Improving Random Vibration Tests for the Transportation Industry

John and Phillip Van Baren, Vibration Research Corporation, Jenison, Michigan

The transportation industry historically has used Gaussian random vibration to simulate real-world transportation environments. However, examination of field measurements reveals the environments to be non-Gaussian in nature. Consequently, transportation test engineers should simulate real-world environments using non-Gaussian random vibration. Non-Gaussian random vibration (kurtosis control) increases the number of large peak accelerations (arising in field measurements due, in part, to the pot-holes of typical roadways) that the Gaussian random vibration tests "average away" with their vibration controllers. By implementing kurtosis control, the transportation industry would be well on its way to making its laboratory simulation tests much more realistic. And this, in turn, would result in better packaging – putting more products in the customer's hands without damage.

Millions of packages are transported along American roads daily.[1] Whether the package contains highly sensitive electronics or that special birthday present for your 9-year-old son, the safety of the contents is of great importance. Packages come in all size and shapes and must be transported through a large range of temperatures and vibration environments. To ensure the safe arrival of goods from one neighborhood to another and from country to country, the packaging industry has had to develop many packaging standards and shipment tests. Although the packaging industry has benefited greatly from implementing vibration industry tests, these tests could be improved. Present-day random vibration testing utilizes a technique that averages out the large acceleration peaks that are found in the field. These acceleration extremes cause damage to products. Today, a more realistic random vibration test is available to the packaging industry. The newest innovation in random vibration testing is Kurtosion® – a patented technique that raises random vibration testing to a much more realistic level.

Problems with Present-Day Random Testing

Prior techniques of random testing assumed that acceleration with Gaussian statistics was required. Accordingly, controllers were designed to generate and maintain a signal with a bell-shaped Probability Density Function (PDF), a mean value of zero and a normalized kurtosis equal to three. A random signal of desired spectral shape is feedback-controlled to have a desired RMS (sigma) level. value.Gaussian control averages the data in such a way that the highest peak acceleration produced by this process will be ±3 sigma or less. (Examine Figure 1 to see the Gaussian distribution of accelerations in a sample kurtosis test).

Consequently, this testing process removes the very large peak accelerations observed in field data. A Gaussian random test contains the same amount of energy as the original field data, but it does not contain the same peak g-levels. Thus, the Gaussian method of random vibration is not realistic. It under-tests the tested device, because it lacks the very large accelerations that are responsible for damaging the product. Therefore, in the context of the transportation industry, these Gaussian random tests will fail to identify the large peak accelerations that a product will encounter via road, rail or air. The packaging industry, therefore, will be prone to under-package its products.

A Better Testing Method

A better method of testing products than using Gaussian random vibration would be to adjust the probability distribution of the test excitation to more closely fit field-replicated data. Such a method would require an adjustment of kurtosis. Kurtosis is a statistical term used to describe the relative distribution of data.

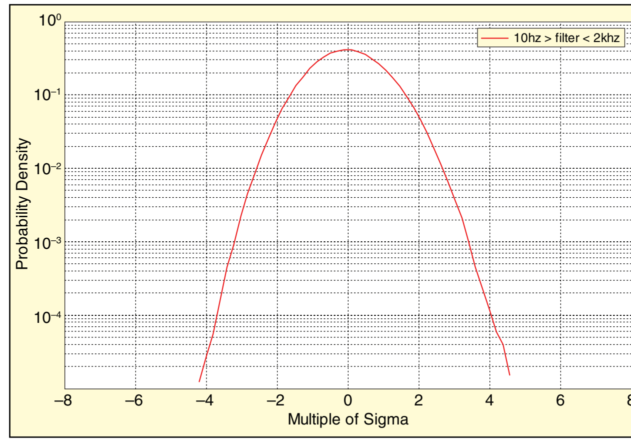

Figure 1. Probability density function (PDF) for road data with Gaussian (k=3) distribution.

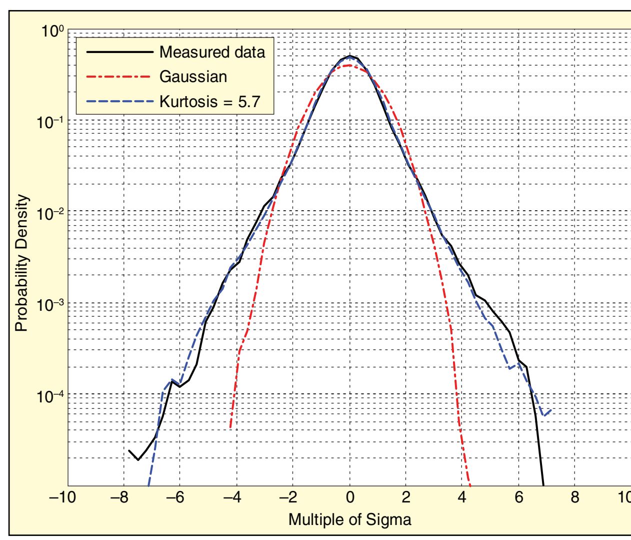

Figure 2. Probability density function for data gathered from interior automobile vibrations in road test by Vibration Research Corp. Note how higher kurtosis value contains more high peak accelerations (±6 sigma) than Gaussian (±3 sigma). Also, note how kurtosis control distribution more closely resembles real-life measured data than does the Gaussian distribution.

In simplified terms, kurtosis describes how many of the large peak accelerations are kept in the data set. If you want a greater number of peak accelerations in your test, then you need to increase the kurtosis level. This parameter includes the higher peak accelerations without increasing the overall energy of the test.

Graphically speaking, kurtosis is a measurement of the size of the probability distribution's "tails." A set of data with a high kurtosis value will produce a distribution curve with higher peak values at the mean and longer "tails," or in other words, more data points at the extreme values from the mean. Compare the distributions shown in Figure 2 for a kurtosis value of 5.7 with a traditional Gaussian distribution (kurtosis value of 3). Note how the distribution with the higher kurtosis values have more data points within the "tails" – data points that are far from the mean.

Rather than using Gaussian test excitations, which are commonplace in vibration testing today, it would be far preferable for the transportation industry to utilize random vibration excitations at higher kurtosis levels. This is preferable, since recent published

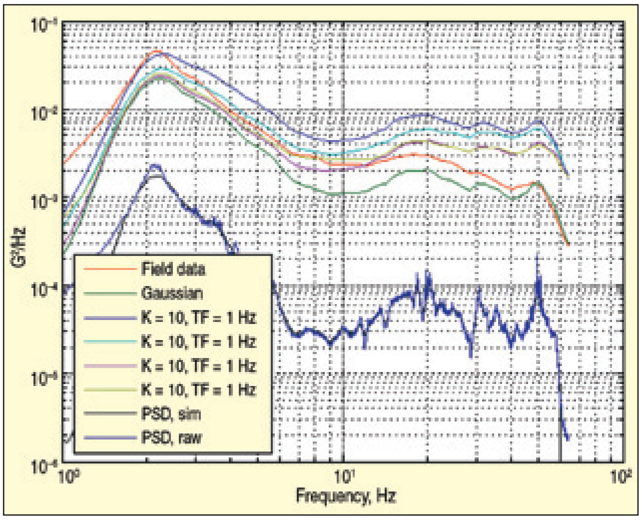

Figure 3. SRS plot of transportation data LB4 with random vibration tests with varying kurtosis values and varied transition frequency. Note how the SRS plot is a handy way to see how an increasing kurtosis value brings higher accelerations across the frequency spectrum. Note also how the plot of the PSD is identical for both the original data and the laboratory test data, indicating the tests are identical in terms of the "energy" of the test.

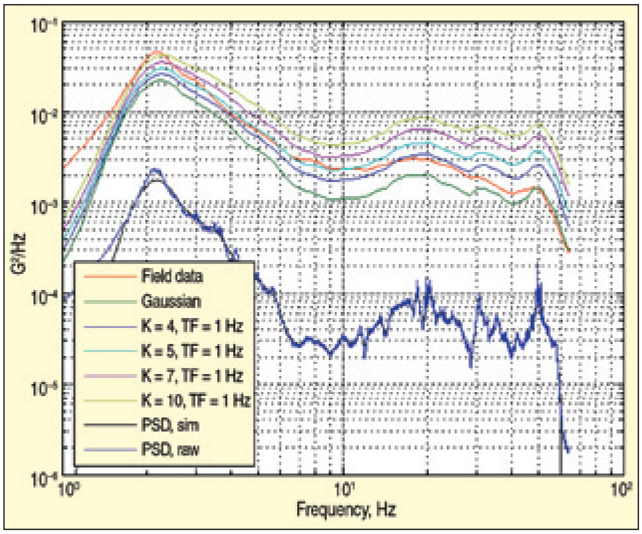

Figure 4. SRS plot of field data and various kurtosis values at transition frequency = 1 Hz. Note how the higher kurtosis values also have higher SRS plots and how the Gaussian (k=3) SRS plot is considerably below the SRS plot of the field data.

studies show that real-life data *does not fit* the Gaussian distribution, but fits rather, a higher kurtosis level.[2] Figure 2 also shows how a higher kurtosis distribution more closely resembles actual measured data than the Gaussian distribution.

Vibration Research Corporation developed, refined and patented Kurtosion®, a random control methodology which uses measured feedback to maintain a random acceleration's kurtosis at a desired level. This level may be set to 3 or higher, allowing both traditional Gaussian and more realistically damaging tests to be run by the same controller. Adjusting the kurtosis level will allow the product to be tested nearer to real-life scenarios.[3,4] Kurtosion will make testing by the transportation industry much more realistic.

The Shock Response Spectrum

What tools does the test engineer have to determine if the laboratory test satisfactorily matches real-world data? Test engineers examine a test's PSD (power spectral density). The PSD reveals the overall "energy" of the vibration test. When making a laboratory test, the test engineer must be sure that the PSD of the laboratory test matches the PSD of the field data. (see Figure 3.)

However, two tests identical in terms of PSD may have completely different kurtosis values. Ideally, the test engineer should be sure that the overall energy of the tests and the kurtosis of the tests match. While the PSD plot shows the overall energy of a vibration test, an SRS (shock response spectrum) shows the peak accelerations that occur during a test and at what frequencies they occur. The SRS plot essentially displays a representation of the kurtosis of the test. Since the test engineer wants the kurtosis of both the field data and the laboratory test to match, the engineer should ensure that the SRS plots also match. Figure 3 shows that tests with the same PSD can have different SRS plots because the tests can have different kurtosis values.

Case History

To illustrate that the packaging industry would benefit from using Kurtosion, a transportation data set representing measurements from a truck-rail-truck run from California to Chicago was analyzed. Data were recorded on an IST EDR-4 recorder and obtained from Steve Smithson from Smithson and Associates, Edina, MN. The transportation measurements were played back in the laboratory, varying the kurtosis and transition frequency parameters and generating SRS plots for each test.

The data were examined to determine peak acceleration levels, and the PSD and SRS of the data were analyzed. Then the data were replicated in the laboratory with VibrationVIEW™ software. The data set was played back in "random" and the kurtosis control method was applied. Various kurtosis values were used and compared. The kurtosis control method keeps the overall PSD (the amount of energy of the test) the same regardless of the kurtosis setting. The SRS plots will differ for each trial, because the tests with higher kurtosis settings will have higher peak accelerations.

Consider the results of this demonstration as shown in Figure 4. Note that the PSD of the original data and the PSD of the replicated data are the same for all tests – indicating that the tests are identical in terms of total energy. Note also that the SRS plot nicely illustrates that as the kurtosis increases for each test; the peak acceleration levels also increase across the frequency spectrum. This shows how a test engineer could manipulate the peak acceleration levels by adjusting the kurtosis level.

Finally, note that the Gaussian distribution (sigma=3) undertests the product, since the Gaussian SRS plot is lower than the SRS plot of the original field data. This further substantiates that field data are non-Gaussian and the transportation industry would better replicate field data by using Kurtosion. This allows the adjustment of test kurtosis, rather than assuming an unrealistic Gaussian distribution.

Conclusions

In a global society, the transportation industry will be called upon more than ever to move goods from country to country and from home to home. The vibration industry has known for some time now that field data are not always Gaussian in nature; this has been assumed for many years. In fact, the data sets from Steve Smithson that were examined here illustrate that transportation data is certainly not Gaussian either.

With Vibration Research Corporation's patented Kurtosion, the transportation industry need no longer assume Gaussian vibration when replicating field data. Kurtosion allows the test engineer to create a random vibration test with the same kurtosis level measured in the field data while maintaining the same energy (PSD) and other attributes of the test. This provides much more realistic excitation, ensuring that the product is tested more closely to the environment it will experience on the road, on the rail, or in the air. Using Kurtosion, the transportation industry can bring more precious packages safely to their customers.

References

1. http://www.ups.com/pressroom/us/press_releases/press_release/0,1088,4995,00.html.
2. Steinwolf, A., "Shaker Simulation of Random Vibration with a High Kurtosis Value," *Journal of the IEST,* May/June 1997; 40, 3.
3. Van Baren, John, "Kurtosis – the Missing Dashboard Knob", *TEST Engineering & Management*, October/November 2005.
4. Van Baren, Philip. "The Missing Knob on Your Random Vibration Controller," *Sound & Vibration*, October 2005.

S/V

The authors can be reached at: jvb@vibrationresearch.com.