29-ID-C,D beamline.
- Compare vibration levels in Sector 29 to generic vibration criteria NIST-A and VC criteria.
- Compare Sector 29 to other sectors at the APS. If the results in Sector 29 are not typical diagnose the source of the noise.
- Verify Hewlett Packard E1432A 16 Channel data acquisition system by comparison to data obtained using Brüel & Kjær Photon+ 4 Channel system.
- Measure and assess long timescale changes in ambient vibration levels at various locations in Sector 29 as well as the other sectors compared to Sector 29.

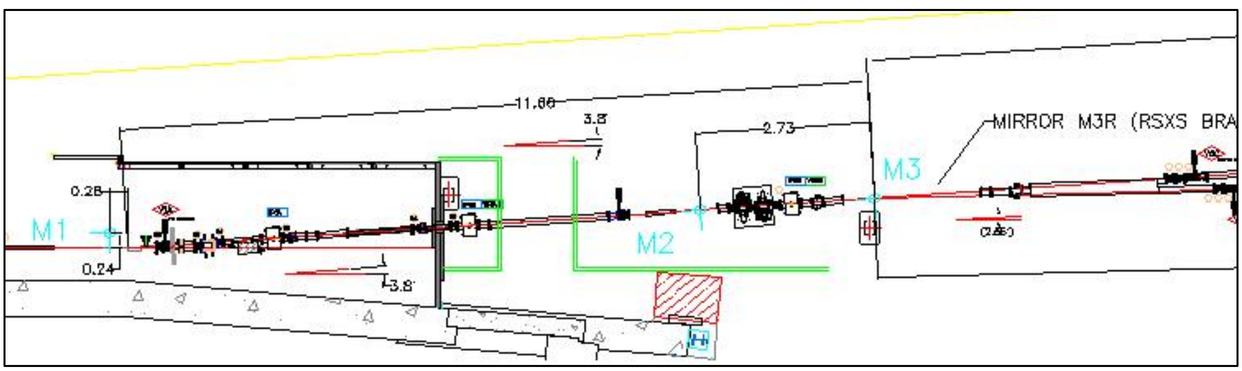
3 Ambient vibration level measurements

3.1 Methodology

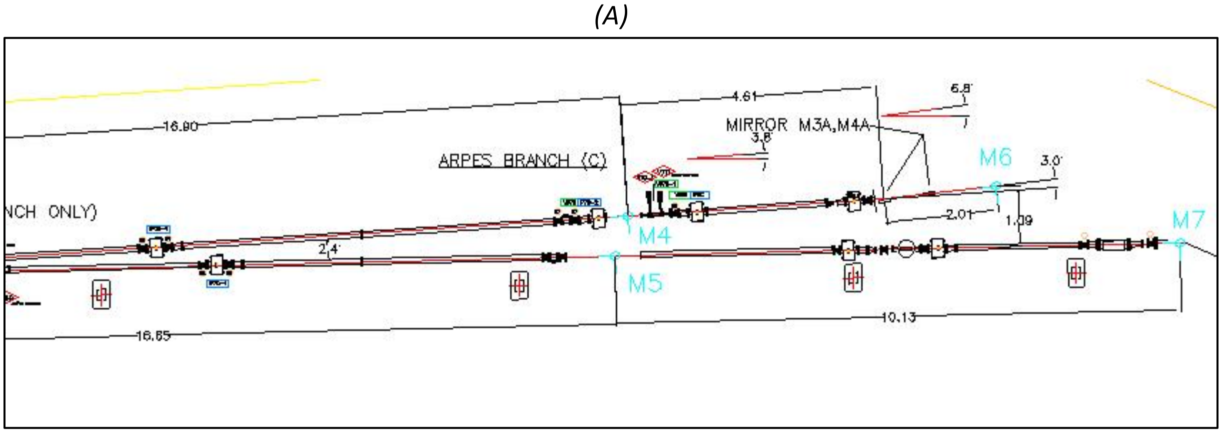
Accelerometers were placed in 7 locations in Sector 29. At each location there were 3 sensors. Each was mounted perpendicular to the other. The three accelerometers were positioned so that at each location there was one vertical accelerometer, one in line with the beamline (or future beamline), and the final one perpendicular to the beamline (or future beamline). The locations of the accelerometers and their orientation are shown in Figure 1.

Two models of high sensitivity, low-frequency accelerometers were used during the ambient vibration measurements: VibraMetric Model 1030 and PCB Piezotronics model 393B31.

The Accelerometers along with a Hewlett Packard (HP) E1432A 16 Channel 1.2 kSa/s Digitizer plus Digital Signal Processor and Data Physics Corporation's Signal Calc 620 Dynamic Signal Analyzer measured the acceleration in the vertical and horizontal directions. The acceleration data was then converted into rms displacement and plotted using MATLAB software. Displaying data in displacement is consistent with previous reporting on ambient vibration levels at APS [2].



(A)



(B)

Figure 1: Accelerometer locations M1-M7 with coordinate frames shown. All dimensions in meters. The original image is split to fit the page. The left side of (B) is a continuation of the right side of (A)

3.2 Results

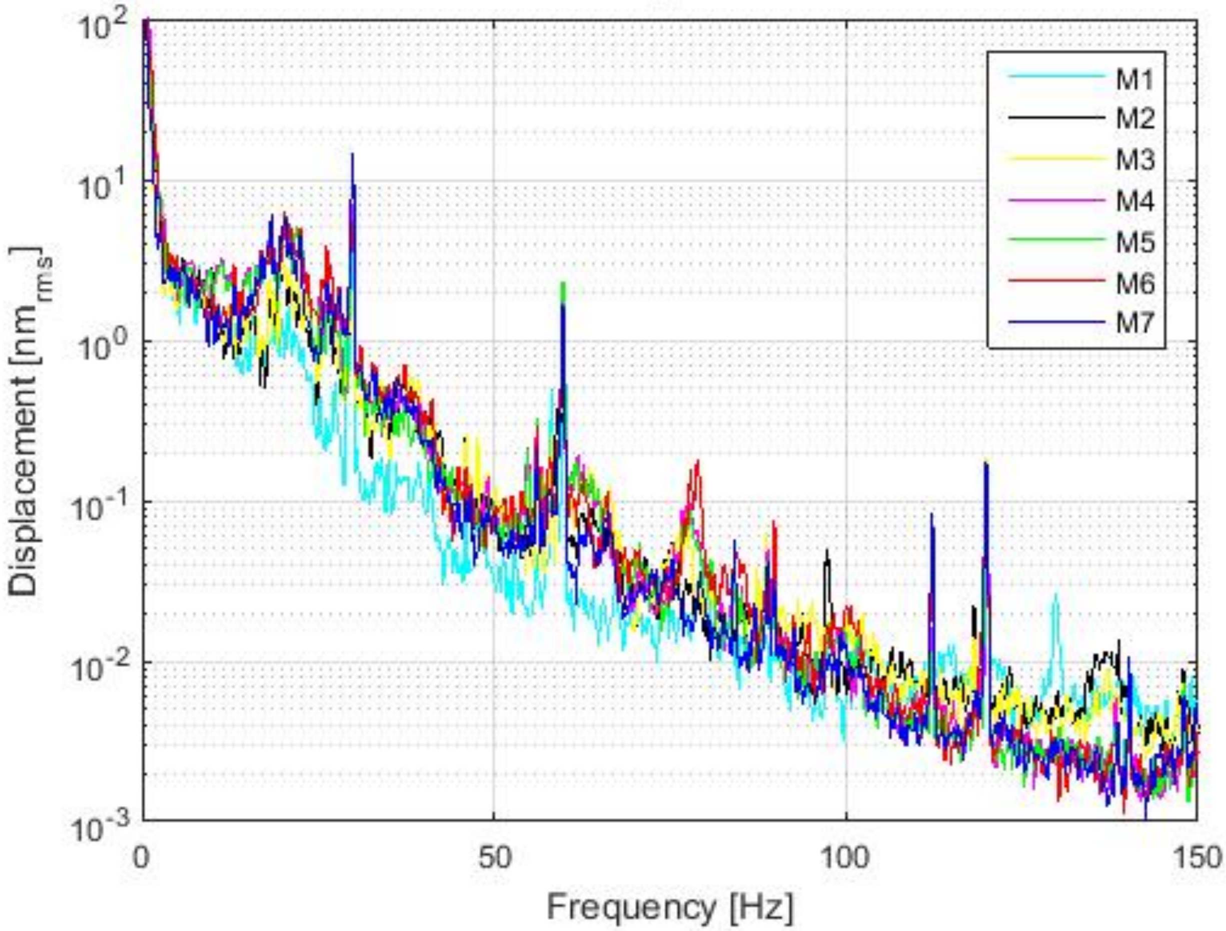


Figure 2: Vertical Displacement Spectra 0-150 Hz

Location	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**
M1	29.9	3.44	60.0	0.75	119.9	0.11
M2	29.9	9.61	59.8	1.14	119.9	0.16
M3	29.9	12.64	59.8	1.45	119.9	0.19
M4	29.9	6.88	59.8	1.29	120.1	0.11
M5	29.9	5.18	59.8	2.30	120.1	0.07
M6	29.9	5.50	59.8	1.21	119.9	0.15
M7	29.9	14.56	59.8	1.71	119.9	0.17

Table 1: Peak Vertical Displacements in Sector 29

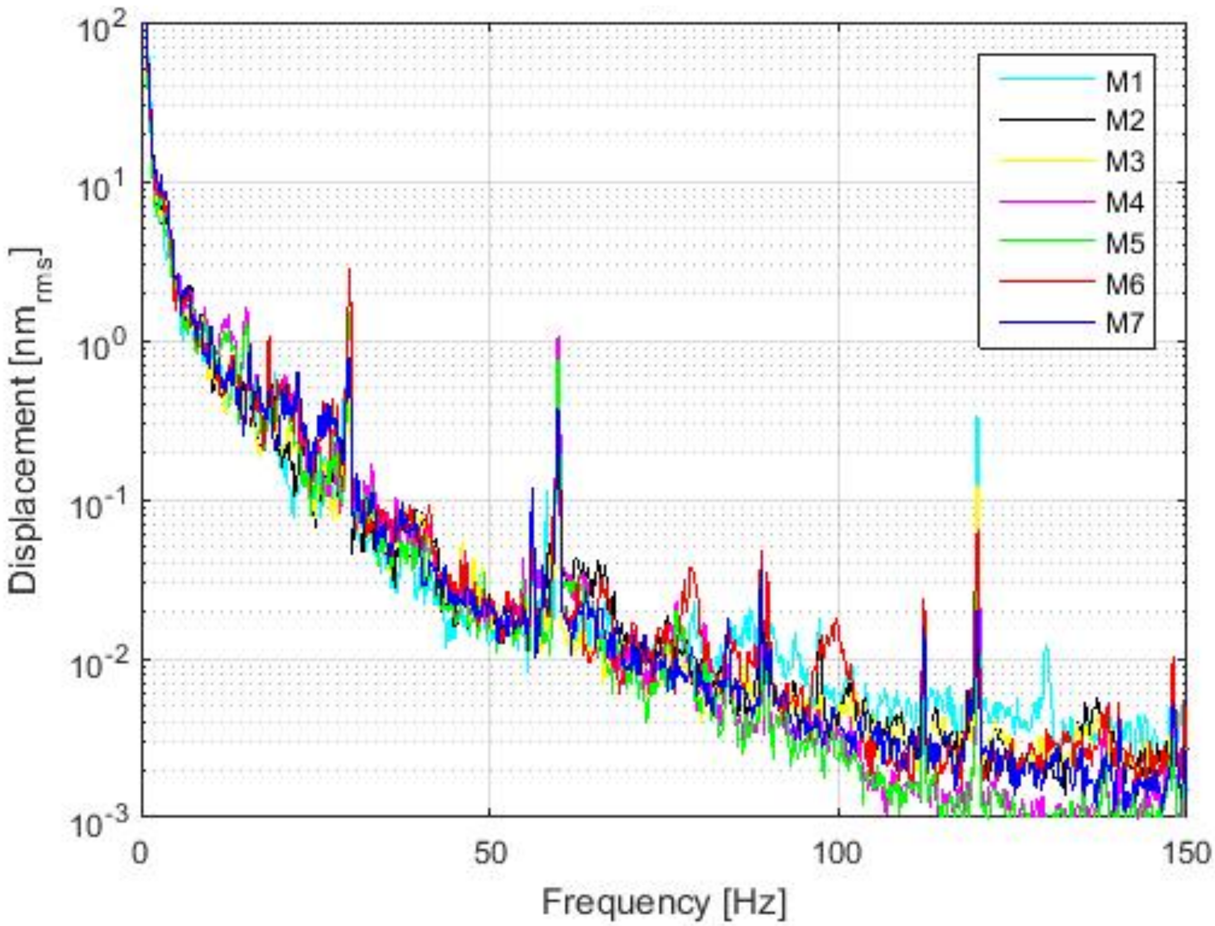


Figure 3: Perpendicular to Beamline Displacement Spectra 0-150 Hz

Location	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**
M1	29.7	0.56	60.0	0.44	119.9	0.338
M2	29.5	0.86	59.8	0.22	119.9	0.080
M3	29.7	0.60	59.8	0.35	119.9	0.123
M4	29.9	1.49	60.0	1.05	120.1	0.064
M5	29.9	1.51	60.0	0.75	120.1	0.032
M6	29.9	2.83	59.8	0.27	119.9	0.061
M7	29.7	0.75	59.8	0.37	119.9	0.020

Table 2: Peak Perpendicular to Beamline Displacements in Sector 29

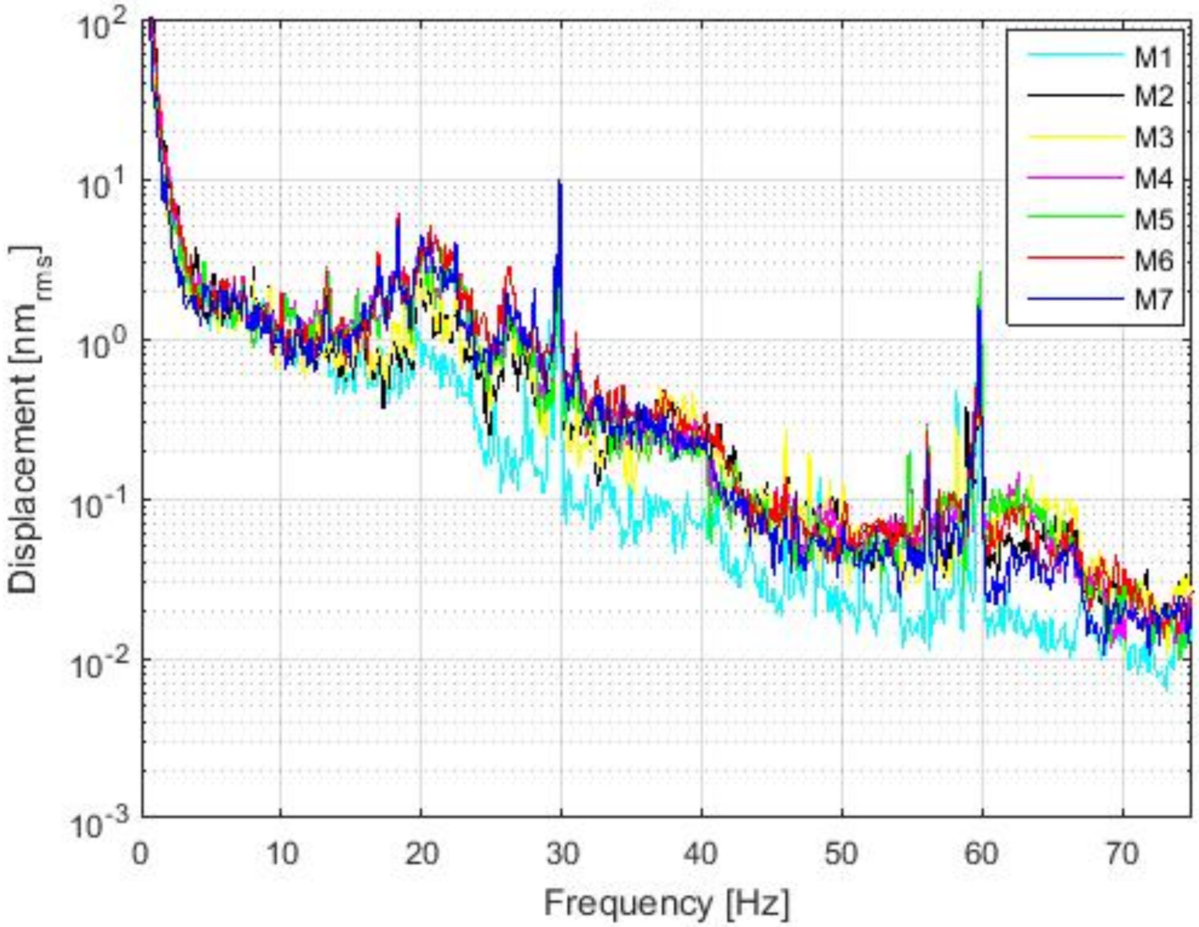


Figure 4: Vertical Displacement Spectra 0-75 Hz

Location	Freq. [Hz]	Mag. [nm$_{rms}$]	Freq. [Hz]	Mag. [nm$_{rms}$]	Freq. [Hz]	Mag. [nm$_{rms}$]
M1	15.8	1.31	29.9	2.23	60.0	0.72
M2	19.9	2.85	29.9	9.13	59.9	1.07
M3	19.7	3.59	29.9	10.01	59.9	1.38
M4	20.0	4.10	29.9	7.91	59.9	1.38
M5	20.0	3.70	29.9	5.74	59.9	2.59
M6	18.4	5.99	29.9	9.96	59.8	1.13
M7	18.4	5.40	29.9	10.03	59.8	1.59

Table 3: Peak Vertical Displacements in Sector 29 Between 0 Hz and 75 Hz

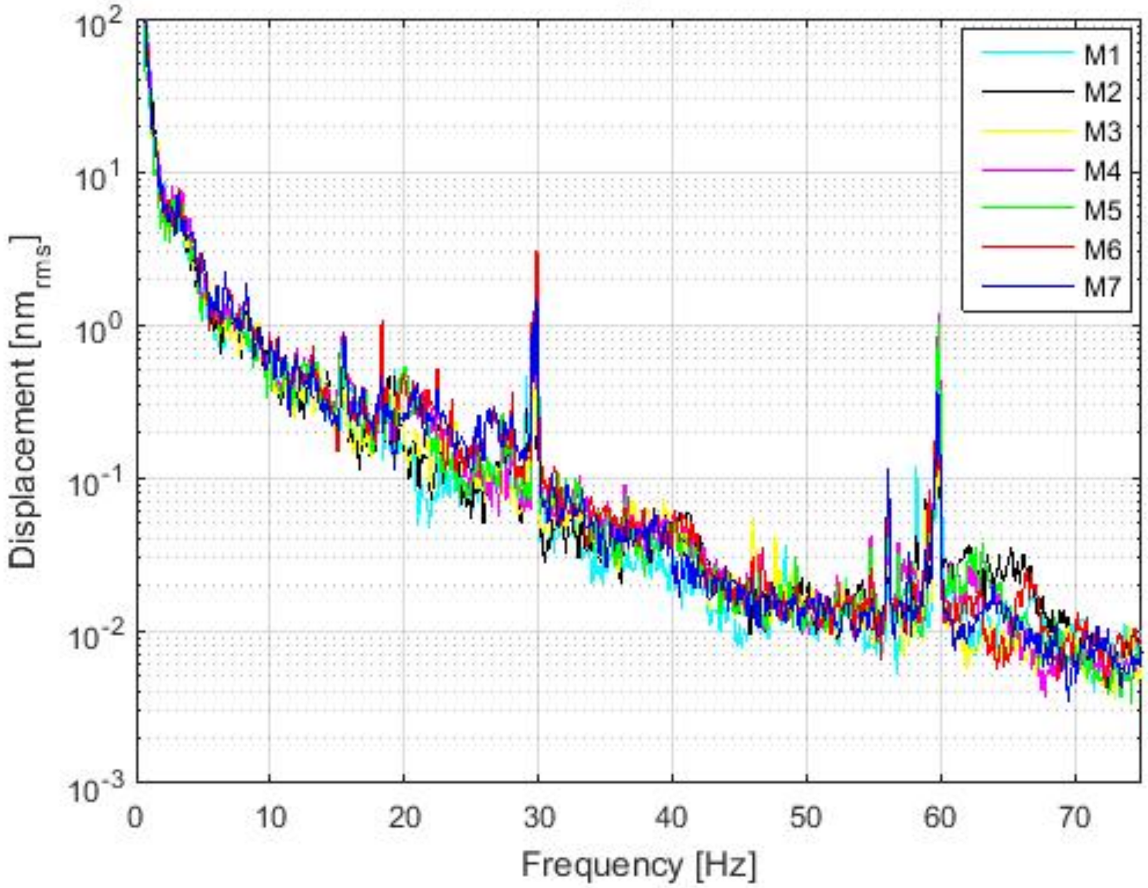


Figure 5: Perpendicular to Beamline Displacement Spectra 0-75 Hz

Location	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**	**Freq. [Hz]**	**Mag. [nm$_{rms}$]**
M1	19.3	0.52	29.6	0.71	60.0	0.43
M2	19.3	0.46	29.6	0.92	59.9	0.20
M3	18.4	0.60	29.6	0.67	59.9	0.33
M4	15.3	0.82	29.9	1.54	59.9	1.19
M5	15.3	0.72	29.9	1.85	59.9	1.01
M6	18.4	1.07	29.9	3.07	59.8	0.18
M7	15.5	0.85	29.9	1.44	59.8	0.36

Table 4: Peak Perpendicular to Beamline Displacements in Sector 29 Between 0 Hz and 75 Hz

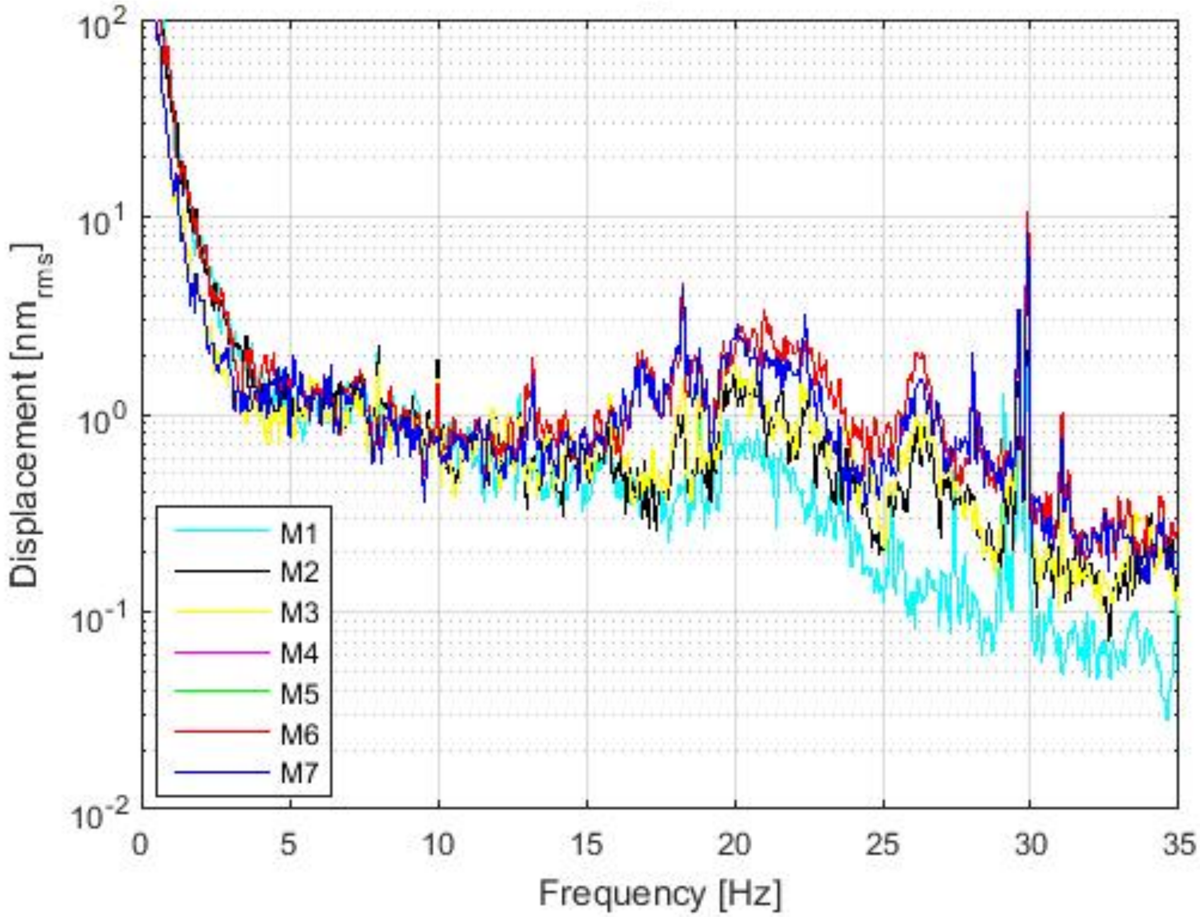


Figure 6: Vertical Displacement Spectra 0-35 Hz
NOTE: Measurements at locations M4 and M5 were not taken for the 0-35 Hz bandwidth

Location	Freq. [Hz]	Mag. [nm_{rms}]	Freq. [Hz]	Mag. [nm_{rms}]	Freq. [Hz]	Mag. [nm_{rms}]
M1	8.0	2.26	18.8	1.12	29.9	2.83
M2	8.0	2.20	20.0	1.61	29.9	7.55
M3	8.0	1.81	19.9	1.95	29.9	7.69
M4	-----	-----	-----	-----	-----	-----
M5	-----	-----	-----	-----	-----	-----
M6	13.2	1.60	18.3	4.56	29.9	10.57
M7	13.2	1.94	18.3	4.36	29.9	8.29

Table 5: Peak Vertical Displacements in Sector 29 Between 0 Hz and 35 Hz

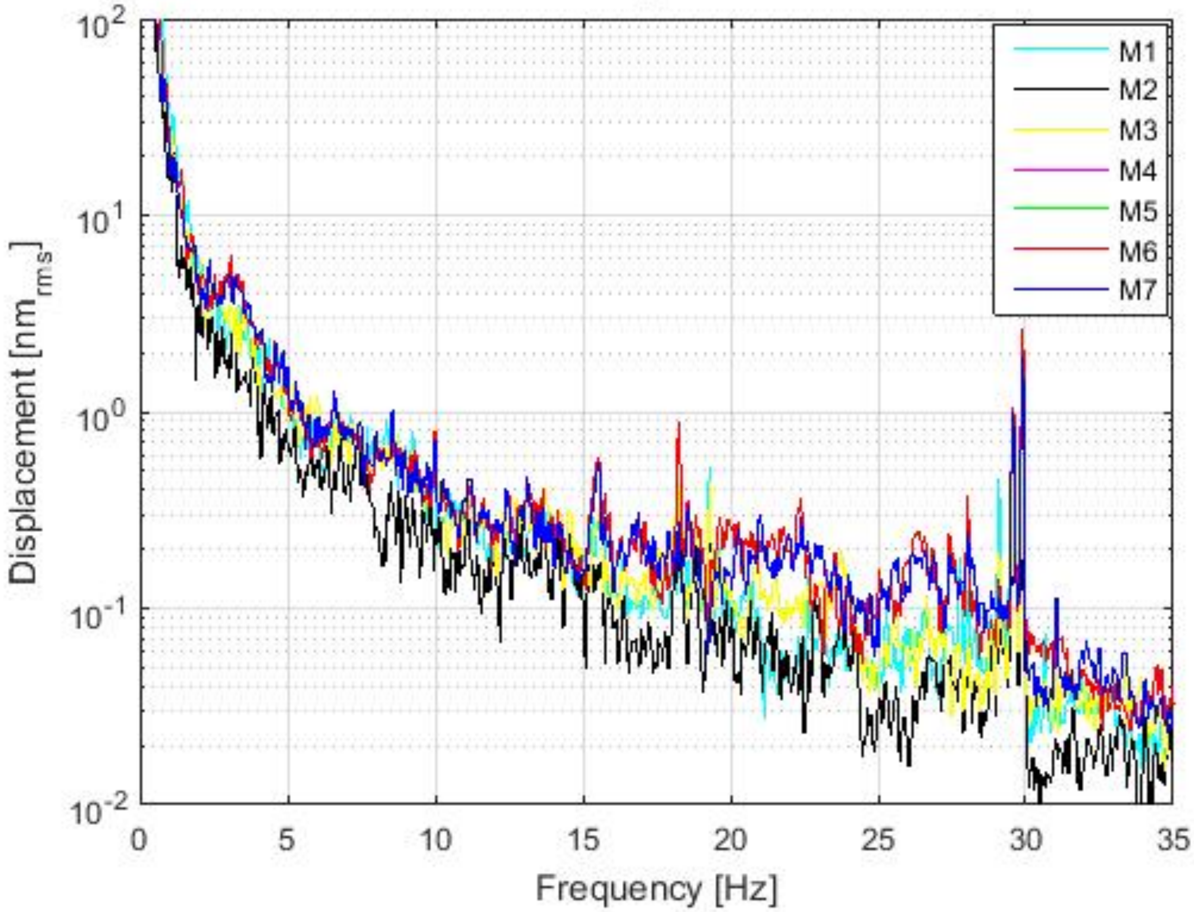


Figure 7: Perpendicular to Beamline Displacement Spectra 0-35 Hz
NOTE: Measurements at locations M4 and M5 were not taken for the 0-35 Hz bandwidth

Location	**Freq. [Hz]**	**Mag. [nm_{rms}]**	**Freq. [Hz]**	**Mag. [nm_{rms}]**	**Freq. [Hz]**	**Mag. [nm_{rms}]**
M1	2.45	4.19	19.3	0.53	29.6	0.74
M2	1.95	3.46	19.3	0.36	29.6	0.39
M3	2.35	4.31	19.3	0.44	29.9	0.60
M4	-----	-----	-----	-----	-----	-----
M5	-----	-----	-----	-----	-----	-----
M6	3.10	6.18	18.3	0.89	29.9	2.65
M7	3.10	4.97	15.6	0.55	29.9	1.89

Table 6: Peak Perpendicular to Beamline Displacements in Sector 29 Between 0 Hz and 35 Hz

3.3 Comparison to Generic Vibration Criteria

The ambient vibration levels in Sector 29 are plotted against the generic vibration criteria in figure 1 for the vertical direction and figure 2 for the perpendicular to beamline direction. The figures show the vibration measurements in 1/3 octave bands. The 1/3 octave bands have a proportional bandwidth instead of the fixed bandwidth used in the previous figures. The mean of the seven measurement locations is shown as well as the mean plus one standard deviation and the mean minus one standard deviation. The minimum and maximum value measured at each 1/3 octave band is also plotted.

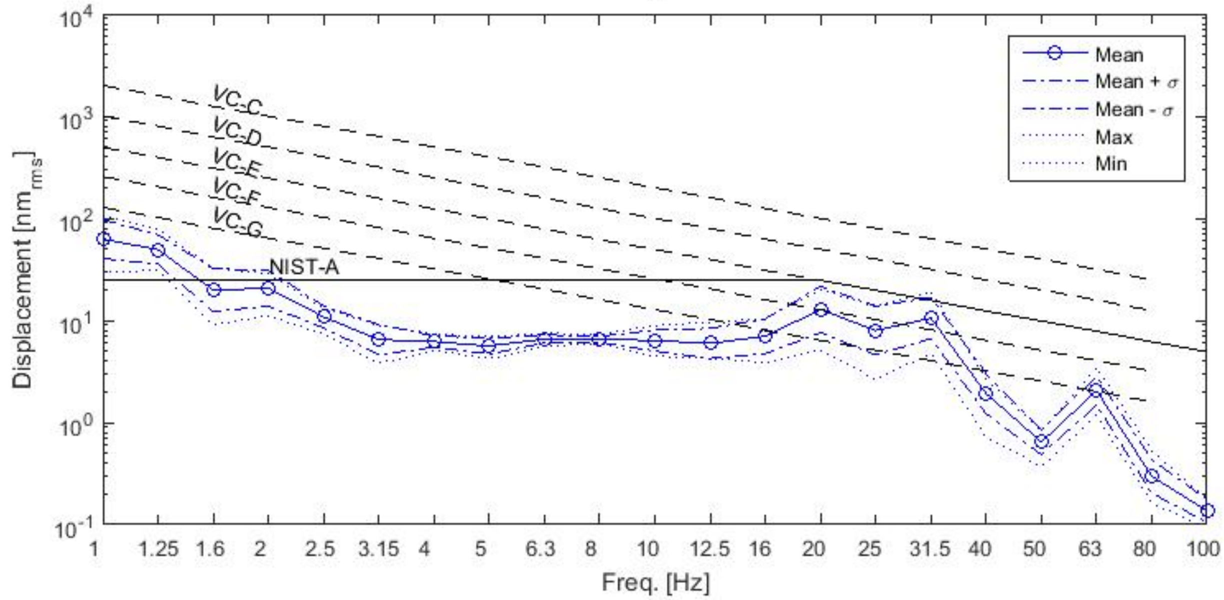


Figure 8: Sector 29 Vertical Ambient Vibration Levels in 1/3 Octave Bands compared to Vibration Criteria

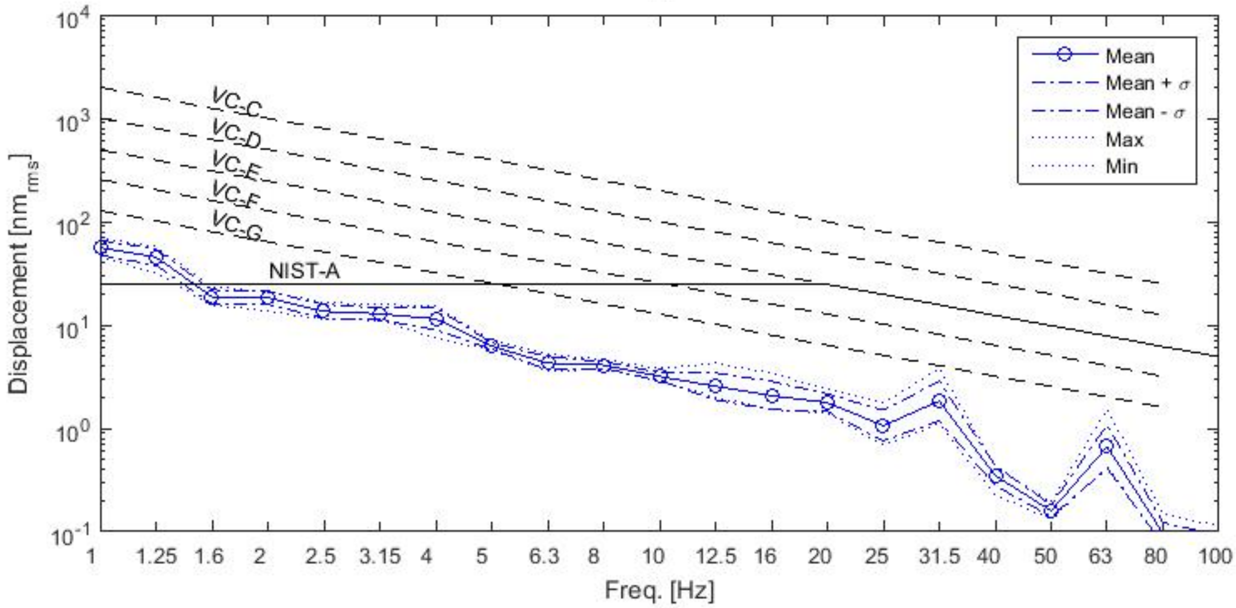


Figure 9: Sector 29 Vertical Ambient Vibration Levels in 1/3 Octave Bands compared to Vibration Criteria

3.4 Comparison to Other Sectors

Similar ambient vibration measurements were taken in three nearby sectors. Measurements were taken in; Sector 26 on May 26th, 2005; Sector 23 on October 11th, 2005; and Sector 21 on September 19th, 2011. Figure 8 shows the vertical displacement spectra for the four sectors from 0 Hz to 150 Hz. Table 7 shows the peak displacements measured in those sectors within that bandwidth.

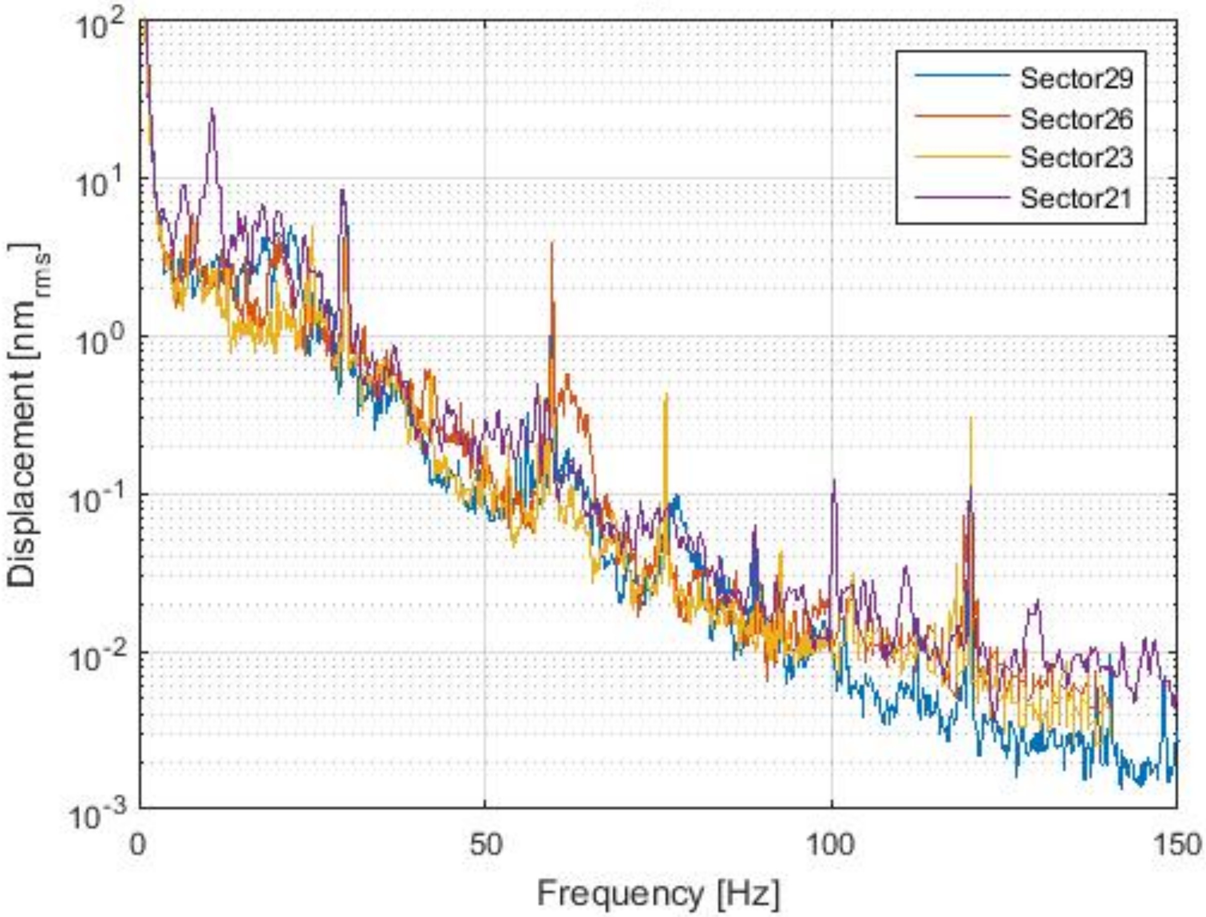


Figure 10: Sector 29 Compared to 3 Other Sectors. Vertical Displacement Spectra 0-150 Hz.

Location	Freq. [Hz]	Mag. [nm$_{rms}$]	Change S29	Freq. [Hz]	Mag. [nm$_{rms}$]	Change S29	Freq. [Hz]	Mag. [nm$_{rms}$]	Change S29
Sector 29	29.9	6.88	-----	59.8	1.29	-----	120.1	0.11	-----
Sector 26	29.8	5.72	-16.9%	59.7	3.90	202%	120.0	0.10	-4.6%
Sector 23	25.0	4.87	-29.2%	59.7	0.71	-45.1%	120.0	0.30	186%
Sector 21	29.4	8.38	21.7%	57.5	0.50	-61.4%	120.0	0.11	6.5%

Table 7: Peak Vertical Displacements in Sector 29, 26, 23, and 21 with corresponding frequencies and percent change from Sector 29.

3.5 Verification of Results

Between vibration measurements with the HP E1432A system, a different data acquisition system was used. A comparison between the two is used to verify the results of the HP system. The new acquisition system was a Brüel & Kjær Photon+ 4 Channel digital signal analyzer with LDS Test and Measurement's RT Pro Photon Signal Analysis software. Figure 9 shows a typical result for the comparison between the HP E1432A and Photon+ systems. Table 8 lists the peak displacements measured with both data acquisition systems.

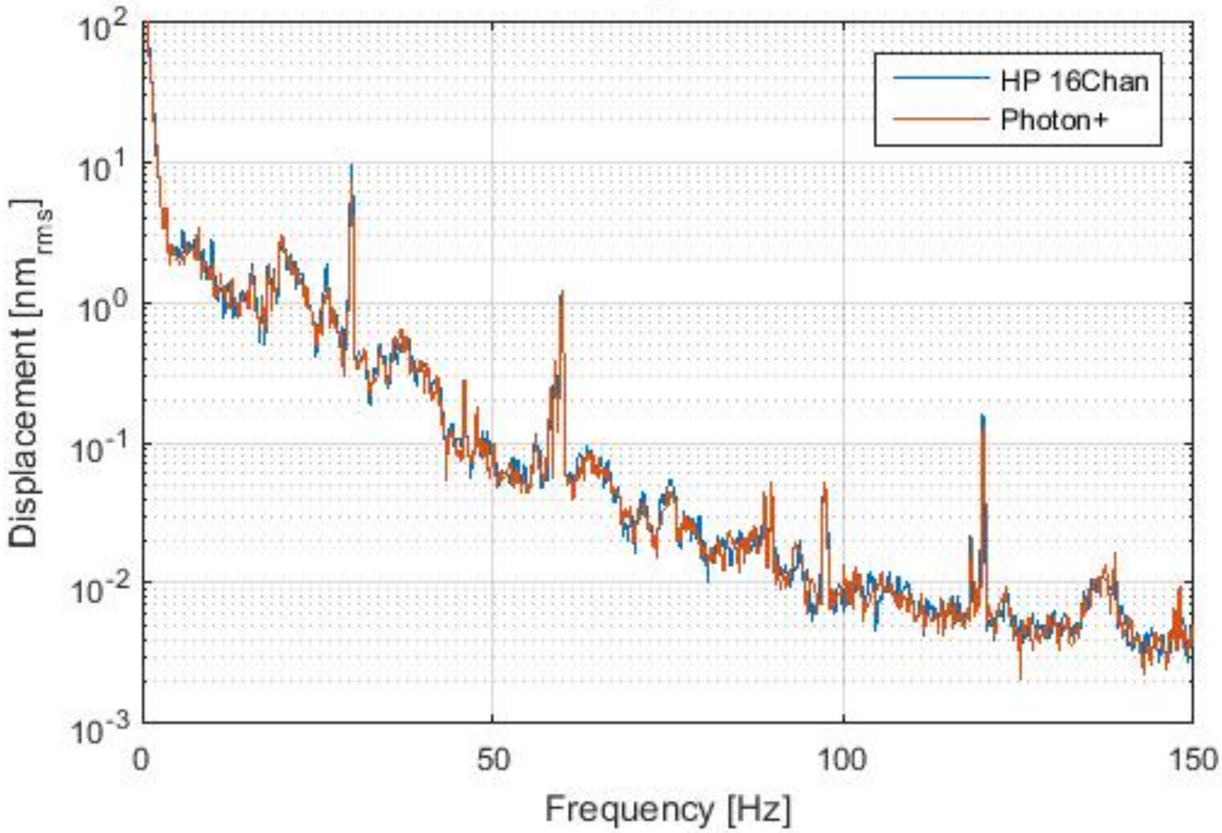


Figure 11: HP E1432A Compared to Photon+ Data Acquisition System
Sector 29-M2 Vertical Displacement Spectra 0-150 Hz

DAQ	**Freq. [Hz]**	**Mag. [nm_{rms}]**	**Change HP**	**Freq. [Hz]**	**Mag. [nm_{rms}]**	**Change HP**	**Freq. [Hz]**	**Mag. [nm_{rms}]**	**Change HP**
HP E1432A	29.9	9.61	-----	59.8	1.14	-----	119.9	0.16	-----
Photon+	29.8	7.14	-25.7%	59.9	1.20	5.69%	120.1	0.13	-17.8%

Table 8: Peak Vertical Displacements 0-150 Hz Measured by HP and Photon+ Systems with corresponding frequencies and percent change from the HP System.

Ambient vibration levels were again measured more recently. Comparing previous measurements to the more recent shows if the vibration levels are consistent over time. Ambient vibration was measured in Sectors 21, 26, and 29 on March 14th, 2016 and Sector 29 on March 24th, 2016. Figure 10 and Table 9 compare the measured vibration levels on different dates.

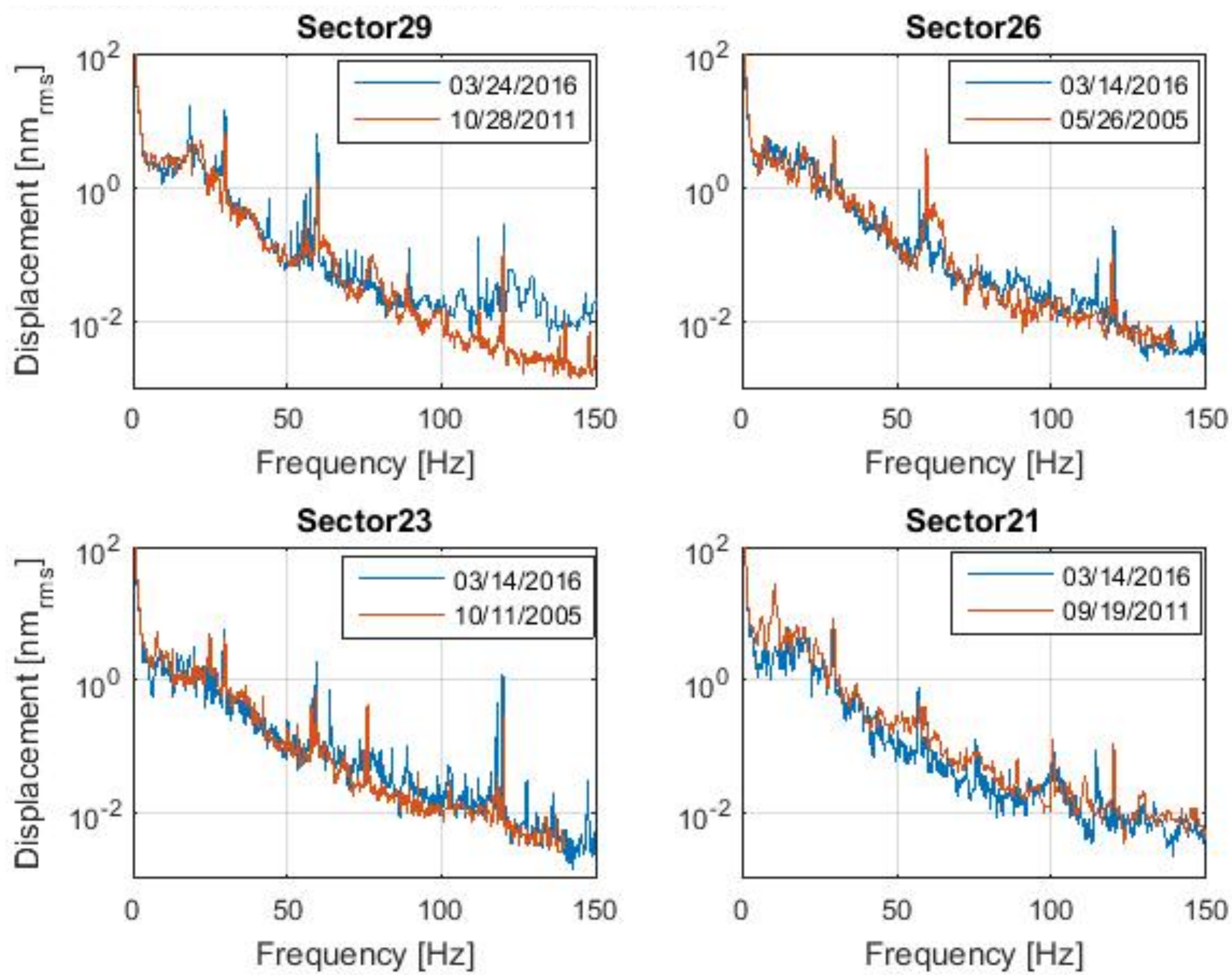


Figure 12: Previous Measurements Compared to Recent Measurements
Vertical Displacement Spectra 0-150 Hz

Location	Date	Freq. [Hz]	Mag. [nm_{rms}]	Change	Freq. [Hz]	Mag. [nm_{rms}]	Change	Freq. [Hz]	Mag. [nm_{rms}]	Change
Sector29	10/28/11	29.9	6.88	-----	59.8	1.29	-----	120.1	0.11	-----
Sector29	3/24/16	29.8	14.31	108%	59.9	6.13	375%	120.0	0.28	169%
Sector26	5/26/05	29.8	5.72	-----	59.7	3.90	-----	120.0	0.10	-----
Sector26	3/14/16	29.7	3.34	-42%	59.6	1.29	-67%	120.1	0.27	164%
Sector23	10/11/05	25.0	4.87	-----	59.7	0.71	-----	120.0	0.30	-----
Sector23	3/14/16	29.7	5.57	14%	59.6	1.87	164%	119.9	1.23	308%
Sector21	9/19/11	29.4	8.38	-----	57.5	0.50	-----	120.0	0.11	-----
Sector21	3/14/16	29.7	8.13	-3%	57.0	0.76	52%	119.9	0.06	-48%

Table 8: Peak vertical displacements 0-150 Hz measured across large timescales with corresponding frequencies and percent change from older measurements.

4 Discussion

4.1 Ambient Vibration Levels

Vertical displacement: The spectra in Figure 2 show the highest displacements are between 0 Hz and about 30 Hz. After 30 Hz the displacement spectra magnitudes decline with a number of local maxima throughout. Table 1 highlights three of the local maxima or peaks at about 30 Hz, 60 Hz, and 120 Hz. From Figure 2 and Table1 it is seen that for frequencies greater than 5 Hz most measured displacements are less than 10 nm_{rms}. The only exception is at measurement locations M3 and M7 at about 30 Hz.

Figure 4 and Figure 6 show the same ambient vibration measurements as Figure 2, but with narrower bandwidths (75 Hz and 35 Hz respectively). Table 3 and Table 5 have the peak values of displacement measured in those narrower bandwidths. In figure 4 it can be seen that vibration levels increase between 15 Hz and about 20 Hz. Figure 6 and Table 5 show that for locations M1 and M2 have peaks between 5 Hz and 15 Hz that have larger magnitudes than those observed between 15 Hz and 20 Hz.

Perpendicular to beamline displacement: These vibration levels are lower than what is measured in the vertical direction (see Figure 3). The general pattern of declining displacements throughout the bandwidth does holds for both perpendicular to beamline and vertical displacements. For frequencies greater than 5 Hz maximum displacement values were measured at about 30 Hz (see Table 2). Measurement locations M4, M5, and M6 measured displacement magnitude greater than 1 nm_{rms} at about 30 Hz. All other locations measured less than 1 nm_{rms}.

The perpendicular to beamline vibration levels in the 0 Hz to 75 Hz range (Figure 5) are seen to have peak displacements between 15 Hz and 20 Hz. Table 4 confirms this observation with peaks occurring between 15.3 Hz and 19.3 Hz and having magnitudes between 0.46 nm_{rms} and 1.07 nm_{rms}.

In Figure 7 there appears to be local maxima at about 3 Hz. The local maxima are most significant for measurement locations M6 and M7. Table 6 shows both locations have peaks at 3.1 Hz and magnitudes of 6.18 nm_{rms} and 4.97 nm_{rms} respectively. These peaks are likely due to a natural frequency in floor or surrounding structures.

4.2 Generic Vibration Criteria

The vertical and perpendicular to beamline directions compare favorably to the generic vibration criteria plotted in figures 8 and 9. Neither direction is below the very strict NIST-A criterion because of their low frequency content (1 Hz and 1.25 Hz).

The vertical direction displacement in Sector 29 can be said to be at the VC-E. While the maximum measured rms displacement as well as the mean rms displacement plus one standard deviation are both slightly above VC-E, “a strict interpretation of a comparison with the criteria is not encouraged” [1]. Given how close those measurements are to the VC-E level one can say most locations in Sector 29 are below that criterion.

The perpendicular to beamline direction displacement in Sector 29 are below the VC-G criterion. This a very difficult criterion to meet and should be more than sufficient for most vibration sensitive equipment.

4.3 Other Sectors

There is significant differences between Sector 29 and the nearby sectors measured. Figure 10 shows the sector's spectra follow a similar pattern in only the most general way. Table 7 shows some large differences in peaks at the same or similar frequencies. In two instances there is greater than a 100 percent change from Sector 29 to another sector.

4.4 Different Data Acquisition Systems

Figure 11 compares ambient vibration levels measured by two different data acquisition systems at measurement location M2 in Sector 29. From Figure 9 there appears to be very close agreement between the two measurement systems. The HP E1432A system does seem to record higher peaks and lower valleys. Table 8 shows the HP system measuring slightly higher displacement magnitudes at about 30 Hz and 120 Hz. The percent change from the HP to the Photon+ system is within a range that suggests the differences normal variations to be expected from vibration measurements [1]. They do not suggest a significant bias from one system to another.

4.5 Changes over Time

The previously measured ambient vibration levels in Sector 29 are significantly higher than what was measured more recently. In Figure 9 it is seen that between 0 Hz and 70 Hz the vibration levels are generally in agreement, except more peaks with higher magnitudes were captured in the more recent round of measurements. For frequencies greater than 70 Hz vibration levels are generally higher in the recent measurements than those previously measured. Table 8 show peaks that are much higher in recent measurements than in previous measurements.

All the other sectors have significant differences between their previously measured vibration levels and the more recent measures. While there are differences, some very large, it is not clear that there is higher vibration levels in the more recent measurements than previously measured, at least not across the entire bandwidth.

5 Conclusion

Ambient Vibration levels: For all frequencies between 5 Hz to 150 Hz all but two measurement locations in Sector 29 measured below 10 nm_{rms}. The vertical displacement measured in Sector 29 as complies with the VC-E vibration criterion. This criterion is, "[a]ssumed to be adequate for the most demanding of sensitive systems" [1]. In the perpendicular to beamline direction all ambient displacement levels measured are below 10nm_{rms}. The measurements in this direction comply with the even stricter VC-G criteria. Sector 29 should be appropriate for any vibration sensitive equipment that are need.

Other Sectors: Sector 29 is significantly different than other sectors near it. However, it does not have consistently higher nor lower vibration levels. Sector 29 fits within the observed variation on the experiment floor at APS.

Data Acquisition Systems: There is no significant difference between the measurements with the HP E1432A 16-channel system and the Photon+ 5-channel system. Measurements with either system should be comparable.

Large Timescale Differences: Vibration levels in Sector 29 are significantly higher in recent measurements compared to previous measurements. The most likely cause of this discrepancy is that in 2011 Sector 29 was mostly open space. Since then beamline 29-ID-C,D was added. There is now extra structures and functioning equipment (such as vacuum pumps) in Sector 29 that there were not previously present. The previous vibration measurements were most likely an accurate picture of the vibration levels in Sector 29 before Beamline 29-ID-C,D was built and began operations. The more recent measurements are most like more accurate now.

The other sectors measured also had significant changes over the measurement periods. But these changes were not consistently higher or lower. Continuing to monitor vibration levels throughout APS will help scientists and engineers get a clearer picture of how vibration levels vary through time.

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References

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