VibrationVIEW Syllabus

Laboratory Manual
Introduction to Vibration

Laboratory Manual for *"Introduction to Vibration"*

using *VibrationVIEW* Demonstration Software

"An Introduction to Vibration Testing, Research, and Control Systems"

Provided by:

Vibration Research

www.vibrationresearch.com

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To the Student:

Vibration Research designs and manufactures leading edge vibration control systems for electro-dynamic and servo-hydraulic shakers. Established in 1995, Vibration Research has become a pioneer in the industry and a leader in the field of vibration control. Our success is based on reliable, user friendly software packages, excellent customer service, and a constant search for ways to improve ourselves and our product.

Every engineering student who is faced with vibration testing would greatly benefit in his/her studies and preparation for the workforce by having had access to vibration software.

The following laboratory manual is a brief introduction into the realm of vibration testing and the use of software for vibration control. It is our hope that with access to *VibrationVIEW* software and this manual, the student may become better acquainted with the concepts of vibration testing, and even delve into some of the more complex areas of this field.

We hope you use this manual thoroughly and become comfortable with *VibrationVIEW* software through which you better understand and enjoy the exciting field of vibration research.

Warm Regards,

Vibration Research

Background

A. Why Test?

"The continuing demand for engineering products which can withstand severe dynamic environments has led to a steady growth in the sophistication of vibration test procedures. Increased reliability and performance are required of many products ranging from consumer electronics to military hardware, and a demonstration of survival in a simulated vibration environment is a prime requirement of many procurement specifications" (Andy Tomlinson, SoE, Cranfield University; http://www.cranfield.ac.uk/sme/pep/em/cpd/vib-test.htm).

In essence, it is important to test products to ensure the capability of handling the abuse in transportation and shipping as well as the wear and tear caused by typical use during serviceable years. As the industrial realm has become more involved in testing over the years, engineers have had to find sources of failure and fix them before sending out a product. This has resulted in more reliable products that perform at a higher standard. The study of vibration research has improved this field by developing test equipment for vibration and shock which can be used to accelerate the failure of the product. Through testing and analysis the product can be changed in some ways to lessen vibration, remove unwanted vibration, or compensate for the effects caused by vibration leading to a more reliable product with a longer life span.

The reasons to test a product are summarized well by Mr. Bill Fleenor, a mechanical engineer for Tinker Air Force Base, in Oklahoma. He notes that "If an item is going to fail, I want it to fail on my table and not with the warfighter" (as reported by Jeanne Grimes: 72nd Air Base Wing Public Affairs; May 23, 2005: http://www.af.mil/news/story.asp?storyID=123010586). Vibration testing has improved the methods of ensuring a product does not fail due to minor flaws or even entire design flaws. Vibration was allegedly the cause of the destruction of the NASA space shuttle *Columbia* (February 1, 2003).

B. Testing Standards

Industry Testing Standards have been developed and improved based on history. Wayne Tustin, founder and president of the Equipment Reliability Institute at Santa Barbara, CA, notes that many vibration standards find their historical roots in military standards, which, in many cases, were "written around" the capabilities of the shakers at the time these standards were created. Also, many original standards had good basis, but are no longer valid today. Nevertheless, many of these original standards continue to be used. Tustin relates a story to help understand why some standards are chosen and still used.

"Here is a non-vibration example: the standard US railway gage (distance between centers of the tracks) is 4 feet 8.5 inches. Why? Because that was the gage of the earliest railway equipment, imported from England. Why? Because that was the gage of English tram cars. Why? Because that was the gage of English wagons. Why? Because that was the spacing of the ruts on early British roads. Why? Because that was the gage of Roman chariots, brought in by the conquerors. Why? Because that was the width of the rear ends of a pair of Roman horses" (Tustin, pg. 197).

Some standards have changed over years to reflect the changes in new technology, testing ability, and industrial requirement. For example, MIL-STD-810 is used for testing a wide range of vibrations from gunfire to transport shock, and is constantly being revised as weapons and transportation methods are changed.

Commenting on the 810G revision, Tustin said "A major change is how a new Test Method 527 calls for the use of multiple vibration exciters. One application is in simultaneous multi-axis shaking. This will replace the present three tests – shaking a load first in its x-axis, then in its y-axis, and finally in its z-axis. Single-axis testing originated with mechanical shakers before 1950 and has persisted 50-plus years, even though recognized to be unrealistic." (http://www.edn.com/design/test-and-measurement /4380987/Revision-G-planned-for-MIL-STD-810)

Two major organizations that try to establish standards to be used in product testing are ASTM International (American Society for Testing and Materials) and ISTA (International Safe Transit Association). These two organizations have established numerous test standards for various situations. Companies try to demonstrate the quality, safety, and reliability of a product by meeting or exceeding these standards. For example, in Canada CCM® tests hockey helmets to meet the impact standards of the Canadian Standards Association (CSA).

ASTM International was founded in 1898 by a group of engineers and scientists who wanted to solve frequent rail breaks in the railroad industry. This work led to the development of standards in the steel industry, improving rail construction. Over time ASTM International grew to develop standards for a wide range of industrial needs which have resulted in safer, better, and more cost effective products. (ASTM Internationals Webpage www.astm.org)

The development of standards ensure that industries continue to provide safe, usable products to the market. A lack of standards could lead to poorly constructed products, and lead to disaster.

C. Tools for Testing

Robert Frey, from State University of New York, in *Sound and Vibration* (Feb 1999), writes of the importance of university students working with "automated, computer based data acquisition systems" in connection with vibration studies. The basic components required for closed loop vibration testing are:

1. Electro-dynamic or servo-hydraulic shaker
2. Transducer (typically an accelerometer)
3. Vibration Controller (VR9500 Revolution)
4. Software Package (*VibrationVIEW)*

D. What does the controller (VR9500 Revolution) do?

Supplied with this manual is the *VibrationVIEW* software package and a vibration controller (VR9500 Revolution). Although a shaker is not provided, *VibrationVIEW* is capable of operating in "Demonstration Mode". This will generate data as if the test profiles were being run on a shaker. WARNING: The test profiles in the appendix are designed for Demonstration Mode ONLY. Before running on an actual shaker ensure that the System Limits are set to ensure that the shaker is not damaged!

VibrationVIEW includes System Check Mode which is used to test and calibrate a system. Optional Software Modules include:

1. Sine
2. Random
3. Shock
4. Field Data Replication
5. Sine on Random
6. Random on Random
7. RecorderVIEW

Each of these modules has various sub-options that are specific to different test requirements and the needs of our customers.

The VR9500 accomplishes the following tasks:

1. Sends signals to the shaker amplifier that cause shaker excitation in the exact, controlled manner as driven by a specific output signal. It is responsible for the type of vibration observed on the shaker head.
2. Receives data from transducers. Each VR9500 can receive data from four transducers simultaneously.
3. Has the capability to receive outside information via the remote inputs/outputs. (e.g. current and voltage monitors, low voltage relays)

E. How *VibrationVIEW* helps in testing, data acquisition, and data analysis.

Human senses are limited. Noise below 100 Hz and millimeter displacement cannot be judged by any person without equipment. *VibrationVIEW* is used as an extension of the natural senses by recording and displaying the results of testing performed.

The following is a small sample of possible reasons to use *VibrationVIEW:*

1. Records and replicates "real life" data
2. Tests a product to any parameter desired
3. Presents data in a number of different graphs
4. Saves data from tests allowing profiles to be generated from test data
5. Standard Sine, Random, and Shock tests
6. Limits test profiles to protect the shaker through "System Limits"
7. Resonance Tracked Dwell
8. Produces MS Word and Excel reports

## Using *VibrationVIEW*

A. Getting Started

1. Install *VibrationVIEW*
   a. From the CD provided with this lab manual
   b. From www.VibrationResearch.com
2. Open *VibrationVIEW*
3. Select the **Configuration Tab**, click on **Hardware**
4. Under Select Network Card choose **Demonstration Mode**
   a. NOTE: if using a VR9500 controller, select the IP address of the network card being used to connect to the controller, then select the serial number of the unit for Channel 1-4.
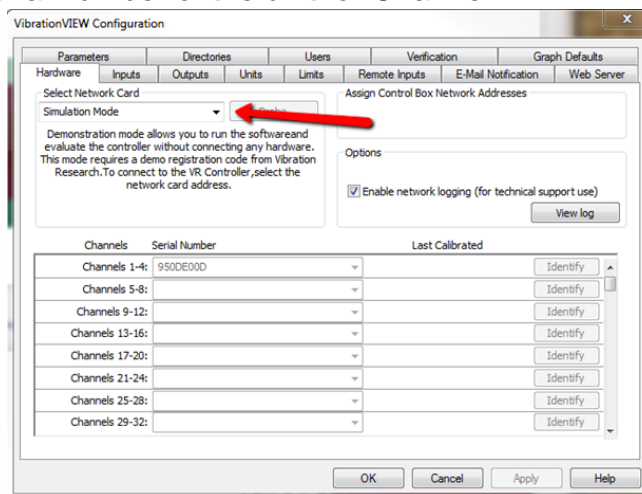
5. The **Configuration Tab** contains all the global configuration settings for the *VibrationVIEW* Software. These settings apply to all tests:
   a. **Hardware** – Setup connection from PC to VR9500 Controller
   b. **Inputs** – Configure input sensitivity, accel power, and setup
   c. **Outputs** – Adjust settings to the Drive, configure differential mode
   d. **Units** – Adjust default units
   e. **System Limits** – Set limits to ensure no test is run that will cause damage to the shaker
   f. **Remote Inputs** – Configure Auxiliary Inputs and Outputs
   g. **Email Notification** - Allows the user to receive emails from *VibrationVIEW* regarding status changes of tests while running
   h. **Webserver** – Allows for remote supervision, control, and shutdown
   i. **Parameters** – Configure overall settings
   j. **Directories** – Organize where different file types will be stored during the testing process. Data Files, Reports, Test Profiles, etc
   k. **Users** – Allows for the creation of an administrator and sub-groups that can be restricted from access or capabilities in the software. For example a user could be restricted from editing test profiles.

6. Configure **Inputs**
   a. Select the **Configuration Tab**, click on **Inputs**
      1. Typically connecting and reading the TEDS (Transducer Electronic Data Sheet: Data stored on digital memory of the transducer that includes make, model, calibration date, and sensitivity) of an accelerometer will automatically set the sensitivity and load other unique data about a particular transducer into the system.
   b. The sensitivity values can be entered manually. When using Demonstration Mode the sensitivity is used to control the response from the sound card on the computer. Increasing the sensitivity has the same effect as turning up the volume of a speaker. Typically this value is set between **200 – 300 mV/G**.
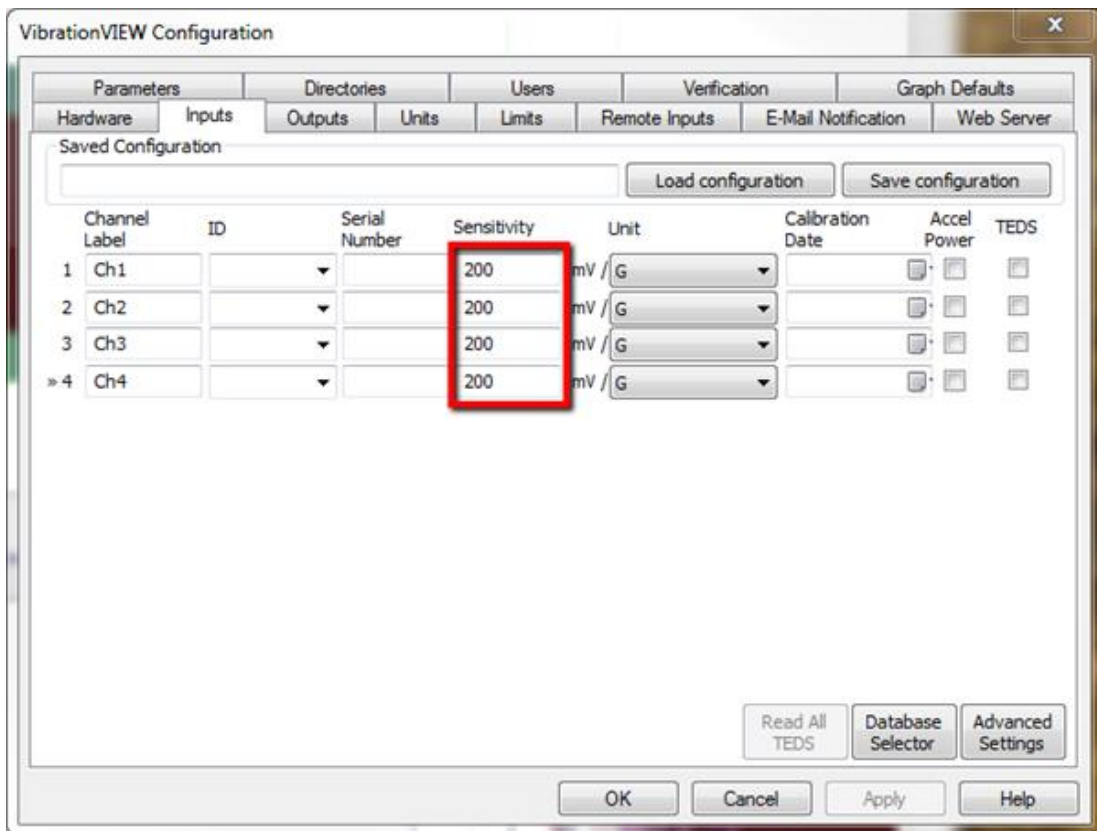
B. Before Starting a Test
   1. Typically tests are ran in one of four test types
      a. System Check
      b. Sine Testing
      c. Random Testing
      d. Shock Testing
   2. **Always Run System Check** before a sine or random test in real time to ensure the system is operating properly

C. Test Types
a. System Check

System check is used to determine if the shaker and accelerometers are functioning. It also ensures that the system is setup allowing the controller to control the vibration of the shaker.

b. Sine Test

Sine testing has a limited place in the industry because "real world" vibration cannot be generated from sine testing. Its usefulness comes from simplicity and therefore is a good point of entry into the study of vibration. Sine testing requires a basic understanding of resonant frequencies. A resonant frequency is a particular frequency at which a product will experience magnified vibration when shaking at that particular frequency.

Sine testing is primarily used to determine damage to equipment or products. According to Tustin "The best pro-sine reasons are to search for product resonances to: 1. Study modal responses; 2. Determine fatigue life in each mode" (pg. 205).

A digital controller (VR9500) is used to apply a sinusoidal vibration to a shaker. The controller can sweep a frequency band to determine the frequencies that cause a product to resonate. After locating these frequencies a test can be set up to "dwell" at those locations for a set amount of time to determine how long a product can resonate before failing.

Think of bending a paper clip back and forth until it breaks, as time passes the paper clip becomes easier to bend until it reaches failure. Dwelling at resonance has much the same effect, and as the product deteriorates the resonant frequency will begin to shift. The VR9500 has the ability to "track" this shift in resonance and automatically adjust to ensure that the peak resonance is maintained. (See Module 1.2 for example)

Other than testing for resonant frequencies, sine testing can also be used to determine damage to equipment. By running a sine sweep prior to any random or shock test a baseline can be generated. After the damaging tests are conducted another sweep is ran. By comparing the differences in the data files one can determine damage. A simple example is a shift in the natural resonant frequencies, possible suggesting loose bolts that need to be better secured or tightened.

Sine tests are simple, and do not have any "real world" applicability, but are still widely used in testing labs for baseline readings, resonance studies, and damage estimation.

c. **Random Test**

"Real world" vibration is not repetitive or predictable. Consider a vehicle on a common roadway; a rocket in take-off; an airplane wing in turbulent airflow; none of these have a predictable vibration pattern. The goal of random vibration testing is to create a vibration spectrum that can be used to simulate real world vibration in the lab.

The acceleration waveform in Figure 1.1 is a recording of the dashboard vibration found on a vehicle traveling on Chicago Drive near Hudsonville, MI. The vibration shown are in no way repetitive. Random vibration testing is used extensively in the transportation industry. One of the main goals in random testing is to bring the DUT (device under test) to failure.
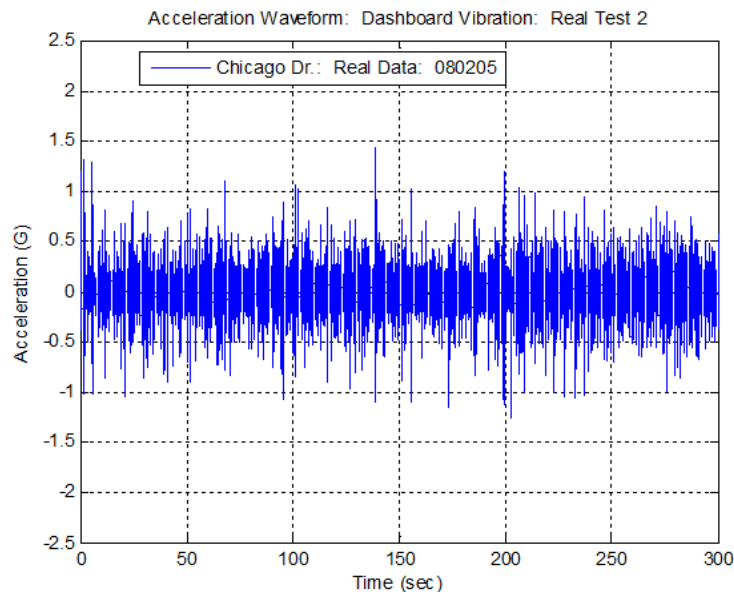

Figure 1.1 – Data collected on vehicle dashboard in Hudsonville, MI

How does Random testing differ from Sine testing? Sinusoidal vibration tests consist of a single frequency at any moment in time. Random vibration consists of all the frequencies in a defined spectrum being sent to the shaker at any given time. Consider Tustin's description of random vibration. "I've heard people describe a continuous spectrum (*random vibration*, VRC), say 10-2000 Hz as "1990 sine waves 1 Hz apart". No. That is close, but not quite correct….Sine Waves have constant amplitude, cycle after cycle….Suppose that there were 1990 of them (*constant amplitude sine waves*, VRC). Would the totality be random? No. For the totality to be random, the amplitude of each slice would have to vary randomly, unpredictably….Unpredictable variations are what we mean by *Random*. Broad spectrum random vibration contains not sinusoids but rather a continuum of vibration (*with differing amplitudes*, VRC)" (pg. 234-235)

In order to accomplish the same degree of testing, multitudes of sine tests would need to be administered, where a simple random test accomplishes all of this in one test. **Random vibration testing is, therefore, much more efficient and precise.**

Random testing is also more realistic than sinusoidal testing. A random spectrum simultaneously includes all the forcing frequencies and "simultaneously excites all our product's resonances" (Tustin, pg. 224). Under a sinusoidal test a particular resonant frequency might be found for a single part of the DUT, and as the test progresses in time another resonant frequency will be hit. Exciting these resonant frequencies at different times may not cause any kind of failure, but when all the resonant frequencies are excited at the same time failure might occur. Random testing allows a bandwidth of frequencies to be excited simultaneously causing all the resonant frequencies inside that band to be forced at the same time.

In order to perform random testing, a random test spectrum must be developed. Computer software collects real-time data over a time period and combines the data using a spectrum averaging method to produce a statistical approximation of the random vibration spectrum. Traditionally, this new spectrum is converted into an amplitude probability density graph (similar to **Figure 1.2**) assuming that the majority of the data is in the ± 3 sigma range (i.e. Gaussian distribution).

The assumption that the amplitude probability density falls within the ± 3 sigma range removes much of the real time data. The acceleration values that were of extremely large magnitude are omitted from the probability density by all those who use the traditional Gaussian distribution method. Consequently, present day methods of random testing are unrealistic because they fail to take into account these higher level accelerations. Furthermore, random testing with Gaussian distribution will result in a longer time-period to test the product to failure because these high level accelerations have been omitted.
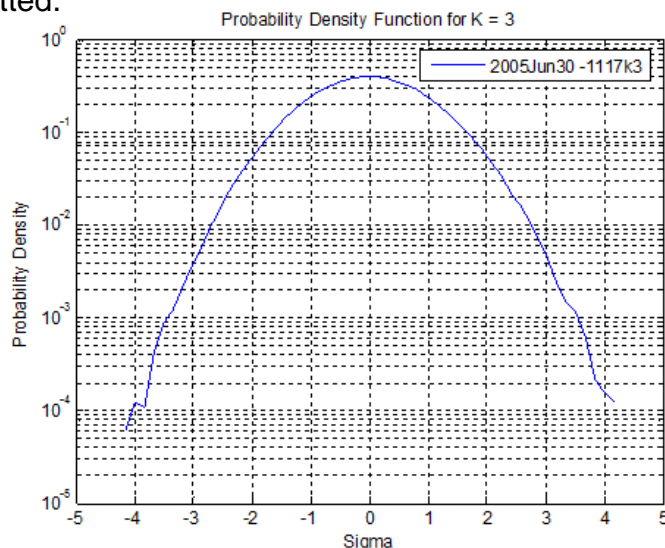
Figure 1.2 – Probability density for a Light bulb test using Gaussian distribution (k=3)

Random Vibration – Power Spectral Density

One of the more complex aspects of random vibration is the way the vibration is traditionally displayed. Logically, vibration is displayed in the "time" domain because vibration happens over time, however random vibration is generally displayed in the "frequency" domain. Converting time domain data to frequency domain data is done using Fast Fourier Transforms (FFT) (for more details on this process, see: **Kipp, Bill. "PSD and SRS in Simple Terms," *ISTA Conference*, Orlando, FL, 1998)**. Consequently, the random vibration spectrum is displayed as a power spectrum, which is a plot of acceleration spectral density (typically G^2/Hz) versus frequency (**Figure 1.3)**. A power spectrum shows which frequencies contain the power.
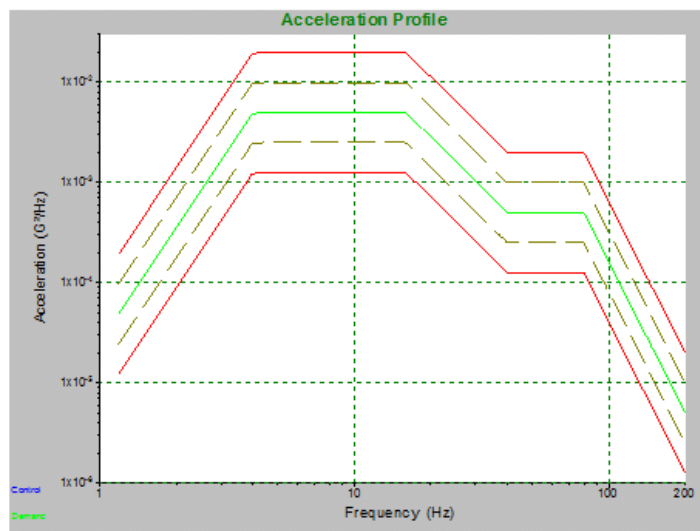

Figure 1.3 – Amount of *power* per unit (*density*) of frequency (*spectral*) as a function of the frequency

"The power spectral density, PSD, describes how the power (or variance) of a time series is distributed with frequency. Mathematically, it is defined as the Fourier Transform of the autocorrelation sequence of the time series. An equivalent definition of PSD is the squared modulus of the Fourier transform of the time series, scaled by a proper constant term" (http://www.cbi.dongnocchi.it/glossary/PowerSpectralDensity.html).

The PSD demonstrates how hard the shaker is working. It does not show any information about the forces experienced by the DUT. Since the PSD is the result of an averaging method that produced the statistical approximation of the spectrum, an infinite number of real-time waveforms could have generated such a PSD. Thus, at any time during the test, it is impossible to know specifically from the PSD what forces the DUT is experiencing. Test engineers use the PSD to make an appropriate test profile for the shaker that will come close to the real world vibration the DUT will experience.

For example, note the following graphs (**Figure 1.4 – 1.7**) and how they demonstrate the idea that different waveforms will "average" out to make the same PSD profile graph. Data collected at Vibration Research on June 28, 2005 and June 30, 2005 is shown below. Note how the acceleration waveforms, although very similar, are different waveforms. Note also the PSD spectra formed from each acceleration waveform is exactly the same even though the data is from different waveforms.
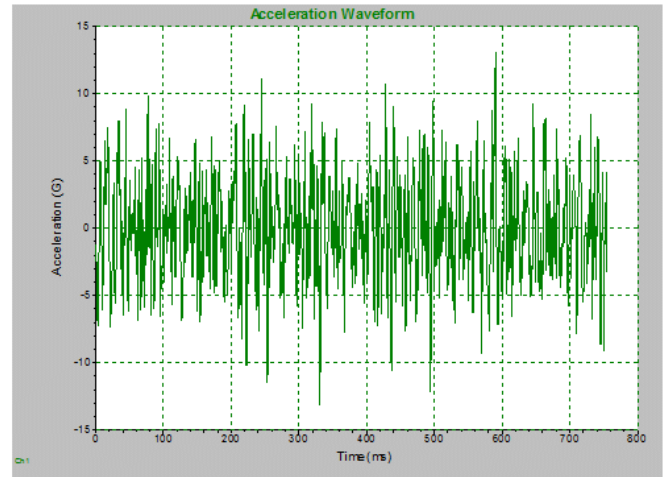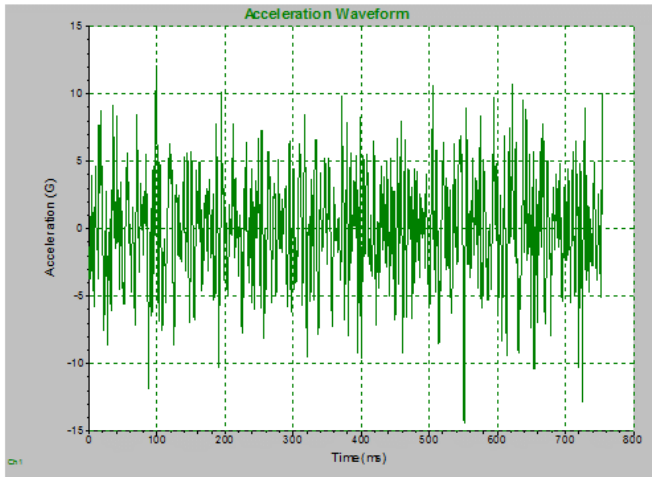
Figure 1.4 – Waveform for Body and IP Profile Lightbulb-4 for trial 2005Jun28 – 1330

Figure 1.5 – Waveform for Body and IP Profile Lightbulb-4 for trial 2005Jun30 – 1110
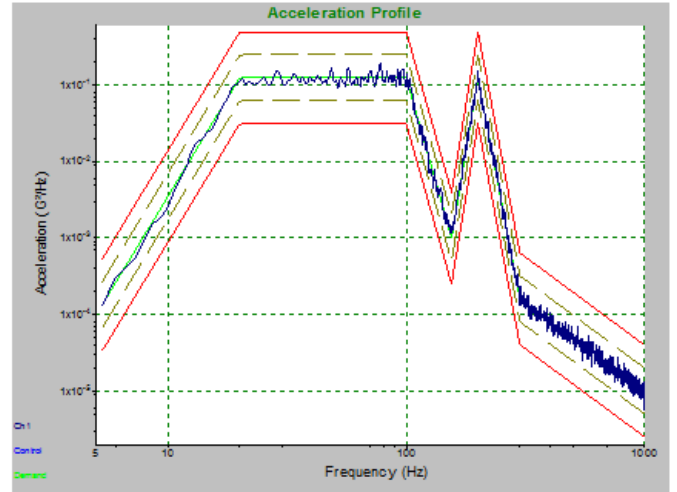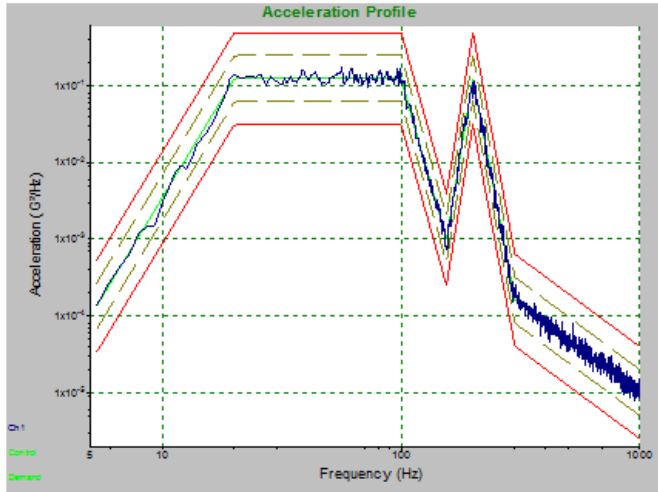
Figure 1.6 – PSD spectrum for trial 2005Jun28 - 1330

Figure 1.7 – PSD spectrum for trial 2005Jun30-1110

Random testing has many advantages over sinusoidal testing, but has its own disadvantages, and a better method of testing products would prove more valuable. Vibration Research has developed a very important improvement upon traditional Gaussian distribution in random testing with a patented technique of kurtosis control called Kurtosion®. Using this technique it is possible to put the peak accelerations that are typically removed back into a vibration test.

Random Vibration – Kurtosis Control

Kurtosis control, or non-Gaussian vibration is a recent development in vibration testing. Present day computer software programs collect real-time data over a time period and combine the data, using a

"spectrum averaging method to produce a statistical approximation of the vibration spectrum….As an inherent part of the spectrum measurement process itself, infrequently occurring vibration events are "discounted" in terms of their contribution to the overall measured spectrum. Discounting of potentially important but infrequently occurring vibration events is an unavoidable part of the spectrum analysis method. This measurement limitation must be recognized as a fundamental barrier that detracts from our ability to bring uncompromised acceleration time history data from the field to the vibration test lab" (Unholtz-Dickie Corporation – www.udco.com/trac.htm)

This averaging method results in a Gaussian distribution of data in which the highest peak accelerations are approximately ± 3 times the average acceleration. **Gaussian distributions omit the highest accelerations which are the cause of the greatest damage to a tested product and results in "under-testing" the DUT.**

Gaussian distribution has been universally accepted as a legitimate averaging technique, in part, because it has been assumed that "real world" data is Gaussian. However, several studies have shown that real world data is NOT Gaussian. (See: Steinwolf, A. "Shaker simulation of random vibration with a high kurtosis value", *Journal of the IEST,* May/June 1997; 40,3 and Van Baren, Phil. "The missing knob on your random vibration controller", *Sound and Vibration*, October 2005, pg. 10-17) **Figure 2.1** shows 40 real world tests in Automotive, Aeronautical, Agricultural, and Industrial
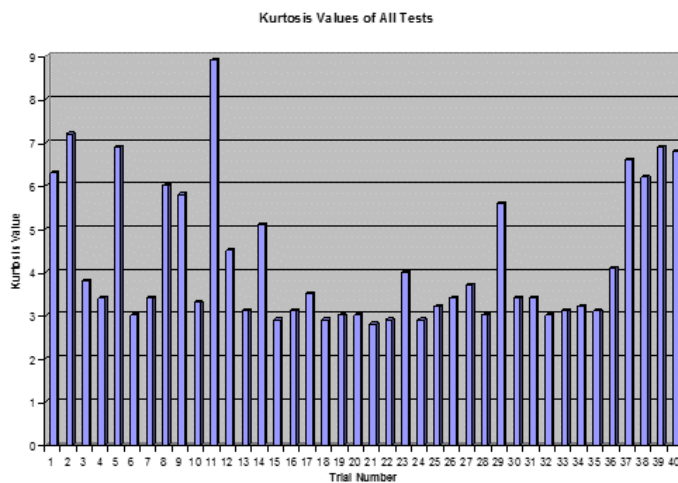

Figure 2.1 – Kurtosis values for 40 tests conducted by Vibration Research Corporation; note the variety of kurtosis values and that 23 tests have k > 3.3.

environments; many of which are non-Gaussian.

Since real world data is often non-Gaussian, random vibration must be improved through a technique that can keep the test profile spectrum the same while manipulating the number of large peak accelerations. "Kurtosis control (non-Gaussian vibration) is a means of increasing the amplitudes of the peaks without changing the spectrum shape or the overall average acceleration level" (Kipp, Bill. "New considerations for random vibration testing of packaged products", *2008 International Transport Packaging Forum™*). **Figure 2.2** shows a Probability Density Function Graph with a typical Gaussian curve (Red) and a curve with a higher kurtosis containing higher peak
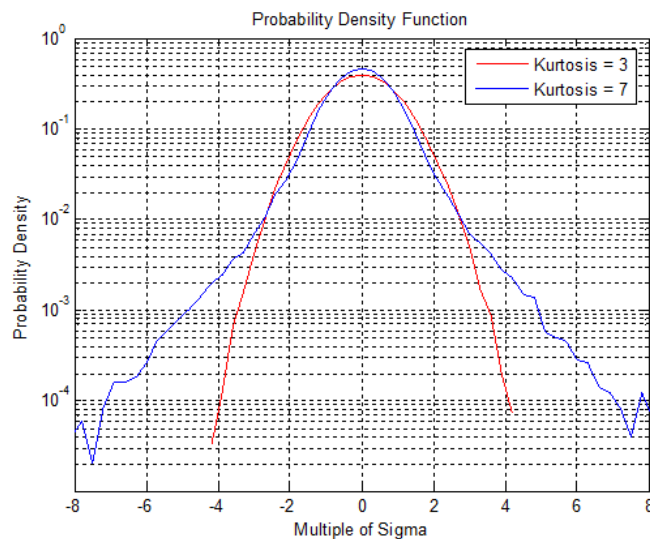
Figure 2.2 – A comparison of kurtosis values 3 and 7. Note how the higher kurtosis value includes higher sigma values (higher peak accelerations).

acceleration values (Blue).

Vibration Research's patented kurtosis control technique, called Kurtosion®, includes the higher peak accelerations while maintaining the original test profile and average energies. Module 2.3 details the differences and shows that the when changing the kurtosis value the PSD profile is not affected, but the peak accelerations are significantly higher.

Figure 2.5 and **Figure 2.6** illustrate how kurtosis control produces a more realistic waveform and probability density function than Gaussian distribution. By including the larger peak accelerations in the data, kurtosis control more accurately represents the kind of peak accelerations that occur in the real world. **Figure 2.5** is a PDF of the accelerations of a side window of a Cessna during landing. **Figure 2.6** is a comparison of acceleration waveforms for SUV dashboard vibration.
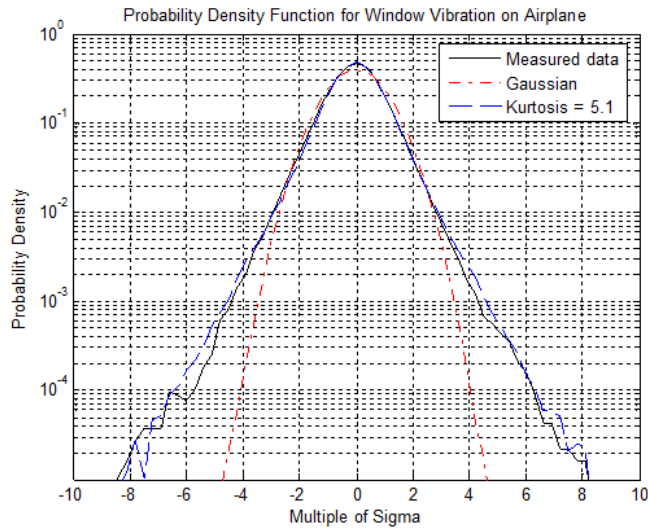
Figure 2.5 – Cessna landing in Ludington, MI: Side window mounted: 16:17 08/05/05
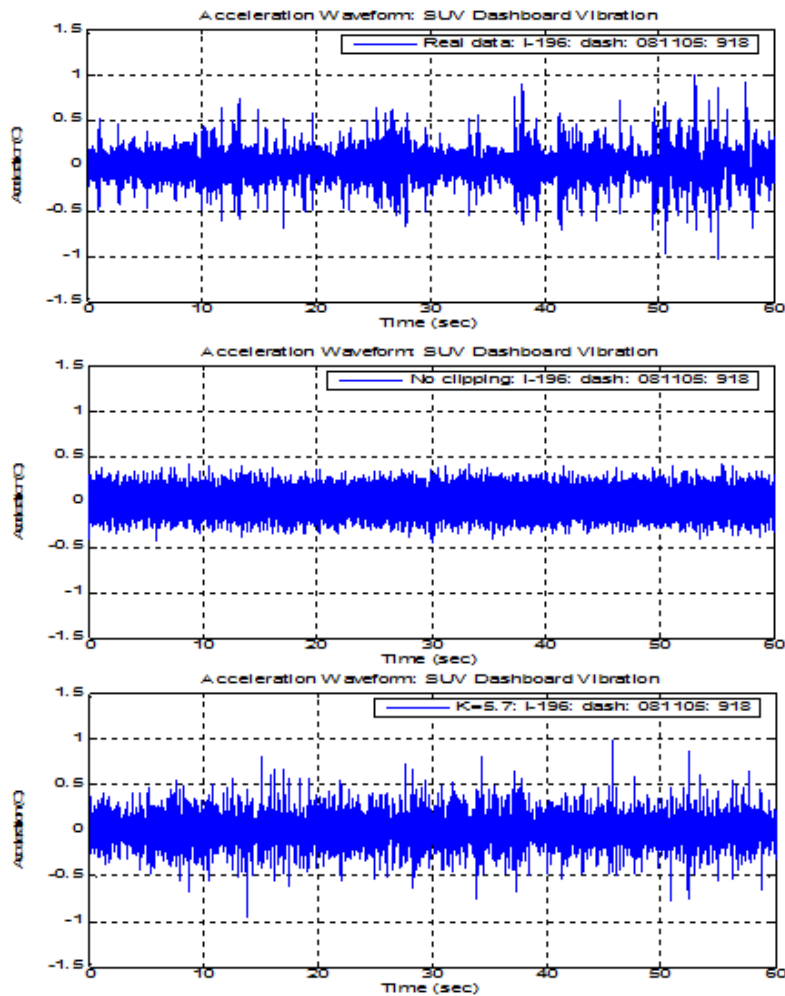

Figure 2.6 – Acceleration Waveforms for Bravada Dashboard vibration on I-196 (9:18 08/11/05).
Measured real-life data, Gaussian (no clipping), and Kurtosis Control (k=5.7) waveforms.

Kurtosis control is a more effective method of conducting random vibration tests because the acceleration waveform more closely replicates real world vibration. In addition, for those industries that test products to find points of failure, kurtosis control will shorten the time needed to reach failure in the lab environment. A simple study to illustrate this point was conducted by Vibration Research. Ordinary 75 Watt light bulbs were tested with a slightly modified standard automotive specification. The bulbs were subjected to random vibration until the filaments broke and the bulb "burned out". A total of 66 light bulbs were tested, 22 bulbs at kurtosis levels 3, 5, and 7. The time to failure for each bulb was measured and recorded. The time to failure for all tests is shown in **Figure 2.7** and **Figure 2.8**. The results clearly show that as the kurtosis values increased the time to failure decreased. The higher kurtosis values include the higher peak accelerations which are responsible for a more damaging test, and shorter amounts of time testing a product. Kurtosis control proves to be a great improvement on traditional random vibration from every perspective.
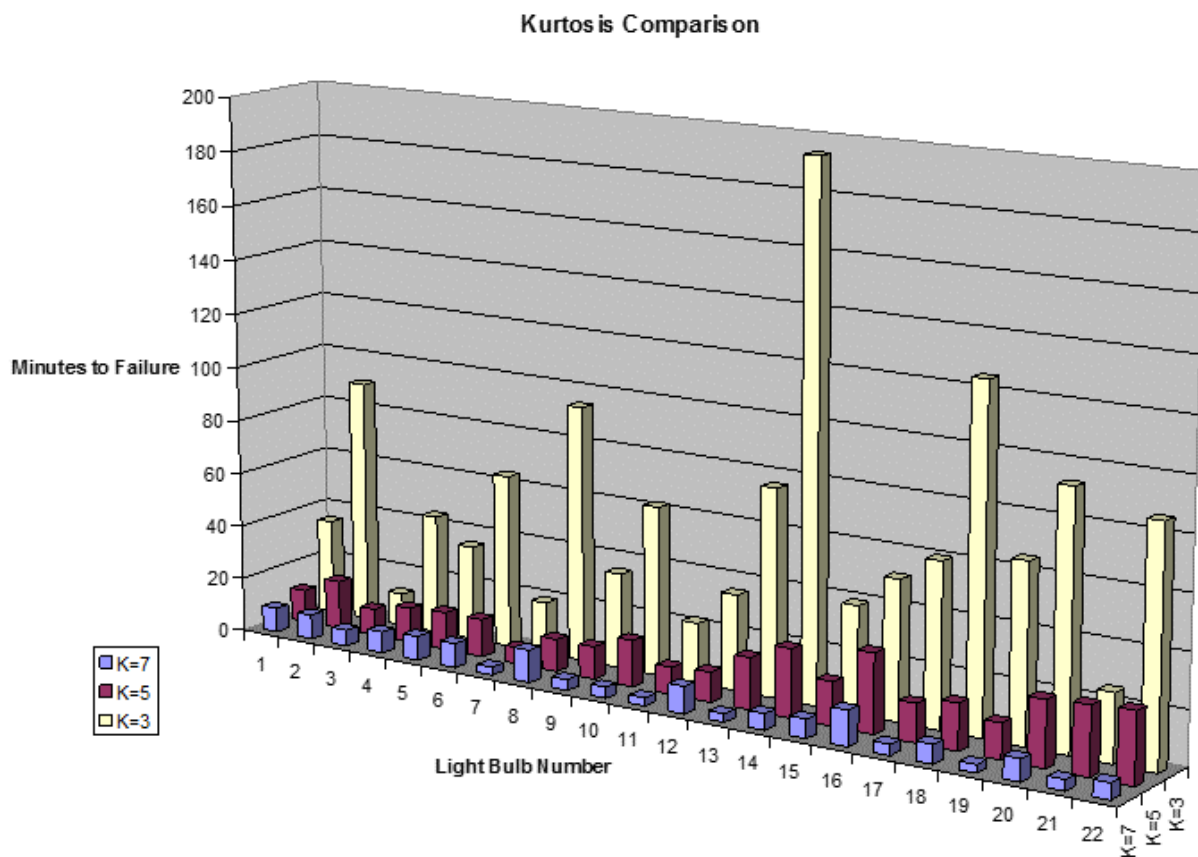
Figure 2.7 – Kurtosis Comparison of Light Bulb Failure Tests
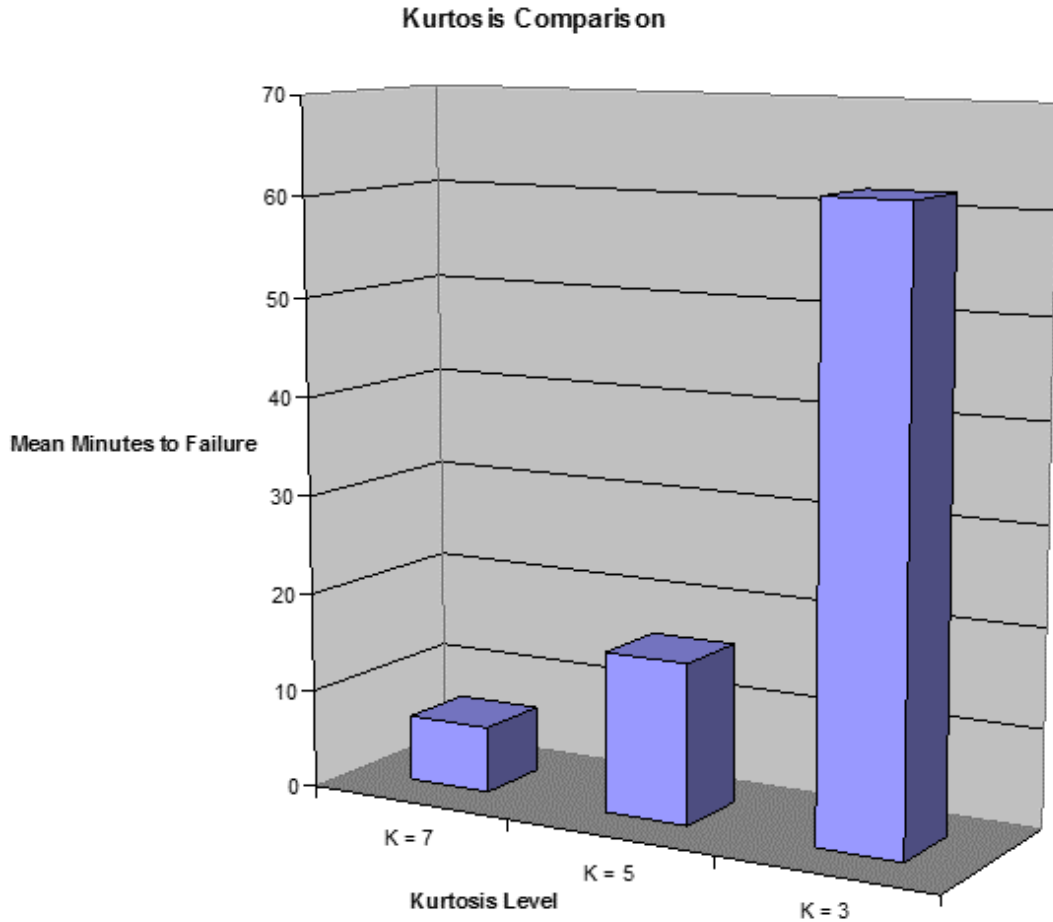
Figure 2.8 – Mean Minutes of Failure vs. Kurtosis Level

Random Vibration – Fatigue Damage Spectrum

FDS is another new method of testing. The goal of an FDS test is to create a realistic random vibration test that can be used to inflict the damage a product would experience over a lifetime in a much shorter timeframe. FDS takes a time history file that is representative of the actual life of the product, then creates a test that takes into account multiple levels of acceleration. An example of these levels of acceleration could be the road surface that a vehicle travels on during its lifetime; 80% highway, 10% city streets, and 10% gravel road. Traditional random tests do not differentiate between these levels and either lose the peak accelerations, or concentrate only on the peaks. Once an FDS profile has been generated a time component is applied to scale, for instance, 24 hours of testing to be equal to 1000 hours of product life.

d. **Shock Tests**

Whether it be gun-fire, explosions, or large pot holes many products experience shock pulses over time. Many industries today use shock tests to ensure that their product can withstand not only typical use, but also more extreme accelerations that occasionally appear. A shock test is a time domain test. It applies peak amplitude shock pulses over a particular time duration. These shock pulses are then repeated for a designated time interval or pulse count. *VibrationVIEW* gives the user a number of different shock waveforms to choose from, including half-sine, triangle, trapezoid, and square to name a few (see **Figure 1.8 – 1.9**).

These tests are often required by MIL-STD. Although shocks do not occur frequently during use, it is an expected occurrence that is often tested for. An example is the gun-fire test required to be performed on military vehicles. These vehicles have turrets that hold large-caliber machine guns. When fired these weapons cause shocks to run through the entirety of the vehicle. If not properly tested the damage caused by
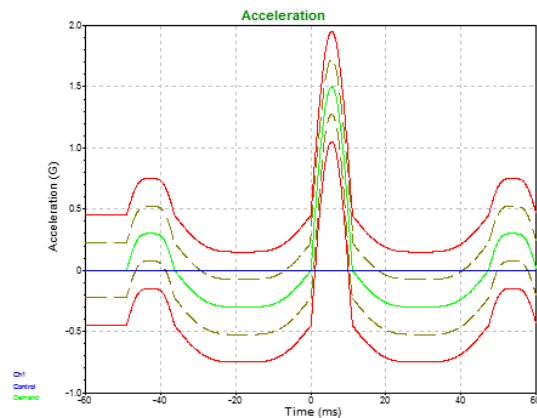
Figure 1.8 – Shock pulse (sine wave)
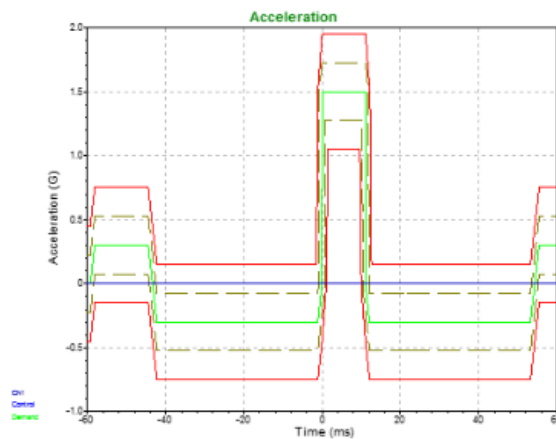
Figure 1.9 – Shock pulse (square wave)

these shocks could permanently damage the vehicle.

e. **Mixed Mode Testing**

Mixed mode testing is a combination of sine and random vibrations which are performed simultaneously to simulate sources where both modes are present. Mixed mode testing has been shown to better simulate a real world environment than sine or random vibration separately. There are many sources of vibration in the real world. In order to better replicate this in the lab it is necessary to combine sine and random vibrations into a single test profile.

Sine on Random

This mixed mode version is very common. The helicopter gunfire test is an excellent example of why sine on random should be used. A helicopter is constantly subject to random vibration, the vibration of the engine, the rotors cutting through the air, and the movement of the entire body against the air are all sources of random vibration. Cyclic gunfire has a distinct sinusoidal vibration, and when a weapons system is mounted to the frame of a helicopter that vibration is introduced into the structure of the helicopter on top of the pre-existing random vibration. This cyclic gunfire is not a constant vibration, but when it occurs has very a high acceleration value that must be considered when testing. In order to properly test the components of this helicopter a Sine on Random test can be used to closely represent this real world environment to ensure that the products can withstand the harsh changes caused by gunfire during flight.

Random on Random

Random on random is another common occurrence when closely simulating real world vibration. An airplane propeller serves as an excellent example for random on random vibration. The noise generated by the engine is sinusoidal, but as that noise and all the harmonics travel further from the engine they begin to "smear" causing random bandwidths of noise rather than purely sinusoidal. Random on Random allows the engineer to build a test profile that includes the broadband spectrum of energy, while including the narrowband spectrums of higher energy caused by the engine noise and its harmonics.

Sine and Random on Random

This test mode is a more complex version of either of the previous examples. Separating the Random vibration source in the helicopter gunfire test, or adding a cyclic gunfire to the tracked vehicle test. Although more complex, this test mode does give the engineer the ability to make changes to specific portions of the random energy that is to be excited upon the DUT.

f. **Shock Response Spectra - SRS**

While shock tests hit the product with regular shock pulses of a prescribed acceleration in the time domain, SRS hits the product with shock pulses of various accelerations in the frequency domain. In other words, an SRS is a set of shock pulses with different acceleration values at every frequency in a particular frequency range which are simultaneously imposed on the DUT. This allows the engineer to design a test that applies different shock pulses to the product at different frequencies.

g. **User Defined Transient**

User defined transient is a tool for recreating transient events that have been recorded in the real world. Also, it is used to create sine burst or sine chirp transients which are required by some specifications. Weapons sight and optics manufacturers use this to replicate the transient event that effects the sight when the weapon it is mounted on is fired.

h. **Transient Capture**

Transient capture is a data acquisition tool that captures a transient waveform for post processing. Most often it is used with SRS to analyze each pulse as it is captured.

i. **Field Data Replication - FDR**

Field data replication is exactly what it says: a method of recording real-world data and "playing it back" on the shaker. The test is similar to a "shaped" random test because the spectrum is the same as the real application. This method is realistic, but does have some shortcomings. It is often difficult to record a representative waveform, especially in the aerospace industry. When a waveform is obtained it only represents a specific product in a particular situation and more than likely does not represent the
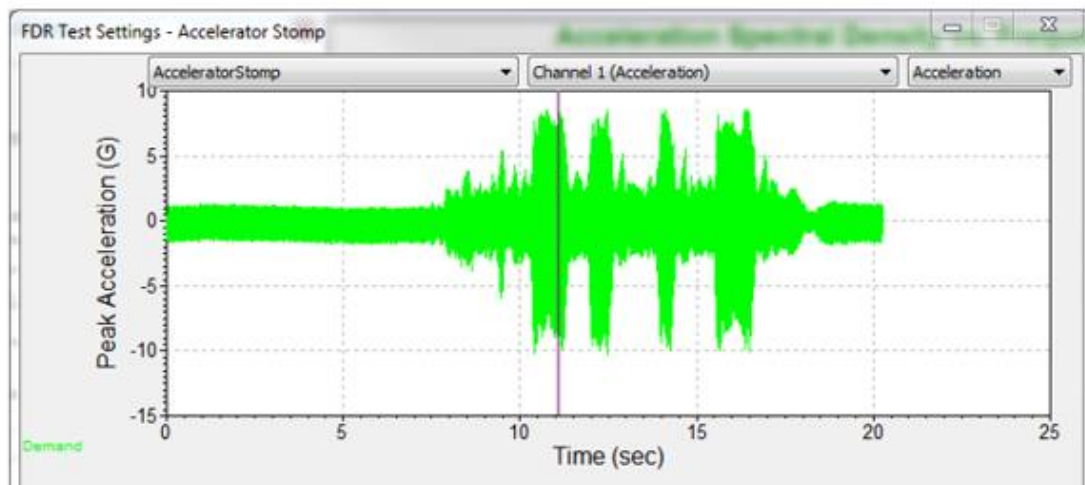

Figure 1.10 – Accelerator Stomp FDR Waveform

entire life of the product. (**Figure 1.10**).

D. Creating Test Profiles

Sine

Sine testing is the simplest form of vibration testing to understand and serves as an excellent point of entry for this study. **Modules 1.1 – 1.3** serve as an introductory tool to create profiles, graphs, and reports using *VibrationVIEW*.

Module 1.1 covers a basic sine test. In addition to configuring system limits and the inputs, the student creates a simple Sine Sweep from 20 Hertz to 2000 Hertz. Resonant frequencies are programmed into Demonstration Mode on Ch2, Ch3, and Ch4 in relation to Ch1 as control. The Ch2 resonance will frequently be used to show the test capabilities of *VibrationVIEW.*

Module 1.2 introduces Sine Resonance Track and Dwell by expanding on the test created in module 1.1. After the sweep a resonance table will be generated displaying the resonances found during the sine sweep. Particular resonant frequencies will be chosen from the list, and *VibrationVIEW* will dwell at these frequencies for a set period of time.

Module 1.3 completes the study of sine testing by introducing the advanced test configuration. Every aspect of the test profile can be changed using the advanced test configuration, and many of these changes are made in this module. Much like Module 1.2 the test goal is to conduct a Sweep then Resonance Track and Dwell over a certain frequency range. In this case the amplitude and force varies over the range. While dwelling at resonance, *VibrationVIEW* will track any phase change caused by deterioration of the product. Deterioration will cause the resonance to shift. *VibrationVIEW* will constantly adjust to ensure that the frequency dwell is causing the peak acceleration on the resonating frequency.

Random

In order to create a random test profile a breakpoint table must be entered. This is a list of frequencies, and the correlating PSD. The breakpoint table determines the power distribution over a range of frequencies. **Modules 2.1 – 2.4** begin with an introduction to random vibration testing and quickly accelerate to advanced random testing, kurtosis control, and transition band frequency.

Module 2.1 is a basic introduction to random testing. Create the breakpoint table, set the graphs, run the test, create reports, and evaluate the data. While this test is running look at the relationship between Ch2, and the control channel (Ch1). Any resonant frequency will clearly show on the probability density graph.

Module 2.2 is the advanced random test. Create the breakpoint table and explore the various tabs of the advanced random test configuration. Take special note of the Gaussian curve on the Probability Density Function Graph.

Module 2.3 serves as a comparison between Kurtosion®, Vibration Research's patented method of kurtosis control, and traditional Gaussian random tests. Starting with no kurtosis, and incrementally increasing to a kurtosis of 7 will clearly show the effects of increasing the kurtosis while maintaining the same acceleration profile.

Module 2.4 introduces transition band frequency (TB), which is a parameter that dictates how long the random vibration will dwell at the higher amplitude vibrations. As TB decreases, the kurtosis increases. Combining kurtosis with a low TB can create an incredibly violent, high acceleration test. This module shows the effects of varying both the kurtosis and TB.

Shock

Module 3.1 is a basic shock test. The output is a positive trapezoid and the test, while running, produces a distinct sound. The test is designed to help the student grasp the concepts required for a shock test and the parameters required to run a shock test.

Mixed Mode

Module 4.1 is an introduction to MIL-810. This creates a helicopter vibration exposure test to replicate the vibration experienced in the general areas of a helicopter.

Module 4.2 creates a mixed mode random on random test. This test begins as a typical random test, but as time progresses 3 narrowband sweeping spectrums rise out of the random band and sweep up while increasing in amplitude. Watch the effects that the sweeping bands have on the random band of energy and on the Ch2-4 resonances.

SRS

Module 5.1 takes a Frequency vs Acceleration breakpoint table and synthesizes it to create an SRS tab. Note the wavelets that appear on the SRS graph when creating the test. Adjustments are made to the synthesis type to see the effects of each on the same breakpoint table.

FDR

Module 6.1 uses a pre-recorded file (.vfw) and "plays it back" using the field data replication tool. This is a simple module that reproduces the noise created when a driver stomps on the accelerator in a vehicle.

E. Test Sequencing

VibrationVIEW allows the user to run a number of tests sequentially without stopping or requiring any user interface. This is especially useful when a product needs to tested using multiple profiles. The engineer has the ability to run tests through the hours when he/she is not in the lab (e.g. nights, and weekends).

To use the test sequencer, select the **Test Tab**
Select **Test Sequencer**
Add Test – Choose the tests to be sequenced
Save Sequence – easier accessibility for future testing.
Run Test – The sequence will run each test, transition to the next, and cycle as many times as defined in the sequence.
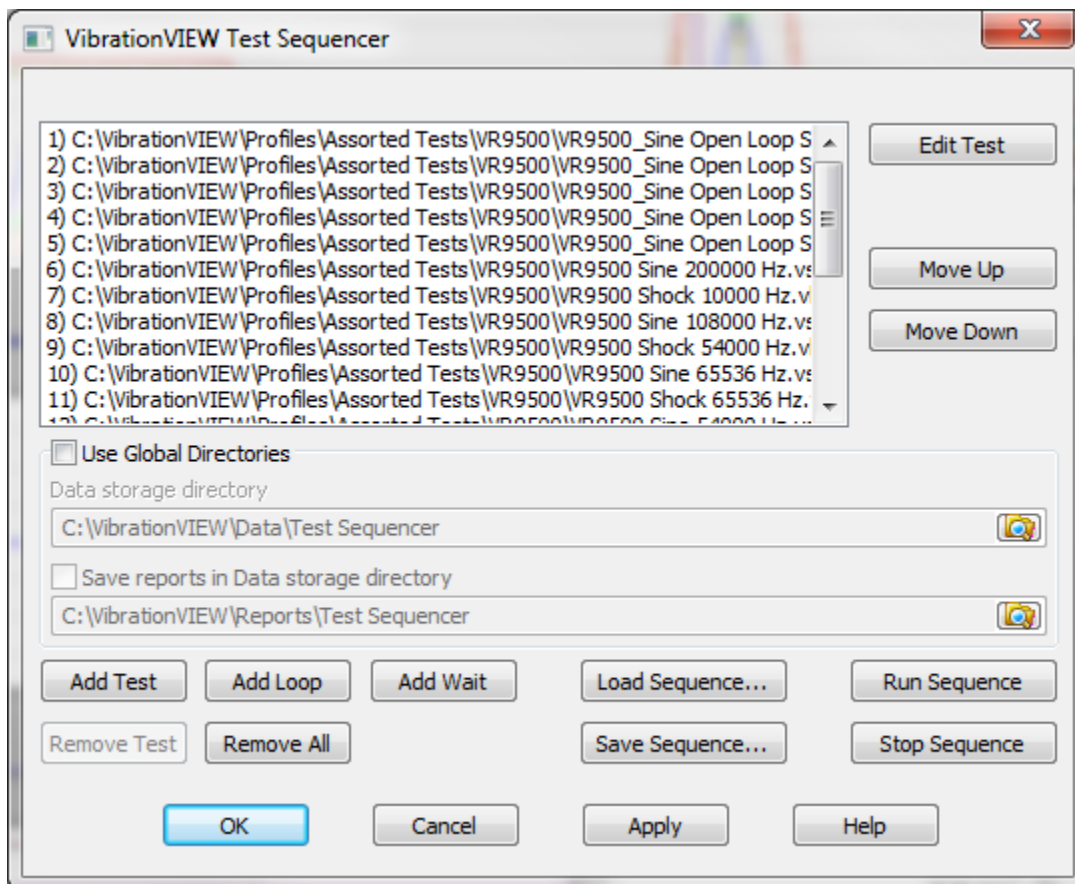
F. Reports and Analysis

Report generation is made simple using *VibrationVIEW*. There are multiple methods to creating reports from using a quick report, which can be generated using the report button on the toolbar, to creating a custom report that meets an individual companies requirements. More information on creating reports can be found at:

http://www.vibrationresearch.com/training_video/Webinar/formsreports_v10.htms

G. Evaluating and Using Data

Understanding and evaluating the data collected in a vibration test is essential to understanding the effects of the various forms of vibration testing. At what frequency did the DUT fail? How does this test compare to the required standards? How much acceleration was the DUT experiencing at a particular time, or frequency? How much displacement is required from the shaker to run the test profile? The answers to these questions can be obtained through an understanding of the graphs and data that is generated by *VibrationVIEW*.

Acceleration vs. Time Graph (Acceleration Waveform)

The acceleration waveform graph communicates the acceleration experienced by the DUT for a snapshot of time. Specifically it is the acceleration value that is being measured at the exact point where the accelerometer is mounted on the DUT at a specific moment in time.
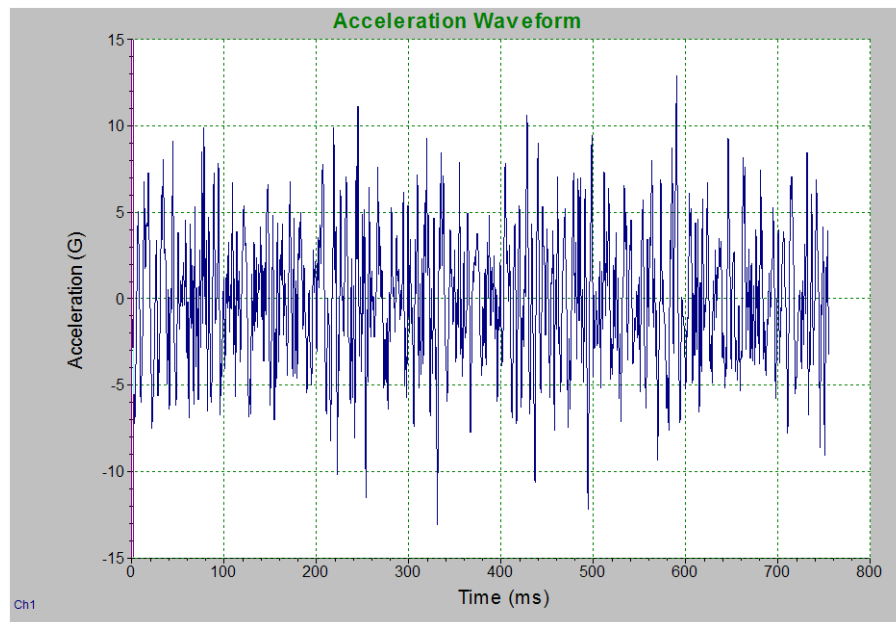
Acceleration Spectrum

This graph is used mostly in System Check. It shows changes in acceleration with respect to frequency. It is useful to observe harmonic frequencies and noise.
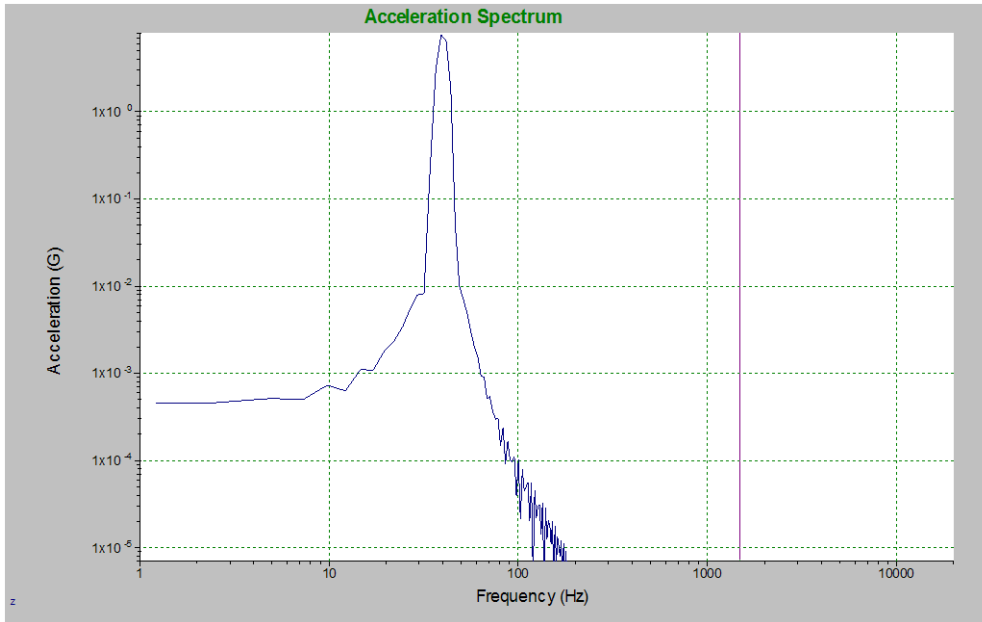
Acceleration vs. Frequency Graph (Acceleration Profile)

This graph indicates test progression. Also displayed are the tolerance and abort limits set in the test profile. This graph can also be used to view resonances or noise in
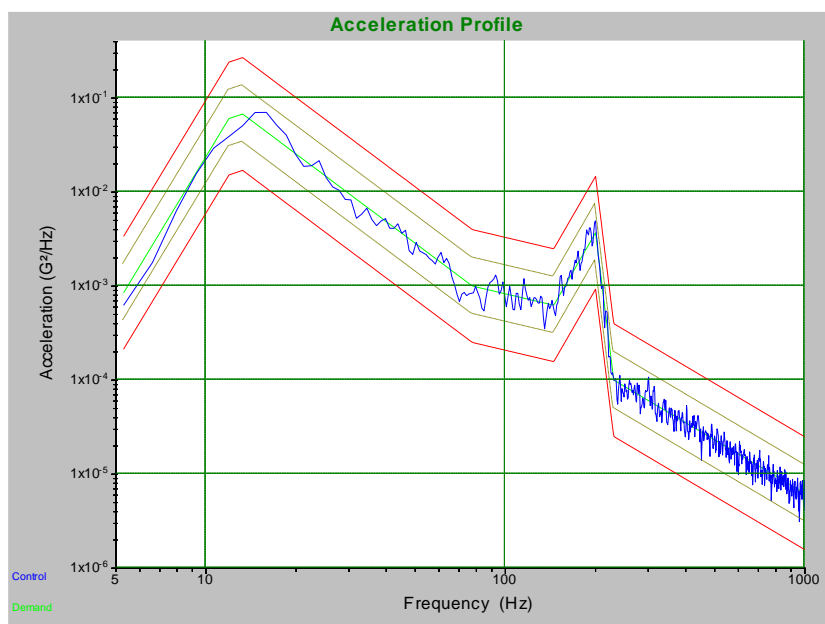
relation to the control channel via a response accelerometer.

Drive Signal

This graph indicates the voltage density as it changes with respect to frequency
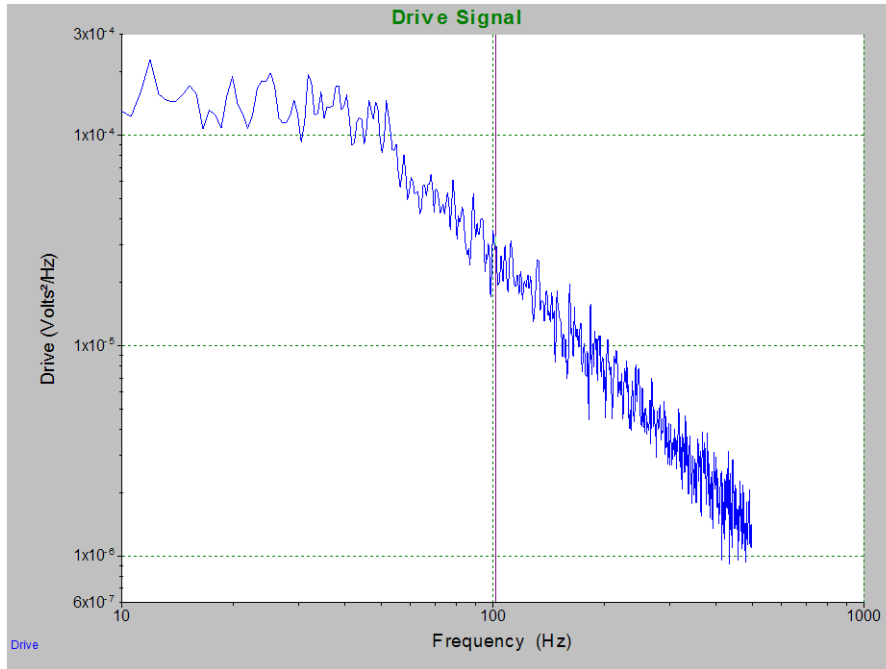
Transmissibility

Transmissibility is a ratio of the acceleration of one channel to another. It is used to view resonances that may be occurring.
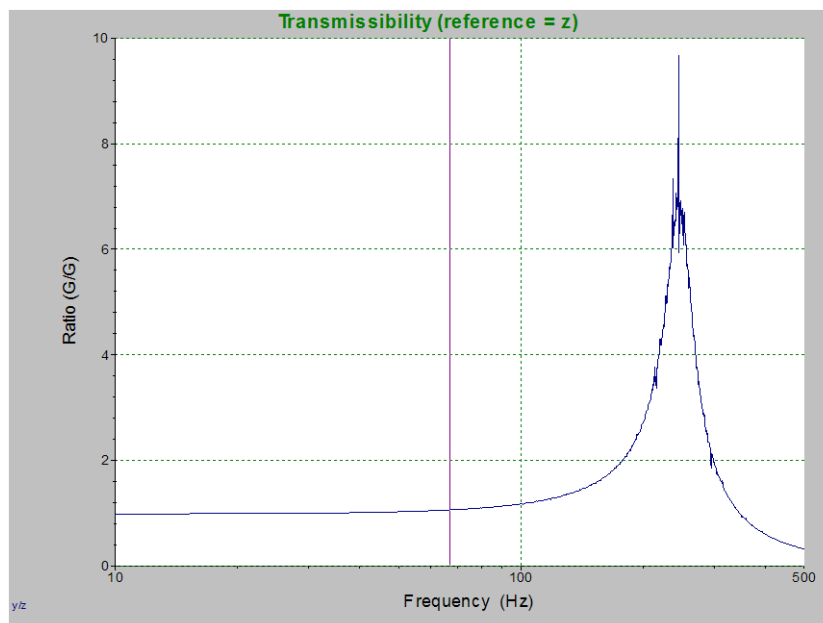
Probability Density Function

PDF graphs indicate how the acceleration of a test profile is distributed. As a test progresses the curve will be shaped showing where the majority of the test acceleration is happening. Look at a random acceleration waveform and compare to observe how
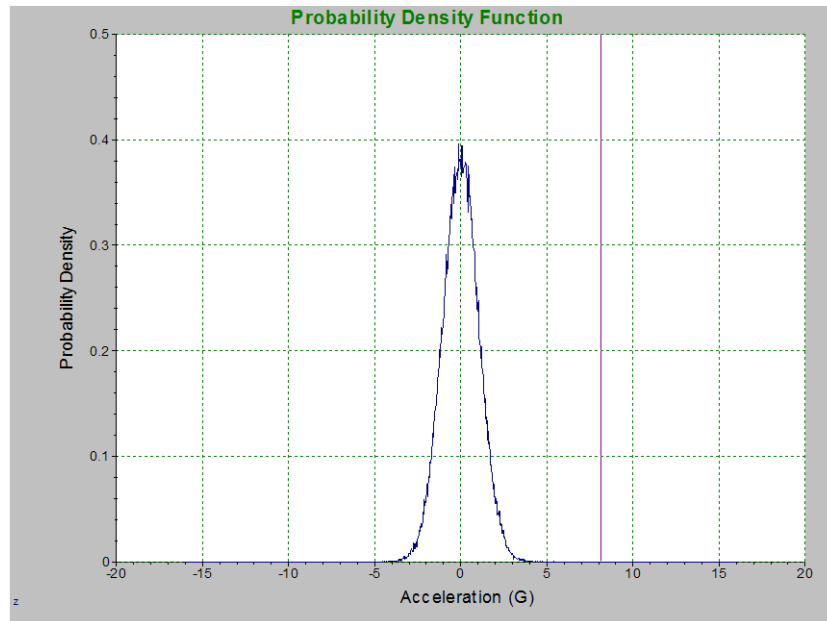
this curve is generated.

Time History – Acceleration, Velocity, Displacement, Frequency

This graph allows to see a time history of the test profile. Typically this is used to observe any changes that have occurred due to dwelling at resonance by observing the
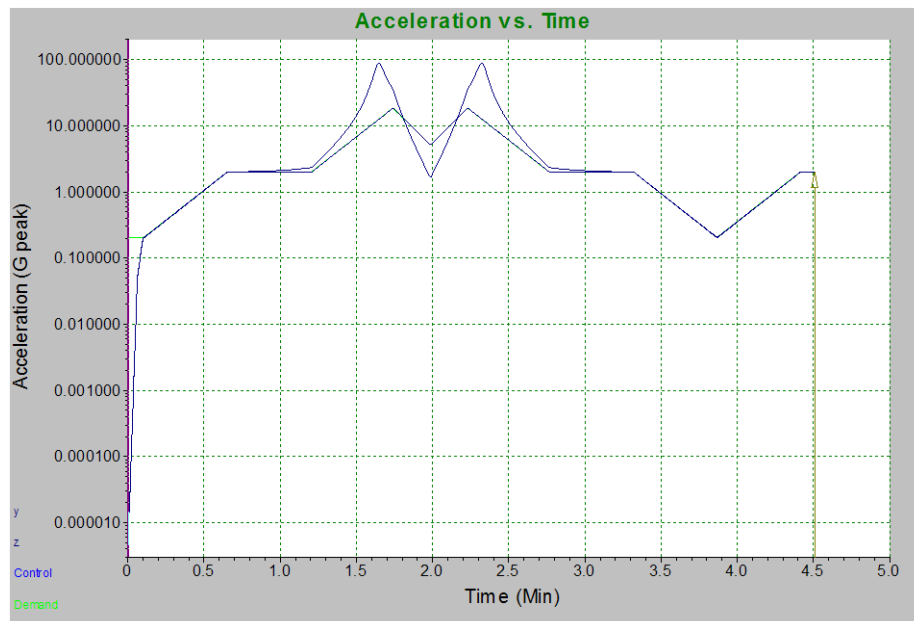
changes in acceleration over time.

Using the Data

After a test profile has run, the data must be post processed. There are a variety of forms of post processing that can be done depending on the goal of the test. If the goal of a test was to minimize resonances at various frequencies, and the test results show high resonances at a particular frequency, then the product must be redesigned to reduce that resonance. *VibrationVIEW* can be set up to automatically generate reports that will display various measurements and graphs that relate to the test profile.

H. Special Features

VibrationVIEW has many unique features and capabilities. Some have been covered in this manual, but much of the capability of the software is still to be discovered. Many of the capabilities of the software are best explained using a visual format. To that end, the Vibration Research sales and support team constantly creates new Webinars and Training Videos, all of which are available at:

http://www.vibrationresearch.com

Key introductory webinars include:

1. *VibrationVIEW 11* Features
2. Setting up your controller
3. VR9500: VR Software Overview
4. Safety Limits: Protecting your system and product
5. Data, Data, Data: Saving, Converting, Importing, and Exporting Data
6. Tips and Trick for running *VibrationVIEW*

Laboratory Exercises

The following laboratory exercises are designed to give the student experience creating and running test profiles that are similar to testing that is conducted in the real world. These tests will show the difference between the various kinds of tests that have been discussed. There are various degrees of difficulty in both the exercises and the questions at the end of each exercise. Some sample answers can be found in the Appendix.

The modules are designed to be used with *VibrationVIEW* in Demonstration Mode. To configure *VibrationVIEW* to run in Demonstration mode a key will have to be obtained. Select **Configuration → Hardware**. Set the **Network Card** to **Demonstration Mode**. The program will then instruct you on how to get a key from
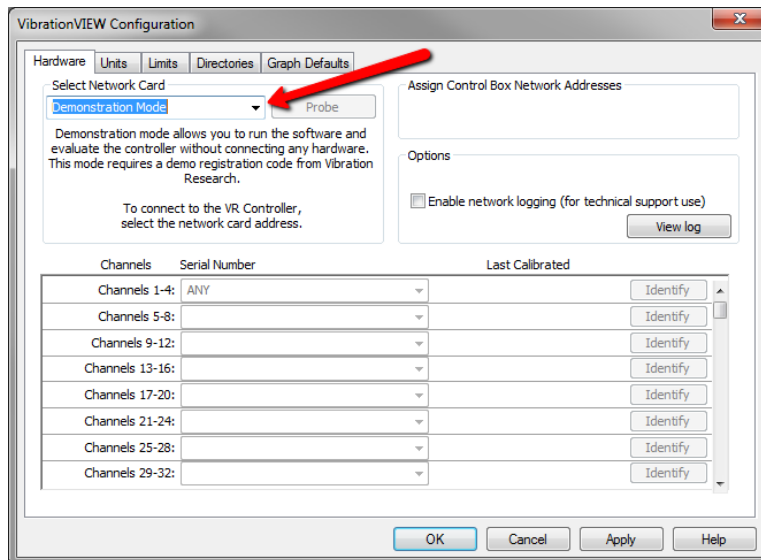
Vibration Research.

If your University is equipped with shaker systems and Vibration Research VR8500 or VR9500 Hardware, these test modules will need to be edited to work within the limits of the shaker that is connected. **WARNING** - Do not attempt to run these test profiles on a live shaker without properly configuring the system limits to reflect the safe operating parameters of that specific shaker. These test profiles are designed specifically for Demonstration Mode and will cause damage to a shaker if not properly configured.

It is our hope that these exercises will provide a base knowledge of how to operate *VibrationVIEW* and serve as an introduction into the field of vibration testing. If you have any questions please contact Vibration Research.

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Web: www.vibrationresearch.com

Module 1.1 – Simple Sine Test

Procedure:

1. Hardware
   a. Demonstration Mode
      i. Click **Configuration** and then **Hardware**
      ii. Set **Network Card Address** to **Demonstration Mode**
      iii. Use this setting if you are not hooked up to a real shaker and controller
   b. With actual shaker and controller
      i. Click **Configuration** and then **Hardware**
      ii. Set **Network Card Address** to the IP Address of the network card that the VR9500 controller is connected to.
      iii. Select the appropriate Serial Number for Channels 1-4
   c. Click **Apply** and **OK**
2. Inputs
   a. Click **Configuration** and then **Inputs**
   b. Set **Sensitivity** of Ch1 and Ch2 to **100 mv/g .**
   c. Click **OK**
   d. In real world testing the accelerometer's sensitivity would be 10 mv/g but in order to hear in Demonstration mode what you would hear in a real world test the sensitivity must be increased. This increase will permit the hearing of the sound card's rendition of real world test sounds
3. System Limits (FOR DEMONSTRATION MODE ONLY)
   a. Click **Configuration** and then **System Limits**
   b. Set the Sine Max, Random Max, and the Shock Max ratings:

Moving Mass			Sine	Random	Shock	Data Replay	
Product		Force (peak)	9999		9999	9999	F-lbs
0.1	lbs-mass	Force (rms)		9999		9999	F-lbs RMS
Fixture		Velocity (peak)	9999	9999	9999	9999	in/s
	lbs-mass	Displacement (pk-pk)	9999	9999	9999	9999	in
Armature		Acceleration (peak)	9999		9999	9999	G
	lbs-mass	Acceleration (rms)		9999		9999	G RMS
Slip Plate		Drive Threshold Voltage	1		1		Volts (pk)
	lbs-mass	Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar		Drive Maximum Voltage	10		10		Volts (pk)
	lbs-mass	Drive Maximum Voltage		10		10	Volts (rms)
Misc							
	lbs-mass						
Total		Max Acceleration (peak)	9999		9999	9999	G
0.1	lbs-mass	Max Acceleration (rms)		9999		9999	G RMS

Edit locked settings   Save these settings

   c. Click **OK**

4. Create a Simple Sine Test
   a. Select **New Test** button on the toolbar
   b. Select **Sine**
   c. This will bring up the Simple Sine Test Settings
   d. Set the following parameters
      i. Frequency: 20 Hz to 2000 Hz
      ii. Displacement:
      iii. Acceleration: 1 G
      iv. Sweep Rate: 3 oct/min
      v. Duration: 1 sweep
   e. Click **OK**
   f. Save as **Name_SimpleSine1**
5. Creating Graphs
   a. Close any existing graphs (small "x" in upper right hand corner)
   b. Select **New Graph** on the toolbar
   c. Graph 1 Configuration
      i. Graph Type
         1) Acceleration vs. Frequency
      ii. Graph Traces
         1) Control Loop Traces
            a. Demand, Control (Last Pass), Tolerance, and Abort
         2) Input Channels (Last Pass)
            a. Ch1 and Ch2
   d. INSERT GRAPH
   e. Graph 2 Configuration
      i. Graph Type
         1) Acceleration vs. Time
      ii. Graph Traces
         1) Input Channels
            a. Ch1 and Ch2
   f. INSERT GRAPH
   g. Graph 3 Configuration
      i. Graph Type
         1) Displacement vs. Frequency
      ii. Graph Traces
         1) Control Loop Traces
            a. Demand, Control (Last Pass), Tolerance, and Abort
         2) Input Channels
            a. Ch1, Ch2
   h. Click **OK**
   i. Auto scale the Graphs by clicking the **Autoscale** button on the toolbar or double right clicking on each graph
6. RUN THE TEST

      a. While the test is running watch and listen. You should hear the test as the frequency rises, and can visually observe the effects of the sine test on the DUT (Device under test).

7. Save the data in an appropriate location and create a report to answer

Questions

Creating Reports

1. Objective: to produce a "Word" document report on the data obtained during the test. Include the report graphs as follows:
   a. Customer Information (Your Name, Module Number, and Course Name)
   b. Graphs:
      i. Vibration VIEW Screen
      ii. Velocity
      iii. Transmissibility
      iv. Acceleration Time History
      v. Demand, Control, Tolerance, Abort
      vi. Channel 1, Channel 2
   c. Test Definition
      i. Breakpoint Table
   d. Test Status
      i. Accelerometer Calibration Details
2. Are there any peaks in the CH 2 Waveform? Explain the phenomena expressed by that peak(s).

3. At what frequency did you begin to hear the test?

Module 1.2 – Simple SRTD

Procedure:

1. Use **Hardware**, **Inputs**, and **System Limits** Configuration from Module 1.1
2. Create a Simple Sine Resonance Tracked Dwell Test
   a. Select **New Test** button on the toolbar
   b. Select **Sine**
   c. Set the following Sine Test Setting parameters
      i. Frequency: 20 Hz to 2000 Hz
      ii. Displacement:
      iii. Acceleration: 1 G
      iv. Sweep Rate: 3 oct/min
      v. Duration: 1 sweep
      vi. Select the Sine Resonance Tracked Dwell (SRTD) Checkbox
   d. Click "OK"
   e. Save as "Name_SimpleSRTD1"
3. Creating Graphs
   a. Graph 1
      i. Graph Type
         1) Acceleration vs Frequency
      ii. Graph Traces
         1) Control Loop Traces
            a. Demand, Control (Last Pass), Tolerance, Abort
         2) Input Channels (Last Pass)
            a. Ch1, Ch2, and Ch3
   b. Graph 2
      i. Graph Type
         1) Transmissibility vs Frequency
      ii. Graph Traces
         1) Reference Ch1
         2) Input Channels
            a. Ch1, Ch2, Ch3
4. RUN THE TEST
   a. While the test is running watch and listen. You should hear the test as the frequency rises, and can visually observe multiple resonant frequencies on both Ch2, and Ch3.
5. After the test finishes a RESONANCE TABLE will be generated
   a. Select the 1st and 3rd resonant frequencies.
      i. The 1st is approximately 140 Hz on Ch3
      ii. The 3rd is approximately 497 Hz on Ch2
   b. Change the duration to 5 minutes for each selected resonance
   c. Click "Continue"

6. Tracked Dwell
    a. The controller will now output a signal at the first resonant frequency for 5 minutes, and then move to the next resonant frequency selected.

Questions:

1. Under what circumstances might you run a sine test searching for resonances?

2. Why would industry want to track and hold at a particular frequency?

3. In Module 1.2, what was the bandwidth of Ch3 resonant frequency at approximately 140 Hz?

4. Prepare a Word Document Report for Module 1.2 which includes:
    a. Customer Information (Your Name, Module Number, and Course Name)
    b. Graphs
        1.   Transmissibility
        2.   Transmissibility Time History
        3.   Ch2, Ch3
    c. Test Definition
        1.   Breakpoint Table
    d. Test Status
        1.   Accelerometer Calibration Details
        2.   Channel Measurements

5. What can be learned from the transmissibility graphs?

Module 1.3 – Advanced SRTD

Procedure:

1. Use Hardware, Inputs, and System Limits Configuration from Module 1.1
2. Create an Advanced Sine Resonance Tracked Dwell Test
   a. Select **New Test** button on the toolbar
   b. Select **Sine**
   c. At the bottom of the Sine Test Settings box select **Advanced**
   d. **Profile** Tab
      i. Starting Amplitude: 0.01 in at 20 Hz
      ii. Ending Amplitude: 0.01 in at 100 Hz
      iii. Insert New Line
      iv. Starting Force: 1 G at 100 Hz
      v. Ending Force: 1 G at 200 Hz
      vi. Click "Calc" button
         1) This makes a smooth transition between steps and will change the end frequency of the first step
         2) Accept the Changes
      vii. Insert New Line
      viii. Starting Amplitude: 0.0001 in at 200 Hz
      ix. Ending Amplitude: 0.0001 in at 700 Hz
      x. Click "Calc" button behind line 2 and accept any changes
   e. **Schedule** Tab
      i. Line 1
         1) Sweep up from 20 Hz for 1 sweep with 100% modifier
      ii. Insert New Line
      iii. Line 2
         1) Change to "Resonance Table"
   f. **Channels** Tab
      i. Ch 1 is control channel and system limits apply
   g. **Resonance** Tab
      i. Ensure that the program is set to select the **3** largest values above **2**
   h. **Limits** Tab
      i. Change the Running Drive Limits
         1) Max System Gain: 6 Volts/G
         2) Max Output: 6 Volts
   i. Review parameters and click "OK"
   j. Save as "Name_AdvancedSRTD1"
3. Create Graphs
   a. Graph 1
      i. Graph Type
         1) Acceleration vs Frequency
      ii. Graph Traces
         1) Control Loop Traces

> > > > > > **a.** Demand, Control (Last Pass), Tolerance, Abort
> > > > 2) Input Channels (Last Pass)
> > > > > **a.** Ch1, Ch2
> > b. Graph 2
> > > i. Graph Type
> > > > 1) Transmissibility vs Frequency
> > > ii. Graph Traces
> > > > 1) Reference Ch1
> > > > 2) Input Channels
> > > > > **a.** Ch1, Ch2

4. RUN THE TEST
5. At the end of the test a resonance table will appear.
   a. Dwell at resonance 3 (approximately 497 Hz) for 3 minutes
   b. Enable **Phase Tracking**
   c. Click Continue
6. While the test is running
   a. Click the **View** Tab
      i. Enable **SRTD Controls**
   b. **Use the SRTD Controls**

   i. Click the button
   ii. This will automatically display graphs associated with time.
   iii. Use the Phase Angle Adjustment Bar to change the Phase angle. Observe the effects of this adjustment on the Time Graphs.

   iv. Click the button
   v. This will automatically display graphs associated with phase
   vi. Use the Phase Angle Adjustment Bar to change the Phase angle. Observe the effects of this adjustment on the Phase Graphs.
7. Save data in an appropriate location

Questions:

1. What is the G/G ratio of Ch2/Ch1 for the resonance at 497.5 Hz?

2. What benefit does **tracked dwell** bring to Sine Resonance Testing?

3. What is the phase relationship between Ch2 and Ch1

Module 2.1 – Simple Random Testing

Procedure:

1. Use Hardware, Inputs, and System Limits Configuration from Module 1.1
   a. Hardware – Demonstration Mode
   b. System Limits – Sine, Shock, and Random Max

Moving Mass			Sine	Random	Shock	Data Replay	
Product		Force (peak)	9999		9999	9999	F-lbs
0.1	lbs-mass	Force (rms)		9999		9999	F-lbs RMS
Fixture		Velocity (peak)	9999	9999	9999	9999	in/s
	lbs-mass	Displacement (pk-pk)	9999	9999	9999	9999	in
Armature		Acceleration (peak)	9999		9999	9999	G
	lbs-mass	Acceleration (rms)		9999		9999	G RMS
Slip Plate		Drive Threshold Voltage	1		1		Volts (pk)
	lbs-mass	Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar		Drive Maximum Voltage	10		10		Volts (pk)
	lbs-mass	Drive Maximum Voltage		10		10	Volts (rms)
Misc							
	lbs-mass						
Total		Max Acceleration (peak)	9999		9999	9999	G
0.1	lbs-mass	Max Acceleration (rms)		9999		9999	G RMS

Edit locked settings	Save these settings

   c. Inputs – Ch1, Ch2 sensitivity to **300 mV/G**
2. Create a simple random test
   a. Select **New Test** button on the toolbar
   b. Select **Random**
   c. Set the following Random Test Settings
      i. Create a breakpoint table

Frequency (Hz)	PSD (G^2/Gz)
10	0.01500
40	0.01500
500	0.00015
2000	0.00026067

      ii. Set "Run for" 7 minutes and 30 seconds (7m30s)
   d. Click "OK", Save the test as "Name_SimpleRandom"
3. Create Graphs
   a. Graph 1
      i. Acceleration vs Frequency (Acceleration Spectral Density)
         1) Control loop traces
         2) Ch1 and Ch2
         3) Show Active Lines
   b. Graph 2
      i. Acceleration vs Time (Acceleration Waveform)

1) Ch1
        c. Graph 3
                i. Transmissibility
                    1) Reference CH 1
                    2) Ch2, active lines
        d. Graph 4
                i. Probability Density
                    1) Ch1
                    2) Change y-axis to Logarithmic
        e. **OK**
4. RUN THE TEST
        a. While the test is running watch and listen for the differences between a sine and
            random test. Do you still observe a resonance?
5. Save Data in appropriate location

Questions:

1. Create a quick report that shows the following:
        a. VibrationVIEW Screen
        b. Acceleration Waveform
        c. Breakpoint Table
        d. Accelerometer details
        e. Channel Measurements

2. Copy the Probability Density Graph onto your report. What does this graph show?

3. Describe what you hear when the test is running.

Module 2.2 – Advanced Random Test

Procedure:

1. Use Hardware, Inputs, and System Limits Configuration from Module 2.1
2. Create a simple random test
   a. Select "New Test" button on the toolbar
   b. Select "Random"
   c. Click the "Advanced Test" Button
   d. **Table** Tab
      i. Create a breakpoint table

Frequency (Hz)	PSD (G^2/Gz)
2	0.00036
4	0.036
5	0.036
7	0.0016
11	0.013224
21	0.013224
50	0.00032
100	0.00032

   e. **Schedule** Tab
      i. Set "Run for" 7 minutes and 30 seconds (7m30s)
   f. **Limits** Tab
      i. Spectrum Limits

      ii. RMS Limts

iii. Startup and Running Drive Limits

Startup Drive Limits
Max System Gain	5	Volts/G	Use System Threshold ☑ Setting
Output Threshold	50	Volts rms	
First drive check	10	%	Use System Drive Check ☑ Settings
Second drive check	5	%	

Running Drive Limits
Max System Gain	6	Volts/G
Max Output	6	Volts rms

       g. Click **OK**, Save the test as "Name_AdvancedRandom"
3. Create Graphs
       a. Graph 1
           i. Acceleration vs Frequency (Acceleration Spectral Density)
               1) Control loop traces
               2) Ch1 and Ch2
               3) Show Active Lines
       b. Graph 2
           i. Acceleration vs Time (Acceleration Waveform)
               1) Ch1
       c. Graph 3
           i. Probability Density
               1) Ch1
               2) Change y-axis to Logarithmic
       d. **OK**
4. RUN THE TEST
       a. Click the Run Button
       b. Autoscale the graphs as needed
       c. Listen to the test
5. Save data in appropriate location

Questions:

1. What are the maximum force values (G's) shown on the Acceleration Waveform Graph?

2. Compare the PDF graph with the Acceleration Waveform graph. How do these graphs complement each other? Include a copy of each in a report.

3. Why don't you hear anything when this test is running?

Module 2.3 - Kurtosion® vs. Traditional Random Test

Introduction:

Since modern vibration controllers assume a Gaussian distribution of data, then the peak accelerations that are produced in a test will be about 3 times the average acceleration values. Reality is that actual peak accelerations found on the field can exceed 3 times the average accelerations. Random tests using Gaussian distribution can "under-test" the DUT. Vibration Research pioneered a novel technique to make tests more realistic. Their patented technique of Kurtosis Control allows the test technician to adjust the kurtosis value (the value that dictates the probability of greater acceleration peaks to be present in the data) to a value that more realistically represents the kinds of peak accelerations found in the field. Applying an appropriate kurtosis value to a test will make a test more realistic. Also, for test applications where the goal is to bring a product to failure more quickly without changing the test profile, Kurtosion® accomplishes the goal (See Sound and Vibration, October 2005, pg. 10-17). The following module allows the student to run a test at standard Gaussian distributions and compare the results to the same test run at a higher kurtosis value.

Procedure:

1. Use Hardware, Inputs, and System Limits Configuration from Module 2.1
   a. Hardware – Demonstration Mode
   b. Inputs – Ch1, Ch2 sensitivity to **10 mV/G**
2. Create a simple random test
   a. Select **New Test** button on the toolbar
   b. Select **Random**
   c. Click the **Advanced Test** Button
   d. **Table** Tab
      i. Create a breakpoint table

Frequency (Hz)	PSD (G^2/Gz)
60	0.001
200	1.5
210	0.1
1000	0.1

   e. **Schedule** Tab
      i. "Run for" **5 minutes**
   f. **Parameters** Tab
      i. Set "Sigma Clipping" to "No Clipping"
   g. **Limits** Tab
      i. Running Drive Limits
         1) Max System Gain: 6 Volts/G
         2) Max Output: 6 Volts RMS
   h. **Data** Tab
      i. Save Data to an appropriate file
   i. **OK**

      j.   Save test profile as "Random vs Kurtosion® 1"

3. Create Graphs
- a. Graph 1
  - i. Acceleration vs Frequency (PSD)
  - ii. Enable Demand, Control, Tolerance, Abort, and Ch1
- b. Graph 2
  - i. Acceleration vs Time
  - ii. Enable Ch1
- c. Graph 3
  - i. Kurtosis
  - ii. Enable Ch1
- d. Graph 4
  - i. Probability Density Function
  - ii. Enable Ch1, change y axis to logarithmic
- e. **OK**

4. RUN THE TEST
- a. Click run
- b. Listen carefully to the sounds produced by the test
- c. Watch the graphs, giving special attention to the PDF graph

5. Save data in appropriate location

6. Generate a report showing:
- a. Active Graph

7. Save this report as "Random – NO KURTOSIS"

8. Click on the CH1 Labels for the Kurtosis vs Time Graph and the Probability Density Function, drag them off the graph, and then back onto the graph. This will create a permanent trace that will show the difference between each test.

9. Click "Edit Test" on the toolbar

10. Go to the Parameters Tab
- a. Change the following:
  - i. Sigma Clipping
    - 1) Method – Kurtosion®
    - 2) Clip above – 20 Sigma
  - ii. Kurtosion®
    - 1) Kurtosis – **5**
    - 2) Transition Freq – 100 Hz
    - 3) Kurtosis Gain – 0.05

11. RUN THE TEST

12. Click on the CH1 Labels for the Kurtosis vs Time Graph and the Probability Density Function, drag them off the graph, and then back onto the graph. This will create a permanent trace that will show the difference between each test.

13. Generate a report showing
- a. Active Graph

14. Save this report as "Random – K5"

15. Click "Edit Test" on the toolbar

16. Go to the Parameters Tab
- a. Change the following:
    - i. Sigma Clipping
        1) Method – Kurtosion
        2) Clip above – 20 Sigma
    - ii. Kurtosion®
        1) Kurtosis – 7
        2) Transition Freq – 100 Hz
        3) Kurtosis Gain – 0.05

17. RUN THE TEST

18. Click on the CH1 Labels for the Kurtosis vs Time Graph and the Probability Density Function, drag them off the graph, and then back onto the graph. This will create a permanent trace that will show the difference between each test.

19. Generate a report showing
- a. Active Graph

20. Save this report as "Random – K7"

Questions:

1. Compare all 3 tests
- a. What significant differences or similarities are observed?
    - i. In the PDF Graphs?

    - ii. In the Kurtosis vs Time Graphs?

    - iii. In the Acceleration Waveforms?

- b. Explain why these Graphs are different

2. Are the PSD's (Acceleration Spectral Densities) the same for the traditional Gaussian Test and the Kurtosis Control Test? What is the significance?

3. What differences could you hear between the traditional Gaussian test and the Kurtosis Control Tests?

Module 2.4 - Kurtosion® with Varying Transition Band Frequency

Background:

Increasing the kurtosis of a random vibration test improves the realistic nature of random testing. As noted earlier, many real-world vibrations are non-Gaussian, that is, have peak accelerations greater than 3x the average vibration accelerations. Kurtosis control algorithms include many more peak accelerations in the vibration test than are present in a Gaussian test. Therefore, it is necessary to match the kurtosis level of the test to the kurtosis level of the real-world vibration.

Various vibration control systems try different techniques to increase the kurtosis level of the random vibration test. However, the truly effective kurtosis techniques are those that are able to adjust the Transition Band Frequency. The Transition Band Frequency (TB) is a parameter which dictates how long the random vibration test will dwell at the higher amplitude vibrations. A TB value of 10000 Hz, for example, introduces higher accelerations for only a very brief moment. These occasional, short-duration high accelerations are "drowned-out" by the other vibrations in the test, and therefore, do not significantly increase the kurtosis of the test. However, a lower TB value, like 5 Hz for example, will introduce the higher accelerations for a much longer time period. These occasional, long-duration high accelerations are noticeably present in the test, and therefore, increase the kurtosis of the test. Thus, to make a kurtosis control algorithm effective it is necessary to adjust the TB to a low value.

To what value should the TB be set? There is a relationship between the bandwidth of the resonances and the TB. The kurtosis control algorithm is most effective at getting the kurtosis into the resonance when the TB is set to a value equal to the bandwidth of the resonances.

What effect will be observed with a decrease in TB? Since lowering the TB allows the test to dwell longer at the peak accelerations, the DUT will experience more of the large accelerations which are the cause of product failure. So lowering the TB effectively increases the kurtosis value of the test, bringing larger accelerations to the product, and therefore, decreases the life of the product.

Procedure:

1. Configure Hardware, System Limits, and Inputs
   a. Hardware – Demonstration Mode
   b. System Limits – Sine, Shock, and Random Max

Moving Mass		Sine	Random	Shock	Data Replay	
Product	Force (peak)	9999		9999	9999	F-lbs
0.1 lbs-mass	Force (rms)		9999		9999	F-lbs RMS
Fixture	Velocity (peak)	9999	9999	9999	9999	in/s
lbs-mass	Displacement (pk-pk)	9999	9999	9999	9999	in
Armature	Acceleration (peak)	9999		9999	9999	G
lbs-mass	Acceleration (rms)		9999		9999	G RMS
Slip Plate	Drive Threshold Voltage	1		1		Volts (pk)
lbs-mass	Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar	Drive Maximum Voltage	10		10		Volts (pk)
lbs-mass	Drive Maximum Voltage		10		10	Volts (rms)
Misc						
lbs-mass						
Total	Max Acceleration (peak)	9999		9999	9999	G
0.1 lbs-mass	Max Acceleration (rms)		9999		9999	G RMS

Edit locked settings   Save these settings

   c. Inputs – Ch1, Ch2 sensitivity to **10 mV/G**
2. Create an Advanced Random Test
   a. Select **New Test** button on the toolbar
   b. Select **Random**
   c. Click the **Advanced Test** Button
   d. **Table** Tab
      i. Create a breakpoint table

Frequency (Hz)	PSD (G^2/Hz)
20	0.0100476
80	0.04
350	0.04
2000	0.00704187

      ii. Set Ch1 Tolerance and Abort Limits
         1) **Tolerance ± 9**
         2) **Abort ± 15**
   e. **Schedule** Tab
      i. Run for as much time as you want the test to run (recommended time is 30 min at 100%)

      f. **Parameters** Tab
- i. Set "Sigma Clipping and Kurtosis" to **Kurtosion®**
- ii. Clip above **20**
- iii. Kurtosis = **7**
- iv. Transition Frequency = **10000 Hz**
- v. Kurtosis Gain = **0.05**

      g. **Limits** Tab
- i. Spectrum Limits
  1) Plus Abort (+) =   **15dB**
  2) Plus Tol (+) =   **9dB**
  3) Minus Tol (-) =   **9dB**
  4) Minus Abort (-) =   **15dB**
- ii. All RMS Limits (Plus Abort, Plus Tol, Minus Tol, and Minus Abort)
  1) **12dB**
- iii. Startup Drive Limits
  1) Max System Gain =   **1 Volts/G**
- iv. Running Drive Limits
  1) Max System Gain =   **1 Volts/G**
  2) Max Output =   **3 Volts RMS**

      h. **Data** Tab
- i. Save to an appropriate location.

3. Create Graphs
- a. Graph 1
  - i. Acceleration vs Frequency (PSD)
    1) Enable Demand, Control, Tolerance, Abort, and Ch1
- b. Graph 2
  - i. Acceleration vs Time
    1) Enable Ch1
- c. Graph 3
  - i. Kurtosis
    1) Enable Ch1
- d. Graph 4
  - i. Probability Density Function
    1) Enable Ch1, change y axis to logarithmic
- e. "OK"
- f. **Right Click** on the "Kurtosis vs. Time" graph and under "Annotate" enter the following note: Kurtosis = [PARAM:CHkurtosis1]

4. Run The Test
- a. Click the run button and let the test run for at least 10 minutes
- b. Listen carefully to the sounds produced by the test
- c. While the test is running create a Quick Report that shows the following:
  - i. VibrationVIEW screen
  - ii. Demand, Control, Tolerance, Abort
  - iii. Breakpoint Table

    iv. Current Measurements, Channel Measurements
  d. At the end of each test paste the Ch1 Trace to use as a visual reference. This will show the changes as transition band frequency is changed.
    i. Click and Hold on the CH1 label on the "Kurtosis vs. Time" graph.
    ii. Without releasing the hold drag the label off the graph, and then back onto the graph.
    iii. Release the hold
    iv. A new label Ch1-1 should appear. Double-click Ch1-1 and change the label to **TB10000**
    v. Repeat this process on the Probability Density Function graph
  e. **Vary the Transition Band Frequency and Repeat the test**
    i. For each test generate a quick report during the test, and paste and re-label the trace for channel 1. Change the Transition Frequency and Run the test again.
    ii. Click Edit Test; Parameters Tab
      1) Transition Frequency = **1000 Hz** **(Label TB1000)**
      2) Transition Frequency = **100 Hz** **(Label TB100)**
      3) Transition Frequency = **10 Hz** **(Label TB10)**
      4) Transition Frequency = **2 Hz** **(Label TB2)**
    iii. For the final test change the Sigma Clipping Method to **No Clipping**.

Questions:

1. What significant differences are observed?

2. What significant similarities are observed?

3. Explain why the PDF, Kurtosis, and Acceleration Waveform graphs are different.

Module 3.1 – Shock Testing

Procedure:

1. Configure Hardware, System Limits, and Inputs
    a. Hardware – Demonstration Mode
    b. System Limits – Sine, Shock, and Random Max

Moving Mass			Sine	Random	Shock	Data Replay	
Product		Force (peak)	9999		9999	9999	F-lbs
0.1	lbs-mass	Force (rms)		9999		9999	F-lbs RMS
Fixture		Velocity (peak)	9999	9999	9999	9999	in/s
	lbs-mass	Displacement (pk-pk)	9999	9999	9999	9999	in
Armature		Acceleration (peak)	9999		9999	9999	G
	lbs-mass	Acceleration (rms)		9999		9999	G RMS
Slip Plate		Drive Threshold Voltage	1		1		Volts (pk)
	lbs-mass	Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar		Drive Maximum Voltage	10		10		Volts (pk)
	lbs-mass	Drive Maximum Voltage		10		10	Volts (rms)
Misc							
	lbs-mass						
Total		Max Acceleration (peak)	9999		9999	9999	G
0.1	lbs-mass	Max Acceleration (rms)		9999		9999	G RMS

[Edit locked settings]   [Save these settings]

   c. Inputs – Ch1, Ch2 sensitivity to **100 mV/G**
2. Create an Advanced Shock Test
    a. Select **New Test** button on the toolbar
    b. Select **Shock**
    c. Click the **Advanced Test** Button
    d. **Pulse** Tab
        i.   Output **10mS** wide **Positive Trapezoid** shock pulse with a peak amplitude of **5G**
        ii. Trapezoid ramps up in **2mS**
        iii. Trapezoid ramps down in **2mS**
        iv. Select **Square Shape (optimal solution for minimum velocity and displacement)**
        v.   Allow up to **20%** of the peak acceleration prior to the pulse
        vi. Allow up to **30%** of the peak acceleration after the pulse
    e. **Schedule** Tab
        i.   "Run for" **100 Pulses** at **100%** with **1 sec** pulse intervals

    f. **Limits** Tab
      i. Starting Drive Limits
        1) Change the drop box to **Auto**
        2) Max Output = **2 Volts**
        3) Max System Gain = **10 Volts/G**
      ii. Running Drive Limits
        1) Max Output = **2 Volts**
        2) Max System Gain = **10 Volts/G**
    g. Save as **Trapezoid 5g 10mS Demo Trial**
  3. Create Graphs
    a. Graph 1
      i. Acceleration vs. Time
        1) Check Demand, Control, Tolerance, Abort, and Ch1
      ii. Acceleration vs. Frequency
        1) Check Demand, Control, and Ch1
        2) Change X-Axis scale to Log
        3) Change Y-Axis scale to Log
  4. Run the Test for 100 pulses
    a. Listen carefully to the sound or lack of sound produced by the test
  5. Save Data in an appropriate location at the completion of the test

Questions:

1. Describe the sound, if any, that you hear.

2. Create a Report including the following:
  a. VibrationVIEW Screen
  b. Customer Information (your name and module number

3. Explain the benefits of shock testing

Module 4.1 – Multi-Mode Testing – Sine on Random

This test is built according to MIL-810 specification to simulate helicopter vibration exposure for U.S. Army Ch-47M Chinook Helicopter. The specification lists various test settings depending on the type of helicopter and the location of material that is being tested. Essentially, a broadband random spectrum is generated, then sine tones replicate the rotor blade vibrations and harmonic frequencies. These values vary by the type of helicopter, the rotational speed of the main rotor and tail rotor, and the number of blades on the main rotor and tail rotor. In this case the helicopter has two main rotors.

1. Configure Hardware, System Limits, and Inputs
   a. Hardware – Demonstration Mode
   b. System Limits – Sine, Shock, and Random Max

Moving Mass			Sine	Random	Shock	Data Replay	
Product		Force (peak)	9999		9999	9999	F-lbs
0.1 lbs-mass		Force (rms)		9999		9999	F-lbs RMS
Fixture		Velocity (peak)	9999	9999	9999	9999	in/s
lbs-mass		Displacement (pk-pk)	9999	9999	9999	9999	in
Armature		Acceleration (peak)	9999		9999	9999	G
lbs-mass		Acceleration (rms)		9999		9999	G RMS
Slip Plate		Drive Threshold Voltage	1		1		Volts (pk)
lbs-mass		Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar		Drive Maximum Voltage	10		10		Volts (pk)
lbs-mass		Drive Maximum Voltage		10		10	Volts (rms)
Misc							
lbs-mass							
Total		Max Acceleration (peak)	9999		9999	9999	G
0.1 lbs-mass		Max Acceleration (rms)		9999		9999	G RMS

Edit locked settings   Save these settings

   c. Inputs – Ch1, Ch2 sensitivity to **250 mV/G**

2. Create an Advanced Random on Random Test
   a. Select **New Test** button on the toolbar
   b. Select **Sine on Random**
   c. Click the **Advanced Test** button
   d. **Table** tab

Frequency (Hz)	Amplitude (G²/Hz)	Slope (dB/Oct)	Tolerance (+)	Tolerance (--)	Abort (+)	Abort (--)
» 1 3	1e-005					
		>-- 11.51	3	3	6	6
2 10	0.001					
		>-- 3.01	3	3	6	6
3 100	0.01					
		>-- 0	3	3	6	6
4 300	0.01					
		>-- -13.57	3	3	6	6
5 500	0.001					

Abort dB

☑ Use single Tol/Abort setting

Insert   Delete   Last

Scale -->

G RMS: 1.792   in/s RMS: 1.128   in pk-pk: 0.06631

Control Units
G²/Hz

Breakpoint frequency.

      i. Create the following breakpoint table

e. **Schedule** Tab

      i. Run the test for at least 10 minutes

f. **Parameters** Tab

      i. The test specification calls for a Frequency Resolution equal to 1 Hz

         1) **General Parameters**

            a. Sample Rate = 16384.0

            b. Lines = 6500

            c. The frequency resolution will change to 1 Hz

g. **Limits** Tab

      i. Spectrum Limits

         1) Plus Abort (+) =   **15dB**

         2) Plus Tol (+) =   **9dB**

         3) Minus Tol (-) =   **9dB**

         4) Minus Abort (-) =   **15dB**

      ii. All RMS Limits (Plus Abort, Plus Tol, Minus Tol, and Minus Abort)

         1) **12dB**

      iii. Startup Drive Limits

         1) Max System Gain =   **1 Volts/G**

      iv. Running Drive Limits

         1) Max System Gain = **1 Volts/G**

         2) Max Output =   **3 Volts RMS**

h. **Data Tab**

      i. Save to an appropriate location

i. **S-o-R** Tab
    i. Using the following information calculate the 4 sine tones for the CH-47D.
    ii. $f_1 = 1P$
    iii. $f_2 = n * 1P$
    iv. $f_3 = 2 * n * 1P$
    v. $f_4 = 3 * n * 1P$

Helicopter	Rotation Speed, 1P (Hz)	Number of Blades, n
AH-1	5.40	2
AH-6J	7.95	5
AH-6M	7.92	6
CH-47D	3.75	3
MH-6H	7.80	5
OH-6A	8.10	4
UH-1	5.40	2

    vi. Enter the frequencies calculated
    vii. Calculate Gpeak for each frequency

Source Frequency (f_n) Range (Hz)	Peak Acceleration at f_n (G_{peak})
3 Hz to 10 Hz	$0.70/(10.70 - f_n)$
> 10 Hz to 25 Hz	$0.10 * f_n$
> 25 Hz to 40 Hz	2.50
> 40 Hz to 50 Hz	$6.50 - (0.10 * f_n)$
> 50 Hz to 500 Hz	1.50

    viii. Input the calculated G peak for each sine tone
3. Create Graphs
    a. Graph 1
        i. Acceleration vs. Frequency
            1) Enable Demand, Control, Tolerance, and Abort
    b. Graph 2
        i. Output Drive vs. Time
    c. Graph 3
        i. Sine Tone Frequency
            1) Enable Tone 1, Tone 2, Tone 3, and Tone 4
    d. Graph 4
        i. Sine Tone Amplitude
            1) Enable Demand, Control, Tone 1, Tone 2, Tone 3, and Tone 4
4. Run the Test
    a. Click the run button and let the test run for at least 10 minutes
    b. Listen for the effects the low frequency sine tones have on the broadband random spectrum.

5. Change the sine tones to reflect the properties of a different helicopter.

Questions:

1. What effect do the low frequency sine tones have on the tone of the broadband random spectrum?

2. When listening to a different helicopter configuration what changes were noticed?

3. Does increasing the number of blades increase or decrease the Peak acceleration for a specific sine tone?

4. What is the G RMS level of the entire test? (Note: this is not the overall level of the broadband spectrum, but a combination of it and each sweeping tone)

Module 4.2 – Multi-Mode Testing – Random on Random

   This Random on Random test is a variation of a specification used to test hull/sponson vibration. The test includes a broadband random spectrum which is entered in the first breakpoint table. This is the base random noise that is apparent throughout the test. Then three sweeping narrow bands of random energy are inserted into the test. These three bands start below the broadband random spectrum, slowly increase in amplitude, and rise out of the broadband spectrum. In addition to specifying the breakpoint tables required the test also requires that the **Control System Frequency Resolution equal 1 Hz**. This will be configured during the test setup.

Procedure:

1. Configure Hardware, System Limits, and Inputs
   a. Hardware – Demonstration Mode
   b. System Limits – Sine, Shock, and Random Max

Moving Mass		Sine	Random	Shock	Data Replay	
Product	Force (peak)	9999		9999	9999	F-lbs
0.1 lbs-mass	Force (rms)		9999		9999	F-lbs RMS
Fixture	Velocity (peak)	9999	9999	9999	9999	in/s
lbs-mass	Displacement (pk-pk)	9999	9999	9999	9999	in
Armature	Acceleration (peak)	9999		9999	9999	G
lbs-mass	Acceleration (rms)		9999		9999	G RMS
Slip Plate	Drive Threshold Voltage	1		1		Volts (pk)
lbs-mass	Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar	Drive Maximum Voltage	10		10		Volts (pk)
lbs-mass	Drive Maximum Voltage		10		10	Volts (rms)
Misc						
lbs-mass						
Total	Max Acceleration (peak)	9999		9999	9999	G
0.1 lbs-mass	Max Acceleration (rms)		9999		9999	G RMS

Edit locked settings   Save these settings

   c. Inputs – Ch1, Ch2 sensitivity to **250 mV/G**
2. Create an Advanced Random on Random Test
   a. Select **New Test** button on the toolbar
   b. Select **Random on Random**
   c. Click the **Advanced Test** button
   d. **Table** tab
      i. Create the following breakpoint table

Frequency (Hz)	PSD (G^2/Hz)
10	0.00054
60	0.00650
100	0.00800
150	0.01100
200	0.00640
275	0.00400
325	0.00600
375	0.00175
425	0.00160
480	0.00250
530	0.00140
575	0.00075
625	0.00053
700	0.00425
750	0.00150
800	0.00200
850	0.00091
900	0.00048
950	0.00035
1000	0.00040

    e. **Schedule** Tab
        i. Run the test for at least 10 min
    f. **Parameters** Tab
        i. The test specification calls for a Frequency Resolution equal to 1 Hz
            1) **General Parameters**
                a. Sample Rate = 32768.0
                b. Lines = 13000
                c. The frequency resolution will change to 1 Hz
    g. **Limits** Tab
        i. Spectrum Limits
            1) Plus Abort (+) = **15dB**
            2) Plus Tol (+) = **9dB**
            3) Minus Tol (-) = **9dB**
            4) Minus Abort (-) = **15dB**
        ii. All RMS Limits (Plus Abort, Plus Tol, Minus Tol, and Minus Abort)
            1) **12dB**
        iii. Startup Drive Limits
            1) Max System Gain = **1 Volts/G**
        iv. Running Drive Limits
            1) Max System Gain = **1 Volts/G**
            2) Max Output = **3 Volts RMS**
    h. **Data Tab**
        i. Save to an appropriate location

i. **R-o-R** Tab

i. Create Band 1, Band 2, and Band 3
ii. Band 1
    1) Sweep up from 30 Hz

      a. Edit Table
    2) Bandwidth = 4 Hz
    3) Sweep Rate = 1 min/sweep linear

   iii. Band 2

☑ Random-on-Random mode   ☑ Restart bands at level changes

Band		Start Freq (Hz)	Stop Freq (Hz)	Amplitude (G²/Hz)	Bandwidth (Hz)	Sweep Rate:	
» 2	Sweep up from ▼	60	Edit Table	8	1	Min/sweep (linear) ▼	

	Start Amplitude			Start Frequency		End Amplitude		End Frequency	
» 1	0.0026	G²/Hz ▼	60	Hz	to	0.0026	G²/Hz at	60	Hz
2	0.0026	G²/Hz ▼	60	Hz	to	0.0051	G²/Hz at	70	Hz
3	0.0051	G²/Hz ▼	70	Hz	to	0.0432	G²/Hz at	80	Hz
4	0.0432	G²/Hz ▼	80	Hz	to	0.011	G²/Hz at	120	Hz
5	0.011	G²/Hz ▼	120	Hz	to	0.146	G²/Hz at	180	Hz
6	0.146	G²/Hz ▼	180	Hz	to	0.129	G²/Hz at	190	Hz
7	0.129	G²/Hz ▼	190	Hz	to	0.033	G²/Hz at	200	Hz
8	0.033	G²/Hz ▼	200	Hz	to	0.0114	G²/Hz at	220	Hz

Insert breakpoint   Delete breakpoint   Hide Table

G RMS: 1.83   in/s RMS: 1.542   in pk-pk: 0.052

Enable Random-on-Random mixed mode.

    1) Sweep up from 60 Hz
      a. Edit Table
    2) Bandwidth = 8 Hz
    3) Sweep Rate = 1 min/sweep linear
   iv. Band 3

☑ Random-on-Random mode   ☑ Restart bands at level changes

Band		Start Freq (Hz)	Stop Freq (Hz)	Amplitude (G²/Hz)	Bandwidth (Hz)	Sweep Rate:	
» 3	Sweep up from ▼	150	Edit Table	20	1	Min/sweep (linear) ▼	

	Start Amplitude			Start Frequency		End Amplitude		End Frequency	
» 1	0.0005	G²/Hz ▼	150	Hz	to	0.0005	G²/Hz at	150	Hz
2	0.0005	G²/Hz ▼	150	Hz	to	0.0005	G²/Hz at	175	Hz
3	0.0005	G²/Hz ▼	175	Hz	to	0.0022	G²/Hz at	250	Hz
4	0.0022	G²/Hz ▼	250	Hz	to	0.0047	G²/Hz at	275	Hz
5	0.0047	G²/Hz ▼	275	Hz	to	0.0002	G²/Hz at	375	Hz
6	0.0002	G²/Hz ▼	375	Hz	to	0.0009	G²/Hz at	400	Hz
7	0.0009	G²/Hz ▼	400	Hz	to	0.0013	G²/Hz at	500	Hz
8	0.0013	G²/Hz ▼	500	Hz	to	0.0135	G²/Hz at	550	Hz

Insert breakpoint   Delete breakpoint   Hide Table

G RMS: 1.83   in/s RMS: 1.542   in pk-pk: 0.052

Enable Random-on-Random mixed mode.

    1) Sweep up from 150 Hz
      a. Edit Table

        2) Bandwidth = 20 Hz

        3) Sweep Rate = 1 min/sweep linear

3. Create Graphs

    a. Graph 1

        i. Acceleration vs. Frequency

            1) Enable Demand, Control, Tolerance, Abort, Ch2, Ch3, and Ch4

    b. Graph 2

        i. Acceleration vs. RMS History

            1) Enable Ch1, Ch2, Ch3, and Ch4

        ii. RoR Freq

            1) Enable Band 1, Band 2, and Band 3

    c. Graph 3

        i. RoR Amp

            1) Enable Demand, Control, Band 1, Band 2, and Band 3

4. Run the Test

    a. Click the run button and let the test run for at least 10 minutes

    b. Observe the changes in the broadband random spectrum as the individual narrowband spectrums sweep.

Questions:

1. What effects do the narrowband spectrums have on the Ch2, Ch3 or Ch4 resonances as the sweep passes through?

2. What effect does changing the sweep rate of the individual bands have on the test?

3. What is the G RMS level of the entire test? (Note: this is not the overall level of the broadband spectrum, but a combination of it and each sweeping narrowband)

Module 5.1 – Shock Response Spectra Testing

Procedure:

1. Configure Hardware, System Limits, and Inputs
   a. Hardware – Demonstration Mode

Moving Mass		Sine	Random	Shock	Data Replay	
Product		Force (peak)	9999		9999	9999	F-lbs
0.1 lbs-mass		Force (rms)		9999		9999	F-lbs RMS
Fixture		Velocity (peak)	9999	9999	9999	9999	in/s
lbs-mass		Displacement (pk-pk)	9999	9999	9999	9999	in
Armature		Acceleration (peak)	9999		9999	9999	G
lbs-mass		Acceleration (rms)		9999		9999	G RMS
Slip Plate		Drive Threshold Voltage	1		1		Volts (pk)
lbs-mass		Drive Threshold Voltage		1		1	Volts (rms)
Driver Bar		Drive Maximum Voltage	10		10		Volts (pk)
lbs-mass		Drive Maximum Voltage		10		10	Volts (rms)
Misc							
lbs-mass							
Total		Max Acceleration (peak)	9999		9999	9999	G
0.1 lbs-mass		Max Acceleration (rms)		9999		9999	G RMS

Edit locked settings   Save these settings

   b. System Limits – Sine, Shock, and Random Max
   c. Inputs – Ch1, Ch2 sensitivity to 1000 mV/G
2. Create a SRS Test
   a. Select **New Test** button on the toolbar
   b. Select **Shock Response Spectra**
   c. Click the **Advanced Test** Button
   d. **Breakpoints** Tab

      i. Enter the following breakpoint table

Frequency (Hz)	Amplitude (G)
10	0.01
50	0.05
100	0.5
200	1
500	2
1000	3

      ii. Tolerance (-) = **5%**
      iii. Tolerance (+) = **100%**

e. Click **Synthesize**. You should be routed to the **SRS** tab
    i. SRS Analysis
        1) Damping =   **5%**
        2) Q =   **10**
        3) SRS Analysis =   **1/N Octave Intervals**
        4) SRS Range =   **10 to 2000 Hz**
        5) SRS Frequency =   **1/6 Octave**
    ii. SRS Synthesis
        1) Synthesis Type =   **Burst Random**
        2) Pulse Duration =   **1000 mS**
        3) Auto Sample Rate =   **20,000 Hz**
        4) Adjust Synthesis Frequency Range
            a. Deselect Automatic
            b. Start Freq =   **10 Hz**
            c. End Freq =   **2000 Hz**
    iii. Click **Synthesize**
        1) Notice how the SRS graph appears
        2) To make it fit within the limit lines click **Iterate more**
        3) To make finer corrections click **Wavelets**
            a. Adjust various wavelet values to adjust the line.
f. **Schedule Tab**
    i. Adjust number of pulses
        1) 300 pulses ≅ 5 min test when pulse interval = 1
g. **Limits** Tab
    i. Startup Drive Limits
        1) Max Output =   **5 Volts**
        2) Max System Gain =   **5 Volts**
    ii. Running Drive Limits
        1) Max Output =   **6 Volt**
        2) Max System Gain =   **6 Volts**
h. **Parameters** Tab
    i. Feedback Control
        1) Feedback gain =   **0.3**
        2) Minimum Frequency =   **5 Hz**
        3) Maximum Frequency =   **2200 Hz**
    ii. Sample Rate (10x the upper frequency)
        1) Set to at least 20 kHz
i. Click **OK** and save the file as "SRS University Lab Manual Trial"

3. Create Graphs
    a. Graph 1
        i. Acceleration vs. Time
            1) Enable Demand, Control, Ch1
    b. Graph 2

          i. SRS Acceleration
              1) Enable Demand, Control, Tolerance, CH1
              2) Set X Axis to **Log**
              3) Set Y Axis to **Log**

4. Run the Test
    a. Let the test run for at least 300 pulses
5. Save Data in an appropriate location
6. Change the synthesis type (Test settings → SRS Tab)
    a. Damped Sine Wave
    b. WavSyn (Centered)
    c. Linear Chirp
    d. Exponential Chirp

NOTE: To make these synthesis types work properly it may be necessary to make changes to the Wavelets, Damping, or Pulse Duration

Questions:

1. Describe the sound, if any, that you hear.

2. Create a Report for each synthesis type including the following:
    a. VibrationVIEW screen
    b. Customer Information (Include your name and module number)
    c. Breakpoint Table
    d. Measurements
    e. Channel Measurements

3. Explain the benefits of a SRS test

4. Record observations seen and heard for the different synthesis types

Module 6.1 – Field Data Replication Testing

Procedure:

1. Configure Hardware, System Limits, and Inputs
   a. Hardware – Demonstration Mode
   b. System Limits – Sine, Shock, and Random Max
      i. No change from module 5.1
   c. Inputs
      i. Ch1 Sensitivity: 200 mV/G
2. Create a FDR Test
   a. Select **New Test** button on the toolbar
   b. Select **FDR**
   c. **Playback** Tab
      i. Browse, and choose the pre-recorded file **AcceleratorStomp.vfw**
   d. **Schedule** Tab
      i. Run waveform 1)AcceleratorStomp for 1 hour at 100%
   e. **Data** Tab
      i. Save your data
   f. **Record** Tab
      i. Set a location to save a recording of the test
   g. **Limits** Tab
      i. Startup Drive Limits
         1) Select "Use System Threshold Setting" checkbox
         2) Select "Use System Drive Check Settings" checkbox
      ii. Drive Limits
         1) Max System Gain =   **5 Volts/G**
         2) Max Output =   **5 Volts RMS**
   h. OK, Save as **Accelerator Stomp Lab Trial**
3. Create Graphs
   a. Graph 1
      i. Acceleration vs. Freq
         1) Select Demand, Control, Ch1
   b. Graph 2
      i. Acceleration vs. Time
         1) Select Demand, Control, Ch1
4. Run Test
   a. Run the Test
      i. Listen to the test.
      ii. Watch how the acceleration waveform graph changes with changes in sound.

Questions:

1. The goal of FDR is to produce a vibration test that closely resembles the vibrations found in the field. From this demonstration, do you think that FDR accomplishes this goal? Explain.

2. How did the acceleration waveform graph look at various times of this test?

3. Create a copy of the acceleration waveform graph when the vehicle was idling and a second copy of the acceleration waveform graph when the vehicle was "revving". What were the maximum forces (G's) put out by the vehicle in each case?

4. List 4 potential uses for FDR in a real world test environment?

Appendix 1 – Sample Answers for Laboratory Exercises

Module 1.1

Acceleration vs. Time
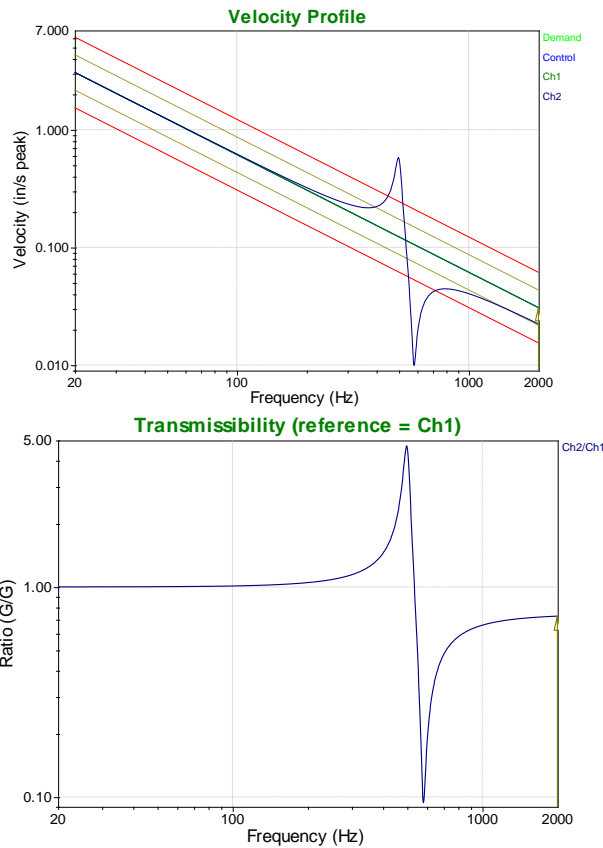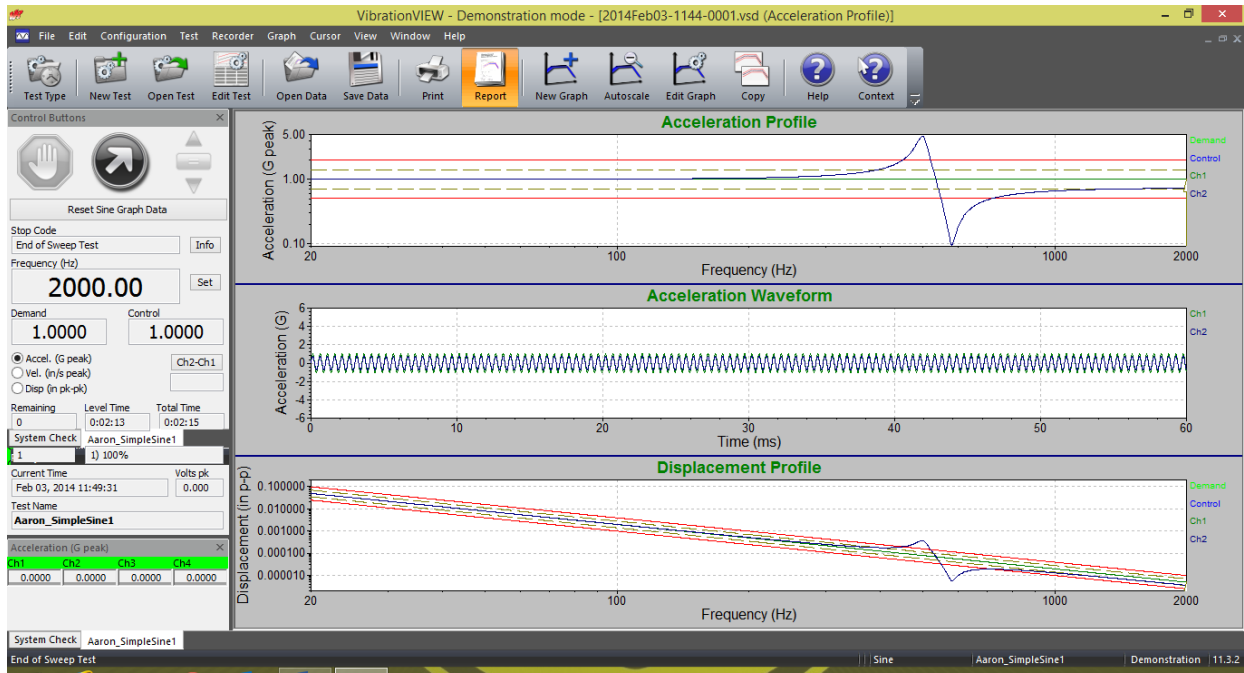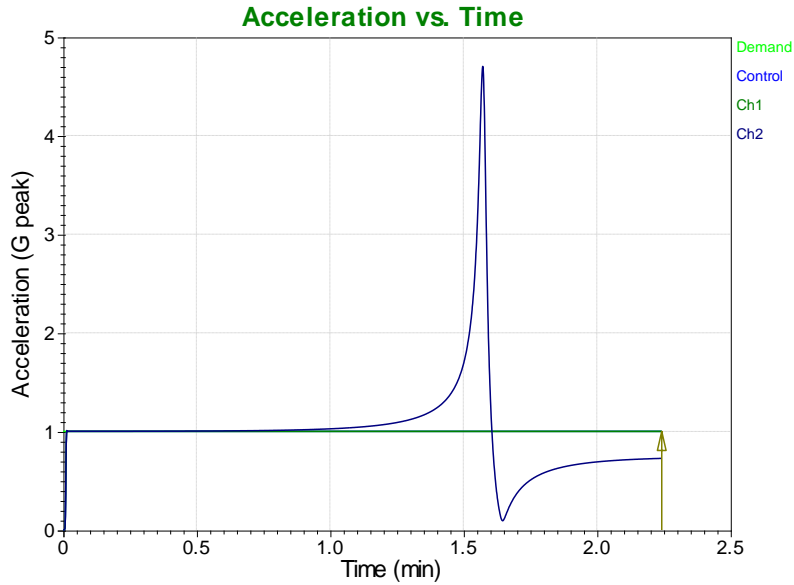
Breakpoint table

Start Freq.	Amplitude	End Freq.	Amplitude
20 Hz	1 G	2000 Hz	1 G

Ch2	0.7261 G	0.03072 in/s	4.89e-006 in

Channel Calibration:

Ch1	100 mV/G
Ch2	100 mV/G

; 499

2**.** There was a peak in the Ch2 waveform between 400 and 500 Hz. Using a cursor on the graph the peak is exactly 499 Hz. This peak would indicate that some sort of resonance is occurring at 499 Hz.

3**.** The level of human hearing varies. Probably between 250 and 300 Hz.

Module 1.2

1. One may choose to run a sine test to search for resonances in a variety of situations:
   a. One may be looking for loose bolts or other structural weaknesses in a product.
   b. One may desire to find places of resonances on the product in order to further test that product at those frequencies.

2. Industry may choose to track and hold at a particular frequency with the goal of fatiguing the product to failure. Thus, they may learn how long a product or part of a product may last before it will fail. They will also learn exactly what part fails and what part of the product is particularly weak. They can make these changes in the next prototype.

3. The Bandwidth of the resonance was 31.73 Hz. This was obtained when I annotated the resonance.

4. Lab Report Below:

Transmissibility (reference = Ch1)

Transmissibility vs. Time (reference = Ch1)
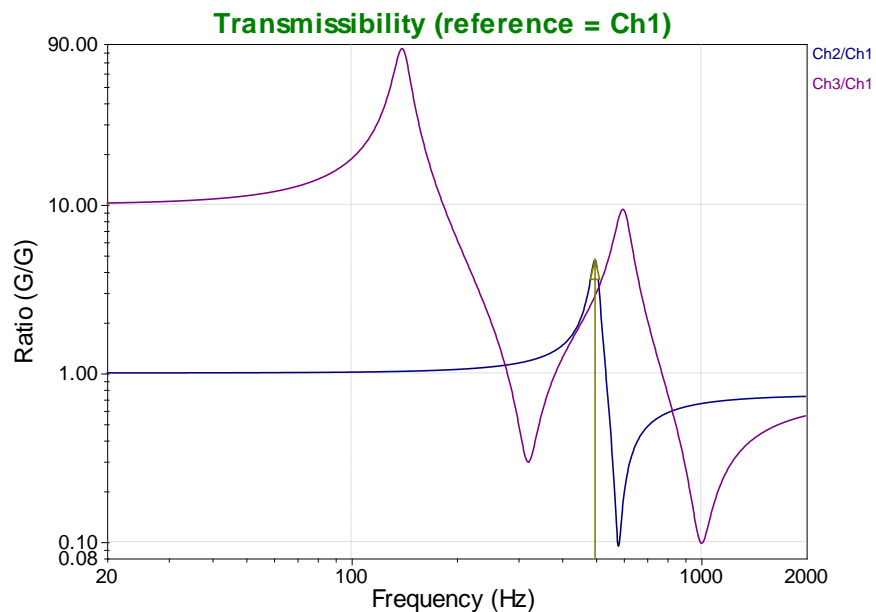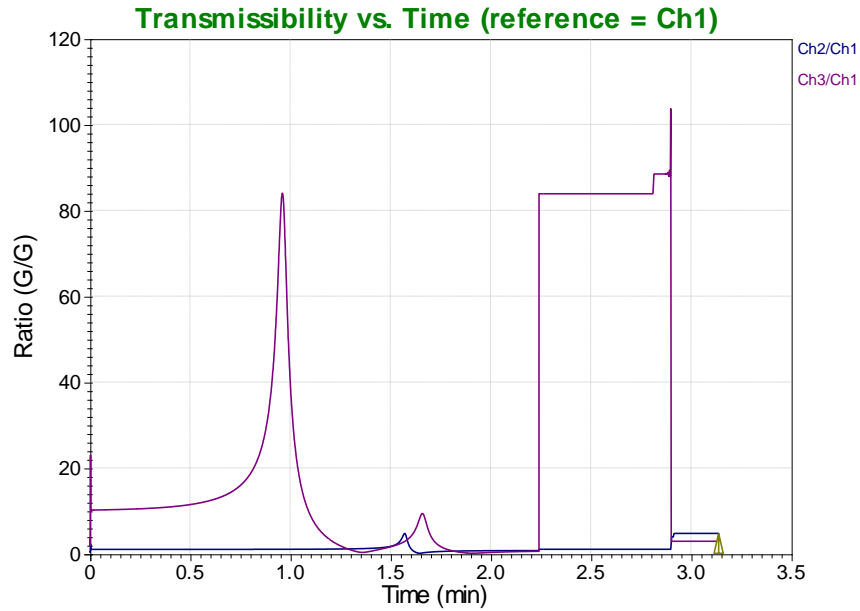
Breakpoint table

Start Freq.	Amplitude	End Freq.	Amplitude
20 Hz	1 G	2000 Hz	1 G

Channel Measurements:

	Accel	*Velocity*	*Displacement*
Ch1	1 G	0.1232 in/s	7.869e-005 in
Ch2	4.714 G	0.1232 in/s	7.869e-005 in
Ch3	2.89 G	0.3561 in/s	0.0002274 in
Ch4	2.211 G	0.2725 in/s	0.0001739 in

Channel Calibration:

Ch1	100 mV/G
Ch2	100 mV/G
Ch3	10 mV/G
Ch4	10 mV/G

5. It can show us the ratio of vibrational force being measured in a system to the vibrational force entering a system.

Module 1.3

1. The ratio of Ch2/Ch1 is 4.731 G/G with a bandwidth of 30.01 Hz

2. As a product deteriorates from the effects of dwelling at resonance the resonant frequency will begin to shift. Tracked Dwell is a process that tracks this frequency shift and in turn shifts the control frequency to match. This ensures that the test is dwelling at the maximum G level for that resonance.

3. Ch 2 is -90 degrees out of phase from Ch 1

Module 2.1

Acceleration Spectral Density

Acceleration Waveform
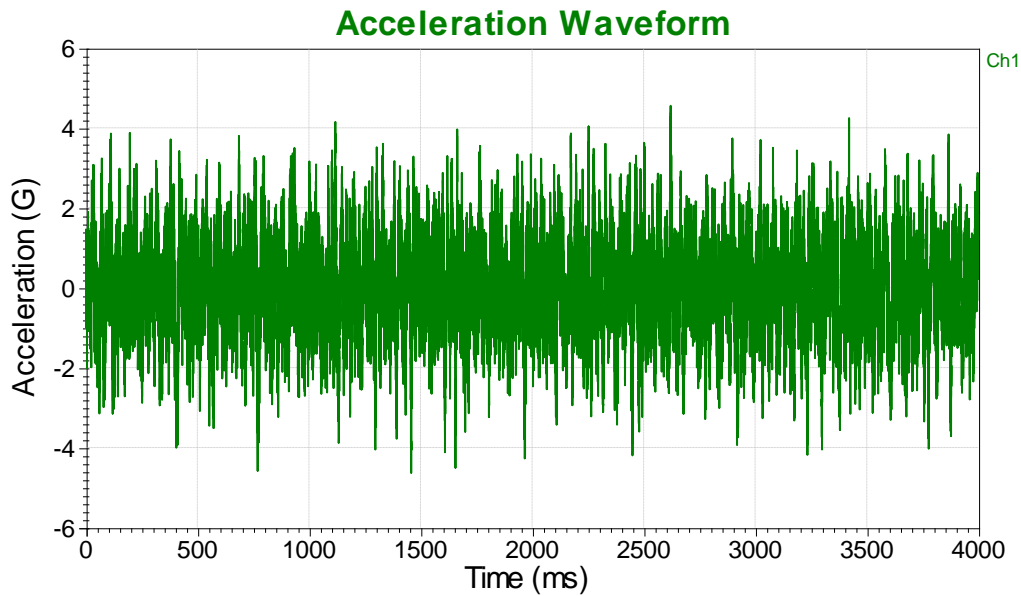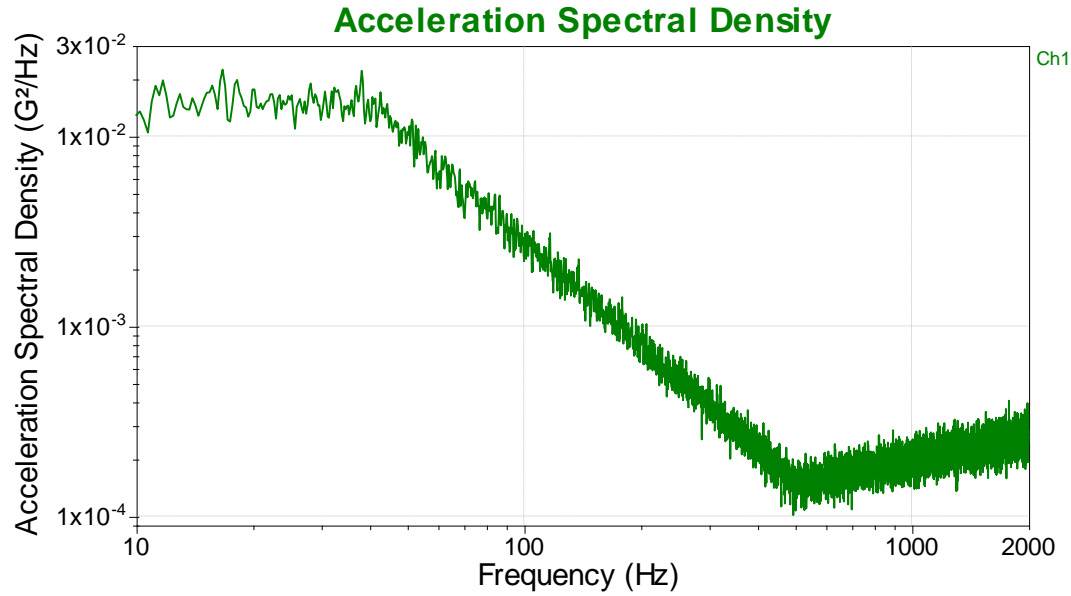
Breakpoint table

Frequency	G²/Hz	dB/Octave
10 Hz	0.015	0
40 Hz	0.015	-5.489
500 Hz	0.00015	1.2
2000 Hz	0.0002607	

Channel Measurements:

	(Overall)	(InBand)
Ch1	1.192 G RMS	1.189 G RMS
Ch2	1.188 G RMS	1.187 G RMS

Ch3	2.752 G RMS	2.763 G RMS
Ch4	2.4 G RMS	2.414 G RMS
Ch2	300 mV/G	
Ch3	200 mV/G	
Ch4	200 mV/G	

1.
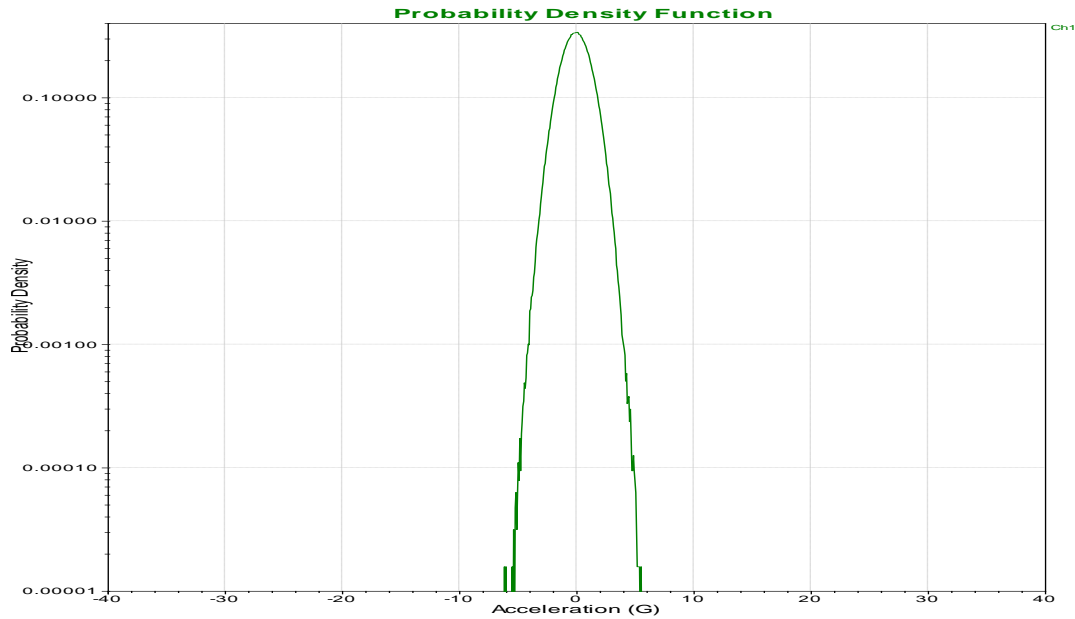
The Probability Density graph shows the distribution of the accelerations of the shaker. In this case a lot of the acceleration are in the +/- 1 G range. This corresponds well with what is observed on the acceleration waveform graph shown in the report for question #1.
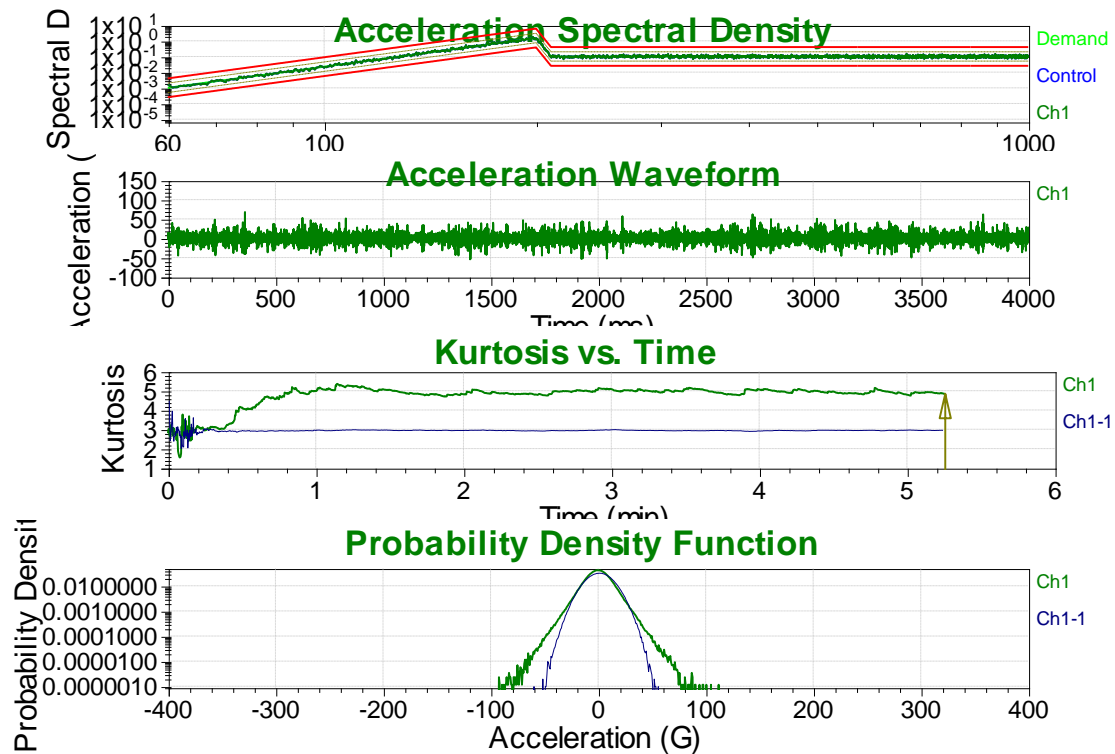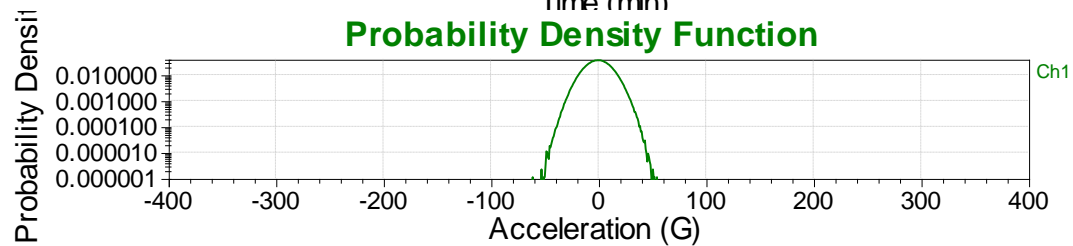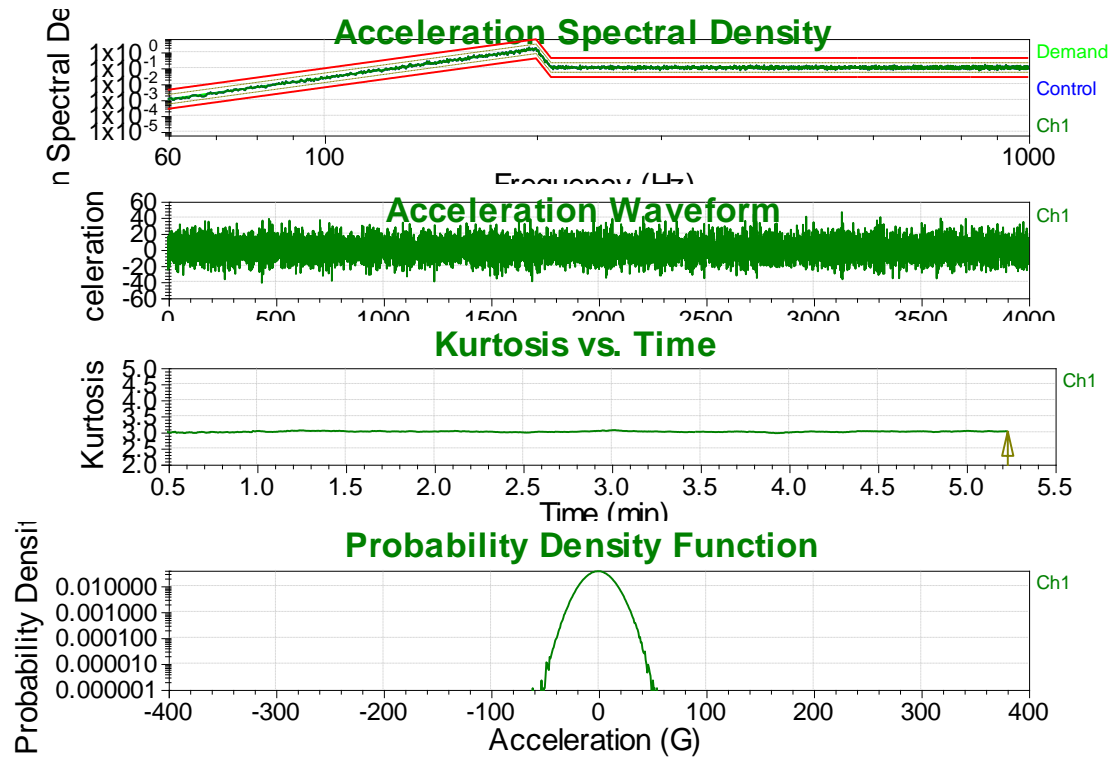

2. The sound is a molded "white noise". There is no particular frequency or pitch, but just a static sound.
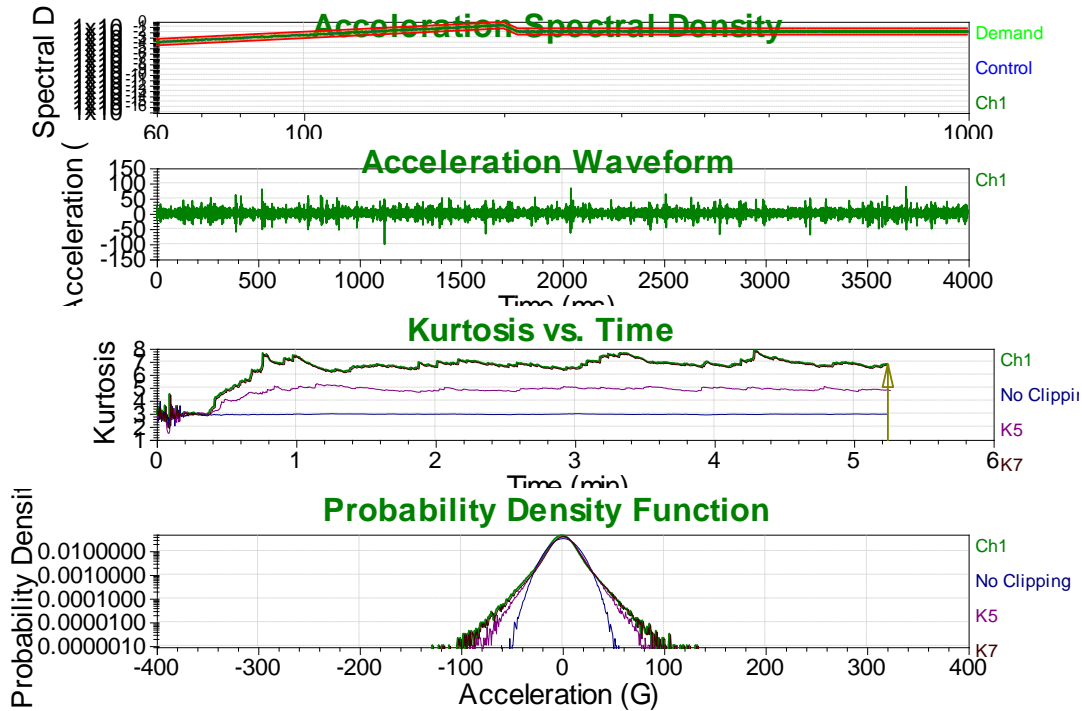
Module 2.2

1. Maximum force values shown on Channel Waveform graph are almost 1.5 G.

2. The Probability Density graph corresponds well with the acceleration waveform graph. The majority of accelerations on the acceleration waveform graph are found at the +/- .5 G level. This is also seen in the probability density function. The majority of the area under the curve is found in the +/- .5 G region, with minimal amounts of outliers.

3. I don't hear anything because the test is being ran below 100 Hz and the human ear cannot hear at that low of a frequency.

Module 2.3

Acceleration Spectral Density

Acceleration Waveform

Kurtosis vs. Time

Probability Density Function

Acceleration Spectral Density

Acceleration Waveform

Kurtosis vs. Time

Probability Density Function

Acceleration Spectral Density
Demand
Control
Ch1

Acceleration Waveform
Ch1

Kurtosis vs. Time
Ch1
No Clippi
K5
K7

Probability Density Function
Ch1
No Clipping
K5
K7

1.
   a. PDF graphs are different in that the "tails" of the kurtosis test go further away from the zero than they do with the traditional test. This shows evidence that more of the higher peak accelerations are present in the kurtosis test.
   b. Kurtosis graphs differ in that the kurtosis value for the traditional test is 3 (typical of Gaussian distribution) while the kurtosis test is 7, matching the value that was set in the test parameters.
   c. Acceleration waveforms are also different. In the traditional tests the peak accelerations are approximately at 3 G while the peak accelerations in the kurtosis test are greater than 5G.
   d. The PDF, Kurtosis, and Acceleration waveform graphs are all different due to the presence of the higher peak accelerations that are included in the kurtosis test but are "averaged out" in the traditional Gaussian test.

2. The acceleration profiles for both tests are identical. This is due to the fact that all other parameters are the same and that the overall average power density is the same for both situations. Although the kurtosis test includes more of the higher accelerations peaks, the average power density remains the same because of the smaller accelerations peaks have been lowered to allow for this same average.

3. The traditional test has a hissing sound, while the kurtosis test has the similar "hiss" sound but with "popping" overtones. The reason for this "popping" difference is due to the higher accelerations peaks that are being introduced due to the kurtosis settings.

Module 2.4
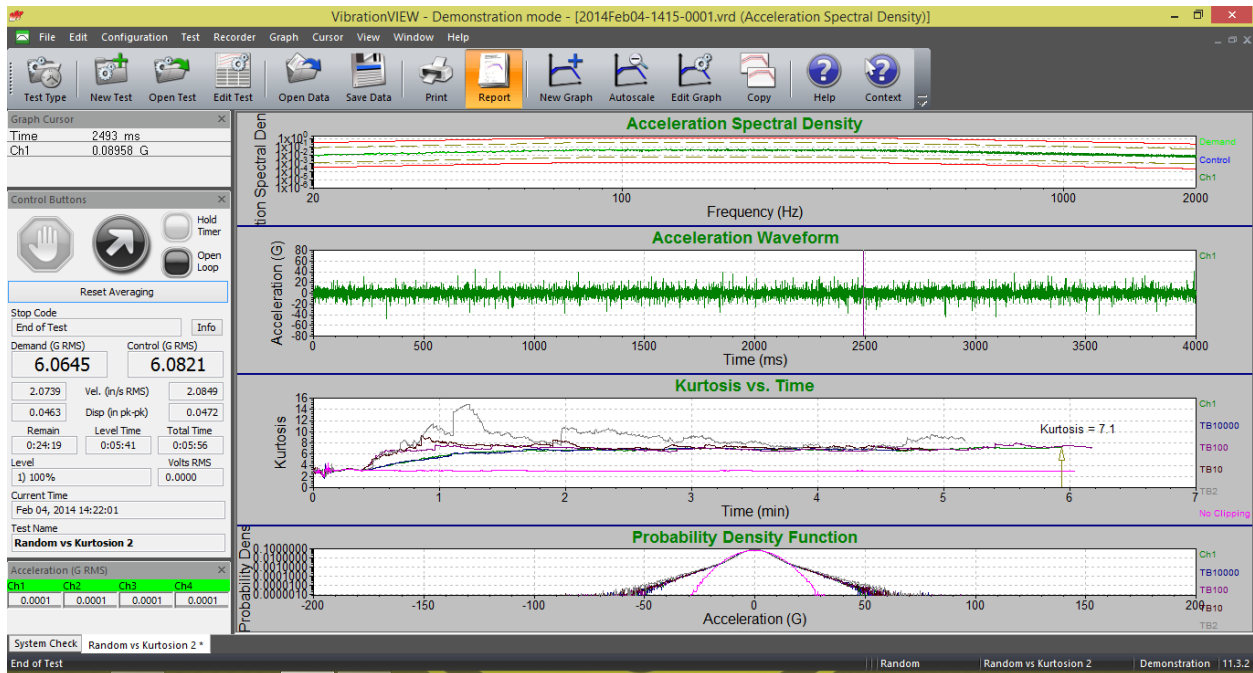
1. The Kurtosis vs Time and the PDF graphs are the most significant differences on any of the graphs. As the tests are changed and the Transition Band Frequency is dropped they progressively become harsher on the product.

2. Acceleration Profiles are identical for all data sets. This is because the test settings are the same for all – the same amount of energy is being put into the test. This is important because this makes the tests identical in every regard except kurtosis value. All tests therefore are giving the same amount of energy to the product. Therefore, the tests will not over-work the equipment in an attempt to break the product more quickly.

3. The PDF graphs all differ from each other. This is because of the changing of the Transition Band Frequency. As the Transition Band Frequency drops the amount the acceleration gets higher on the product. The Kurtosis graphs are all roughly around 7. No clipping was set at 3 because that is the default Gaussian value. The tests with the lower transition band frequency have a bit more variance in the kurtosis – in part due to the higher accelerations that are present in these tests.
Acceleration Waveform graphs are different. A comparison of these graphs shows the higher acceleration vibrations are more prominent in the tests with decreasing Transition Band Frequency.

Module 3.1
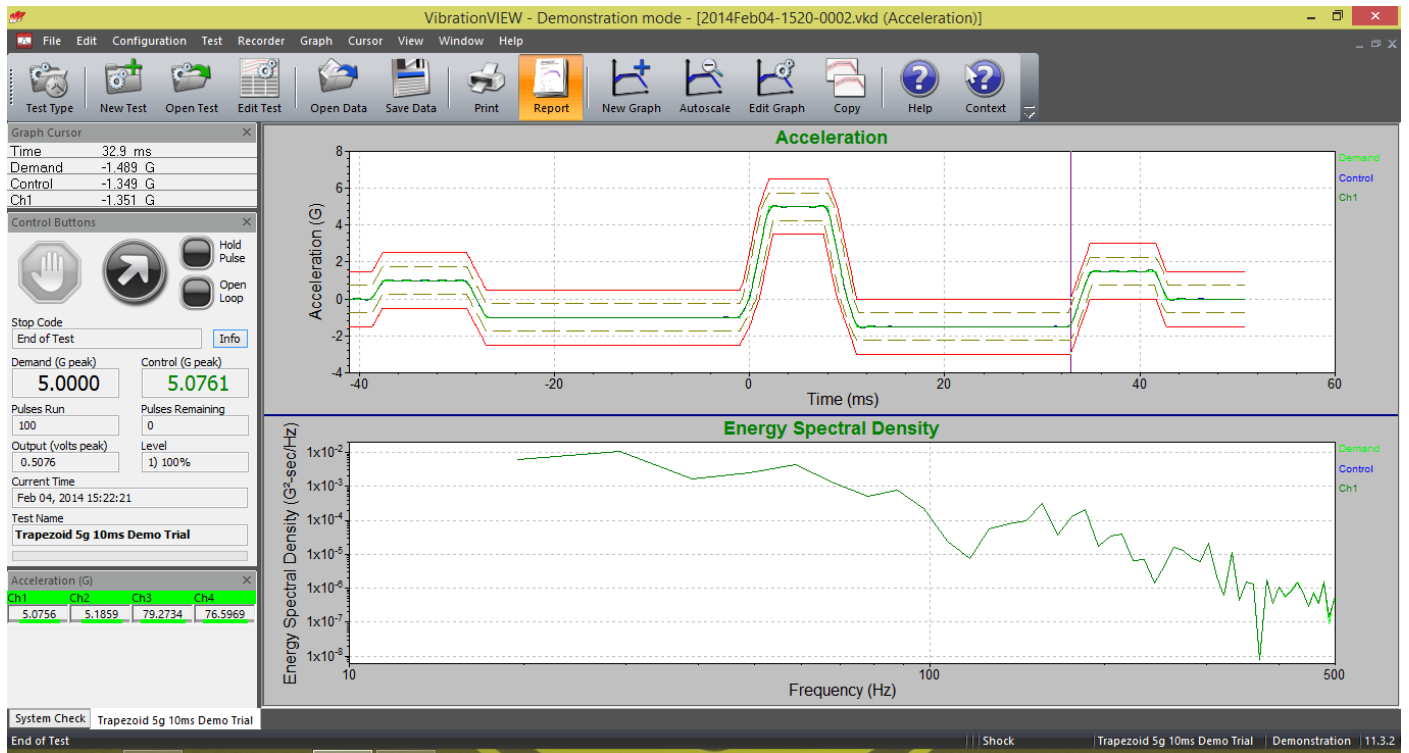
1. I don't hear anything. As you can see in the Energy Spectral Density graph most of the higher energy vibrations are in the lower frequency range. The higher frequency rang sounds, which our ears could very little energy of the test.

2. See Graphs Above

3. The advantage of a Shock test is that you can repeatedly expose your product to the kind of shock waves at particular G levels that they may experience in the field.

Module 4.1

1. It increases the drive output across the frequency board at those specific frequencies for the sine waves.

2. A helicopter with more blades tended to be louder and produces a sine tone that had a higher frequency than those with fewer blades.

3. It increases the peak acceleration for the sine tone.

4. The control G RMS is 3.0744 and the demand G RMS is 3.0829.

Module 4.2

1. As the narrowband spectrums pass through the resonances Channels 2, 3, and 4 begin to accelerate and spike much higher than what the resonance is already at, causing increased amounts of damage.

2. When the bands continuously change their sweep rate the amount of distortion increases. If you watch closely you can see channels "lag" behind because of the amount of distortion added to the test.

3. The demand G RMS for the test is 4.4615 and the control G RMS is 3.2735.

Module 5.1

1. Damped Sine Wave: Sounds like a single guitar string being plucked

   WavSyn(Centered): Sounds like the "tick" of a clock

   Linear Chirp: Sounds like a "wheer" or "siren" sound

   Exponential Chirp: Sounds like a high pitched siren

   The sounds are all different regardless of how you perceive them. The important thing to note from the sounds and graphs is that an infinite number of acceleration waveforms (and test sounds) can be generated from the exact same SRS test specifications (breakpoints). Not how the SRS graphs all appear essentially the same but the waveforms which make those plots are radically different. SRS is a response of the shock response at each frequency. Many different kinds of acceleration waveforms could produce a particular shock at a particular frequency. Thus, one SRS plot can be produced from many different acceleration waveforms.

2.
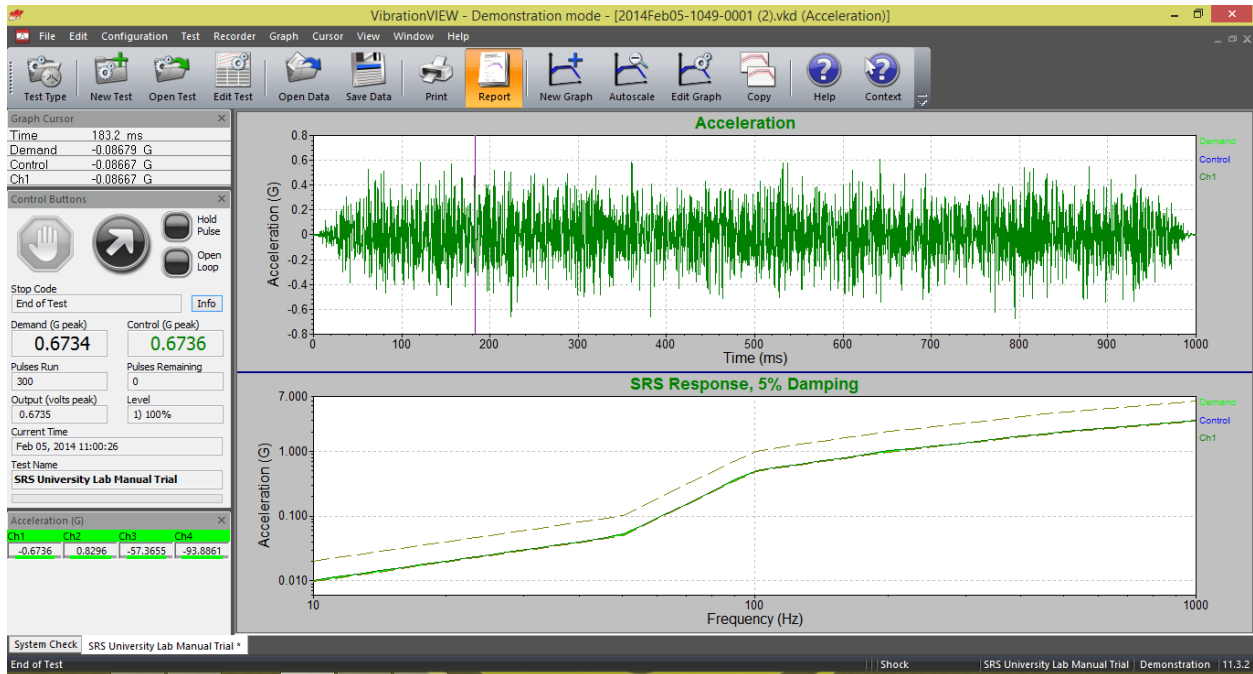
3. The main benefit of the SRS test is that a shock test can be produced that affects the product over a specified range of frequencies.
4. This can vary depending on the user and the amount of iteration used in the test.

Module 6.1

1. FDR was very realistic in its representation of the hitting of an accelerator. It is easy to hear the changes from idle, to the rev of the engine, and to the higher rpm running of the engine.

2. The acceleration waveform is constantly changing just as the sound of the test is. The largest change is from idle to revving.
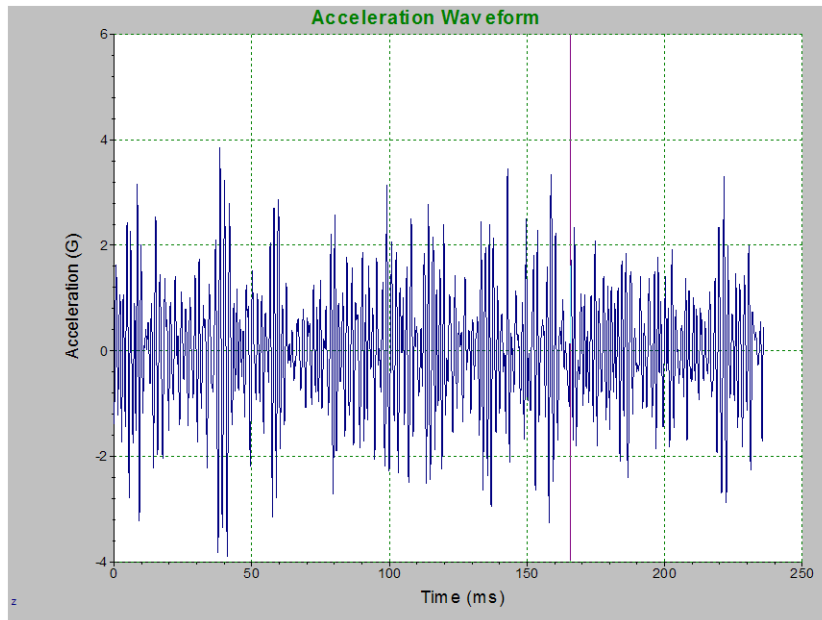
Harley running in random – includes idling and revving
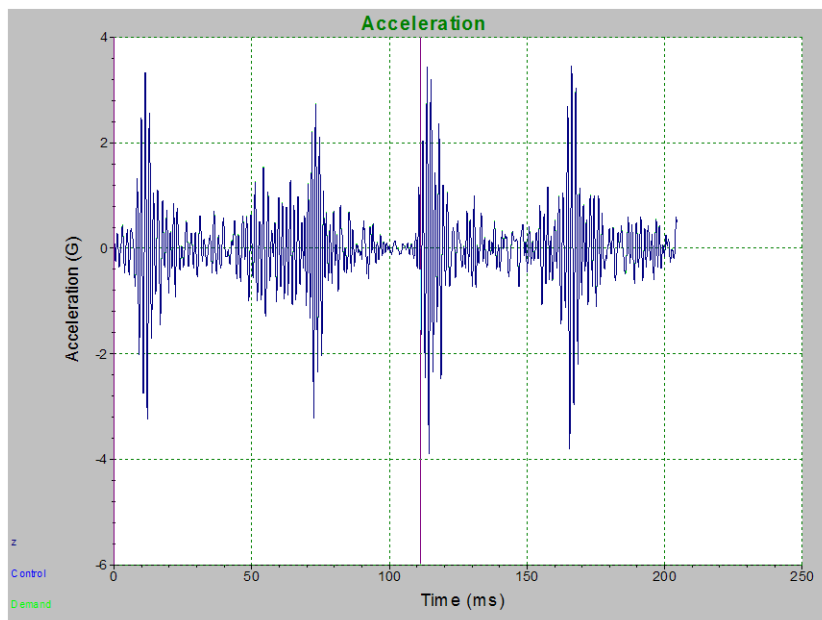
Harley in FDR – while Harley idles
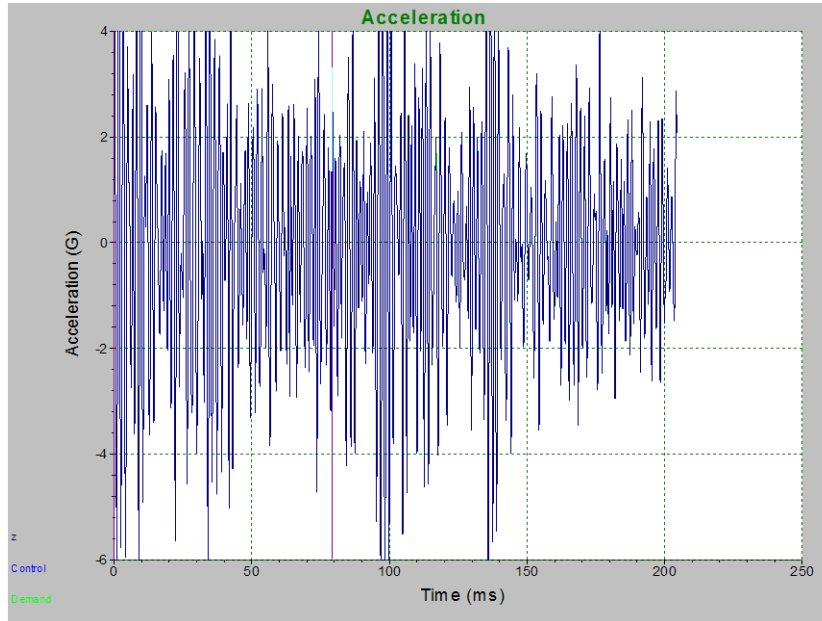
Harley in FDR – while Harley revs

4. Repeating field occurrences, create fatigue damage spectrum, analyze field data to create random test data, visually see what the product is experiencing in the field.

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About This Syllabus

Every engineering student faced with vibration testing could benefit greatly in their studies and in their preparation for the workforce by having access to vibration software. This laboratory manual is a brief introduction into the realm of vibration testing and the use of software for vibration control. It is our hope that with access to our VibrationVIEW software and this manual, the student may become better acquainted with the concepts of sine and random testing and better equipped to analyze and control such tests.

About Vibration Research

Vibration Research has been providing its customers with reliable, user-friendly hardware and software packages for vibration control for more than 15 years. The Vibration Research team brings together experience in vibration testing and hardware and software development along with a strong desire to take vibration testing to a new level. From the delivery of its first vibration control system, Vibration Research has been an innovator and has been producing new testing capabilities and software enhancements. Vibration Research was the first to introduce and offer long time field data replication and is once again a pioneer in offering kurtosis control of random testing through its patented Kurtosion® software module.

Vibration Research has grown every year in sales, product offerings and customers. It has sold to companies throughout the world and is the preferred choice of many testing laboratories. Vibration Research control systems are used today in the fields of automotive, aerospace, military, packaging, medical and seismic, among many others. Vibration Research is continuously innovating to meet the ever-changing demands of its customers, and we pride ourselves in outstanding customer service and support.

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