

# What is Random Vibration Testing?

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There is some confusion about the various tests available to the vibration testing engineer. Difficulties encountered usually center on the differences between sinusoidal vibration (sine testing) and random vibration testing.

Strike a tuning fork and the sound you hear is the result of a single sinusoidal wave produced at a particular frequency as shown in Figure 1. The simplest musical tones are sine waves at particular frequencies. More complicated musical sounds arise from overlaying sine waves of different frequencies at the same time. Sine waves are important in more areas than music. Every structure can vibrate and has particular frequencies (resonance frequencies) in which it vibrates with the greatest amplitude. Therefore sinusoidal vibration testing is important to help understand how any structure vibrates naturally.

The vibration testing industry has made good use of sine vibrations to help assess the frequencies at which a particular device under test (DUT) resonates. These frequencies are important to the vibration testing engineer, because they are the frequencies at which the DUT vibrates with the greatest amplitude and, therefore, may be the most harmful to the DUT.

Because “real-world” vibrations are not sinusoidal, sine testing has a limited place in the vibration testing industry. Part of the usefulness of sine testing is its simplicity, so it’s a good point of entry into the study of vibrations.

Sine testing is used primarily to determine damage to structures. The best pro-sine arguments are to search for product resonances and then to dwell on one or more of them to determine modal properties and to determine fatigue life associated with each mode.<sup>1</sup>

Aside from testing a product to find and dwell at its resonance frequencies to determine fatigue life, one might also use sine testing to determine damage to equipment. A sine sweep prior to any shock or random vibration test will identify the dominant resonances of the tested equipment. Repeating the sine test after otherwise abusing a product should produce the same test results unless the DUT has been damaged. Any differences in the sweeps indicate damage to the equipment – perhaps something as simple as a shift in the natural resonance frequencies that might suggest a few loose bolts need to be tightened.

## Random Vibration

Vibrations found in everyday life scenarios (a vehicle on a typical roadway, the firing of a rocket or an airplane wing in turbulent air flow) are not repetitive or predictable like sinusoidal waveforms. Consider the acceleration waveform shown in Figure 2 for dashboard vibration of a vehicle traveling on Chicago Drive near Hudsonville, MI. Note that the vibrations are by no means repetitive. So there is an important need for tests that are not repetitive or predictable. Random vibration testing accomplishes this.

**Random vs. Sine.** Sinusoidal vibration tests are not as helpful as random testing, because a sine test focusses upon a single frequency at any one time. A random vibration test, on the other hand, excites all the frequencies in a defined spectrum at any given time. Consider Tustin’s description of random vibration – “I’ve heard people describe a continuous spectrum, say 10-2000 Hz, as 1990 sine waves 1 Hz apart. No, that is close but not quite correct. Sine waves have constant amplitude and phase, cycle after cycle. Suppose that there were 1990 of them. Would the totality be random? No. For the totality to be random, the amplitude and starting phase 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 vibrations.”<sup>1</sup>

**Advantages of Random Vibration Testing.** One of the main goals or uses of random vibration testing in industry is to bring a DUT to failure. For example, a company might desire to find out how a particular product may fail because of various environmental

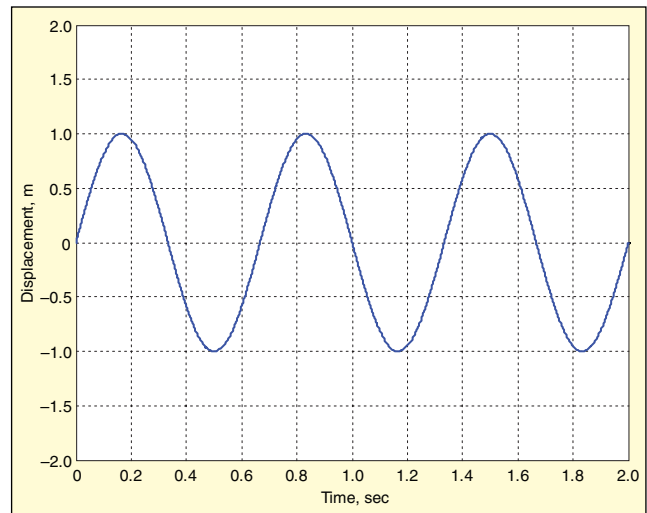


Figure 1. Time history of a sinusoidal waveform. Note its repeatability and predictability.

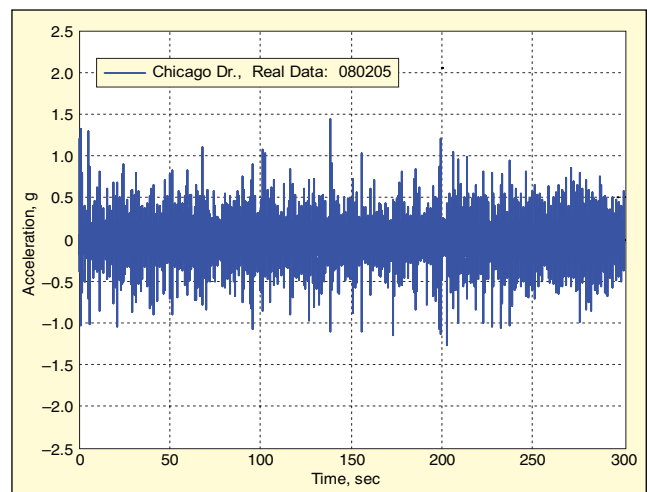


Figure 2. Acceleration time history collected on vehicle dashboard while driving in Hudsonville, MI.

vibrations it may encounter. The company will simulate these vibrations on a shaker and operate their product under those conditions. Testing the product to failure will teach the company many important things about its product’s weaknesses and ways to improve it. Random testing is the key testing method for this kind of application.

Random vibration is also more realistic than sinusoidal vibration testing, because random simultaneously includes all the forcing frequencies and “simultaneously excites all our product’s resonances.”<sup>1</sup> Under a sinusoidal test, a particular resonance frequency might be found for one part of the device under test and at a different frequency another part of the DUT may resonate. Arriving at separate resonance frequencies at different times may not cause any kind of failure, but when both resonance frequencies are excited at the same time, a failure may occur. Random testing will cause both resonances to be excited at the same time, because all frequency components in the testing range will be present at the same time.

## The Power Spectral Density Function (PSD)

To perform random testing, a random test spectrum must be defined. Real-time data acquisition utilizes spectrum-averaging to produce a statistical approximation of the vibration spectrum. Generally the random vibration spectrum profile is displayed as a power spectral density (PSD) plot. This plot shows mean square ac-

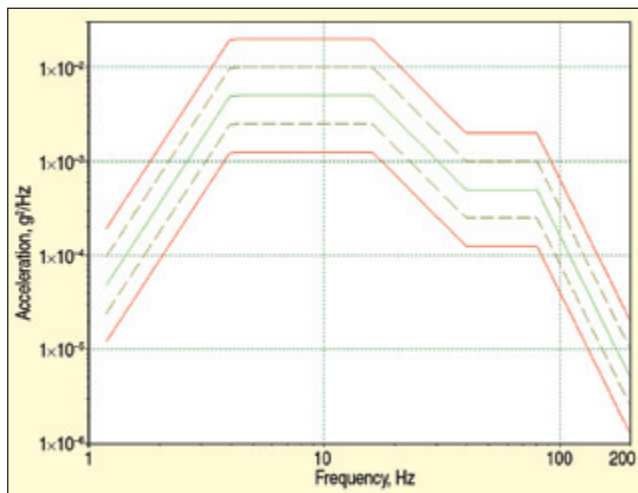


Figure 3. Typical power spectral density vibration testing specification (mean squared acceleration per unit frequency).

celeration per unit bandwidth (acceleration squared per Hz versus frequency as shown in Figure 3). The shape of a PSD plot defines the average acceleration of the random signal at any frequency. The area under this curve is called the signal's mean square ( $g^2$ ) and its square root is equal to the acceleration's overall root-mean-square (RMS) value often abbreviated  $\sigma$ .

A random test is conducted by using closed-loop feedback to cause the random vibration of a single location (typically the shaker table) to exhibit a desired PSD. The PSD demonstrates how hard the shaker is working, but it doesn't give any direct information about the forces experienced by the DUT. The  $g^2/\text{Hz}$  PSD is a statistical measurement of the motion experienced at the Control point on the test object – this is important to remember. Since the PSD is the result of an averaging process, an infinite number of different time waveforms could have generated such a PSD. The idea that an infinite number of real-time waveforms could generate a particular PSD can be seen from the graphs shown in Figures 4-7 produced from data collected at Vibration Research Corporation, June 28 and 30, 2005. Note that the PSD curves (Figures 6 and 7) are virtually identical although they were generated from entirely different waveforms.

### The Probability Density Function (PDF)

An examination of the acceleration waveforms of Figures 4 and 5 will indicate that much of the random vibration acceleration values are nearly the same ( $\pm 5$  g). However, some of the acceleration values are quite large compared to the most common values. To help illustrate the range of acceleration values, another statistic, the probability density function (PDF) is required. A PDF is an amplitude histogram with specific amplitude scaling. Each point in the histogram is a count of the number of times the measured signal sample was found to be within a corresponding small range (an amplitude "bin") of amplitude.

The PDF shown in Figure 8 conveys the probability of the signal being at a particular g-value at any instant in time. Its vertical units are  $1/g$  and the area under this curve is exactly 1. Thus, the area under the PDF between any two (horizontal axis) g values is the probability of the measured signal being within that amplitude range. Note that Figure 8 is drawn using a logarithmic vertical axis. This serves to make the extreme-value "tails" more readable.

Various weighted integrals (moments) of this function are determined by the signal's properties. For example, the first moment is the signal's mean ( $\mu$ ), the averaged or most probable value; this is necessarily equal to zero for a random shaker Control signal. The second moment is the signal's mean square ( $\sigma^2$ ) and it is equal to the area under the previously discussed PSD. The third moment is the signal's skew, an indication of bias towards larger positive or negative values; this is always equal to zero for a random Control signal. The fourth moment is called the Kurtosis and it measures the high-g content of the signal.

The horizontal axis of an acceleration PDF has units of  $g_{\text{peak}}$  (not

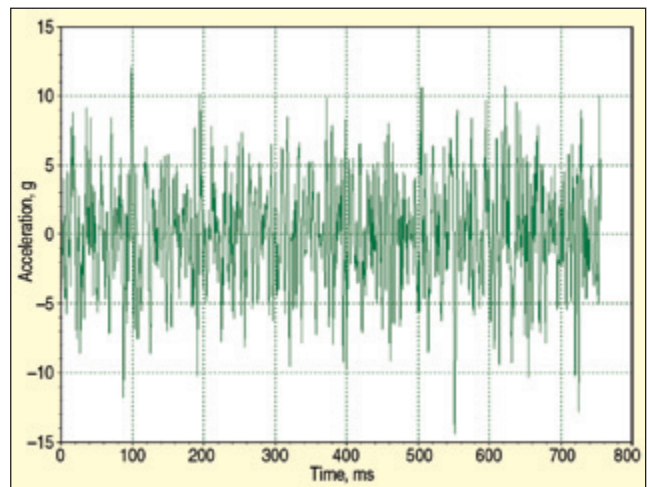


Figure 4. Sample acceleration time history of excitation applied to Light-bulb-4 test, #1330.

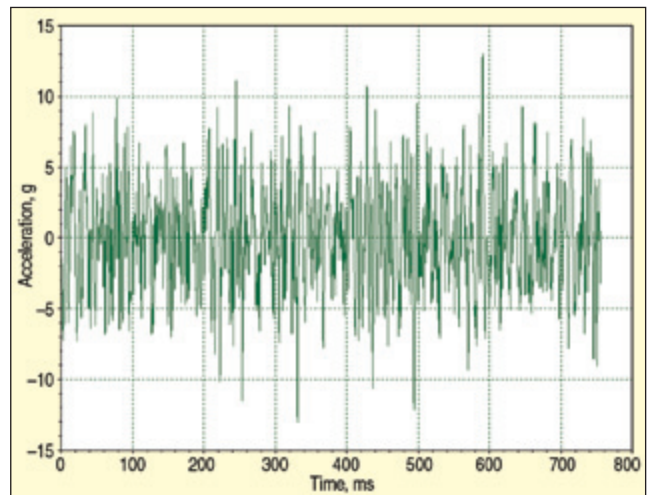


Figure 5. Sample acceleration time history of excitation applied to Light-bulb-4 test, #1110.

RMS). This axis is often normalized by dividing the g values by the signal's RMS value  $\sigma$ . Many signals will exhibit a symmetrical "bell-shaped" PDF with 68.27% of the curve's area bounded by  $\pm\sigma$  and 99.73% within  $\pm 3\sigma$ . Such signals are said to be "normal" or Gaussian. A Gaussian signal has a Kurtosis of 3 and the probability of its instantaneous amplitude being within  $\pm 3\sigma$  at any time is very nearly 100% (actually 99.73%).

There are actually many "real-life" situations where there are more high acceleration values than a Gaussian distribution would indicate. Unfortunately, most modern random control techniques assume the Control signal should be Gaussian with the majority of the instantaneous acceleration values within the  $\pm 3\sigma$  range. This assumption removes the most damaging high peak accelerations from the test's simulation of the product's environment and "under testing" results. In fact, a Gaussian waveform will instantaneously exceed three times the RMS level only 0.27% of the time.

When measuring field data, the situation can be considerably different, with amplitudes exceeding three times the RMS level as much as 1.5% of the time. This difference can be significant, since it has also been reported that most fatigue damage is generated by accelerations in the range of two to four times the RMS level.<sup>2</sup> Significantly reducing the amount of time spent near these peak values by using a Gaussian distribution can therefore result in significantly reducing the amount of fatigue damage caused by the test relative to what the product will experience in the real world. So Gaussian distribution is not very realistic.

Hence, present-day methods of random testing may be unrealistic for some simulations, because they fail to account for the environment's most damaging content. Furthermore, random testing with Gaussian distribution will result in a longer time-to-failure, because

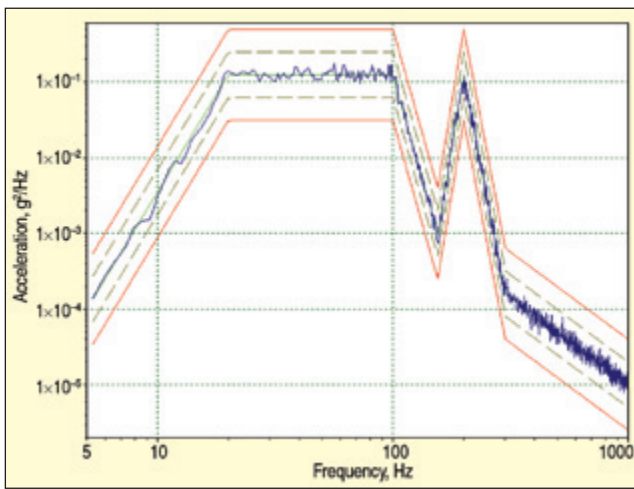


Figure 6. PSD spectrum for trial #1130.

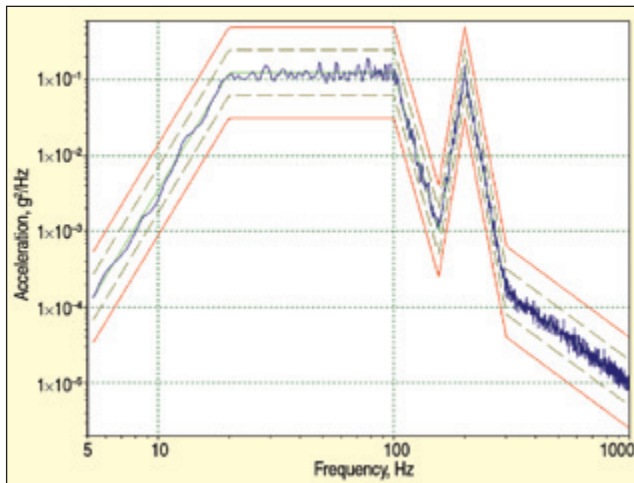


Figure 7. PSD spectrum for trial #1110.

the higher accelerations responsible for failure have been omitted. Therefore, Gaussian random testing, for all its advantages over traditional sine testing, has its own disadvantages, and a better method of testing products is called for. Vibration Research Corporation has developed such a method.<sup>3</sup> It is called Kurtosion™. Kurtosion allows a random vibration test to be run with a user-specified kurtosis of 3 or greater. This amounts to using feedback to force the Control signal's PDF to have broader "tails." That is, more intense peak accelerations are included more often than using a Gaussian controller. This method permits the adjustment of the kurtosis level while maintaining the same testing profile and spectrum attributes. With this new technique, a random vibration test is best described by a PSD and an RMS versus time schedule and an additional kurtosis value. The required kurtosis parameter can be easily measured from field data. This is similar to current random tests but is one step closer to the vibrations measured in the field.

In Figure 8, the data set has a kurtosis value of three (Gaussian distribution) and is a smooth distribution with few large amplitude outliers. However, Figure 9 shows a data set with a kurtosis value of five. Note how the "tails" extend further from the mean, indicating a large number of outlier data points. The contrast between the PDFs of a Gaussian distribution and a higher kurtosis distribution is clearly seen in Figure 10.

Therefore, the fundamental difference between a Gaussian and controlled-kurtosis distribution is that, although the two data sets may have the same mean, standard deviation and other properties, the Gaussian data set has its data points closely centered on the mean, while the controlled-kurtosis distribution has larger "tails" further from the mean.

### Some Other Testing Options

Modern test and measurement systems are blessed with inex-

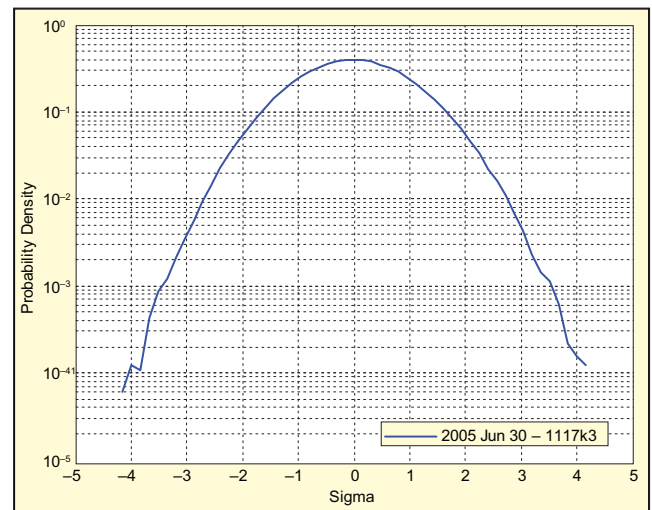


Figure 8. Probability density function for a lightbulb test using Gaussian distribution ( $k = 3$ ).

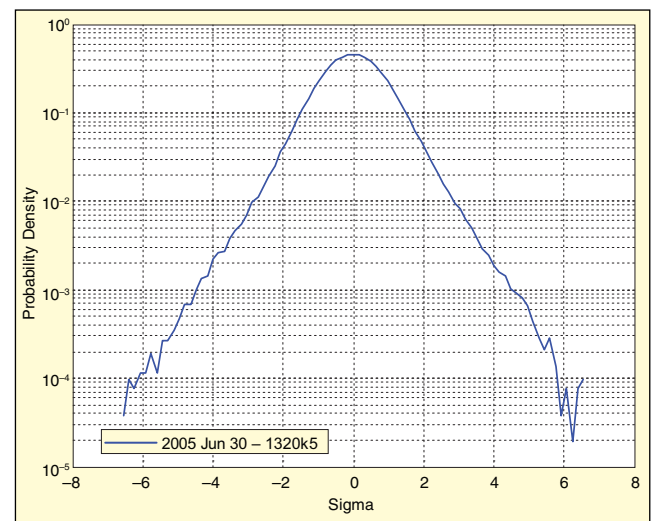


Figure 9. Probability density function for lightbulb test using Kurtosis Control ( $k = 5$ ).

pensive memory. In recent years, it has become feasible to record a long time history and then play it back as a shake-test Control reference. Vibration Research pioneered such Field Data Replication (FDR) testing several years ago and just recently introduced their VR Observer™, a highly portable four-channel recorder in support of this and other testing purposes. While FDR is the preferred solution for many cases, it is not a replacement for random vibration testing. FDR provides an exact simulation of one instance of the environment. Random provides a statistical average of that environment. Where FDR might exactly capture what one driver experiences while driving a prescribed route, random represents the average of thousands of different drivers trying to follow the same course. While an FDR recording uses massive amounts of memory, a random reference requires very little.

Certain mixed signal testing can also provide random signals with high kurtosis, but they are in no way competitive with Kurtosion. Sine-on-random tests may prove useful to simulate a specific environment with random and tonal components, such as an aircraft package-shelf experiencing both random airloads and engine harmonics. Random-on-random tests superimpose narrow-band random noise on broadband random noise. Such tests are claimed useful to simulate aircraft gunfire reactions. Both types of tests are designed to model a very specific class of environment and both are "tricky" to set up.

### Conclusions

Overall, random vibration testing is an excellent general purpose tool for environmental vibration simulation. It is more efficient,

more precise, and more realistic for this purpose than sine testing. Although random vibration testing is not perfect, the testing industry should use the techniques extensively in their screening and qualification procedures.

## References

1. Tustin, Wayne, *Random Vibration & Shock Testing*, Equipment Reliability Institute, Santa Barbara, CA, 2005.
2. Connon, W. H., "Comments on Kurtosis of Military Vehicle Vibration Data," *Journal of the Institute of Environmental Sciences*, September/October 1991, pp. 38-41.
3. Van Baren, Philip D., System and Method for Simultaneously Controlling Spectrum and Kurtosis of a Random Vibration, US Patent Office #7,426,426 B2.



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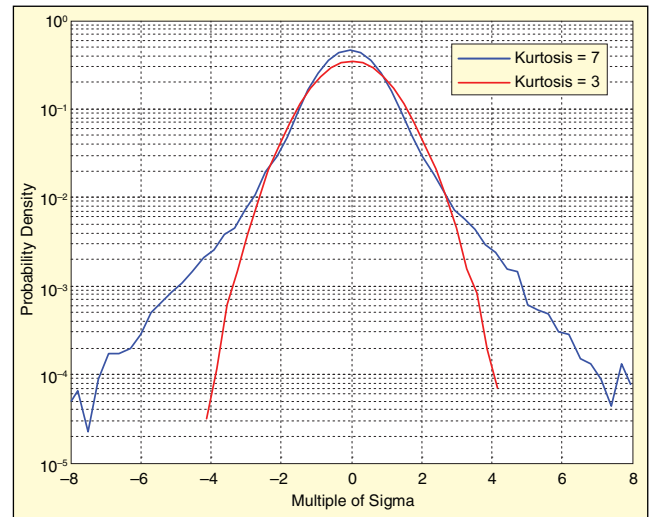


Figure 10. A comparison of kurtosis values 3 and 7. Note how the higher kurtosis value includes higher peak accelerations.