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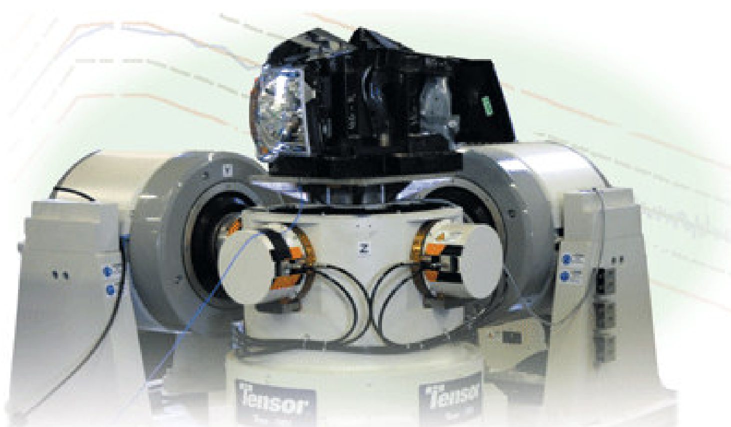
Multi-Axis Vibration Reduces Test Time

by Clyde Harman, Team Corporation, and Michael B. Pickel, Spectrum Technologies

Reproducing real-world vibration environments for testing may introduce a higher level of product reliability.

Widely accepted as a method to improve product quality, vibration testing is used to qualify products for production. Either alone or combined with an environmental chamber, vibration testing is a critical step in the successful development of new products.



Historically, single-axis, single-shaker testing is the method of choice. Vibration tests are conducted by sequentially applying single-axis vibration to a test article along the product's X, Y, and Z axes. These tests are performed using a linear shaker and rotating the test product to the next axis after each test.

However, complex, multi-axis motions are characteristic of field environments. The more a vibration test can replicate the field environment, the more realistically it can induce a vibration stress loading equivalent to that experienced by the product in the field. Testing all three axes simultaneously can reduce traditional test times by two-thirds and more closely duplicate real-world vibration environments.

Standards and recommended practices attempt to contain the spectral peaks of specific environments. However, published standards requiring multi-axis testing are almost nonexistent.

One exception is IEEE 344, a nuclear-power industry standard requiring bi-axial testing. Specifications such as MIL-STD-810-F allow for multi-axis testing but do not require it. As a result, published standards and testing requirements have not pushed for the replacement of single-axis testing by multi-axis testing.

With rigorous environmental testing, design problems can be identified and corrected, life span anticipated, and the where and when of product degradation predicted. Although it is critical that a product's performance meets customer expectations, there is constant pressure to bring products to market faster. For a number of commercial reasons, shortening the product time-to-market cycle is extremely important.

With the preponderance of higher-frequency vibration testing being done with single-axis shaker systems, product qualification testing can be a bottleneck. Instead of running these tests single-axis sequentially, running them using simultaneous multi-axis excitation improves test realism, increases throughput, and decreases risk.

Realism is important for several reasons. First, multi-axis testing excites all modes simultaneously with a more realistic stress loading. However, sequential single-axial excitation may not excite all the critical modes of the test object concurrently and, as a result, may fail to detect defective design.[1] Second, test objects may pass uniaxial testing but fail under actual operating conditions.[2] Third, fatigue damage is increased by a factor of two with three-axis excitation.[3]

In the automotive industry, the lack of published standards has not prevented the use of multi-axis testing procedures. The continued search for improved product quality and reduced warranty has led to the development of a number of multi-exciter, multi-axis test systems.

With the exception of some small-force-rated dual-axis systems, these generally have been servo-hydraulic systems. The result is that the maximum excitation frequency of even the most sophisticated systems is limited to several hundred Hertz.

Product qualification specifications from the major car manufacturers regularly require test profiles that extend to 1,000 Hz. Until now, that requirement has eliminated the multi-axis systems and forced product qualification tests to be done single-axis sequentially using electrodynamic shakers. A high-force, 3-DoF electrodynamic shaker system now exists that meets that requirement and allows significant reductions in testing time and cost.

Automotive Multi-Axis Testing

Automotive qualification tests seek to duplicate the stress a component sees in a required number of passenger-car miles. To ensure that a minimum standard of design has been met, multiple quantities of the component being qualified are tested.

Duplication of the stress accumulated in the specified number of passenger-car miles requires running the product sample for a large number of hours. The tests typically are done using either field data replication or a random-vibration profile based on the analysis of field data usually with some form of time compression.

The length of the tests can be anywhere from several hours to several hundred hours per axis. Multiplied by the number of samples, the length of time required to qualify a product is significant.

The goal is to qualify the product at the appropriate test levels, not break it.

For instance, testing single-axis sequentially, a qualification test 30 hours long will take 90 hours plus setup time between axes to complete. Assuming only one product will fit on the shaker at a time, a 30-hour qualification test with 10 samples and 30 minutes of setup time per axis will require 915 hours of test lab time to complete. If the same tests were run three-axis simultaneously, the testing time would be reduced by 60 hours per sample, and the setup time would be lessened by one hour per sample or a total reduction of 305 hours of test lab time to complete.

Another example of increasing throughput using multi-axis testing is in a production situation requiring 100% testing of all products prior to shipment. For illustrative purposes, assume the product requires a 30-minutes-per-axis vibration test and each axis change takes 15 minutes.

Figure 1 illustrates the time saved for a production run of 500 units. Three conditions are illustrated as:

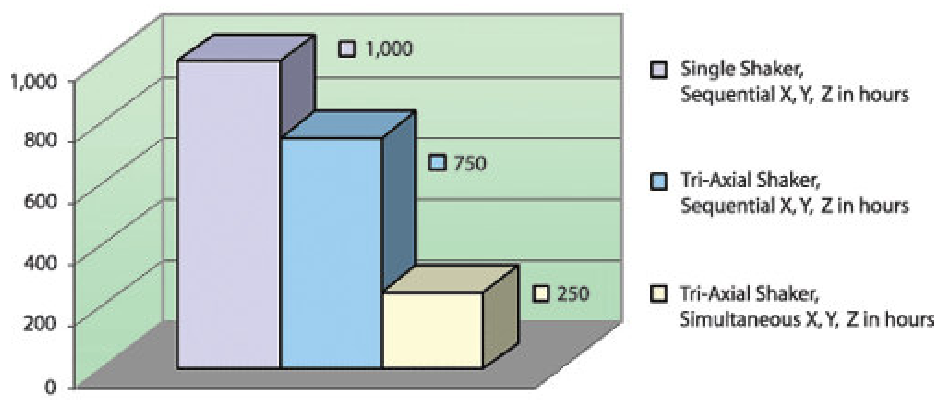


Figure 1. Productivity Improvement

- Single-axis shaker doing sequential X-, Y-, and Z-axis testing, one setup per axis
- Tri-axial shaker doing sequential X-,Y-, and Z-axis testing, one setup
- Tri-axial shaker simultaneous X-,Y-, and Z-axis testing, one setup

Time savings of 25% and 75% are demonstrated for the second and third test options, respectively. Lower cost results from the fewer numbers of setups required, and risk is decreased because the potential for errors inherent in each of those setups is less.

Testing a Lighting Assembly
Spectrum Technologies is an independent test laboratory that provides vibration and environmental testing services to the automotive manufacturing community. The company's focus is on solving warranty problems and offering product qualification testing services.

Spectrum has been using a Team CUBE to provide multi-axis testing services for some time. However, the frequency limitation of the CUBE has prevented Spectrum from running higher-frequency automotive qualification tests simultaneously rather than sequentially.

Until recently, these tests were run using single-axis shaker systems. At the end of 2005, Spectrum took delivery of a Team TE3-9.8 Tensor, a 3-DoF electrodynamic shaker system with 2,200 pounds of force in each axis. The lowest force rated of the three models available, the TE3-9.8, has a frequency bandwidth of 5 to 2,000 Hz.

A major automobile manufacturer has a product qualification test that requires a 2.9-grms random vibration profile from 5 to 1,000 Hz to be run for 30 hours in each axis. The durability test is used for qualifying, among other things, light bulbs and lighting assemblies.

A tier-one OEM providing the vehicle manufacturer with lighting assemblies contracted Spectrum Technologies to run product qualification tests on headlamp assemblies. As part of the test requirement, the lighting assembly must be mounted in a sheet-metal fixture; in the case of the test detailed here, a small portion of the fender assembly.

A contract requirement was to reduce test time while still qualifying the parts for production. Spectrum Technologies succeeded in reducing testing time by more than 66% by using simultaneous excitation and eliminating two 30-minute setup times per pair of headlamp assemblies tested. At the end of the tests, comparisons of product wear on assemblies tested using the Tensor 3-DoF system and using the traditional single-axis sequential method were identical. Put another way, the product tested for 30 hours three-axes simultaneously showed the same product wear as samples tested sequentially for 90 hours one axis at a time.

The tests were conducted using a Vibration Research 8500-12 Vibration Test Controller. It runs three different and independent random profiles simultaneously, one per axis, while using up to four channels of control on each axis.

The VR 8500 offers a control option called Multi-Channel Extremal. The controller uses the highest accelerometer reading from more than one input channel to control the test. Three control accelerometers were mounted on the qualification product and one on the shake table in each axis of excitation for a total of 12 channels of control.

By using the highest accelerometer input and changing the drive signal to control the test in that axis, Spectrum Technologies prevents the product from excessive accelerations. Because the fixturing is sheet metal, it is prone to multiple resonances. Without this control, local accelerations from 70 to 100 times the desired test levels could be experienced. The goal is to qualify the product at the appropriate test levels, not break it.

The acceleration vs. frequency points defining each of the profiles are shown in **Table 1**. The simultaneous test results are shown in **Figure 2a, b,** and **c**. Each axis has a different grms level and power spectral density (PSD) profile.

X Axis		Y Axis		Z Axis	
Frequency	G²/Hz	Frequency	G²/Hz	Frequency	G²/Hz
5 Hz	5.49E-03	5 Hz	9.20E-03	5 Hz	5.47E-03
10 Hz	5.21E-02	8 Hz	7.60E-02	10 Hz	5.87E-02
190 Hz	2.75E-03	12 Hz	7.60E-02	60 Hz	3.48E-02
370 Hz	2.34E-04	1,000 Hz	3.00E-04	200 Hz	6.96E-04
1,000 Hz	2.34E-04			1,000 Hz	3.98E-05
Total PSD 1.4 grms		Total PSD 1.688 grms		Total PSD 1.8 grms	

Table 1. Acceleration Profile Frequency Break Points

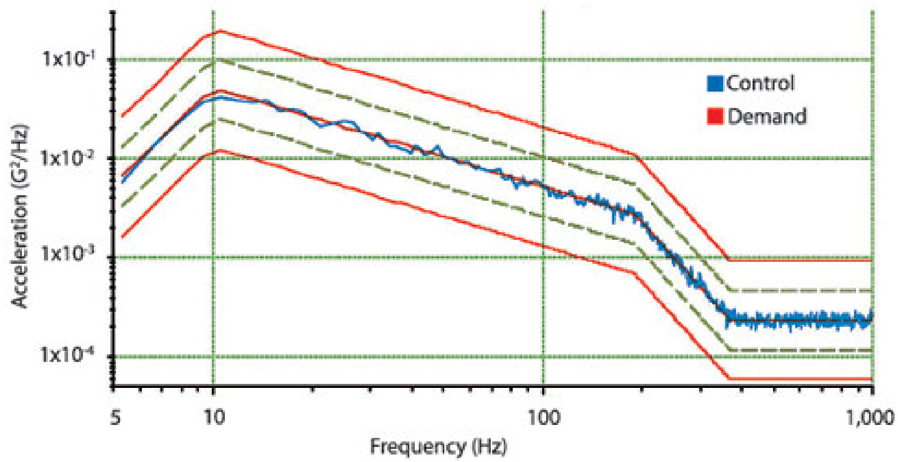


Figure 2a. Loop 1

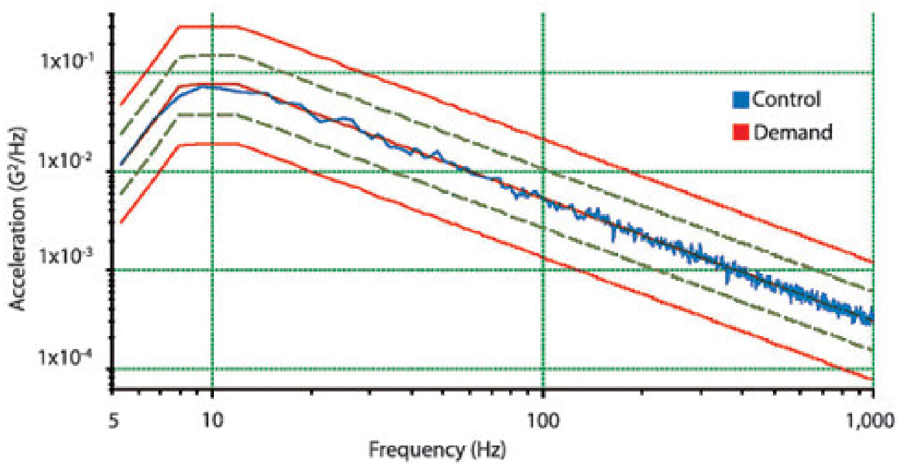


Figure 2b. Loop 2

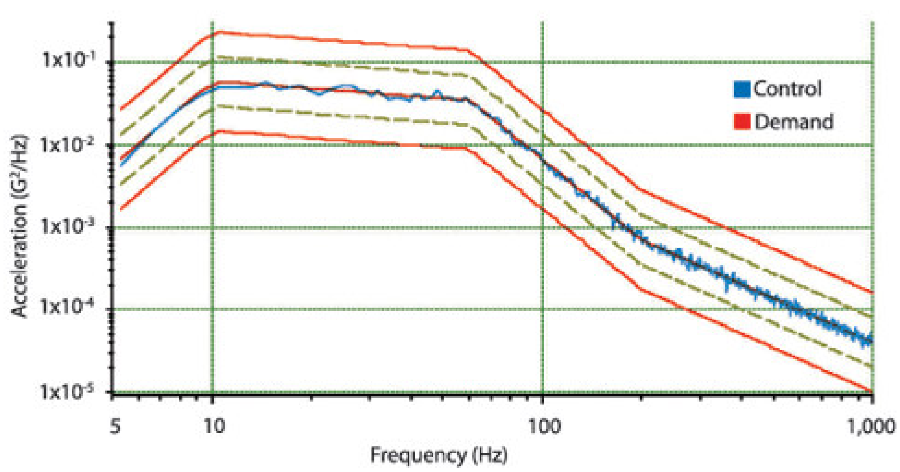


Figure 2c. Loop 3
Figure 2. Acceleration Profiles

Summary

As production cycles shorten, time to market becomes more critical. Product qualification testing, either in batch lots before the start of production or as part of the production process itself, can be a choke point in the production process.

The test requirements often demand frequency bandwidths beyond the capability of servo-hydraulic shaker systems. Traditional testing methods have relied on single-axis electrodynamic shakers to meet the frequency requirements. Until recently, cost-effective, multi-axis electrodynamic shakers and control systems were not available. With the availability of these systems and controls, product qualification managers now can look at more accurately reproducing real-world vibration environments and decreasing product qualification test times.

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