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DIRECTORATE FOR ENGINEERING SCIENCES**



**PORTABLE GENERATOR
VIBRATION MEASUREMENTS**

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1.0 INTRODUCTION

The U.S. Consumer Product Safety Commission (CPSC) staff measured the vibration of two portable generators during start-up, normal operation, shut-down, and transport. This report describes the results of CPSC staff tests to quantify the vibration levels associated with these generators.

1.1 Background

In 2005, to address the carbon monoxide (CO) poisoning hazard associated with portable generators, CPSC staff demonstrated a concept to detect elevated levels of CO in a remote area and shut down a portable generator using wireless communications and on-board electronics. If such a system was developed for use on a generator, the on-board electronics may be subjected to prolonged vibration during the life of the generator, perhaps causing the electronics to fail before the end of generator life. To determine the vibration levels that the electronics may be exposed to during the life of the generator, CPSC staff measured vibration levels on two generators during start-up, normal operation, shut-down, and transport.

1.2 Project Objectives

In this evaluation, the vibration of a generator was measured and analyzed to determine the frequency and amplitude levels of vibration that electronics may experience during the operation and transport of a portable generator.

2.0 VIBRATION

2.1 Basic Vibration Model

Vibration often results from the excitation of a system from a cyclical source. The sine wave is a basic waveform that represents cyclical motion. A mass connected to a spring can represent a vibrating system (Figure 1). In Figure 1, if the weight is pulled down to the -10 mark and released, the spring will pull the weight up and past the zero mark. The weight will almost reach the +10 mark, and then begin to head downward again. When plotted against time, the undulating movement of the weight produces a sine wave. The weight will continue to vibrate, or oscillate, at an amplitude that will slowly decrease due to frictional losses. This sine wave is damped because the energy placed into the system by the initial pull on the weight was transient.

This basic vibrational model may be extended to more complex mechanical systems such as a portable electric generator, which has a vibration profile that consists of a number of sinusoidal waveforms mixed together. The primary, cyclic source of vibration for a portable generator is the gas-fueled engine. In the engine, the piston is connected to a crankshaft by a connecting rod. The rotation of the crankshaft and the repetitive up-and-down motion of the piston position plotted against time produces a sine wave which, in this case, is undamped because the rotation of the motor continuously adds energy to the vibrational system.

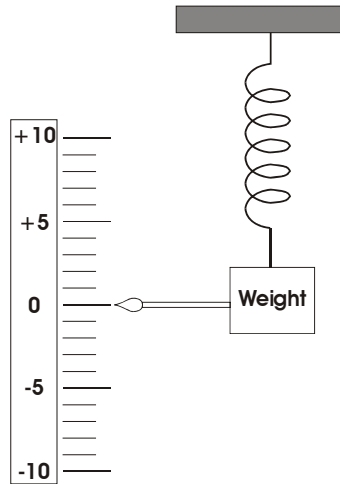


Figure 1. Vibration Levels

Displacement, velocity, and acceleration are related properties of basic motion and thus vibration as well. Displacement is the measure of the distance traveled from the origin, velocity is the rate of change of the displacement, and acceleration is rate of change of the velocity. Figure 2 is an illustration of how displacement, velocity, and acceleration interact with each other. In this illustration, a truck travels forward and backward between two cones. The cones represent the full range of displacement and are marked as negative on the left of center and positive on the right of center. The midpoint is zero displacement. The speedometer in the truck shows the velocity of the truck. A bucket of water on the truck represents the acceleration of the truck. In this illustration, initial conditions are ignored, i.e., assume that the truck is not starting from rest.

As the truck travels to the right, toward the positive cone, the displacement increases. The maximum velocity is at zero displacement, or at the midpoint; then the truck's velocity decreases as it approaches the positive cone. At the same time, the truck is decelerating as the driver is applying the brakes. This continues as long as the truck continues back and forth.

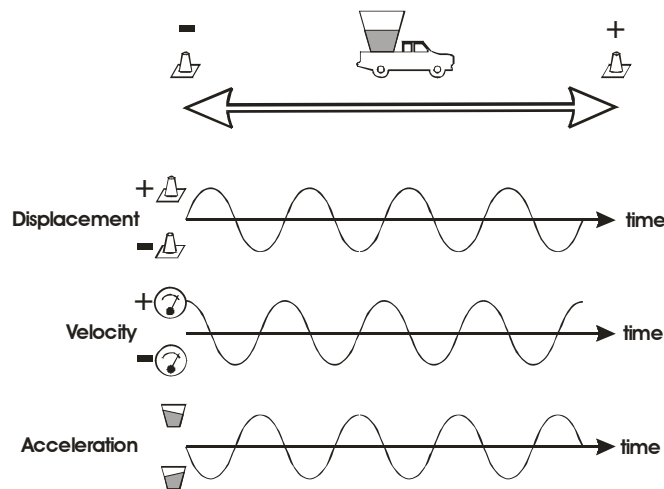


Figure 2. Displacement, Velocity, and Acceleration Relationship

The relationships between displacement (d), velocity (v), and acceleration (a) are defined by the following equations. Acceleration can be converted to velocity and velocity to displacement by using mathematical integration. Acceleration can be determined from velocity and displacement by using mathematical derivation.

a to v to d

$$a = A \sin 2\pi ft$$

$$v = \int a = -\frac{A}{(2\pi f)} \cos 2\pi ft$$

$$d = \int v = \iint a = -\frac{A}{(2\pi f)^2} \sin 2\pi ft$$

a = acceleration

v = velocity

d = displacement

A, D = constants

f = circular frequency

t = time

d to v to a

$$d = D \sin 2\pi ft$$

$$v = \frac{d}{dt} d = (2\pi f) D \cos 2\pi ft \quad -$$

$$a = \frac{d}{dt} v = \frac{d^2}{dt^2} d = -(2\pi f)^2 D \sin 2\pi ft$$

Table 1 lists the common units in SI¹ and English for acceleration, velocity, and displacement.

Table 1. Common Units

	SI	English
Acceleration	$\frac{meters}{sec^2}$	$\frac{ft}{sec^2}$
Velocity	$\frac{meters}{sec}$	$\frac{ft}{sec_{PK}}$
Displacement	<i>meters</i>	inches or mils _{PK}

mil=0.001 inches

PK = peak

3.0 MEASURING GENERATOR VIBRATION

Vibrations can travel through air and objects. In a portable generator, the engine vibrates when running. This vibration from the engine is transferred to the generator's metal frame.

To measure vibration, two accelerometers were mounted to the generator's frame. The accelerometers were mounted perpendicular to the engine shaft's rotation in the horizontal and vertical axes.

Two different-sized (5250 and 2250 watt) generators were tested. The age of the 5250 watt generator was less than one year while the 2250 watt unit was 10 years old. Both generators were driven by four-stroke engines with gasoline as the fuel.

3.1 Test Setup and Instrumentation

A data acquisition system consisting of single-axis accelerometers (meaning they only record acceleration forces exerted in one direction), a digitizing unit, and a computer was used. The accelerometers had a range of ± 500 Gs.² The accelerometers were screwed to mounting blocks, and epoxy was used to mount the accelerometer blocks to a generator's frame. A coaxial cable connected each accelerometer to the digitizing unit. The digitizing unit was then connected to the computer. The test setup is shown in Figure 3. Approximately three minutes of generator operation were recorded for each test. The accelerometers and data acquisition system were calibrated before and after each test series using a calibrator exciter (a mechanical source that vibrates at a known amplitude and frequency).

¹ The International System of Units, abbreviated SI for the French "Système International d'Unités."

² $G = 9.81 \text{ m/sec}^2 = 32.2 \text{ ft/sec}^2$

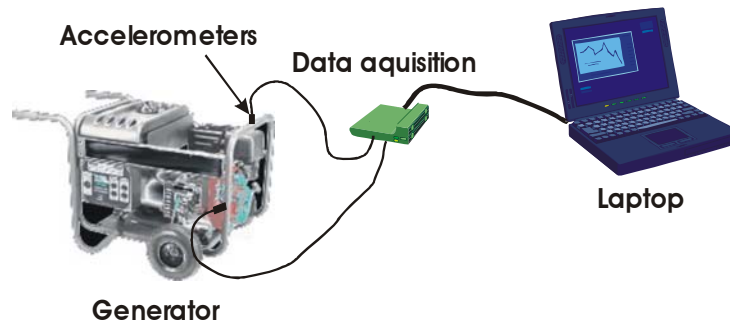


Figure 3. Test Setup

Below is a list of the equipment used in the testing. CPSC does not endorse the equipment and instrumentation used in the project nor state that the equipment or instrumentation used is the best or only for this application. The product and company names listed are trademark or trade names of their respective companies.

Generator Rating	5250 watts Gasoline engine 3,600 RPM (revolutions per minute) Less than 1 year old
	2250 watts Gasoline engine 3,600 RPM Over 10 years old
Accelerometer	Dytran Series 3030B Frequency response, 2 to 10,000 Hz $\pm 5\%$ Range FS (full scale), ± 500 G Sensitivity @ 100 Hz 1G, RMS, $10.0 \pm 5\%$ mV/G Linearity at FS, $\pm 1\%$ Resonant frequency, 30 kHz Equivalent noise floor, 0.007 G, RMS
Digitizing System	Sound Technology, Inc. Model ST191 32 bit PC link
Computer	Laptop 3GHz processor 1GB RAM
Analysis Software	Sound Technology, Inc. LAB432 Enterprise Edition Version 19

Calibration Exciter Rion Co., Ltd.
Model VE-10
Vibration frequency, 159.2 Hz \pm 1%
Acceleration, 10 m/s² (RMS)

The vibration waveform is composed of a combination of frequency components of different magnitudes, rendering it a fairly noisy-looking signal. In order to extract data that can be analyzed, the time-dependent vibration signal must be subjected to a spectral analysis, which processes it and separates it into frequency components. The data for these tests was analyzed by performing a fast Fourier transform (FFT) on the recorded accelerometer signal (an FFT is a discrete digital signal processing technique for converting a time-dependent signal into a frequency spectrum). The spectrum graphs are two-dimensional plots of the spectrum with frequency (Hz) on the horizontal axis and the amplitude of each discrete frequency component on the vertical axis. The amplitude is a peak-hold, displaying the maximum amplitude for that particular frequency in the processed time frame, unless otherwise stated.

An FFT is a discrete process, so there are several parameters that define the limitations of the particular analysis. The total number of available spectral lines is equal to the FFT size divided by two. The FFT size set for the tests was 32,768; therefore, there were 16,384 spectral lines. The spectrum starts at 0 Hz and extends to one-half of the selected sampling rate divided by the Decimation Ratio of 1 (the frequency limit). The sampling rate for these tests was 11,025 Hz, so the frequency limit was 5,512 Hz. The spectral line resolution is the frequency limit (5,512 Hz) divided by the number of spectral lines (16,384) or 0.33 Hz; this is sometimes referred to as the bin size.

3.2 5250 Watt Generator

Six tests were conducted with the 5250 watt generator running. Data was taken at start-up, normal operation, and shut-down of the generator. Figure 4 shows a picture of the 5250 watt generator.



Figure 4. 5250 Watt Generator

The accelerometers were mounted at three different locations on the generator. Only two accelerometers were used at one time. Accelerometers were placed on the generator's frame and/or on the control panel. Figure 5 shows the locations of the accelerometers mounted on the generator. The accelerometers were mounted in the vertical axis and horizontal axis. The accelerometers were mounted perpendicular to the rotation of the engine shaft.

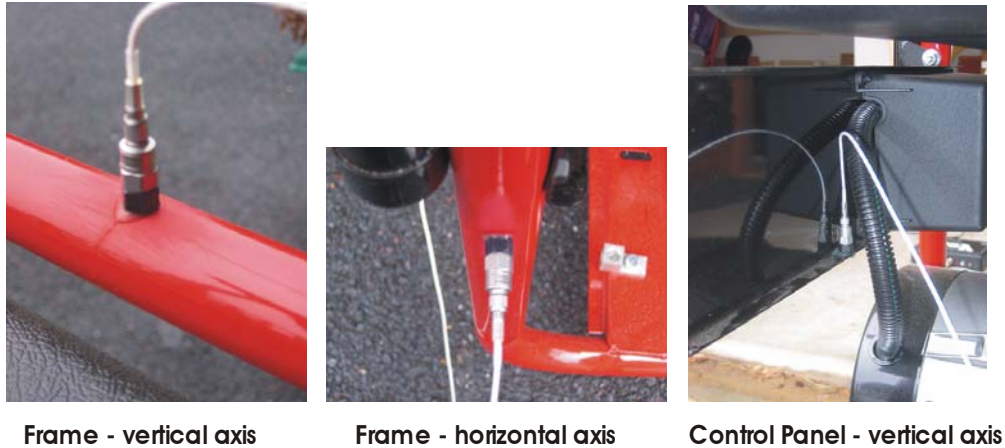


Figure 5. Accelerometers Mounted on the 5250W Generator

Testing was conducted during the day with an outside temperature of 67°F and 47% relative humidity.

3.2.1 Tests 1 to 3 - Accelerometers Mounted on the Generator Frame

In this series of tests, data was collected from the accelerometers that were mounted on the generator's frame during generator start-up, running (without an electrical load) and shut-down for three trials. Figures 6a to 6c show the time domain acceleration waveform for tests 1 to 3, respectively. In the post analysis, all three tests displayed very similar acceleration waveforms in amplitude and frequency. Slight differences in start-up and shut down amplitudes were noticed.

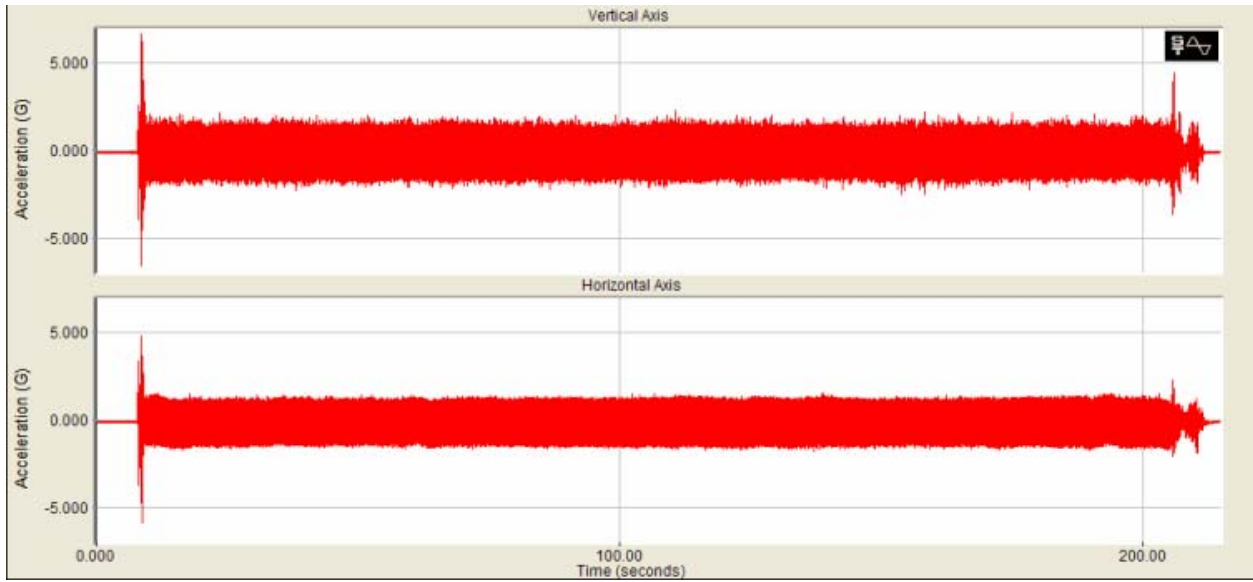


Figure 6a. Test 1 - 5250W Generator, Time Series

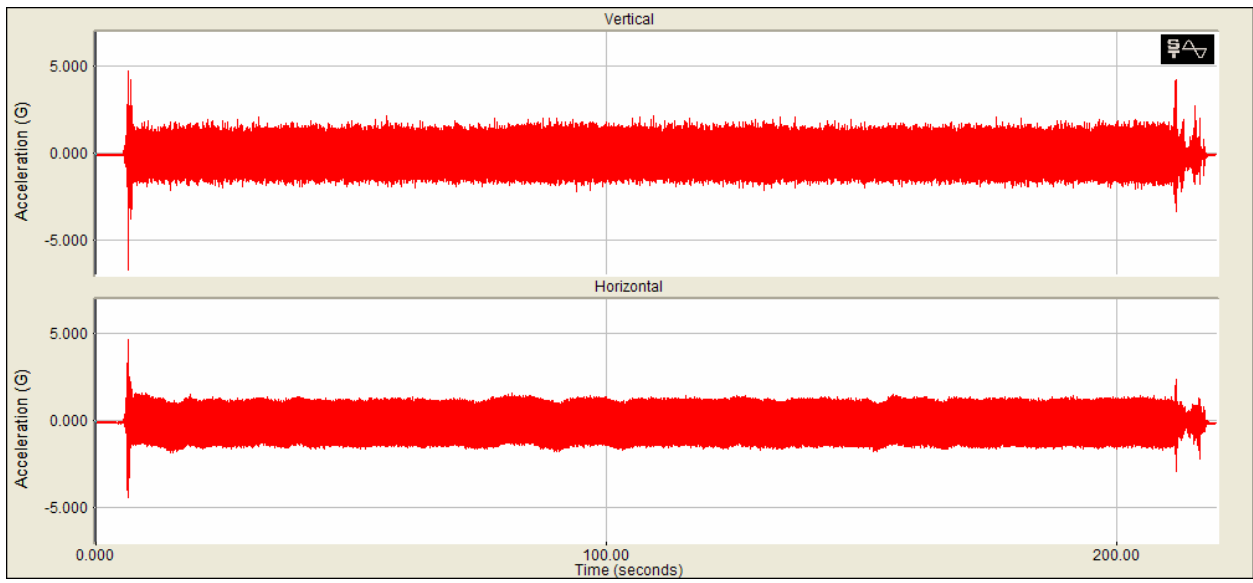


Figure 6b. Test 2 - 5250 W Generator, Time Series

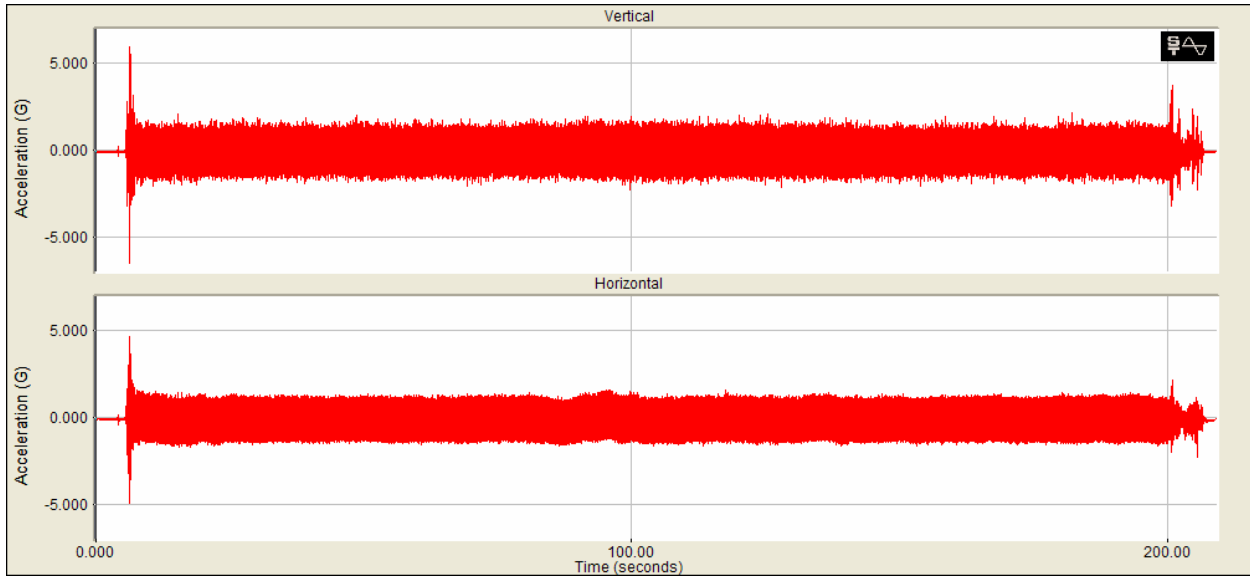


Figure 6c. Test 3 - 5250W Generator, Time Series

3.2.1.1 Test 3 Spectral Analysis

Since the outcomes of tests 1 to 3 were all very similar, test 3 was selected as a representative sample for spectral analysis of these test conditions. The acceleration and displacement are displayed in spectrum format (frequency vs. amplitude). Figures 7a and 7b show the vertical-axis peak-hold acceleration spectra from 0 to 5.5 kHz and from 0 to 650 Hz, respectively. Most of the energy was at 61.57 Hz, which had a peak 0.91 G or 8.9 m/s^2 . It is understandable that the majority of the energy was around 60 Hz since the generator rotates at 3600 RPM or 60 rotations per second (RPS), equating to 60 Hz.

Figures 8a and 8b show the horizontal-axis peak-hold acceleration spectra from 0 to 5.5 kHz and from 0 to 600 Hz, respectively. Most of the energy was at 61.57 Hz, which had a peak 0.87 G or 8.5 m/s^2 . Figure 8b shows considerably more energy at the low frequencies (10 to 15 Hz) than in the vertical-axis figure.

Figure 9 shows the vertical and horizontal axis peak-hold displacement spectrum from 0 to 80 Hz. There was very little displacement at frequencies greater than 70 Hz. The displacement spectrum shows significant vibration at frequencies below 40 Hz. The vertical and horizontal axis peak displacements were 0.35 mm and 9.7 mm at around 1.7 Hz. Peaks in the horizontal axis occurred at frequencies between 10 Hz and 20 Hz. These peaks are a result of the generator at start-up. For frequencies greater than 40 Hz, the vertical and horizontal displacement peaks were 0.06 mm and 0.057 mm, respectively. These peaks occurred at 61.6 Hz.

The displacement peaks at 10 Hz and 20 Hz occurred when the generator was being manually started, as shown in Figure 10. The figure shows the displacement of the generator only at start-up. Figures 11a and 11b show the 3D acceleration and displacement spectra during start-up, respectively. Significant acceleration and displacement peaks at 10 and 20 Hz occurred

when the generator was jerked during pull starting. The figures show acceleration and displacement peaks at 10 Hz in the vertical axis and 10 and 20 Hz in the horizontal axis. The amplitude is greater in the horizontal axis than it is in the vertical axis.

Figure 12 shows the peak-hold displacement while the generator was running. The figure shows smaller displacement peaks at low frequencies and the peak around 61 Hz.

Similar to start-up, low frequency displacement peaks occurred when the generator was shutting down, as shown in Figure 13. Figures 14a and 14b show the acceleration and displacement 3D spectra, respectively, during shut-down. Significant acceleration and displacement peaks occurred when the generator jerked as it was shutting down. The figures show acceleration and displacement peaks at 10 Hz in the vertical axis and 10 and 20 Hz in the horizontal axis. Figures 14a and 14b show the decreasing frequency as the engine slowed down.

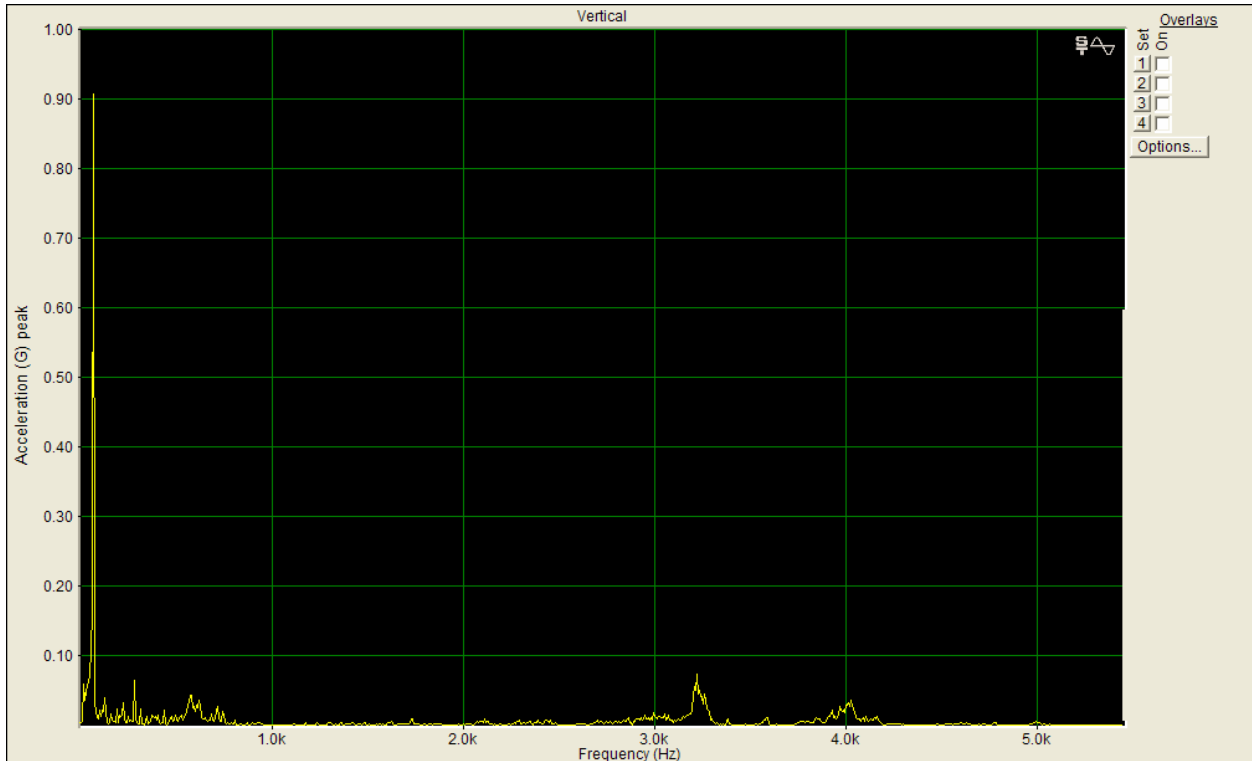


Figure 7a. Test 3 - Vertical-Axis Peak-Hold Acceleration Spectrum (0 to 5.5 kHz)

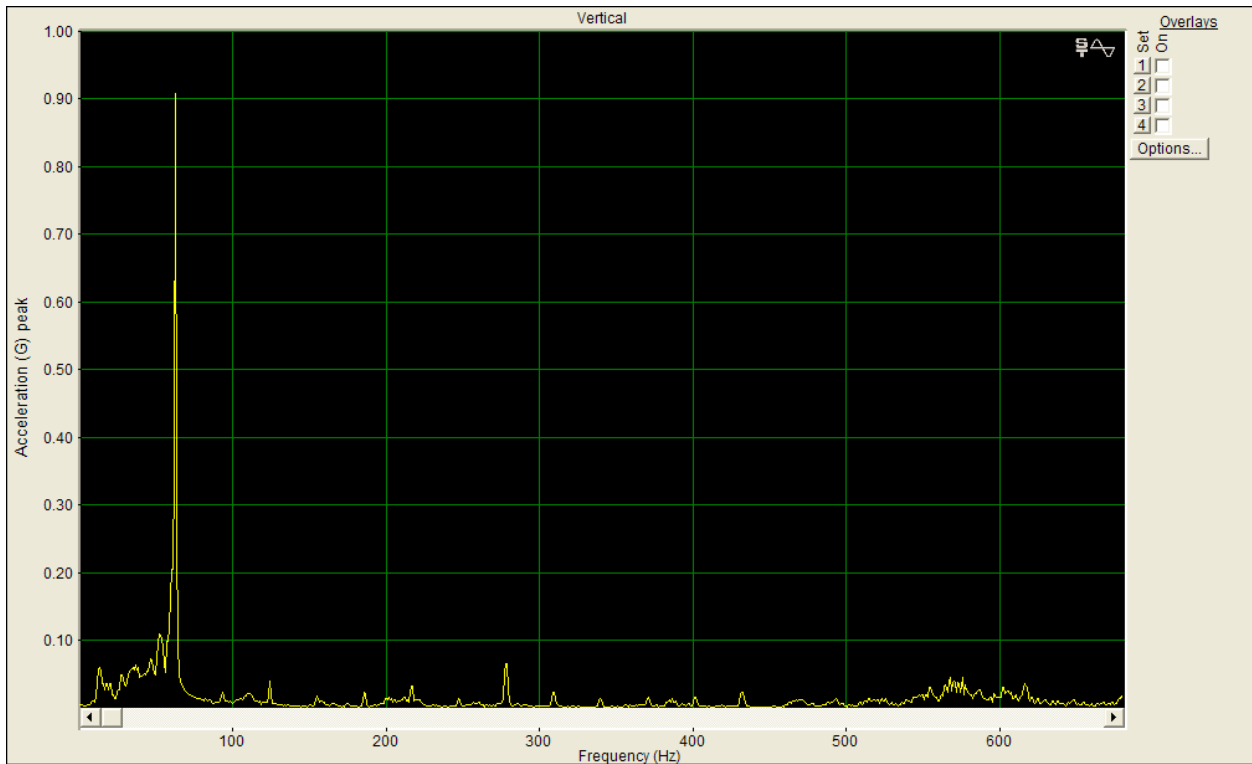


Figure 7b. Test 3 - Vertical-Axis Peak-Hold Acceleration Spectrum (0 to 650 Hz)

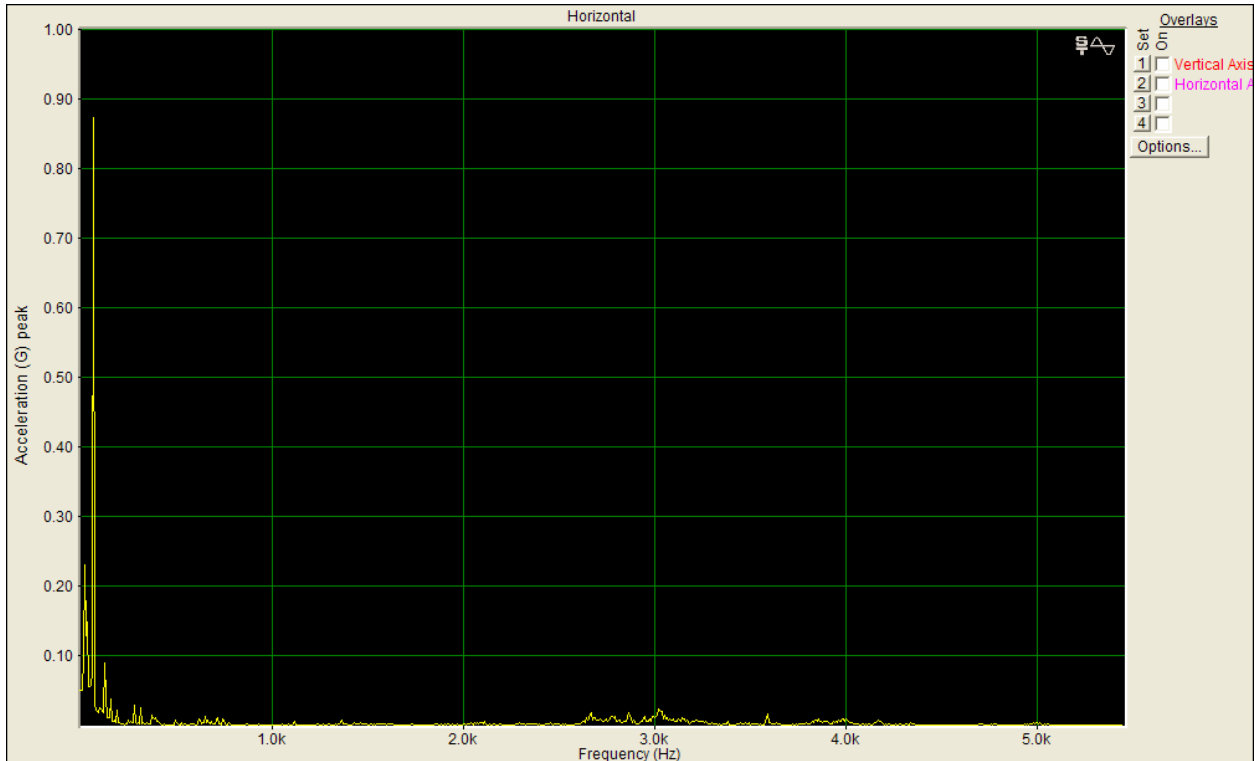


Figure 8a. Test 3 - Horizontal-Axis Peak-Hold Acceleration Spectrum (0 to 5.5 kHz)

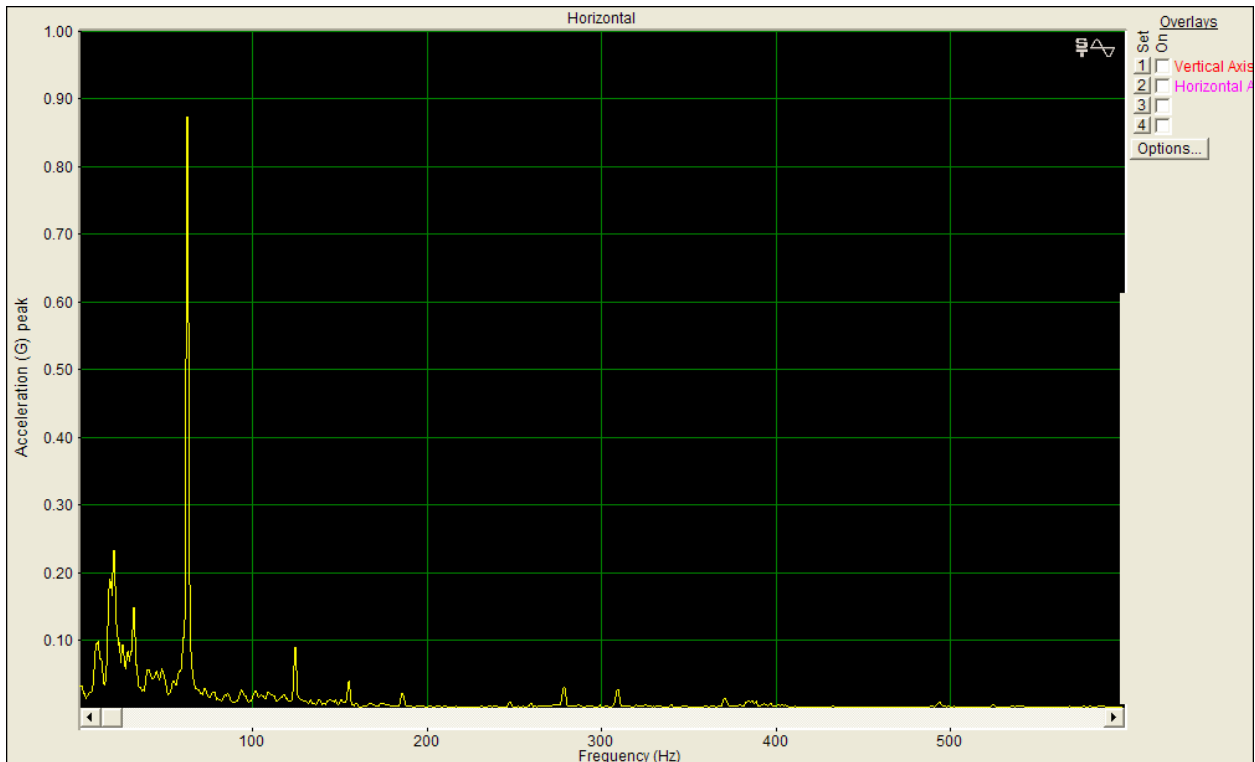


Figure 8b. Test 3 - Horizontal-Axis Peak-Hold Acceleration Spectrum (0 to 600 Hz)

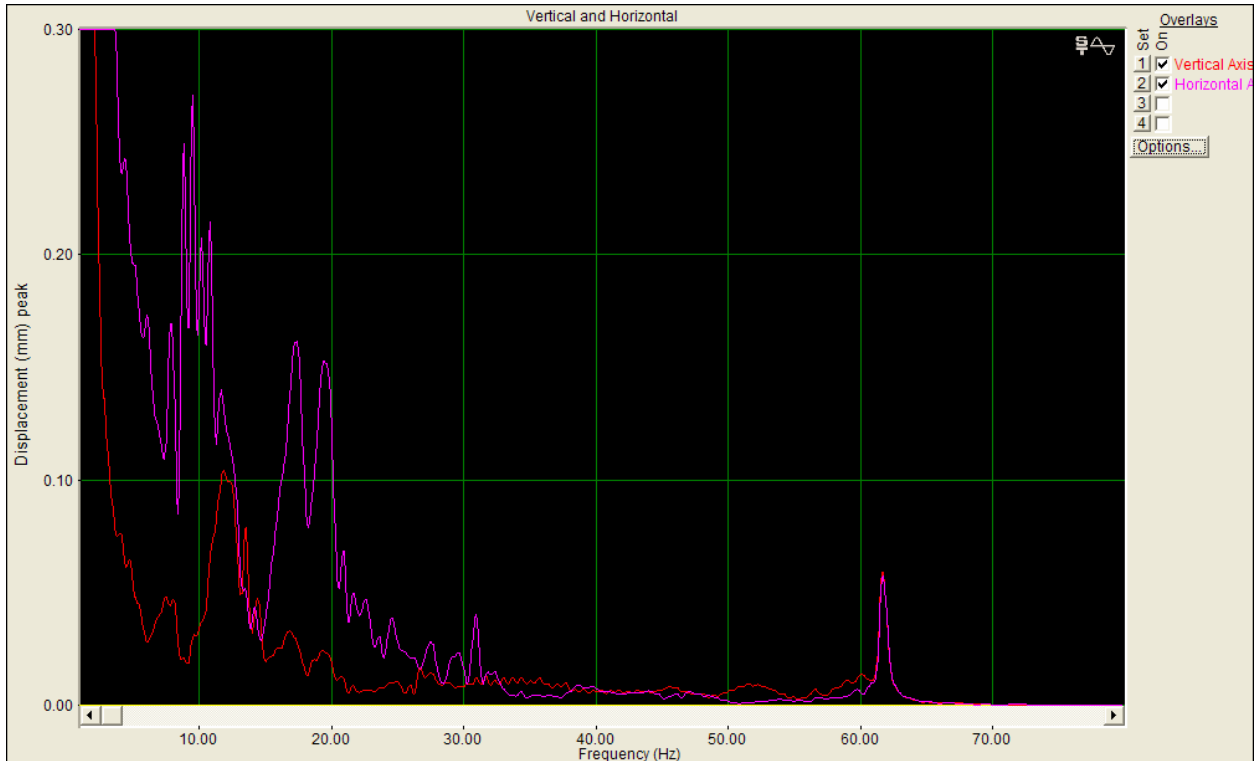


Figure 9. Test 3 - Peak-Hold Displacement Spectrum from 0 to 80 Hz

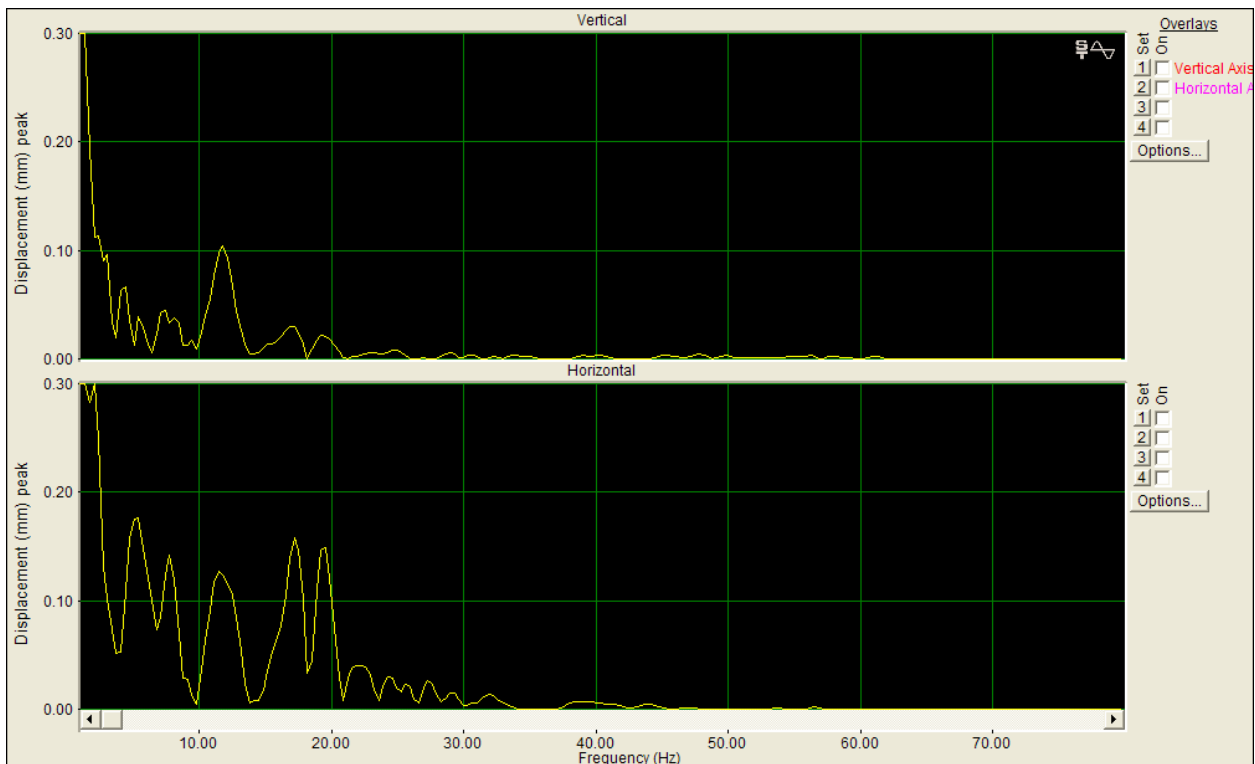


Figure 10. Test 3 - Peak-Hold Displacement Spectra at Start-up

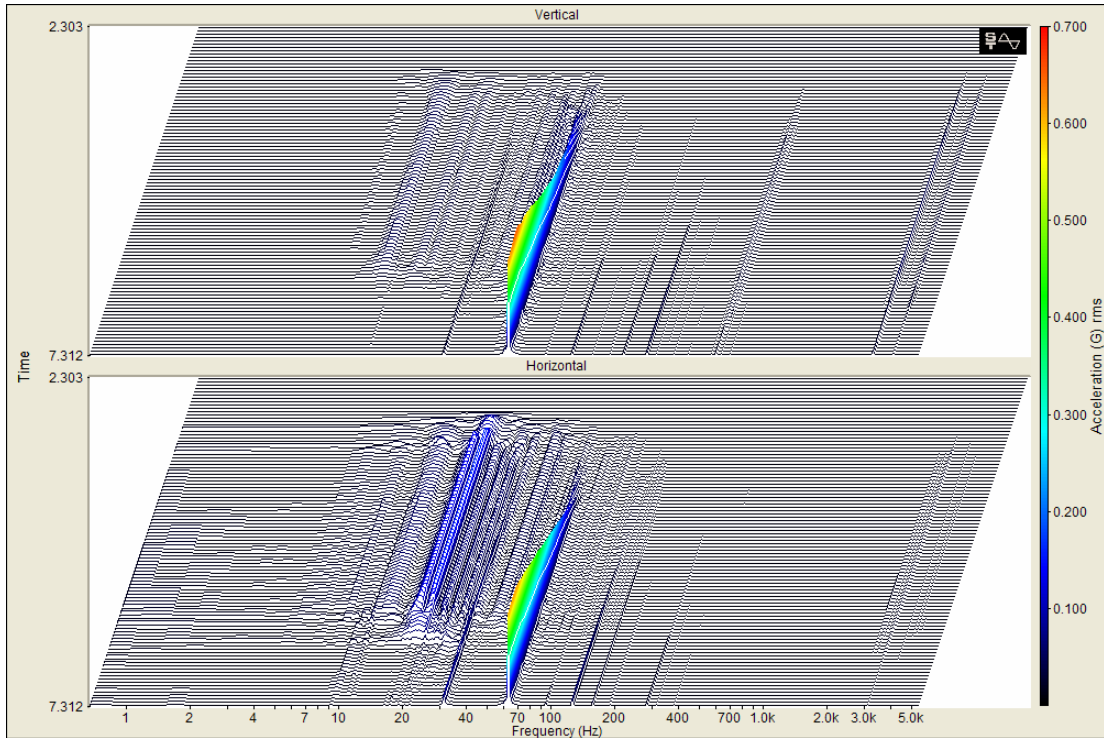


Figure 11a. Test 3 - 3D Surface Acceleration Spectra at Start-up

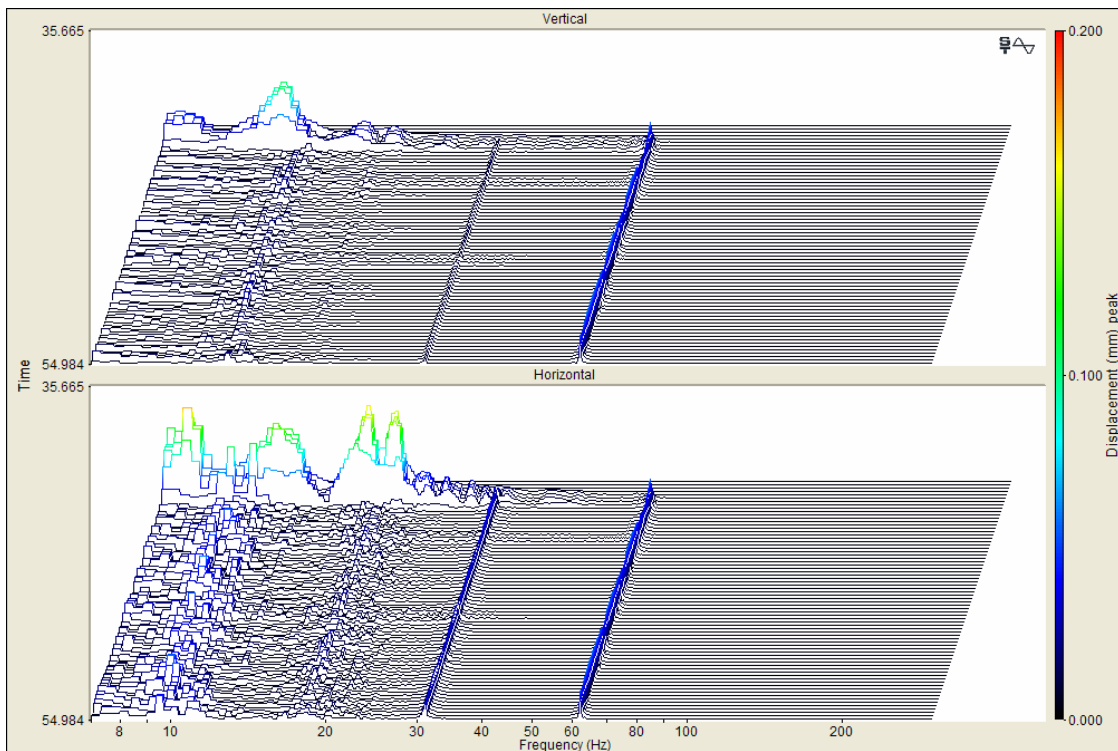


Figure 11b. Test 3 - 3D Surface Displacement Spectra at Start-up

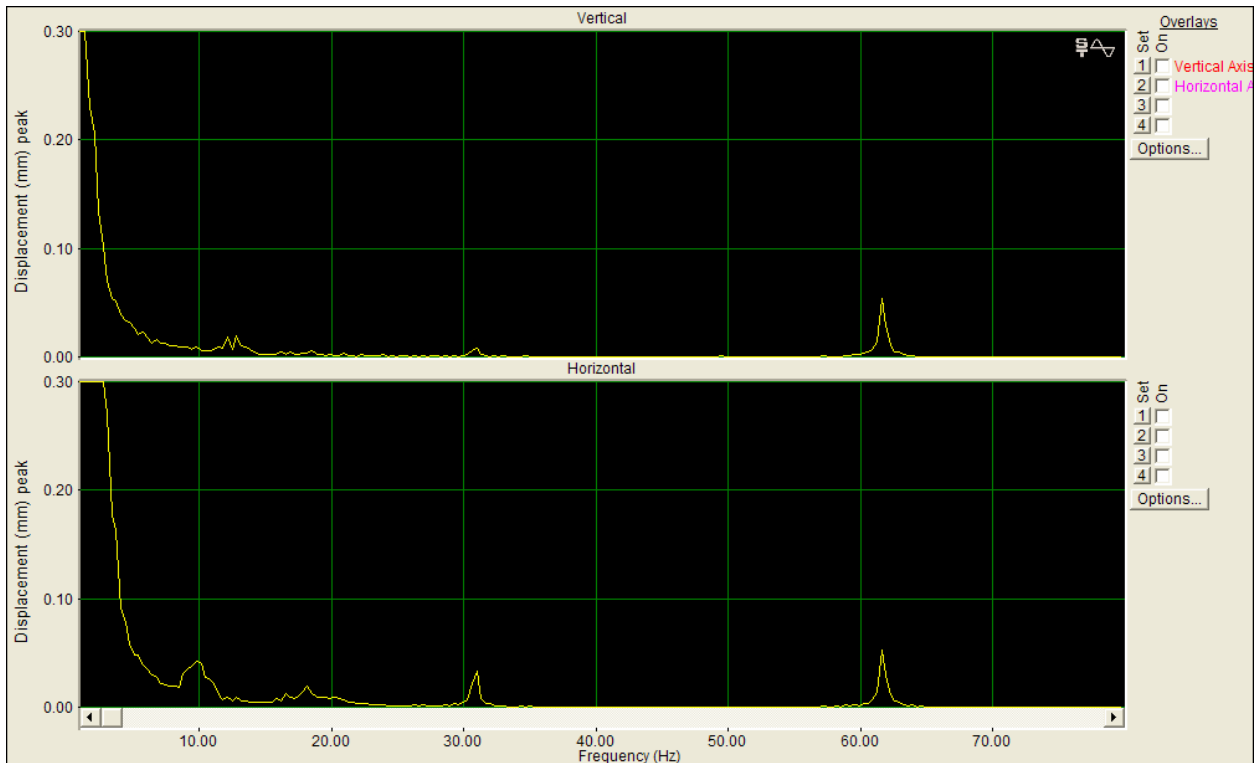


Figure 12. Test 3 - Peak-Hold Displacement Spectrum while Running

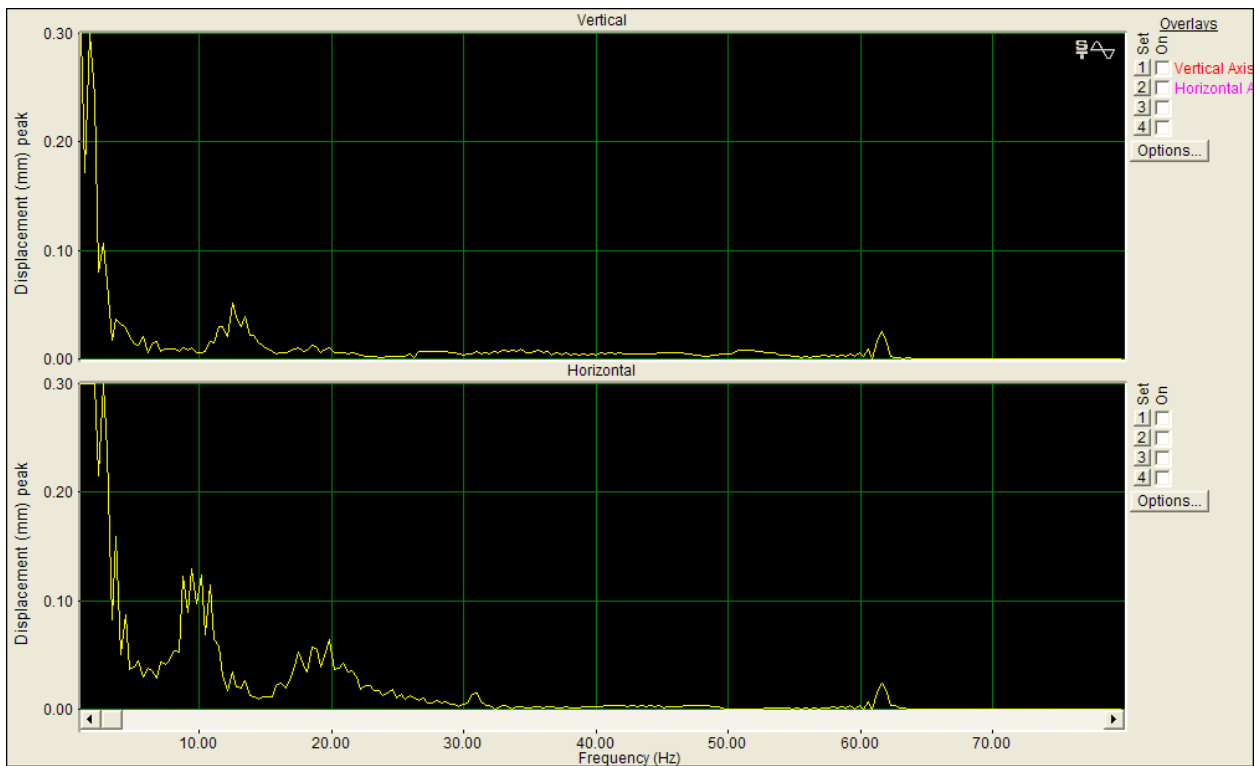


Figure 13. Test 3 - Peak-Hold Displacement Spectrum during Shut-down

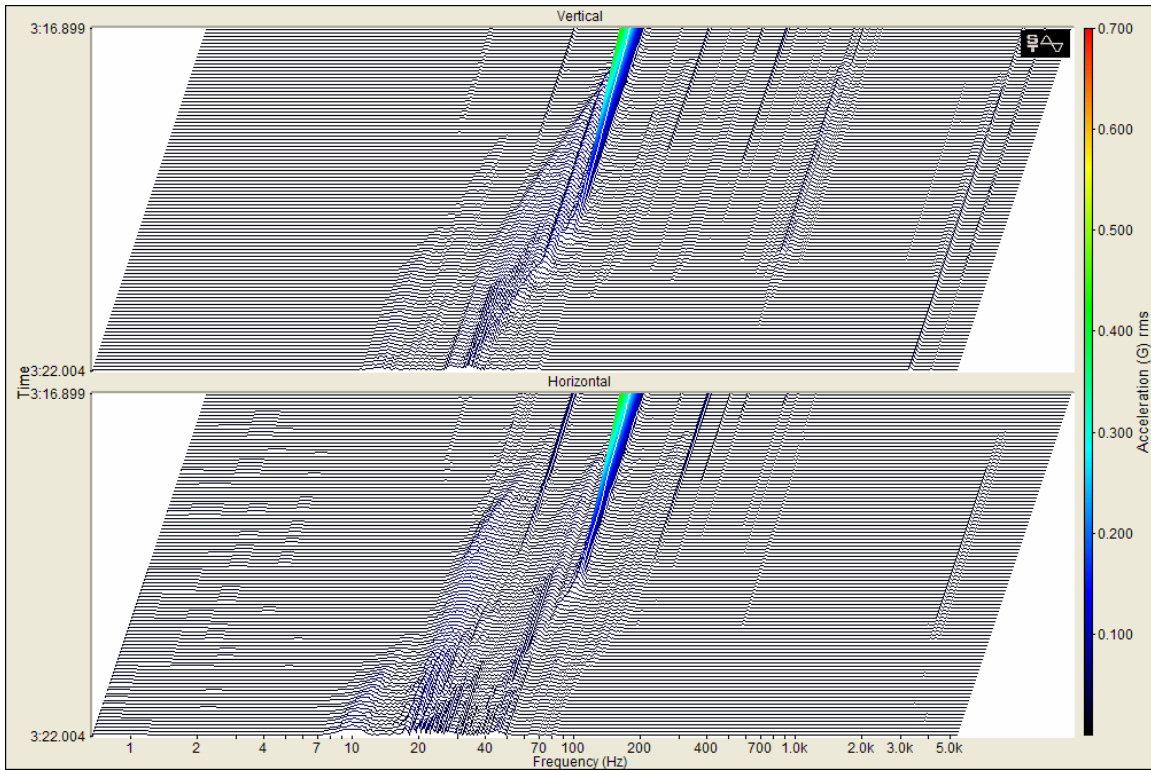


Figure 14a. Test 3 - 3D Surface Acceleration Spectra at Shut-down

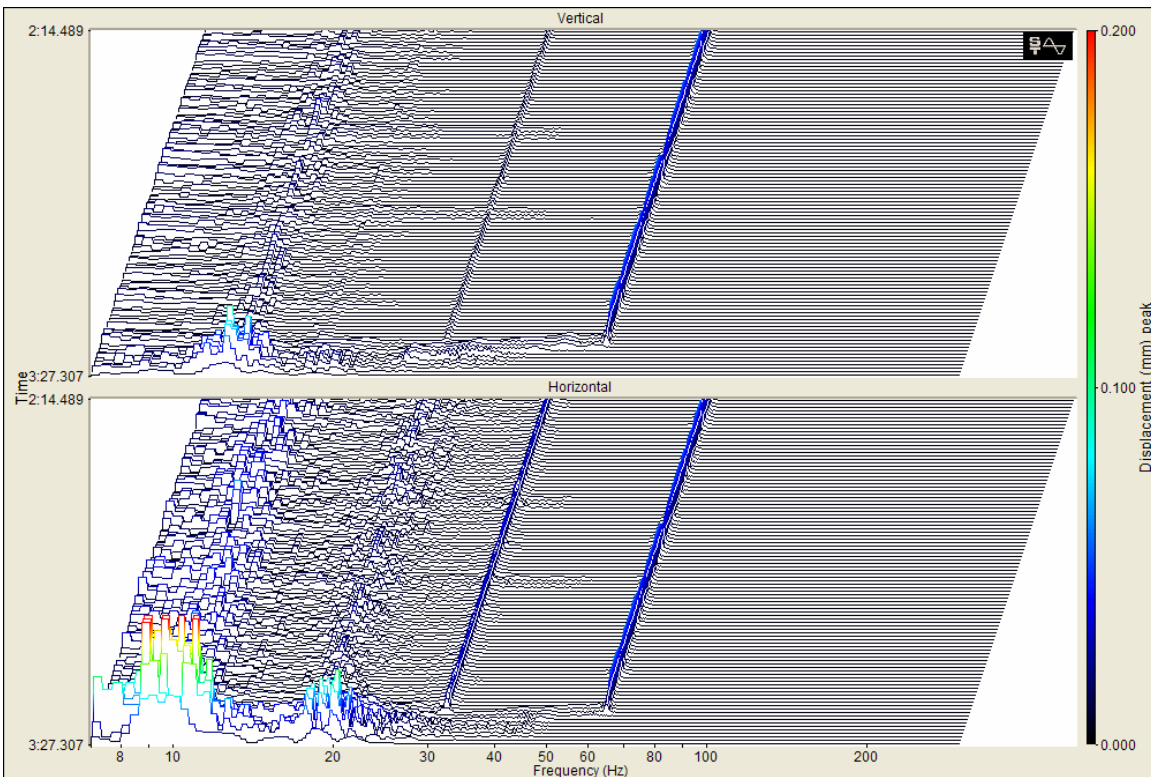


Figure 14b. Test 3 - 3D Surface Displacement Spectrum at Shut-down

3.2.2 Tests 4 to 6 – Accelerometers Mounted on the Generator Frame and the Control Panel

In this series of tests, data were taken from the accelerometers that were mounted on the generator's frame and the control panel. One accelerometer was mounted in the vertical axis on the generator's frame and the other accelerometer was mounted on the control panel in the same axis. Figures 6a to 6c show the time series for tests 4 to 6. The time series shows the start-up, running, and shut-down of the generator. During post analysis, all three tests were very similar in amplitude and frequency. Slight differences in start-up and shut down amplitudes were noticed.

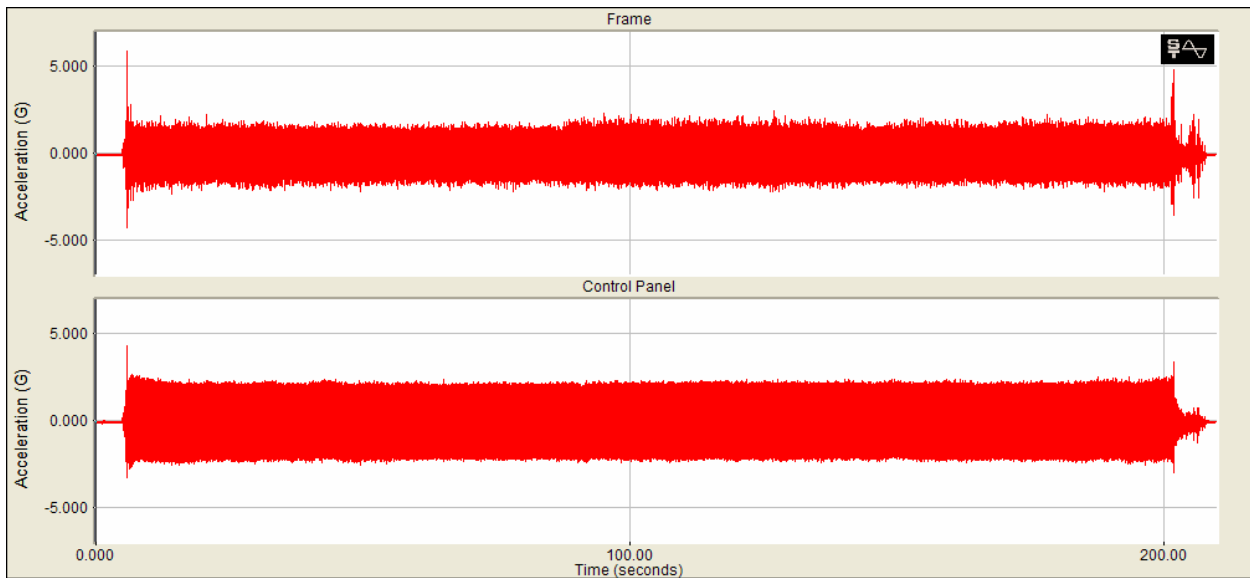


Figure 15a. Test 4 - 5250W Generator, Time Series

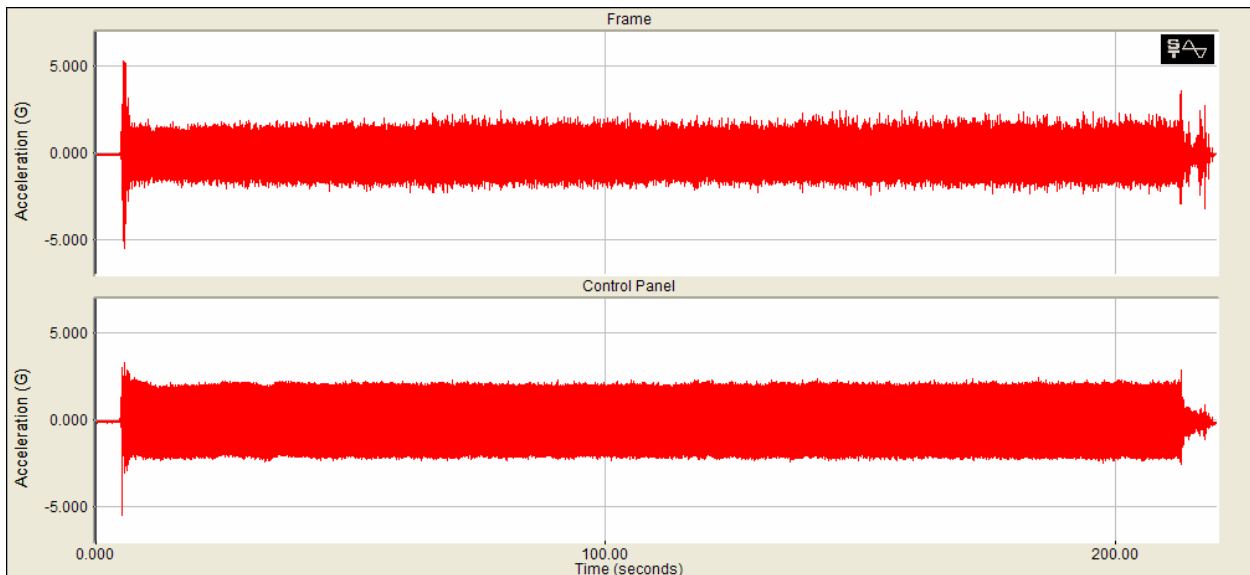


Figure 15b. Test 5 - 5250W Generator, Time Series

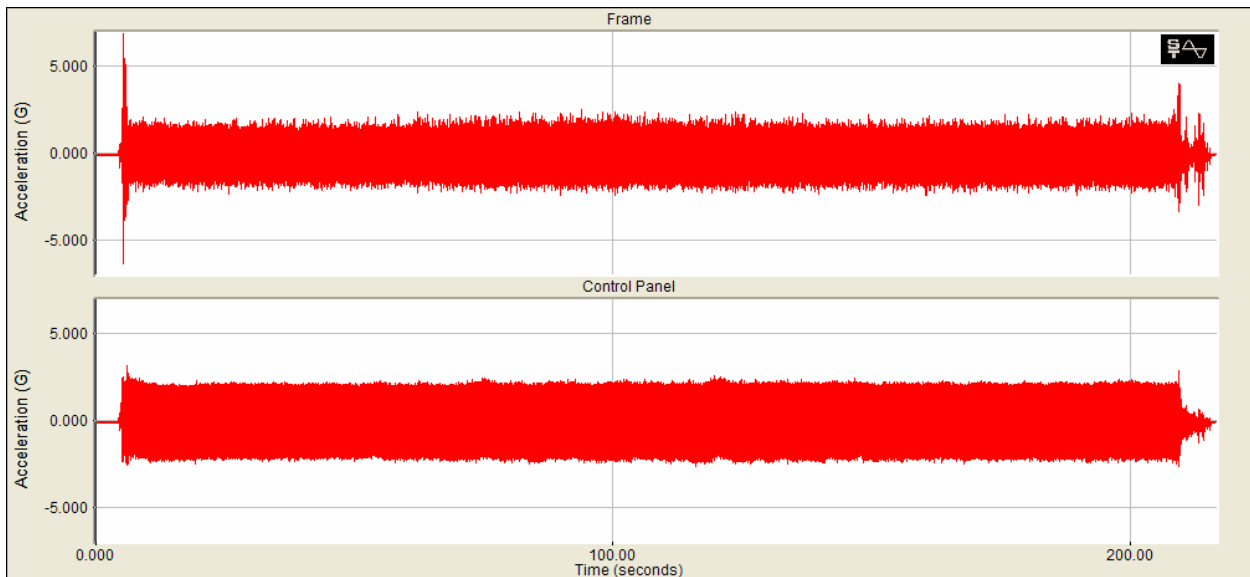


Figure 15c. Test 6 - 5250W Generator, Time Series

3.2.2.1 Test 6 Spectral Analysis

Since the outcomes of tests 4 to 6 were all very similar, test 6 was selected as a representative sample for spectral analysis of these test conditions. The acceleration and displacement are displayed in spectrum format (amplitude vs. frequency). Figures 16a and 16b show the vertical-axis peak-hold acceleration spectrum from 0 to 5.5 kHz and from 0 to 650 Hz, respectively. Most of the energy was at 61.9 Hz, which had a peak 0.94 G or 9.22 m/s^2 .

Figures 17a and 17b show the control-panel peak-hold acceleration spectrum from 0 to 5.5 kHz and from 0 to 600 Hz, respectively. Most of the energy was at 61.5 Hz, which had a peak 1.85 G or 18.1 m/s^2 . The frequencies are similar on the frame and the control panel.

Figure 18 shows the frame-mounted and control panel-mounted peak-hold displacement spectrum from 0 to 80 Hz. There was very little displacement at frequencies greater than 70 Hz. The displacement spectrum shows a significant displacement at frequencies below 40 Hz. The frame and control panel peak displacements were 0.35 mm and 9.7 mm at around 1.7 Hz. Similar to test 3, peaks occurred at frequencies between 10 and 20 Hz, which result from the start-up and shut-down of the generator. For frequencies greater than 40 Hz, the displacement peaks were 0.06 mm and 0.057 mm, respectively. These peaks occurred at 61.6 Hz.

The displacement peaks at 12 Hz and 17 Hz occurred when the generator was being manually started, as shown in Figure 19. The figure shows the displacement at start-up only. Figures 20a and 20b show the 3D acceleration and displacement spectra during start-up, respectively. Significant acceleration and displacement peaks occurred when the generator was jerked when pull started. The figures show acceleration and displacement peaks at 12 Hz on the frame (vertical axis) and 12 and 17 Hz on the control panel (vertical axis).

Figure 21 shows the peak-hold displacement while the generator was running. The figure shows smaller displacement peaks at low frequencies and the significant peak at 61 Hz.

Similar to start-up, displacement peaks occurred around 12 Hz when the generator was shutting-down as shown in Figure 22. Figures 23a and 23b show the acceleration and displacement 3D spectra, respectively, during shut-down. Significant acceleration and displacement peaks occurred when the generator jerked as it was shutting down. The figures show acceleration and displacement peaks at 12 Hz on the frame (vertical axis) and the control panel (vertical axis). The figures show the decrease in frequency as the engine slowed down.

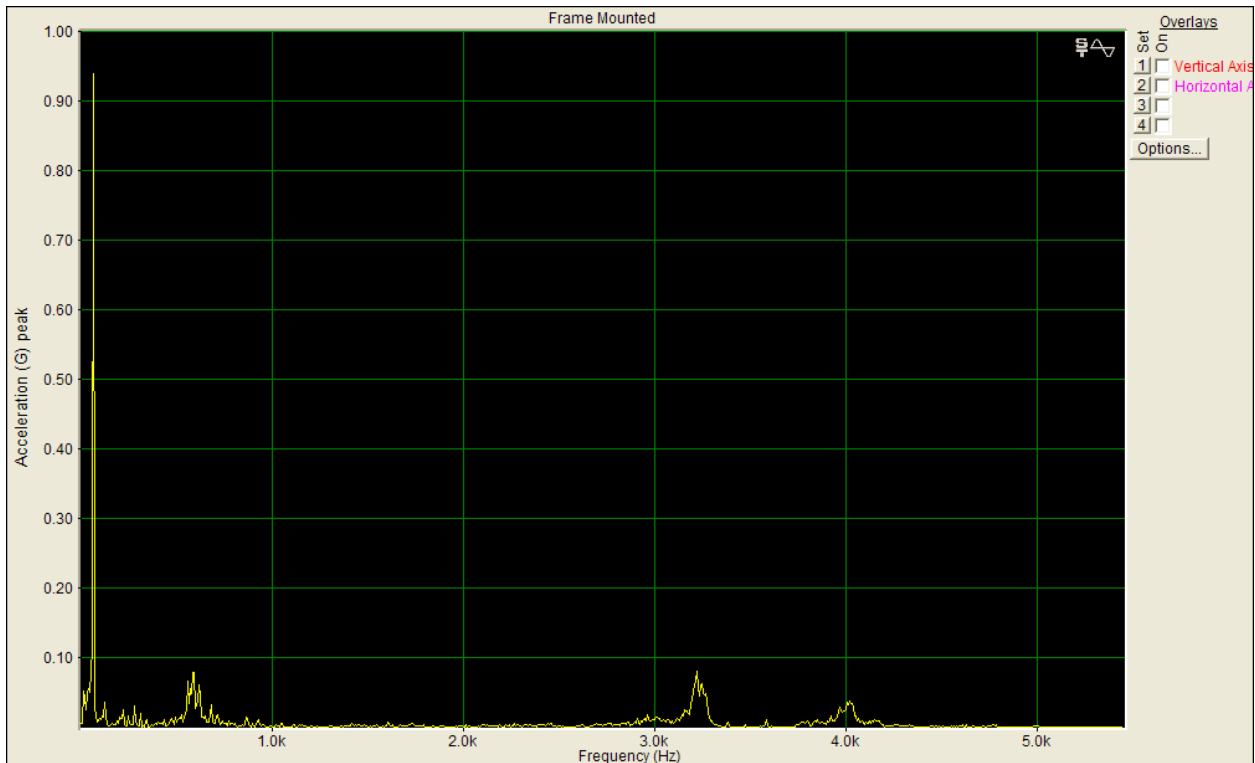


Figure 16a. Test 3 - Frame-Mounted Peak-Hold Acceleration Spectrum (0 to 5.5 kHz)

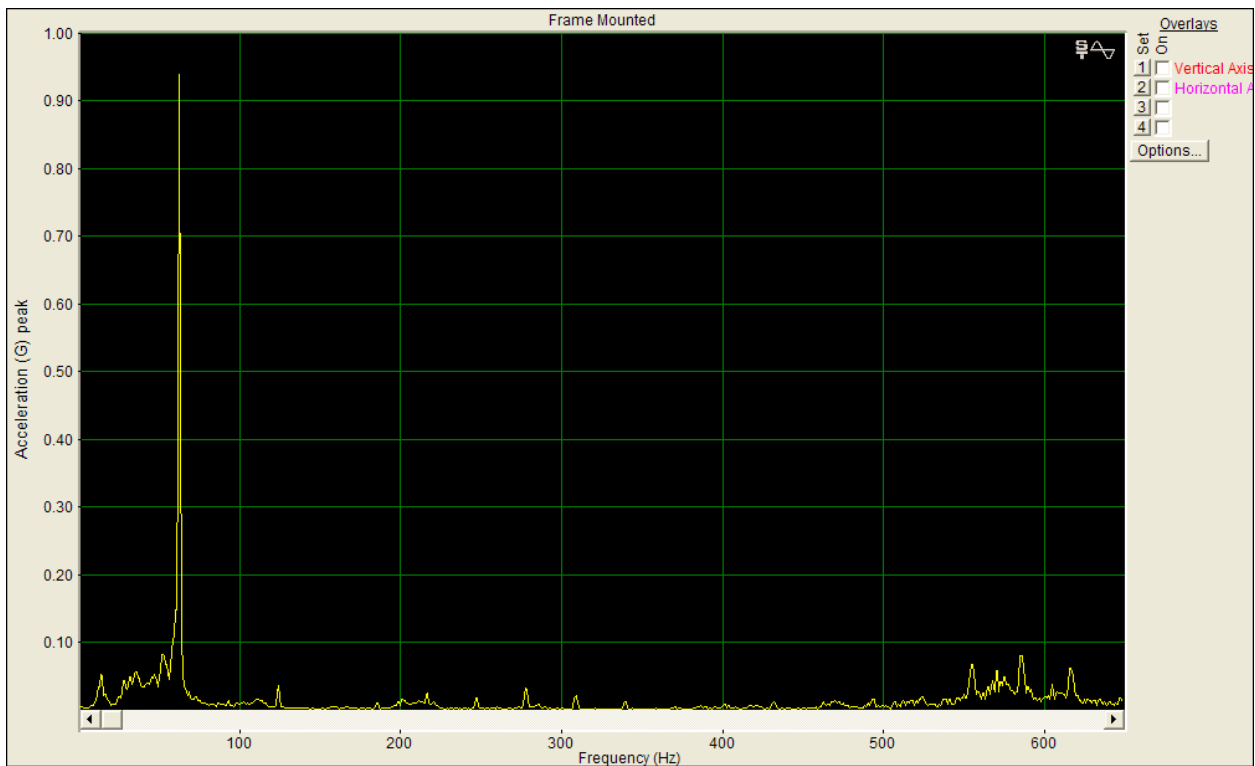


Figure 16b. Test 3 - Frame-Mounted Peak-Hold Acceleration Spectrum (0 to 650 Hz)

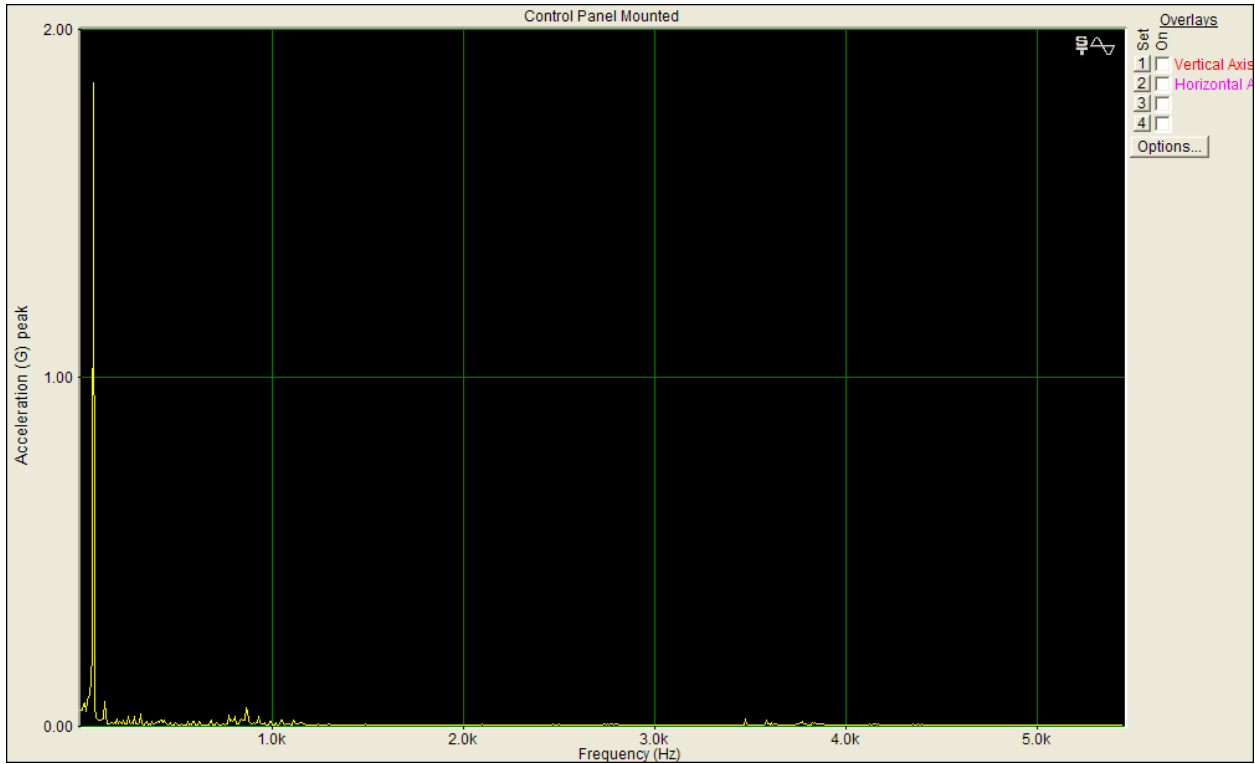


Figure 17a. Test 3 - Control Panel-Mounted Peak-Hold Acceleration Spectrum (0 to 5.5 kHz)

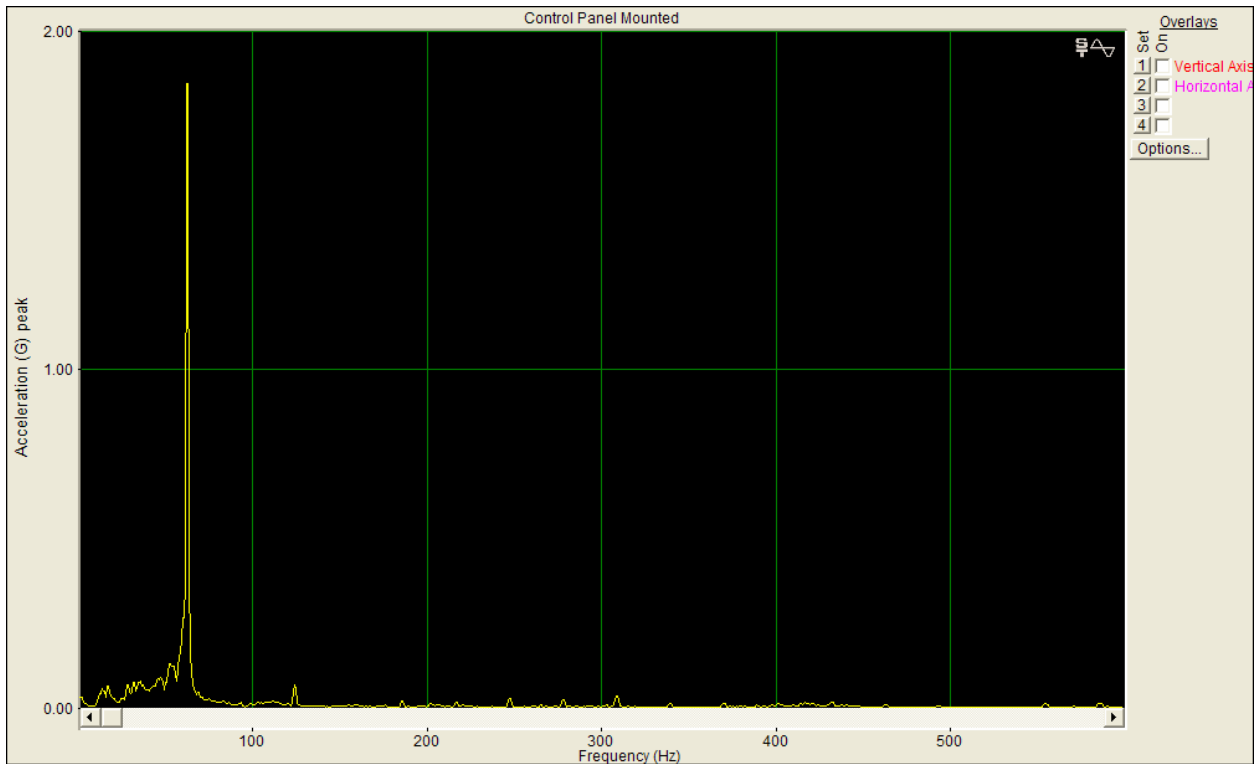


Figure 17b. Test 3 - Control Panel-Mounted Peak-Hold Acceleration Spectrum (0 to 600 Hz)

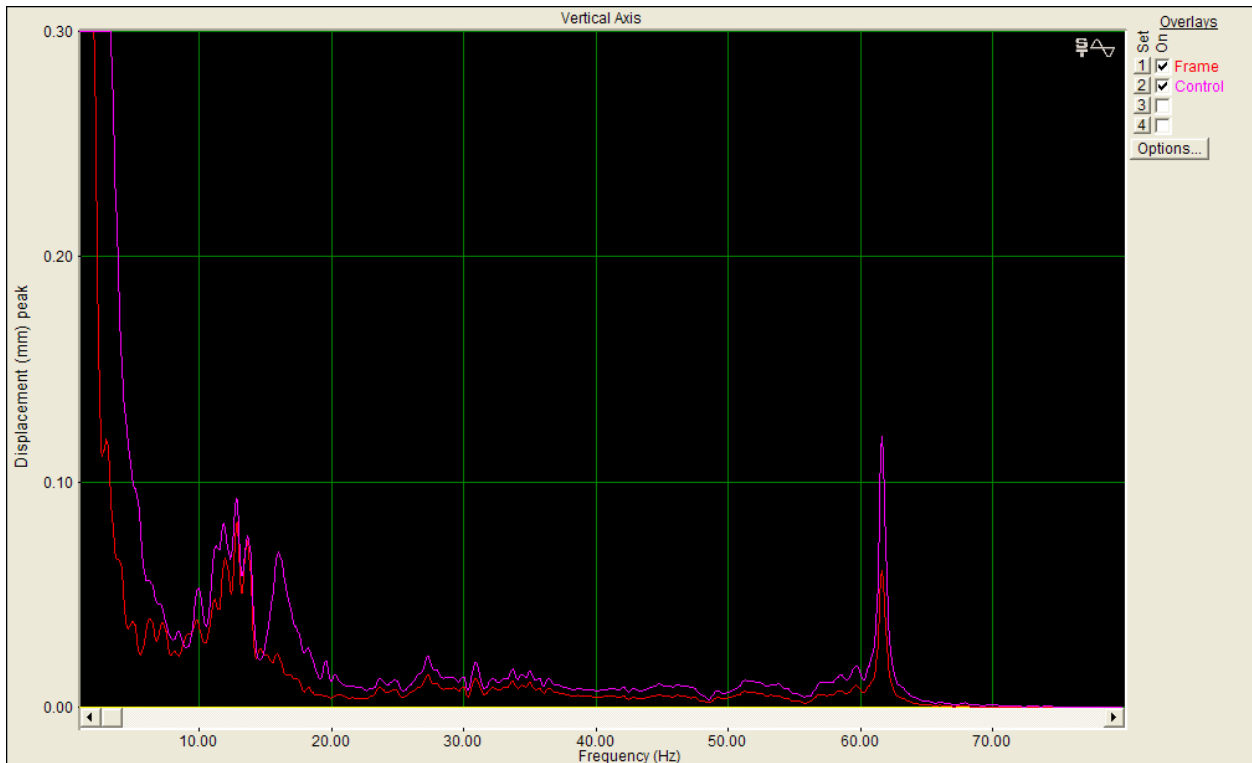


Figure 18. Test 3 - Peak-Hold Displacement Spectra from 0 to 80 Hz

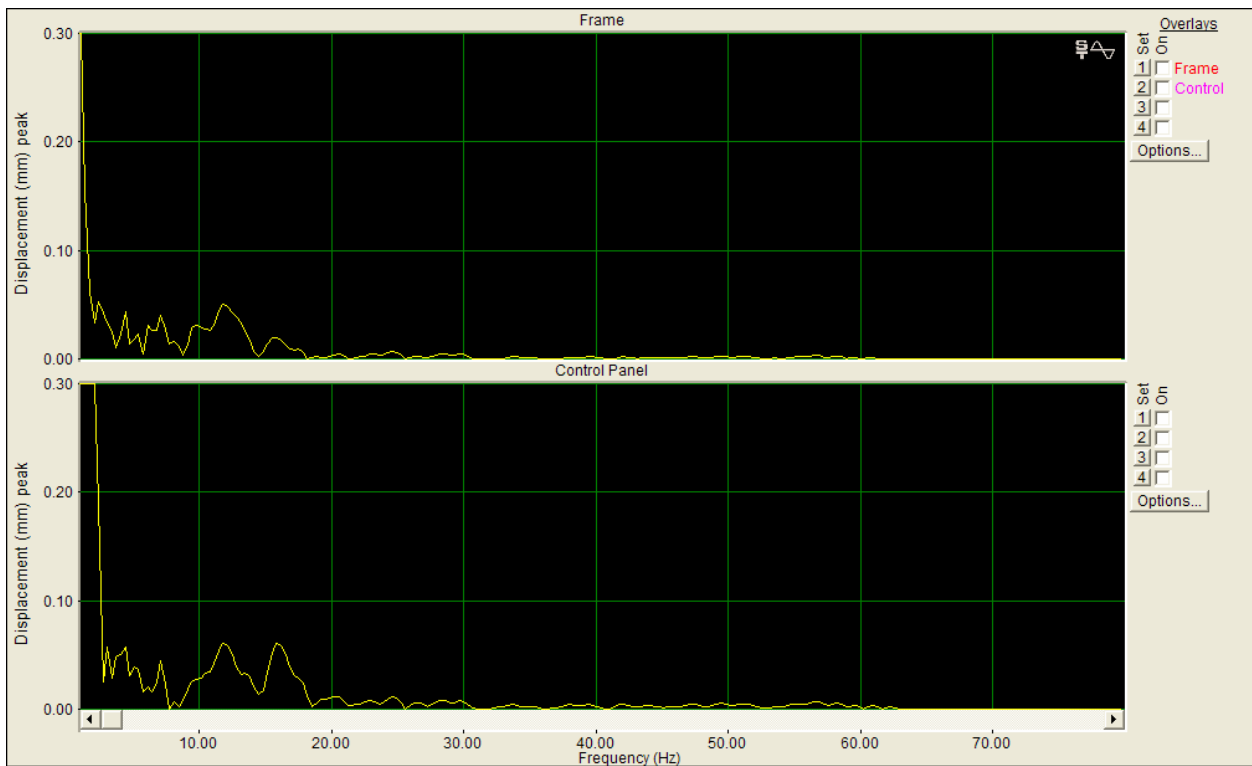


Figure 19. Test 3 - Peak-Hold Displacement Spectra at Start-up

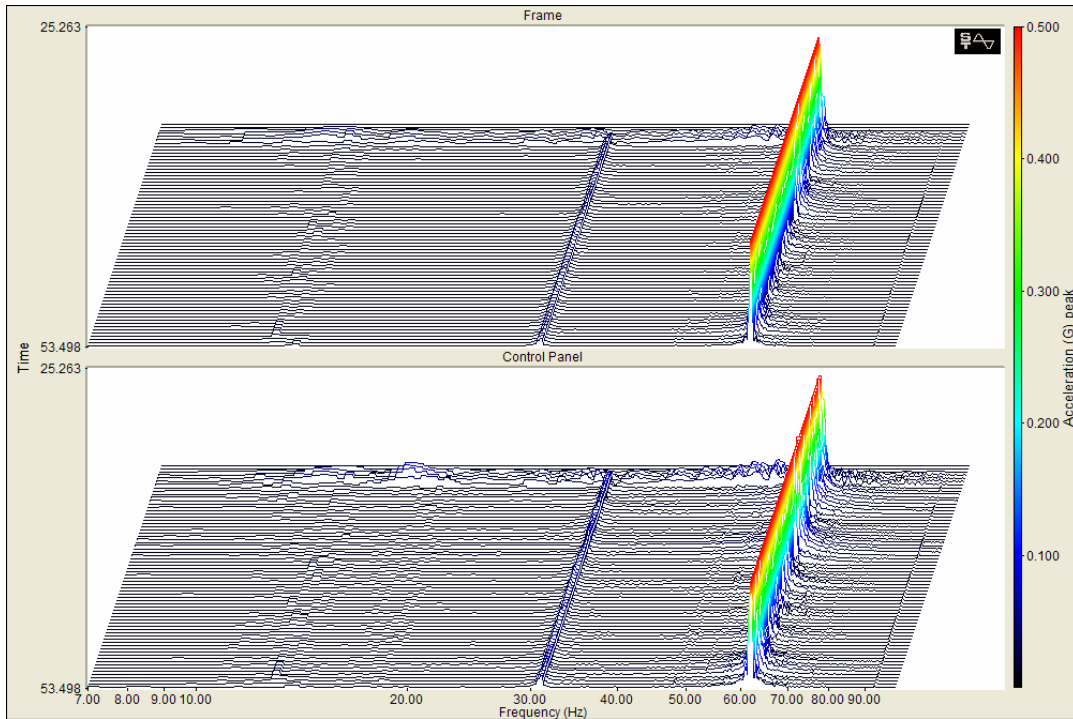


Figure 20a. Test 3 - 3D Surface Acceleration Spectra at Start-up

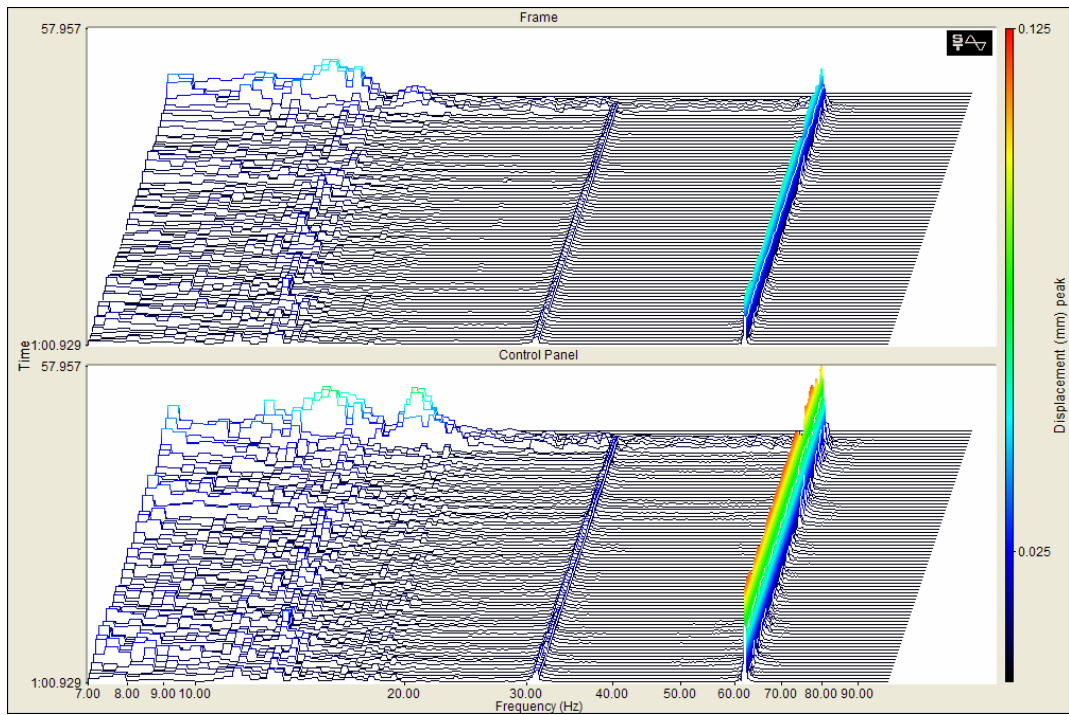


Figure 20b. Test 3 - 3D Surface Displacement Spectra at Start-up

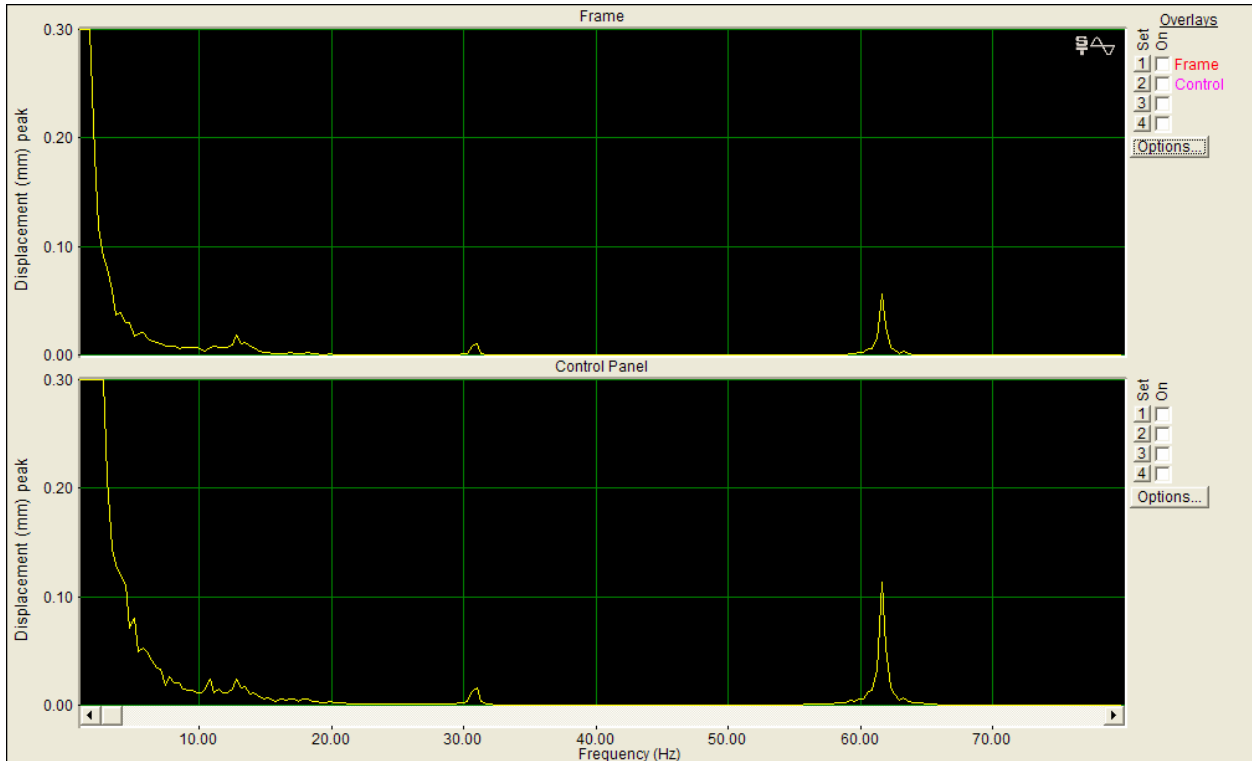


Figure 21. Test 3 - Peak-Hold Displacement Spectra while Running

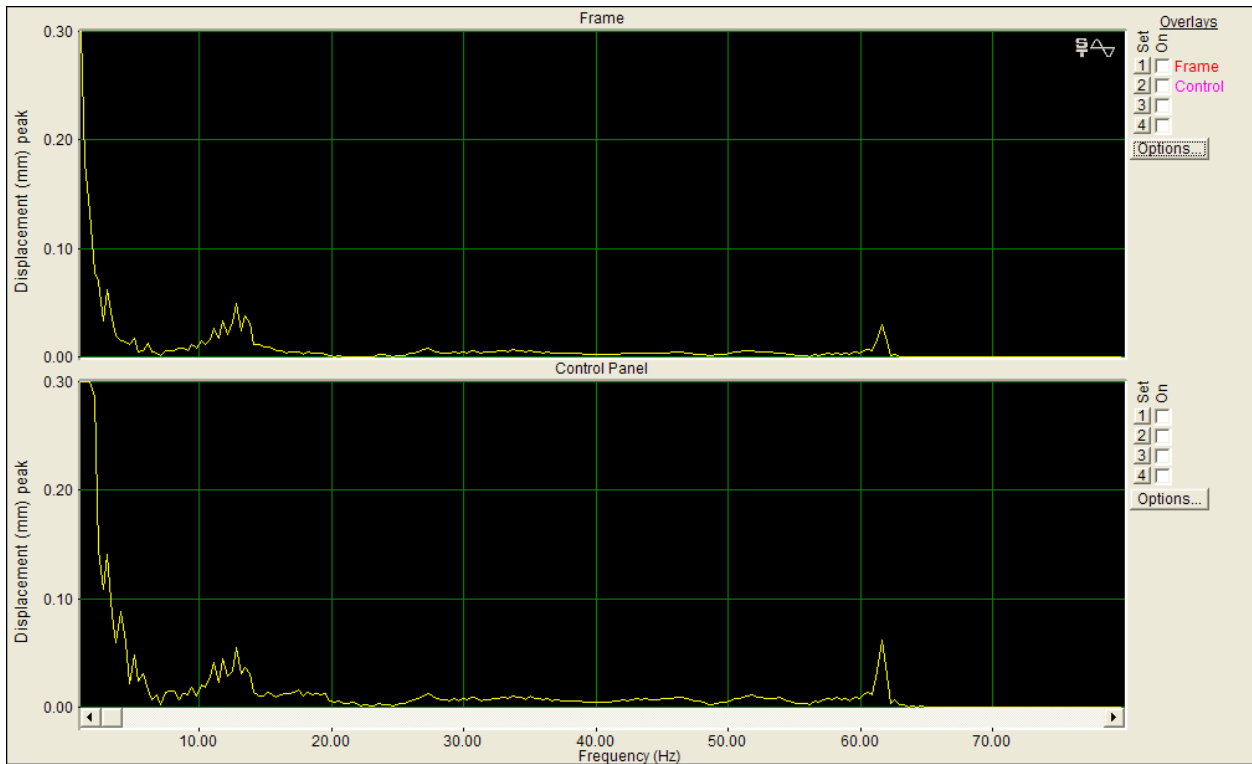


Figure 22. Test 3 - Peak-Hold Displacement Spectra during Shut-down

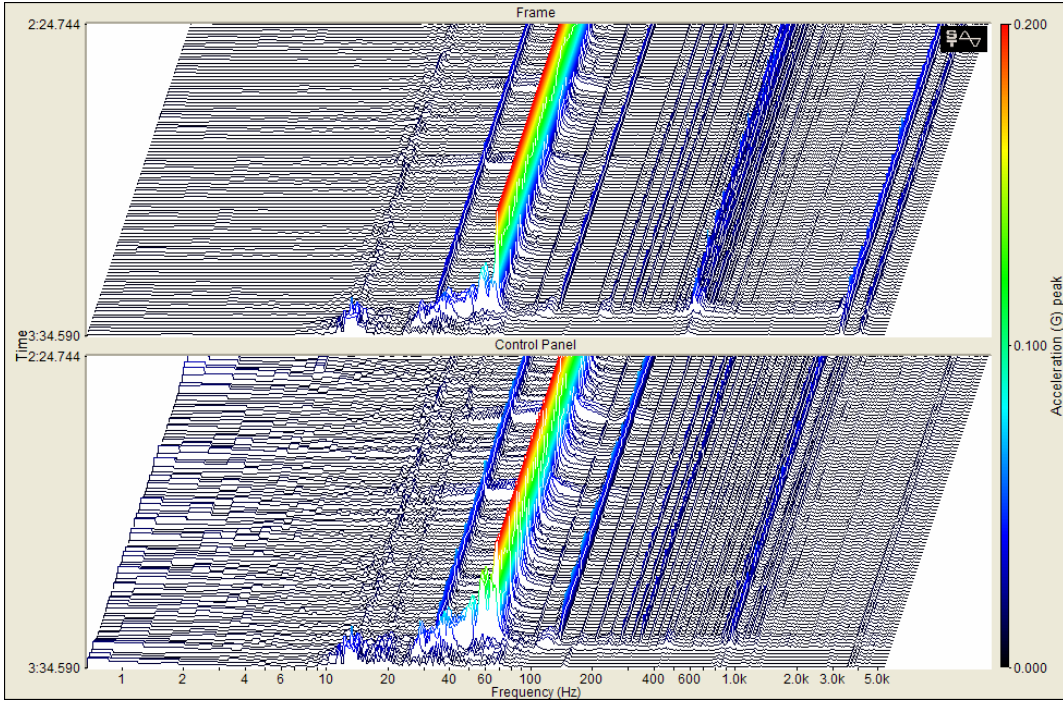


Figure 23a. Test 3 - 3D Surface Acceleration Spectra at Shut-down

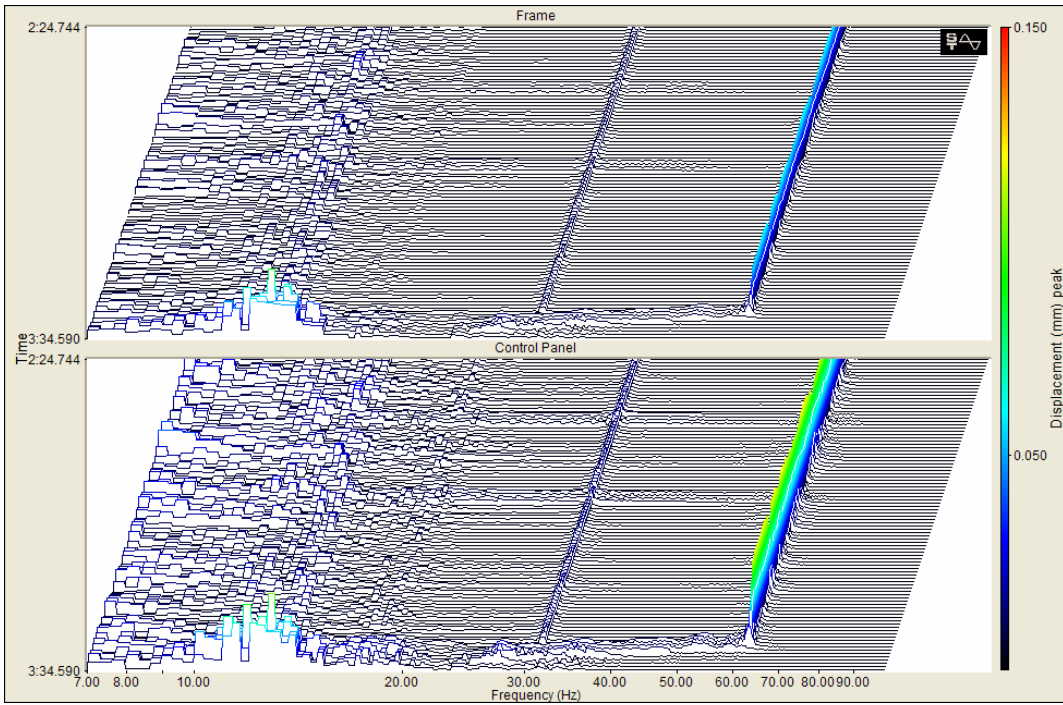


Figure 23b. Test 3 - 3D Surface Displacement Spectra at Shut-down

3.3 2250 Watt Generator

Four tests were conducted with the 2250 watt generator operating. Data were taken at start-up, normal operation, and shut-down of the generator. Figure 24 shows a picture of the 2250 watt generator.



Figure 24. 2250 Watt Generator

Accelerometers were mounted at two different locations on the generator. Accelerometers were placed only on the generator's frame. Figure 25 shows the locations of the accelerometers mounted on the generator.



Frame - vertical axis



Frame - horizontal axis

Figure 25. Accelerometers Mounted on the 2250W Generator

Testing was conducted during the day with an outside temperature of 60°F and 75% humidity.

3.3.1 Tests 7 to 10 - Accelerometers Mounted on the Generator Frame

The accelerometers were mounted on the generator's frame. One accelerometer was mounted in the vertical axis and the other accelerometer was mounted in the horizontal axis. The accelerometers were mounted perpendicular to the rotation of the engine shaft. Figures 26a to 26d show the time series for tests 7 to 10. The time series shows the start-up, running, and shut-down of the generator. All three tests were very similar in amplitude and frequency. Slight differences in start-up and shut down amplitudes were noticed.

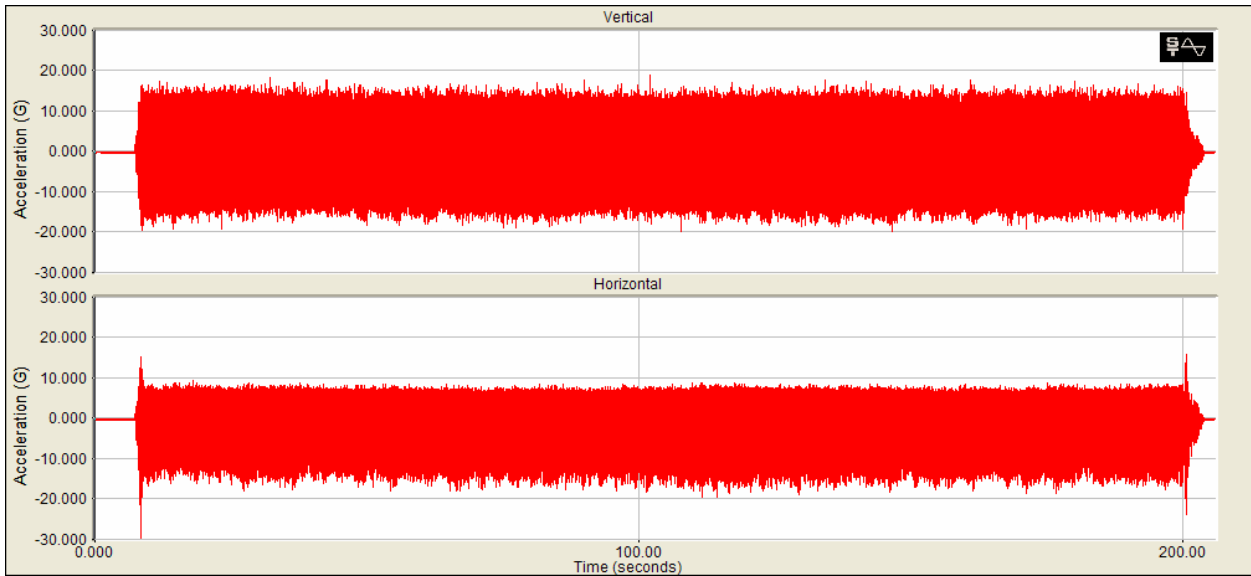


Figure 26a. Test 7 - 2250W Generator, Time Series

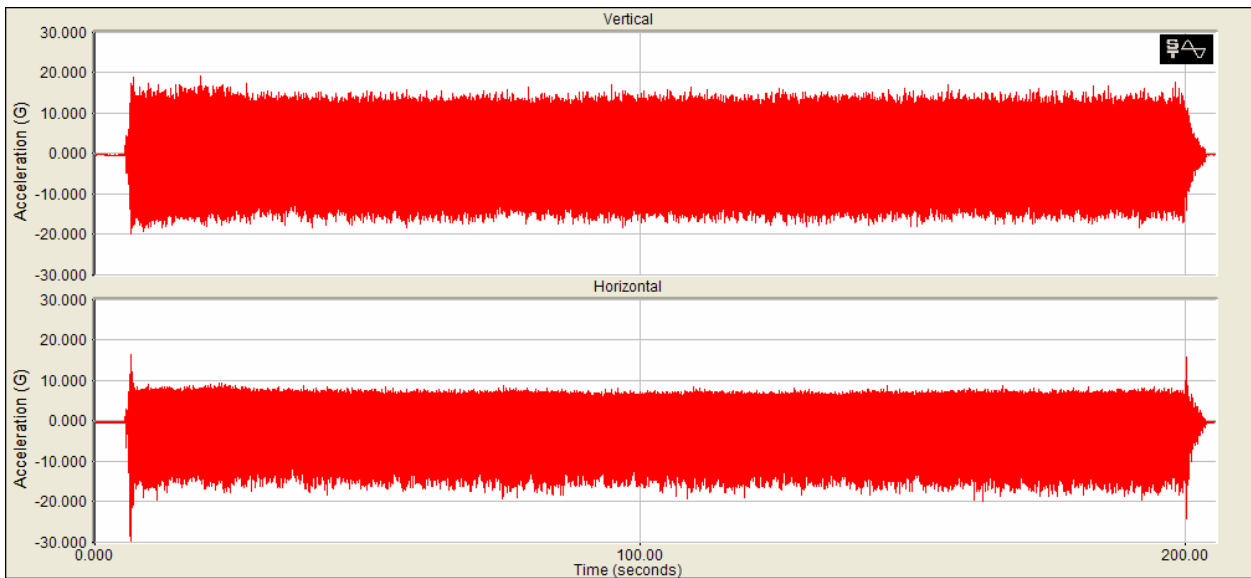


Figure 26b. Test 8 - 2250W Generator, Time Series

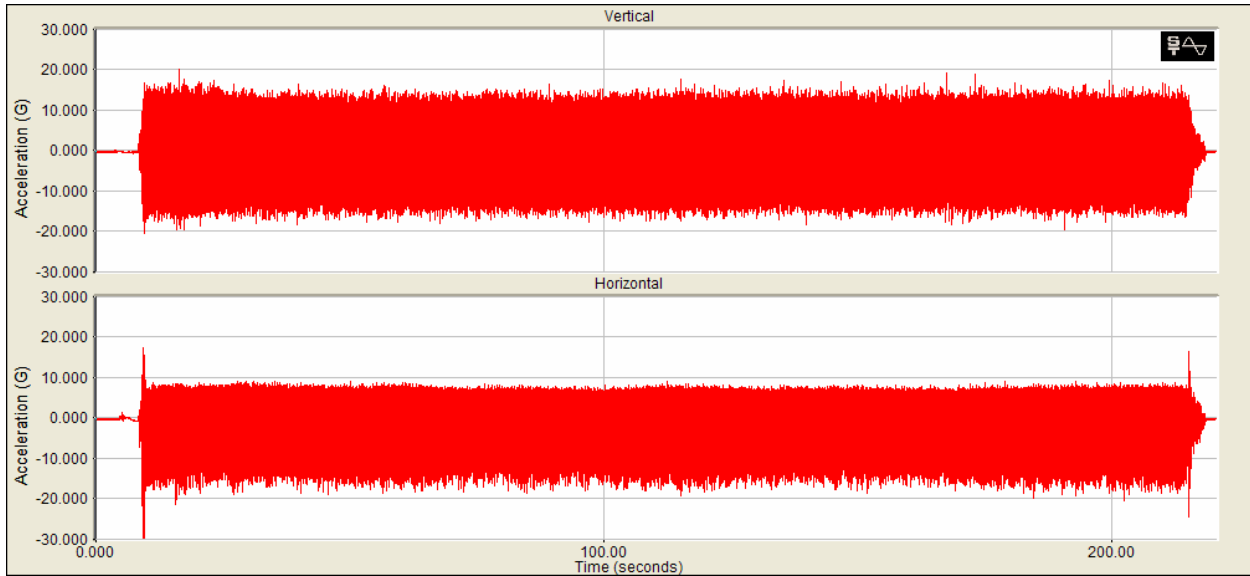


Figure 26c. Test 9 - 2250W Generator, Time Series

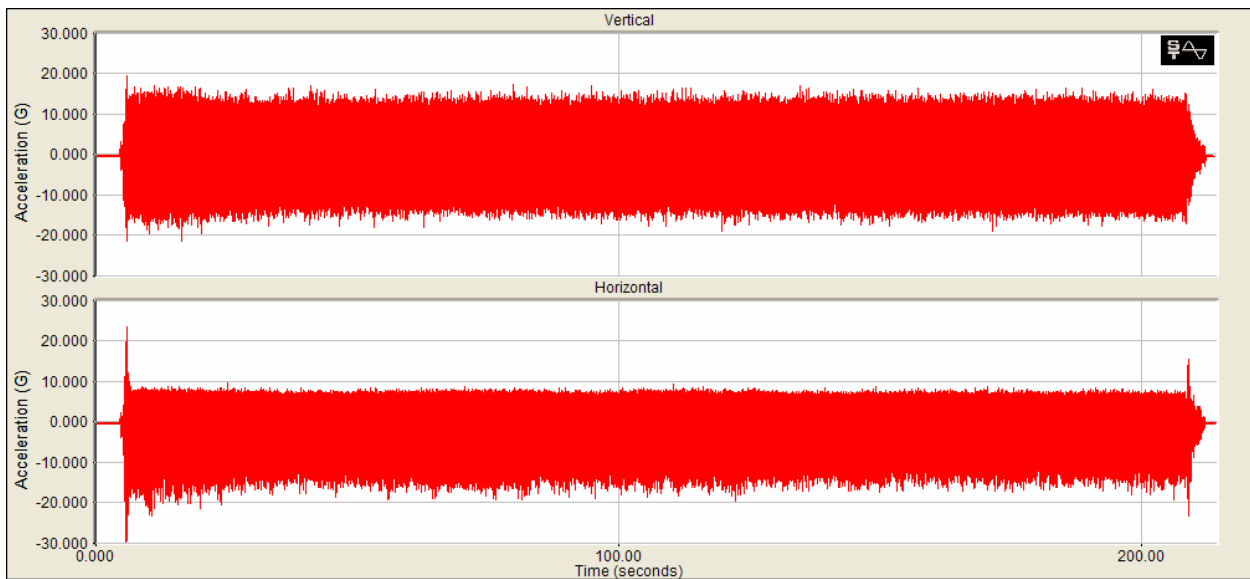


Figure 26d. Test 10 - 2250W Generator, Time Series

3.3.1.1 Test 10 Spectral Analysis

Since the results of tests 7 to 10 were all very similar, only the spectra from test 10 were analyzed. The acceleration and displacement are displayed in spectrum format (amplitude vs. frequency). Figures 27a and 27b show the vertical-axis peak-hold acceleration spectra from 0 to 5.5 kHz and from 0 to 1 kHz, respectively. Most of the energy was less than 1 kHz. In the vertical axis, the largest peaks occurred at the frequencies 66.3 and 132.9 Hz, and at an amplitude of 2.8 G (27.5 m/s^2) and 4.0 G (39.2 m/s^2), respectively. The generator produced more peaks between 0 and 1 kHz than previously seen in the 5250W generator. This may have been due to factors associated with the age of the generator, such as worn bearings or less

elasticity in the rubber standoffs; the generator was more than 10 years old and had more than 100 hours of operation.

Figures 28a and 28b show the horizontal-axes peak-hold acceleration spectra from 0 to 5.5 kHz and from 0 to 1 kHz, respectively. Most of the energy was at frequencies less than 1 kHz. In the horizontal axis, major peaks occurred at frequencies 53.3 and 66.3 Hz at an amplitude of 2.5 G (24.5 m/s^2) and 3.6 G (35.3 m/s^2), respectively. Similar to the vertical axis spectra, more peaks occurred with the 2250W generator than previously seen in the 5250W generator.

Figure 29 shows the vertical and horizontal axis peak-hold displacement spectrum from 0 to 80 Hz. There was very little displacement at frequencies greater than 70 Hz. The displacement spectrum shows significant displacement at low frequencies, less than 30 Hz, and frequencies around 52 and 66 Hz. The vertical and horizontal axes peak displacements were 0.039 mm and 0.23 mm at around 52 Hz, respectively. The vertical and horizontal axes peak displacements were 0.159 mm and 0.204 mm at around 66 Hz, respectively.

The displacement peaks at 52 Hz occurred when the generator was being manually started, as shown in Figure 30. Figures 31a and 31b show the 3D acceleration and displacement spectra, respectively, during start-up. Significant acceleration and displacement peaks occurred when the generator was jerked when being pull started. The figures show acceleration and displacement peaks at 52 Hz in the vertical axis and the horizontal axis. Figure 33b also shows significant displacement at frequencies below 20 Hz during start-up.

Figure 32 shows the peak-hold displacement while the generator was running. The figure shows smaller displacement peaks at low frequencies, below 20 Hz, and at 52 Hz.

Similar to start-up, significant displacement peaks occurred in the horizontal axis at 52 Hz when the generator was shutting down, as shown in Figure 33. Figures 34a and 34b show the acceleration and displacement 3D spectra, respectively, during shut-down. Significant acceleration and displacement peaks occurred in the horizontal axis when the generator jerked as it was shutting down. The figures show acceleration and displacement peaks at 52 Hz in the horizontal axis.

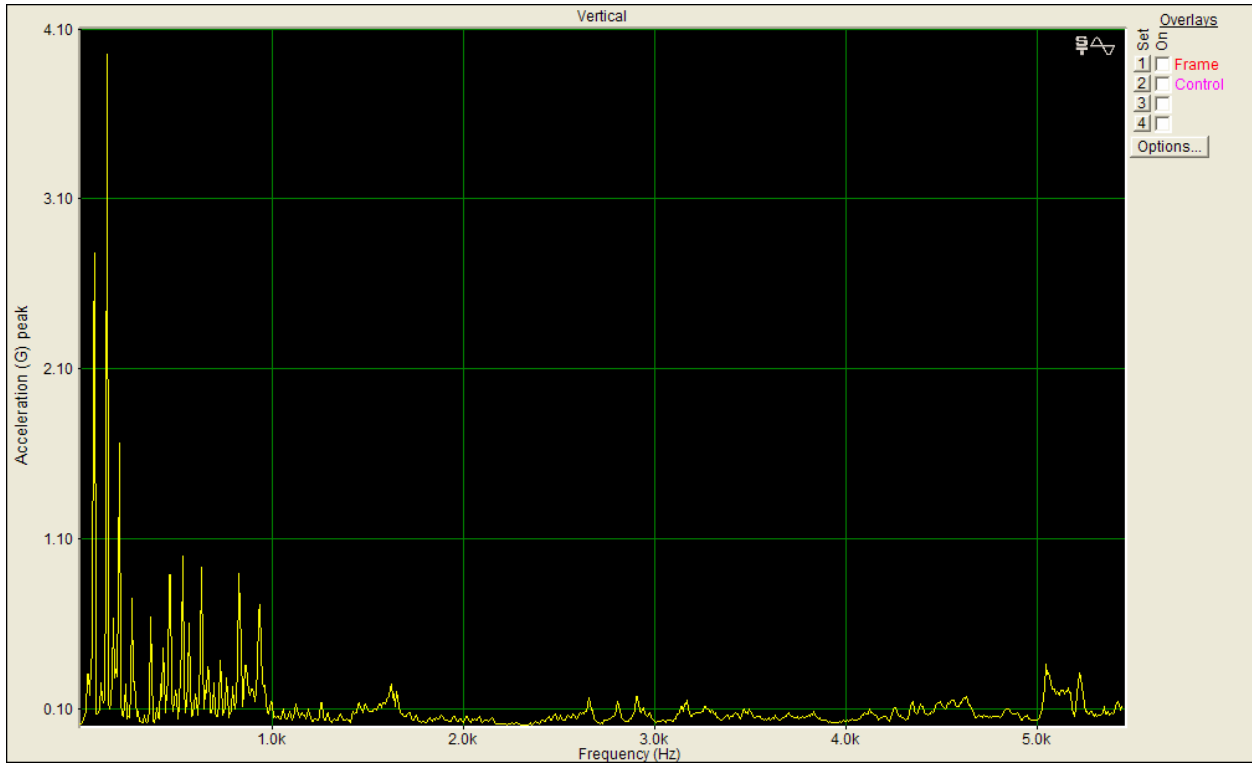


Figure 27a. Test 10 - Vertical-Axis Average Acceleration Spectrum (0 to 5.5 kHz)

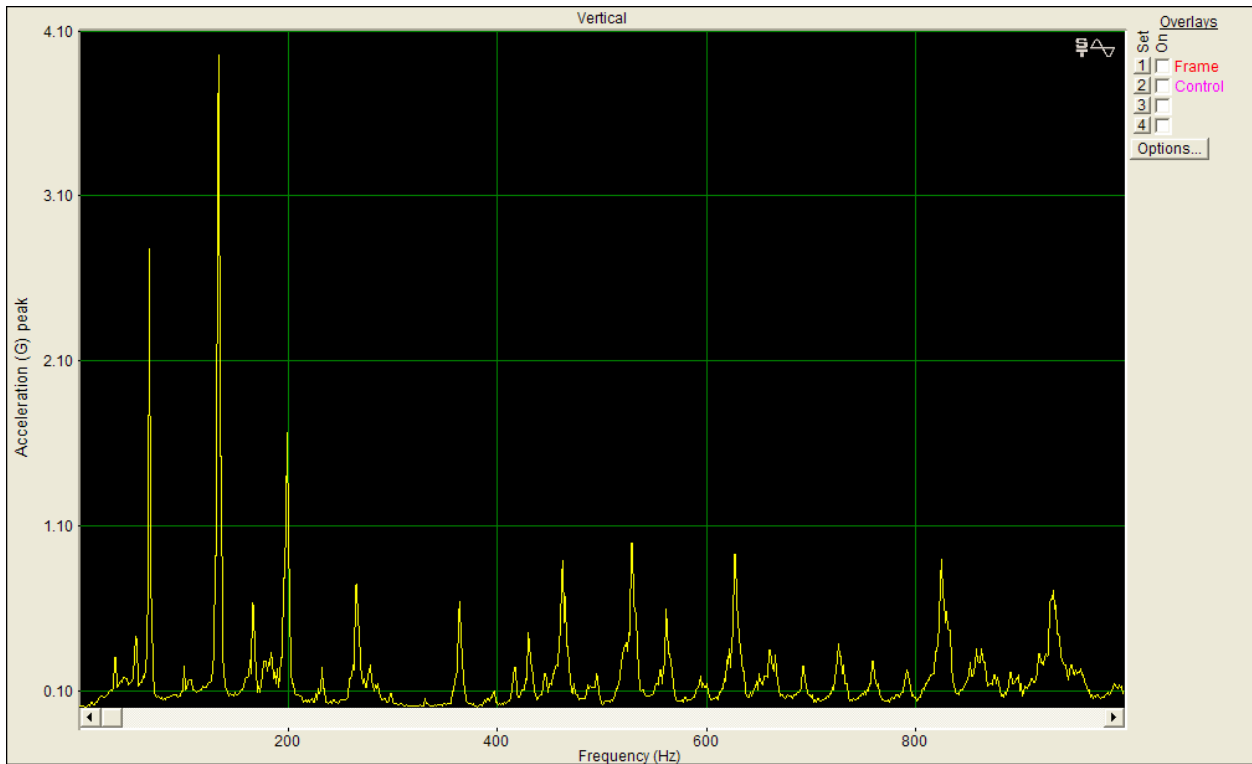


Figure 27b. Test 10 - Vertical-Axis Peak-Hold Acceleration Spectrum (0 to 1 kHz)

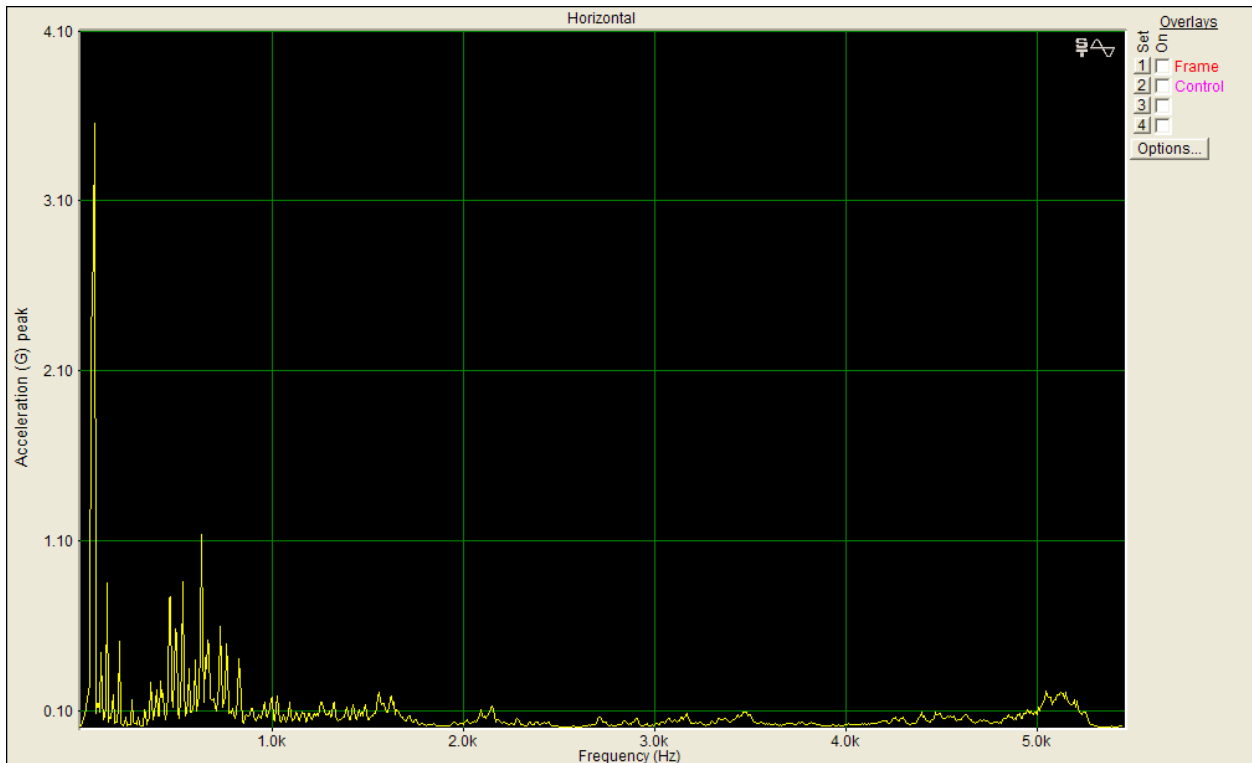


Figure 28a. Test 10 - Horizontal-Axis Peak-Hold Acceleration Spectrum (0 to 5.5 kHz)

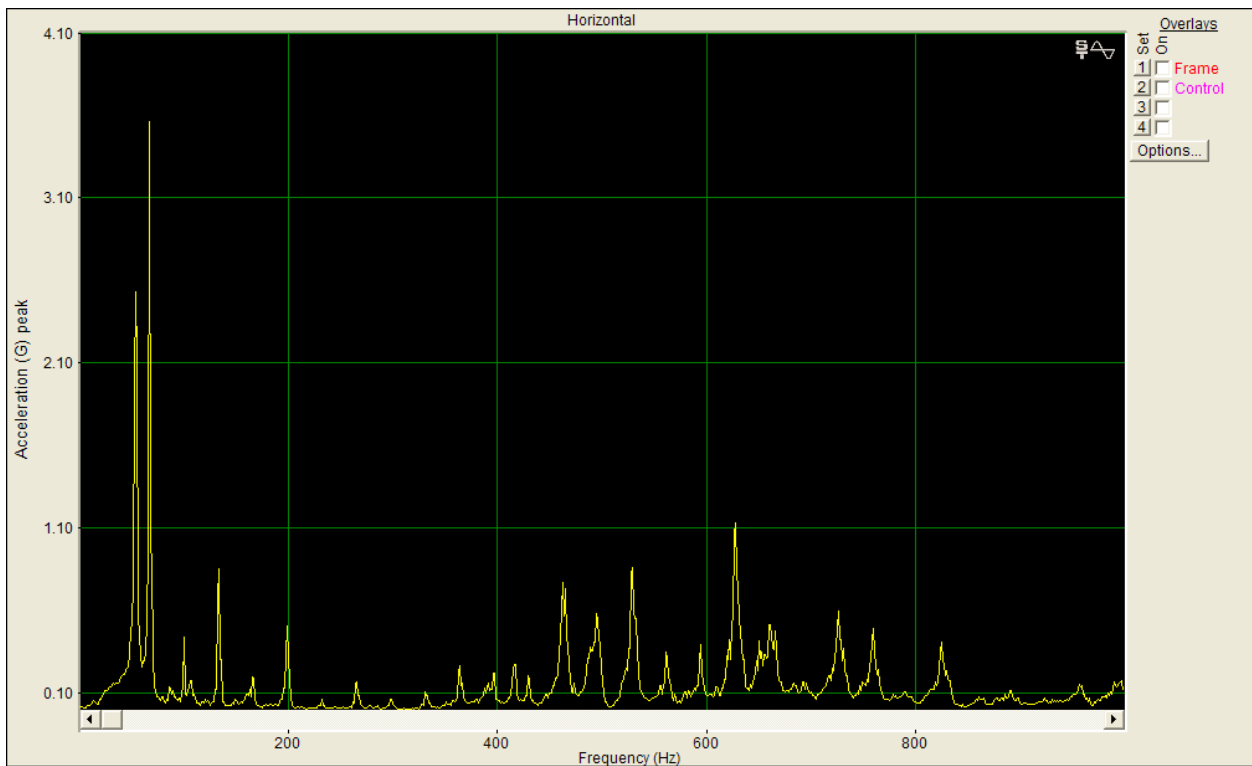


Figure 28b. Test 10 - Horizontal-Axis Peak-Hold Acceleration Spectrum (0 to 1 kHz)

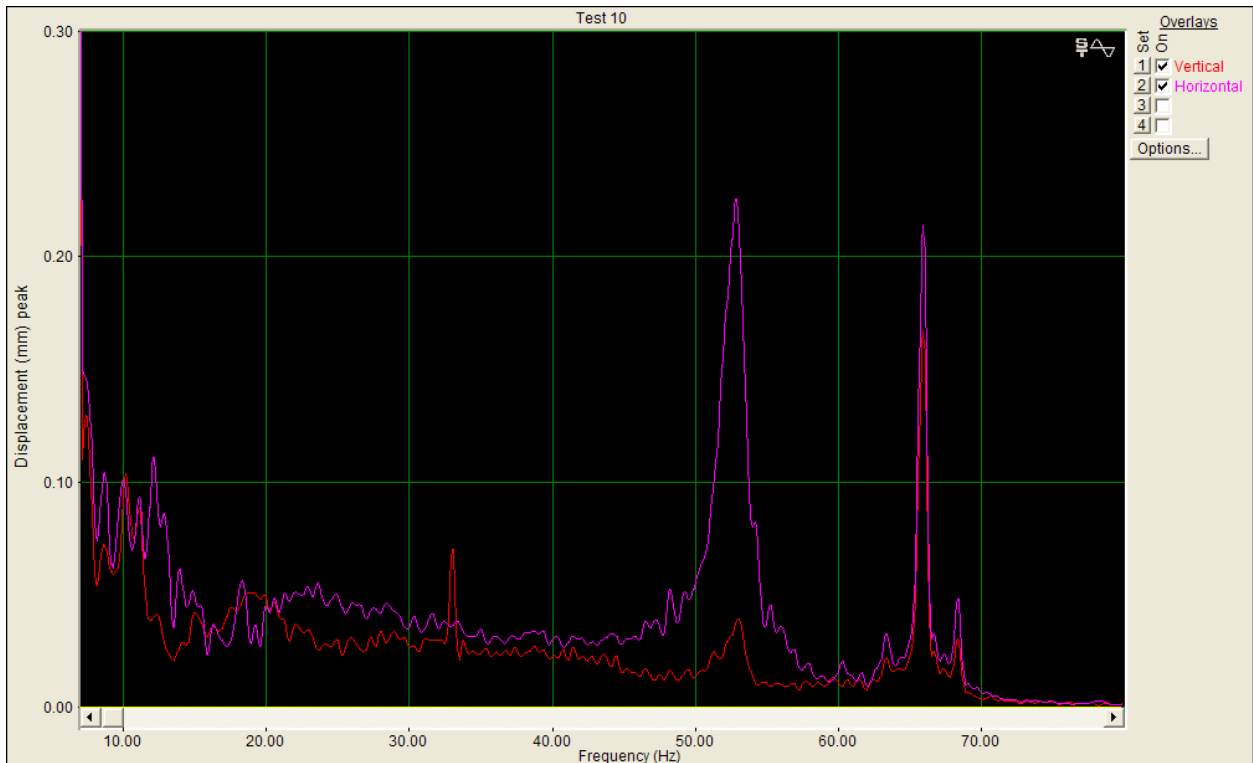


Figure 29. Test 10 - Peak-Hold Displacement Spectrum from 0 to 80 Hz

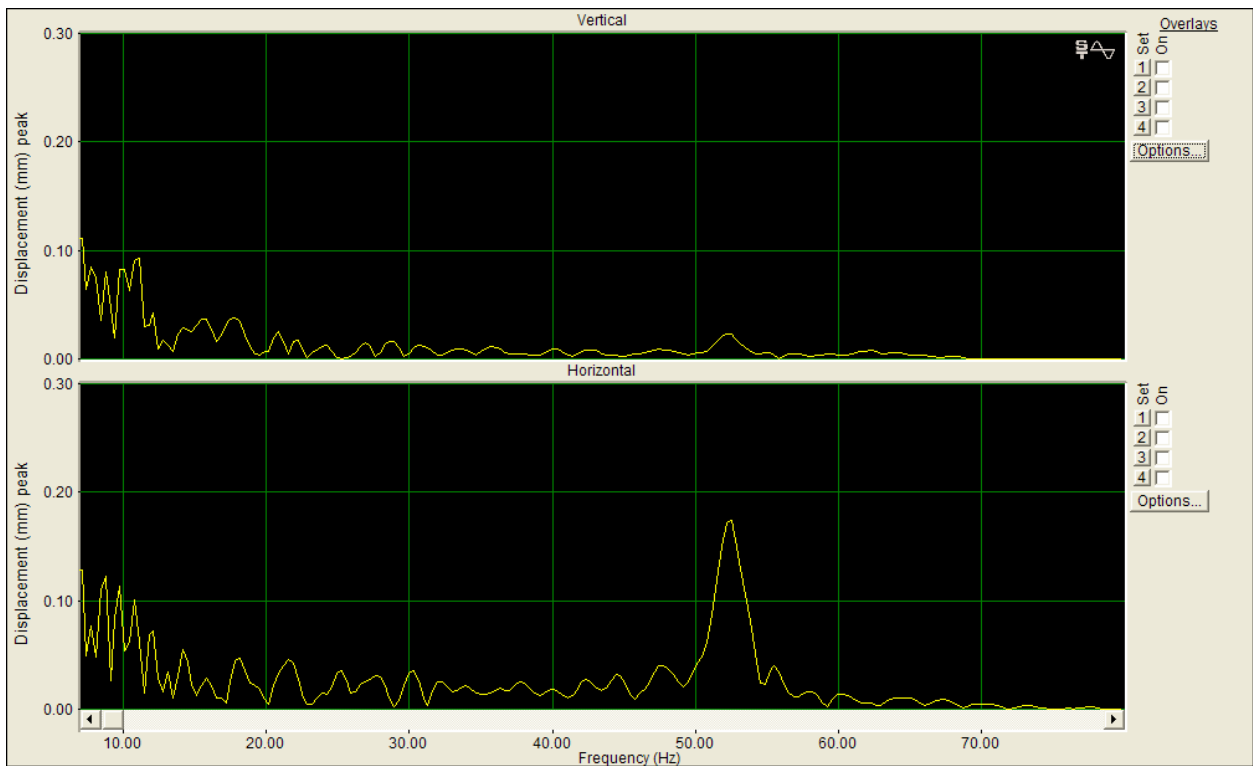


Figure 30. Test 10 - Peak-Hold Displacement Spectrum at Start-up

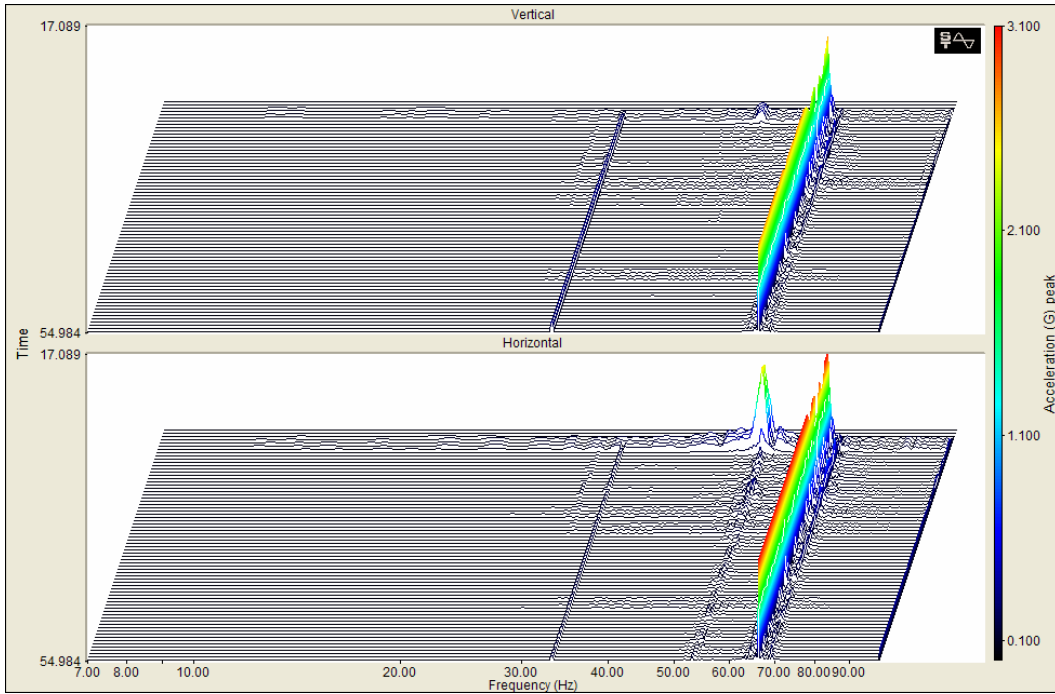


Figure 31a. Test 10 - 3D Surface Acceleration Spectra at Start-up

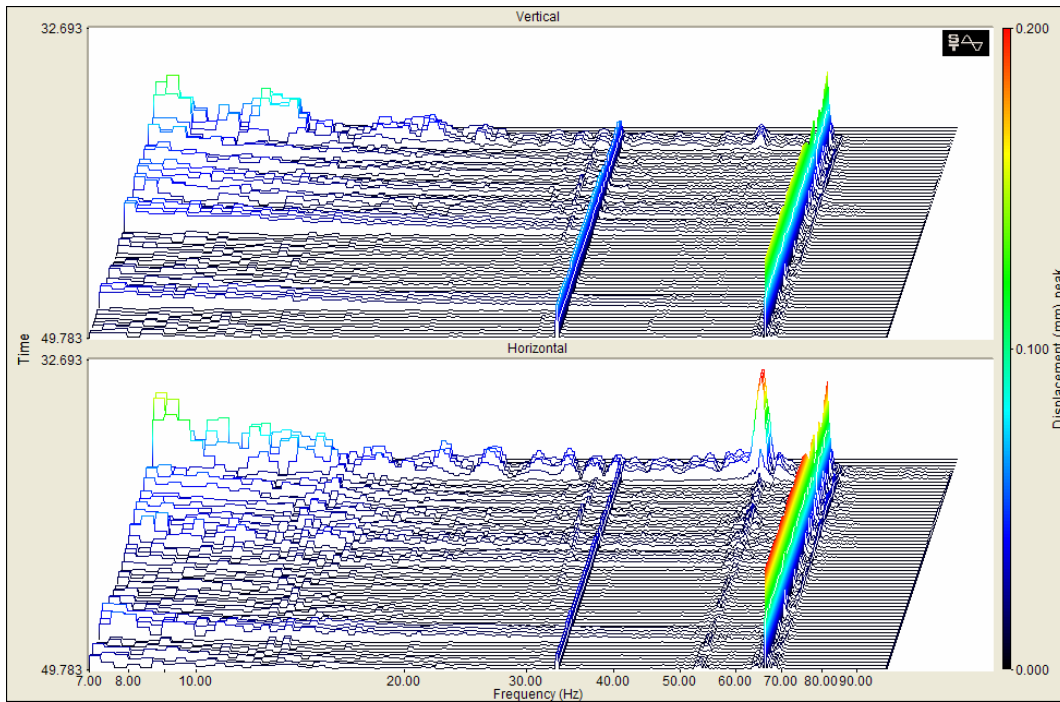


Figure 31b. Test 10 - 3D Surface Displacement Spectra at Start-up

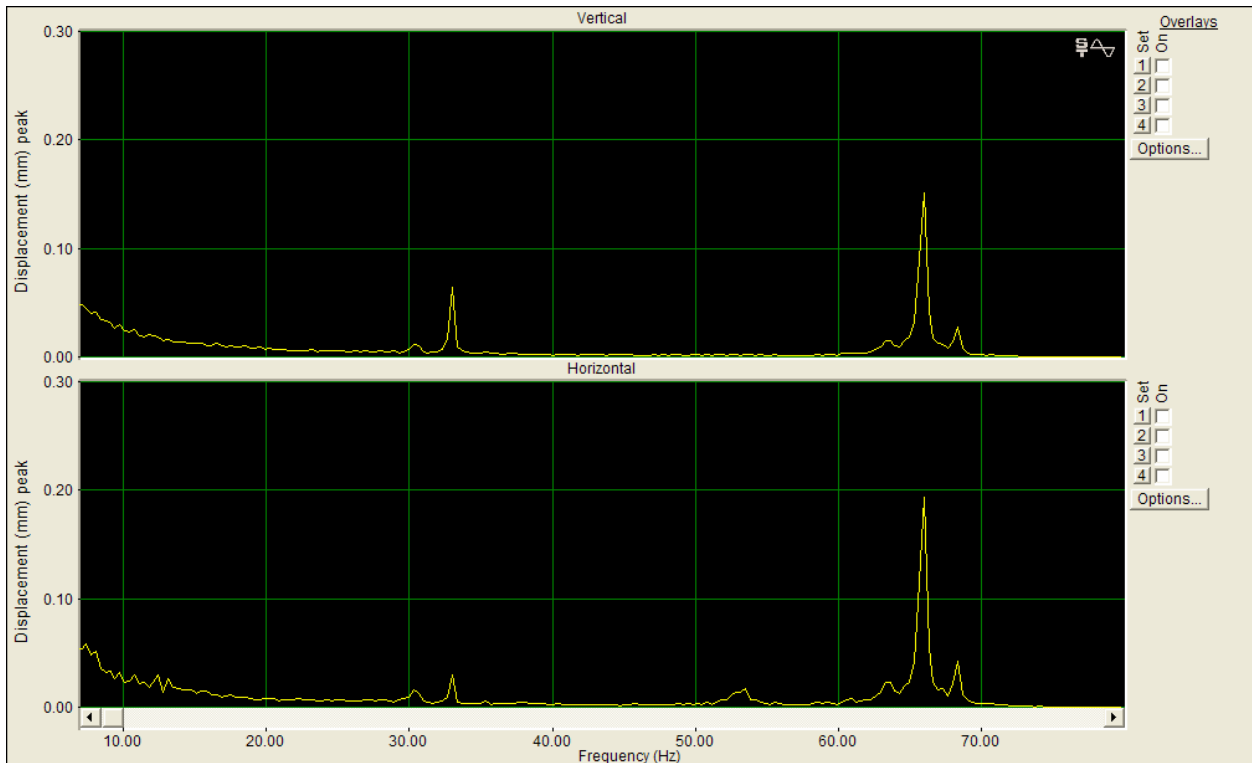


Figure 32. Test 10 - Peak-Hold Displacement Spectra while Running

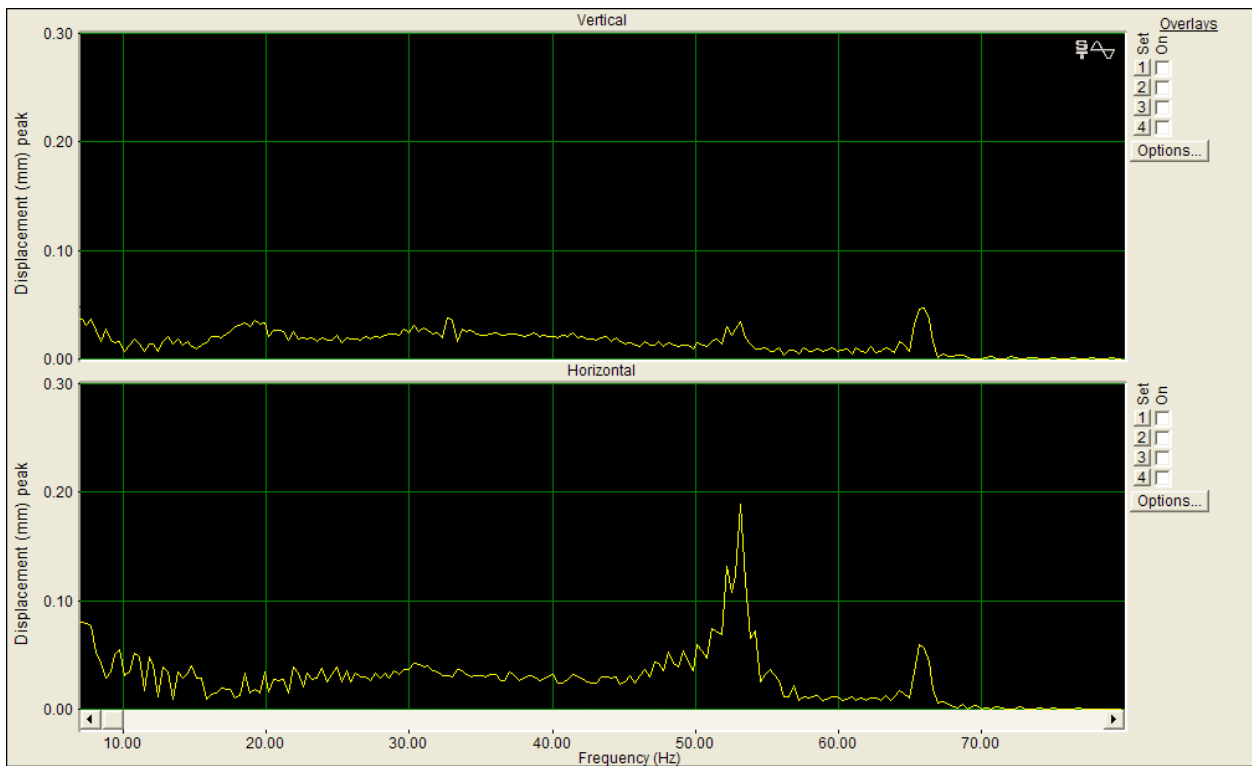


Figure 33. Test 10 - Peak-Hold Displacement Spectra during Shut-down

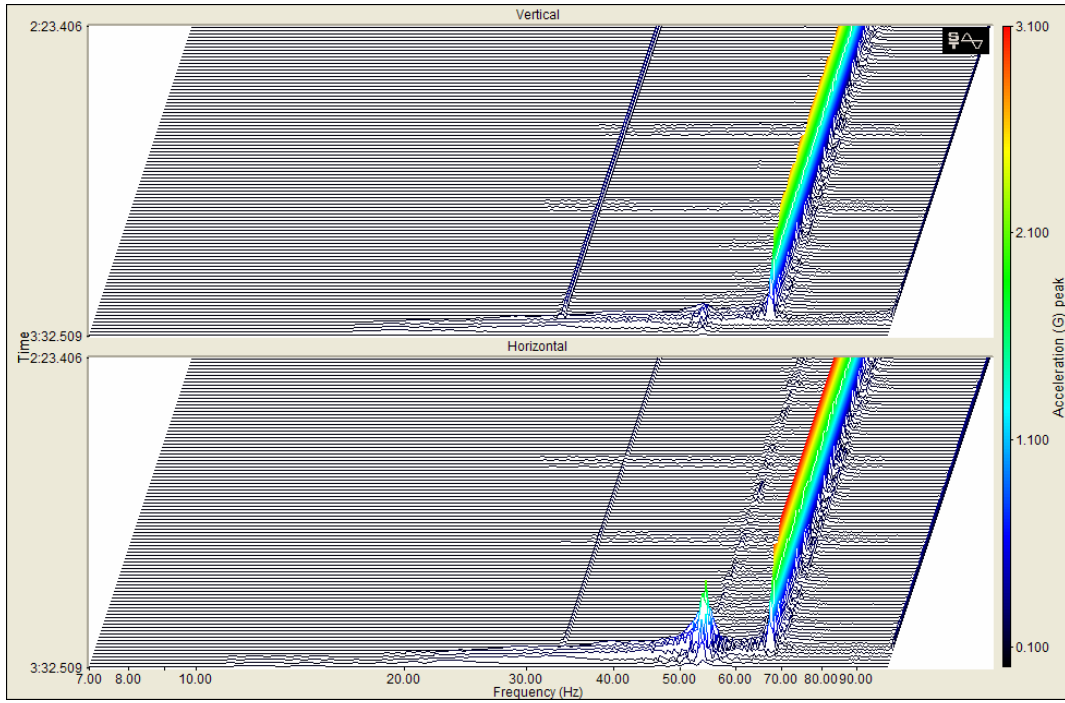


Figure 34a. Test 10 - 3D Surface Acceleration Spectra at Shut-down

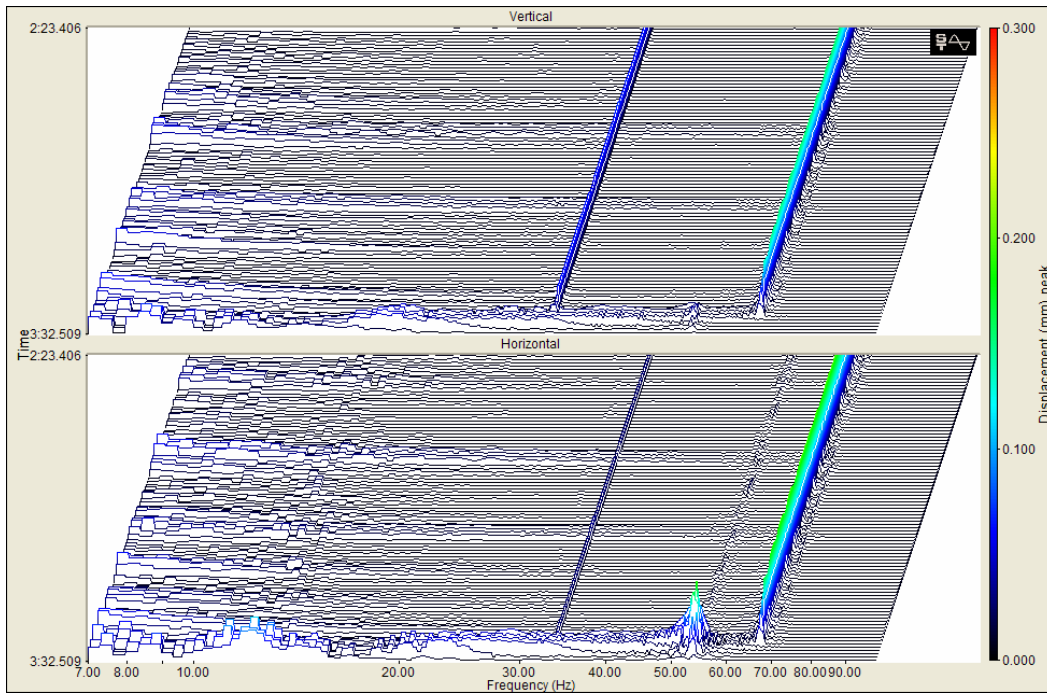


Figure 34b. Test 10 - 3D Surface Displacement Spectra at Shut-down

3.4 Transportation Vibration Measurements

Six tests were conducted with the 5250 watt generator strapped into the bed of a pick-up truck, as shown in Figure 35. The transportation vibration measurements were conducted on four different road types; highway, secondary, country, and unpaved. Highway roads were asphalt roads with speed limits of 55 mph. Secondary roads were medium traveled roads with speed limits of 35 mph. Country roads were lightly traveled surfaces with speed limits of 25 mph. The country roads were paved with asphalt, but were poorly maintained. Unpaved roads were dirt and gravel roads that are not maintained by state or county governments. These tests do not represent all road conditions that a generator may experience during transport. The tests were exploratory to determine possible vibration characteristics that a secured (but otherwise unprotected) generator could experience in transit.



Figure 35. 5250 Watt Generator in the Pick-up Truck

Accelerometers were mounted at two different locations on the generator. Similar to tests 4 through 6, an accelerometer was placed on the generator's frame in the vertical axis, and the second accelerometer was placed on the control panel in the vertical axis. Figure 36 shows the locations of the accelerometers mounted on the generator.

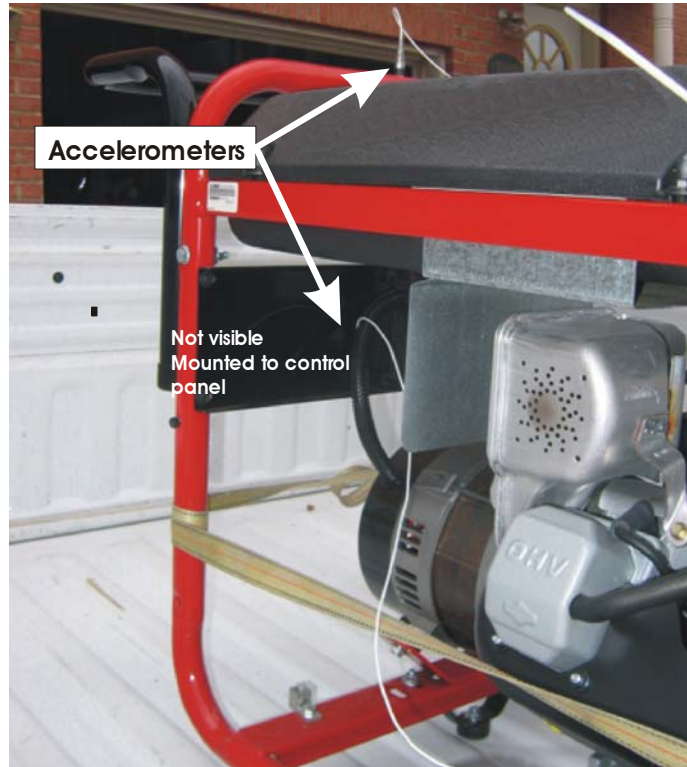


Figure 36. Accelerometers Mounted on the 5250W Generator

3.4.1 Highway Road Vibration Measurements

In this test, the pick-up truck was driven on highway roadways at approximately 50 to 55 mph. Figure 37 shows the time series of the accelerometers. Figures 38 and 39 show the acceleration and displacement spectra, respectively. The energy is mainly at low frequencies, less than 20 Hz.

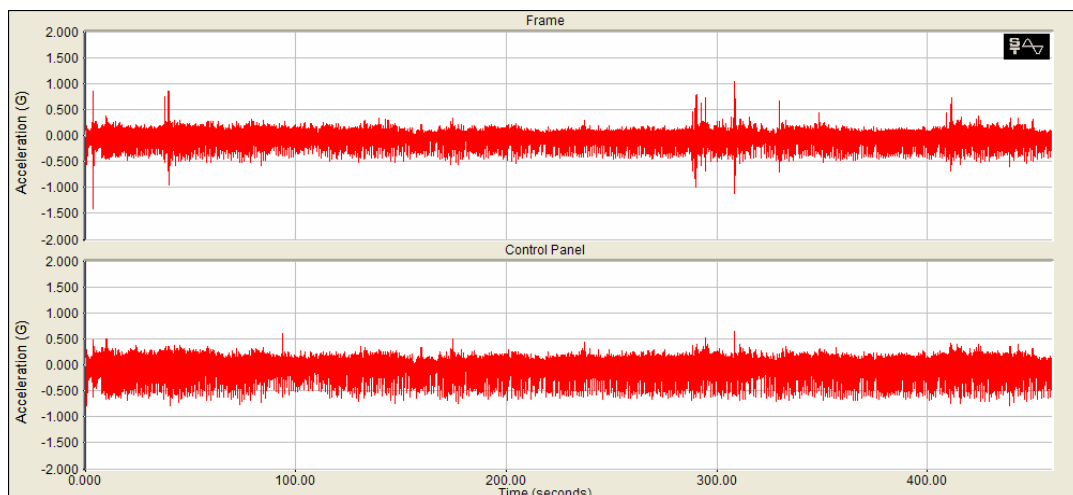


Figure 37. Highway Test - Transportation, Time Series

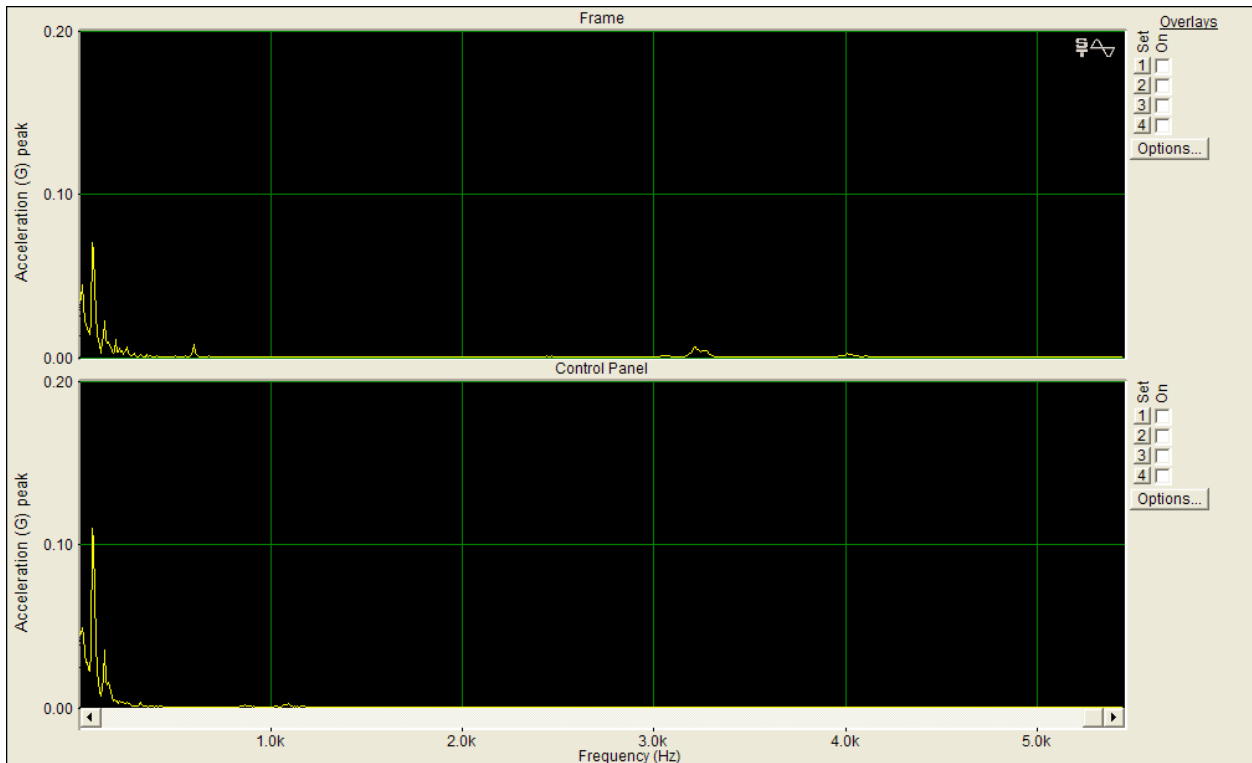


Figure 38. Highway Test - Peak Hold Spectra (Acceleration)

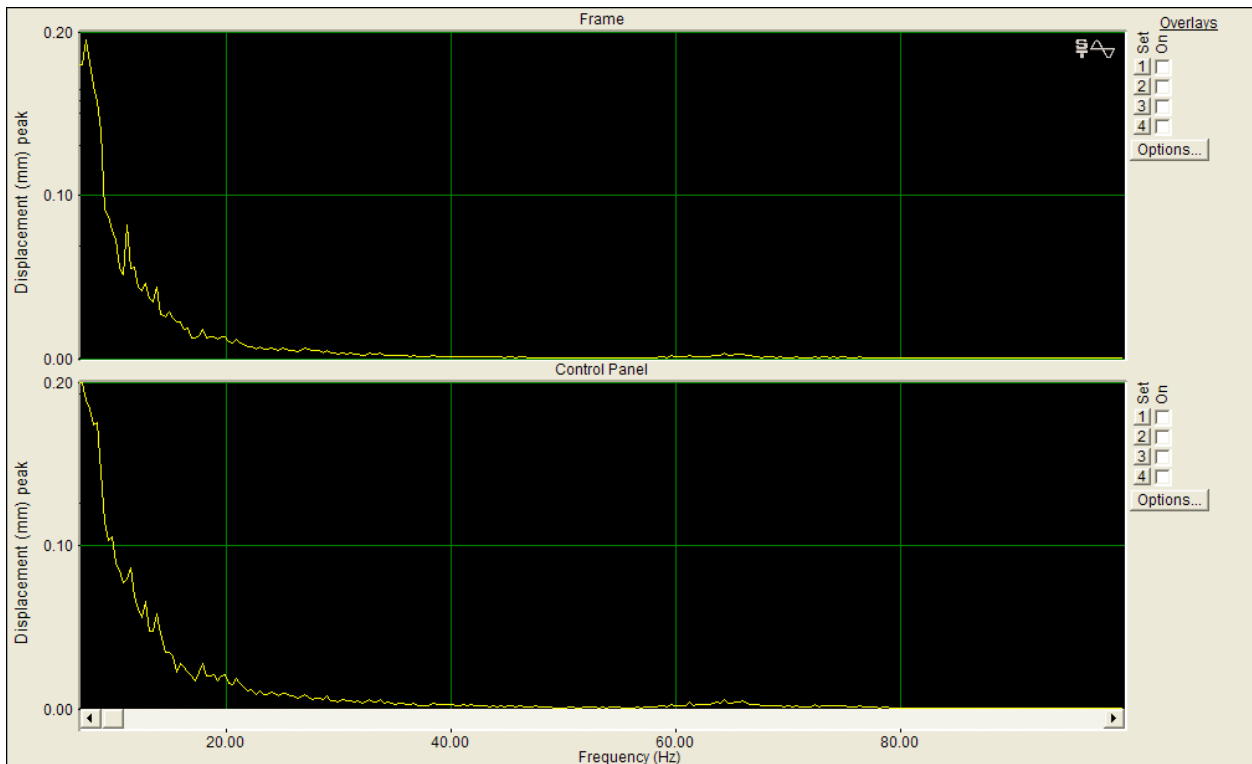


Figure 39. Highway Test - Peak-Hold Spectra (Displacement)

3.4.2 Secondary Road Vibration Measurements

In this series of tests, the pick-up truck was driven on secondary roadways at approximately 30 to 35 mph. Figure 40 shows the time series of the accelerometers. Figures 41 and 42 show the acceleration and displacement spectra, respectively. The energy is mainly at low frequencies, less than 20 Hz. The peak-hold displacement appears to be greater in this test than in the highway test.

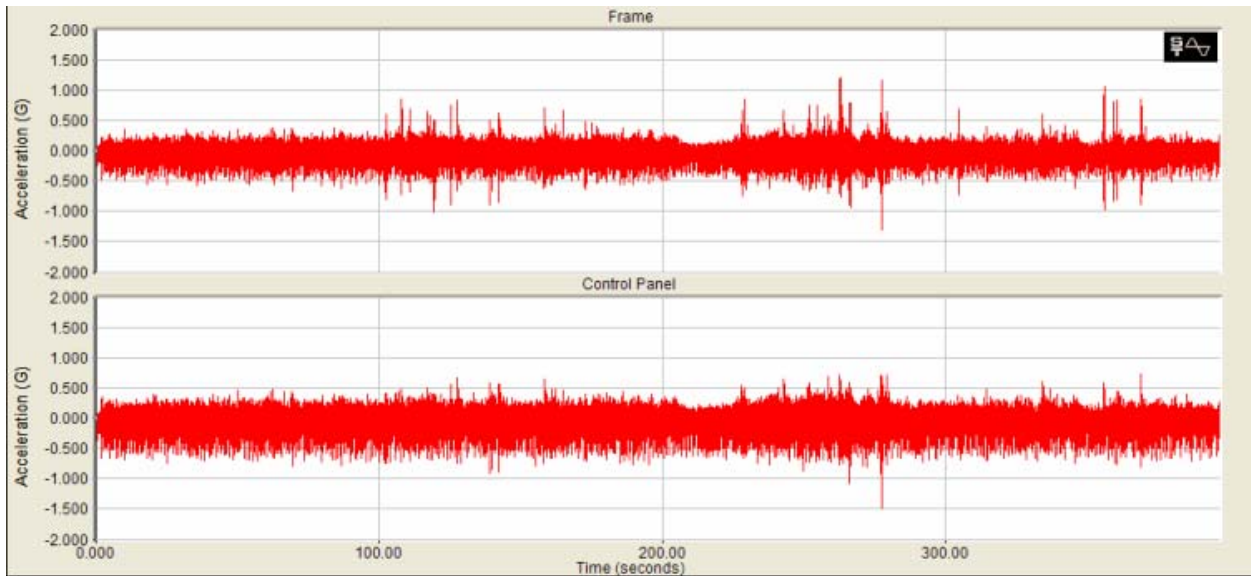


Figure 40. Secondary Road Test, Time Series

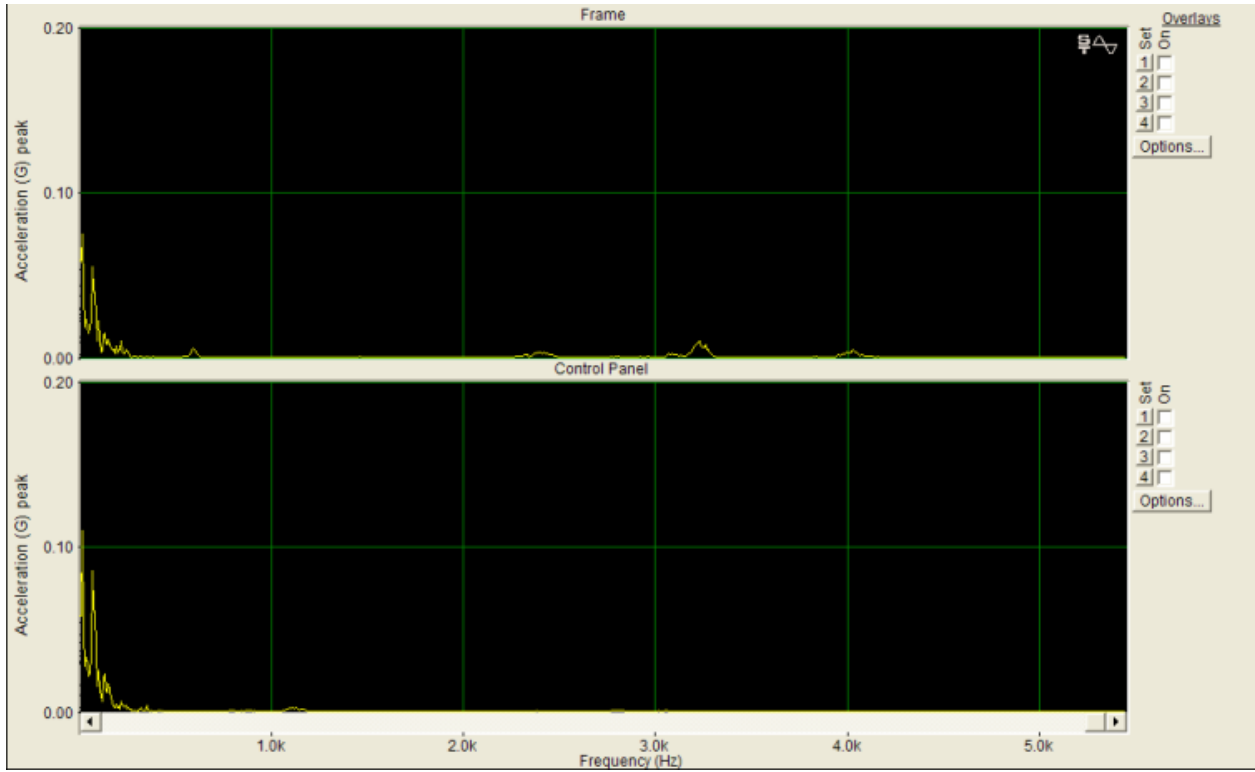


Figure 41. Secondary Road Test Peak-Hold Spectra (Accerelation)

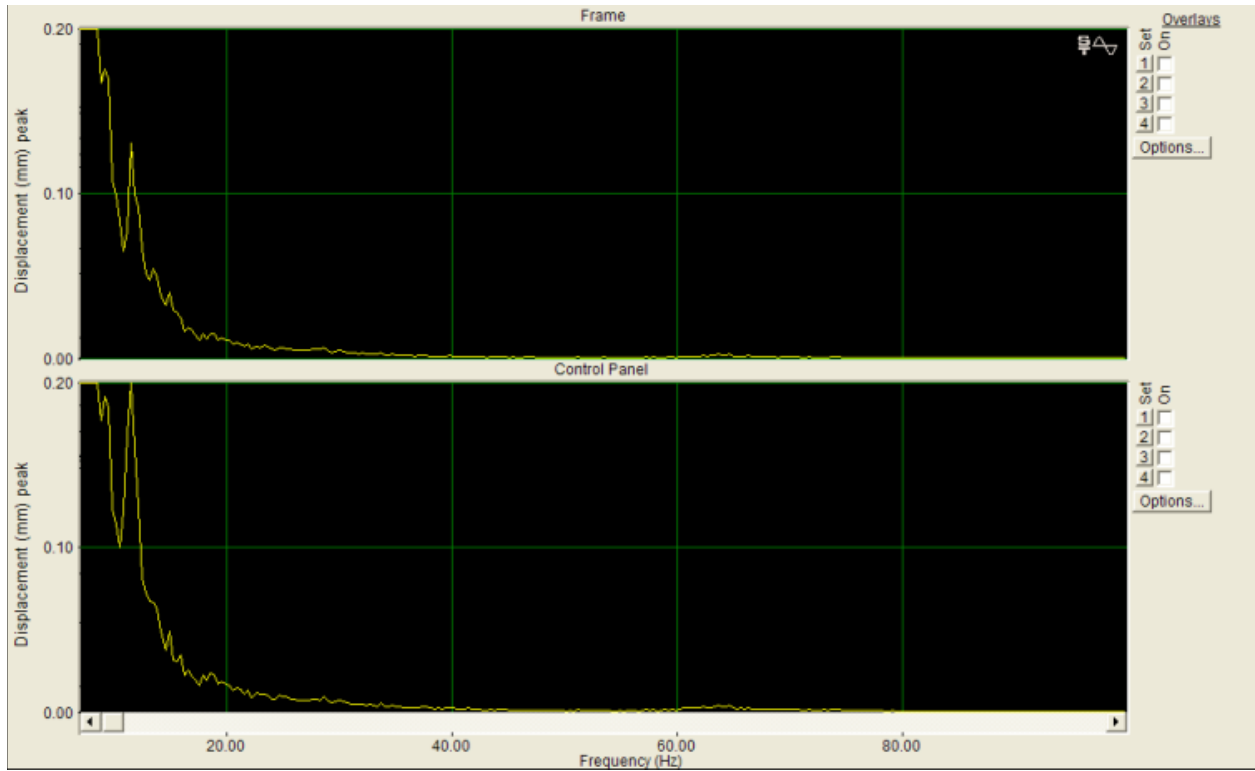


Figure 42. Secondary Road Test Peak-Hold Spectra (Displacement)

3.4.3 Country Road Vibration Measurements

In this series of tests, the pick-up truck was driven on paved roads at approximately 20 to 25 mph. Figure 43 shows the time series waveforms of the accelerometers. Figures 44 and 45 show the acceleration and displacement spectra, respectively. The energy is mainly at low frequencies, less than 20 Hz. There appears to be a slight increase in the peak-hold displacement over that previously seen in the secondary road test.

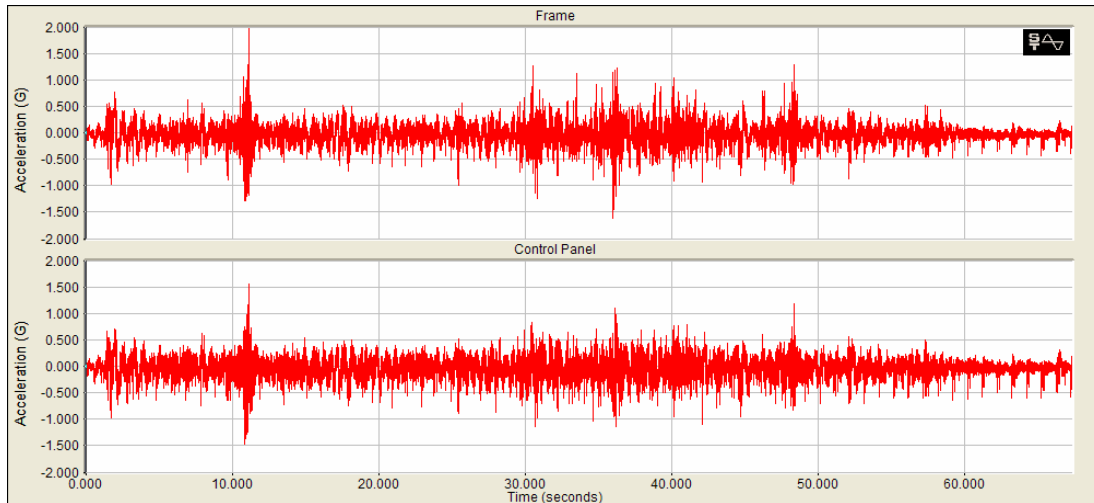


Figure 43. Country Road Test, Time Series

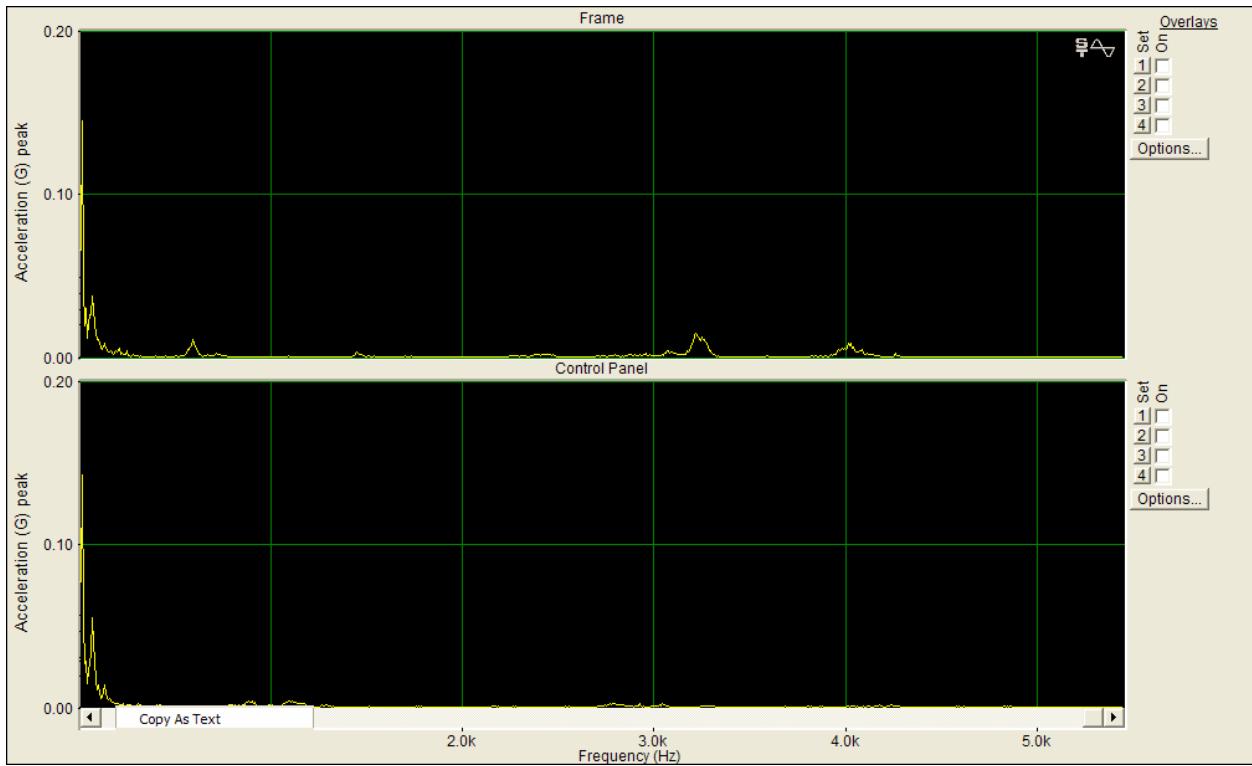


Figure 44. Country Road Test Peak-Hold Spectra (Acceleration)

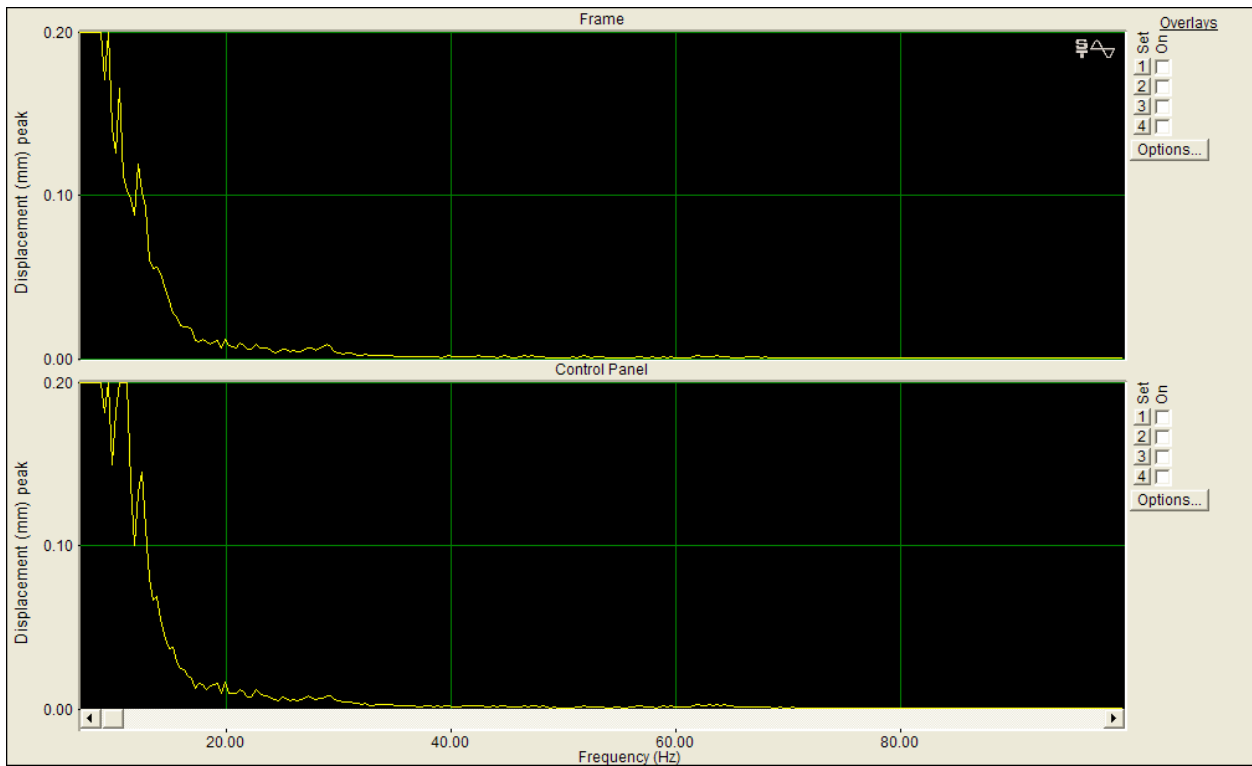


Figure 45. Country Road Test Peak-Hold Spectra (Displacement)

3.4.4 Unpaved Road Vibration Measurements

In this series of tests, the pick-up truck was driven on unpaved roads at less than 5 mph. Figure 46 shows the time series data of the accelerometers. Figures 47 and 48 show the acceleration and displacement spectra, respectively. The energy is mainly at low frequencies, less than 20 Hz.

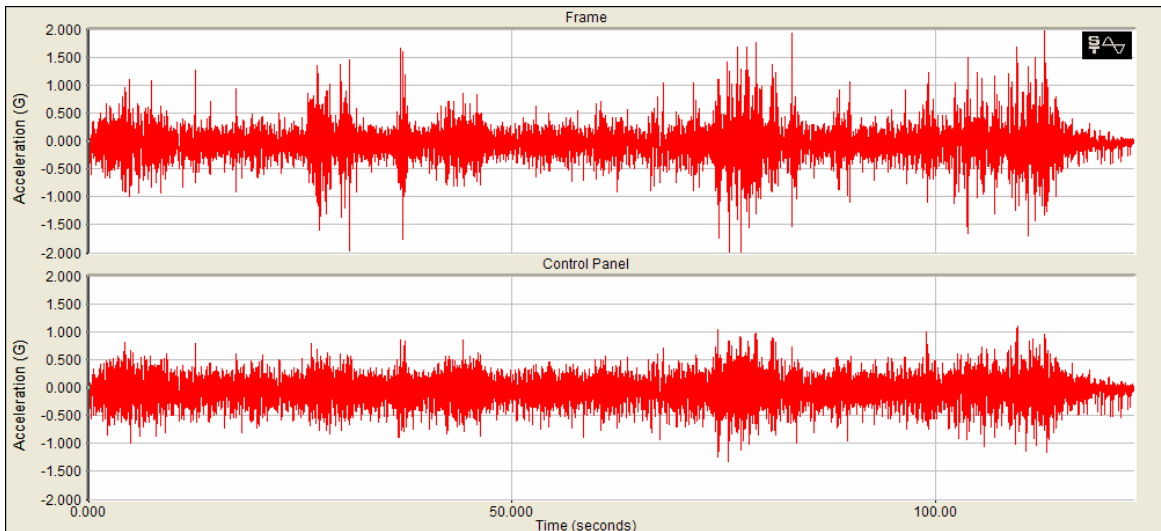


Figure 46. Unpaved Road Test, Time Series

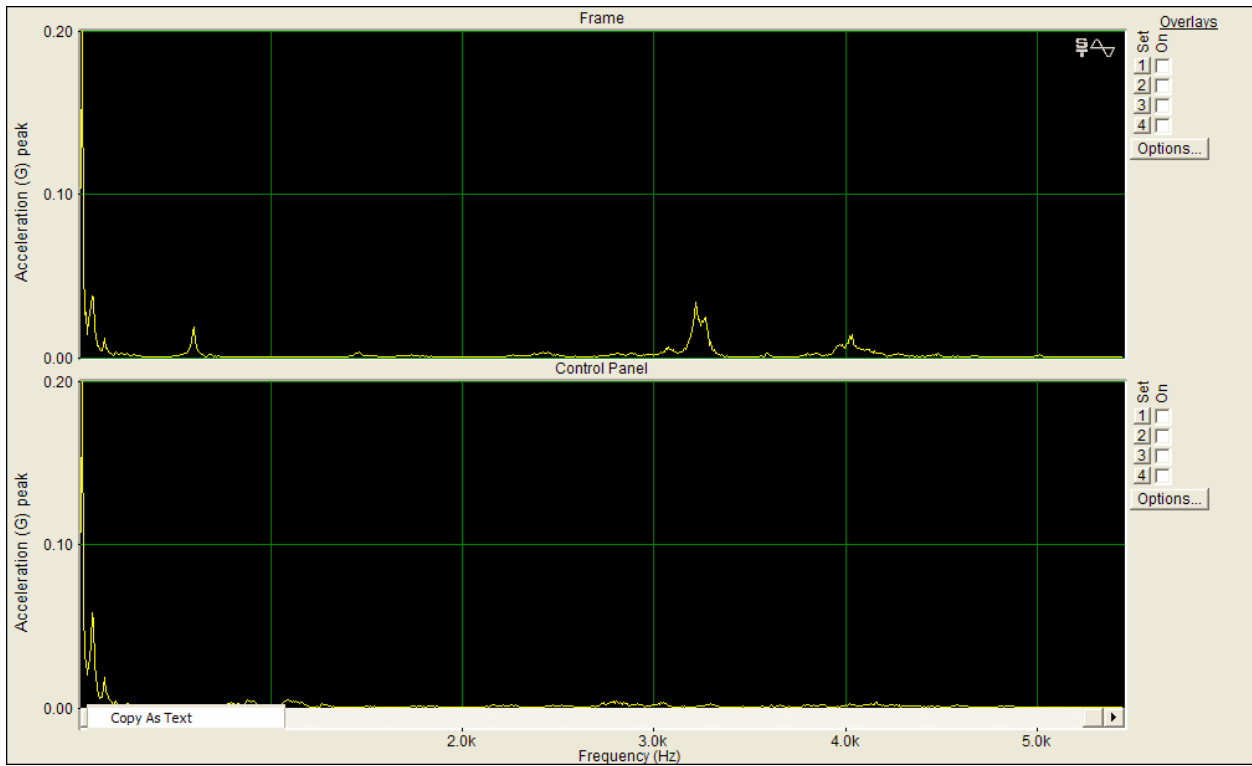


Figure 47. Unpaved Road Test Peak-Hold Spectra (Acceleration)

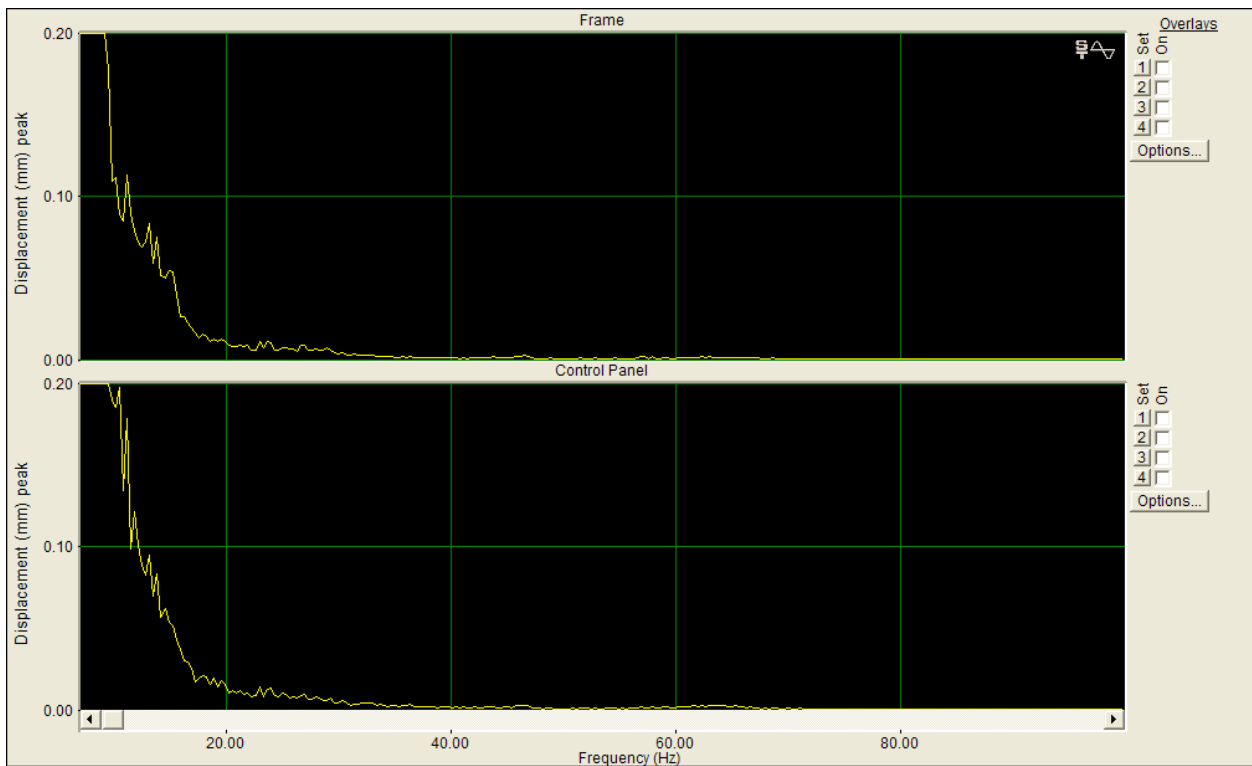


Figure 48. Unpaved Road Test Peak-Hold Spectra (Displacement)

4.0 DISCUSSION AND CONCLUSION

The vibration measurements for the 5250W generator had the highest acceleration and displacement magnitudes at around 60 Hz and below 20 Hz. The acceleration and displacement increased as the frequency decreased below 20 Hz. Peaks at 10 Hz and 20 Hz were caused during the start-up and shut-down of the generator. The most significant peak occurred at 60 Hz as a result of the rotational speed of the engine.

Table 2. 5250W Generator Peak-Hold Measurements (Frame-Mounted)

PEAK-HOLD @ appx. 60 Hz	Vertical Axis (frame mounted)		Horizontal Axis (frame mounted)	
	Acceleration (G)	Displacement (mm)	Acceleration (G)	Displacement (mm)
<i>Test 1</i>	1.090	0.071	0.900	0.620
<i>Test 2</i>	0.987	0.065	0.981	0.060
<i>Test 3</i>	0.908	0.060	0.874	0.057

The vibration measurements for the frame-mounted and the control panel-mounted accelerometers were significantly different for the 5250W generator. These measurements were in the vertical-axis only. The control panel mounted accelerometer measured greater acceleration and approximately double the displacement at around 60 Hz.

Table 3. 5250W Generator Peak-Hold Measurements (Frame- and Control Panel-Mounted)

PEAK-HOLD @ appx. 60 Hz	Vertical Axis (frame mounted)		Vertical Axis (control panel mounted)	
	Acceleration (G)	Displacement (mm)	Acceleration (G)	Displacement (mm)
<i>Test 4</i>	1.004	0.066	1.930	0.127
<i>Test 5</i>	0.880	0.058	1.740	0.115
<i>Test 6</i>	0.941	0.062	1.848	0.121

The measured acceleration and displacement on the two generators were significantly different. The 2250W generator had higher acceleration and displacement than the 5250W generator, most likely because of characteristics resulting from the difference in age of the generators. The 5250W generator was less than 1 year old and had less than 10 hours of operation, whereas the 2250W generator was over 10 years old and had more than 100 hours of operation.

The 5250W generator's energy was mainly in the frequency range of less than 20 Hz, except for the 60 Hz peak; the 2250W generator had peaks ranging up to 100 Hz. The acceleration in the horizontal axis was greater than that measured in the vertical axis. The 2250W generator acceleration and displacement were more than triple the magnitude of that measured in the 5250W generator. These peaks occurred around 60 Hz.

Table 4. 2250W Generator Peak-Hold Measurements (Frame-Mounted)

PEAK-HOLD @ appx. 60 Hz	Vertical Axis (frame mounted)		Horizontal Axis (frame mounted)	
	Acceleration (G)	Displacement (mm)	Acceleration (G)	Displacement (mm)
<i>Test 7</i>	2.819	0.161	3.243	0.185
<i>Test 8</i>	2.715	0.155	3.411	0.195
<i>Test 9</i>	2.820	0.161	3.558	0.203
<i>Test 10</i>	2.790	0.159	3.566	0.204

The transportation tests showed small acceleration and displacement peaks compared to operating the generator. The energy was mainly at low frequencies below 20 Hz. The acceleration and displacement increased as the frequency decreased. As the type of road changed from highway to unpaved roads, the acceleration and displacement also increased.