EDITORIAL

Understand Thy Test Standard or It May be Costly!

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When I answered the telephone, I recognized the voice of a former student. "Dr. McConnell, you know a lot about vibrations and testing." My first thought was to qualify that accusation, but instead I avoided a direct answer by using the old Irish trick of asking another question, "What's the problem?" (Former students never call unless they have a problem.) After receiving a short briefing about the general nature of the problem, it sounded like one within my realm of competence, so we agreed on a consulting arrangement.

My former student's company produces a widget that is used in an industrial process. They made field measurements of the vibration environment according to an industry test standard that assumed the vibration environment was 'random.' They then constructed an envelope over the measured ASD (Auto Spectral Density)[2] and used this envelope in the vibration controller to simulate the vibration environment. These tests predicted that the widgets would last forever, or at least for a very long time.

Of course, had that been the case, this little reunion would not have happened. I was called in because the widgets were failing at a high rate after one year of service. Why did the test procedures not predict this high failure rate? After all, they used the industry standard test procedure!

It took several hours of discussion to get to the bottom of what was happening. The typical industrial process in this particular case starts up very quickly, lasts for approximately 2 to 3 minutes with the apparent random vibration level decreasing with time while there were short periods of intense periodic vibration from a stick slip type of phenomenon occurring at random times. Hence, the first observation is that we were dealing with nonstationary random vibration and *not* a stationary random vibration as the test standard assumes. Second, it became obvious that the intense periodic vibration is suppressed by the long averaging time used in gathering the long random record and corresponding average ASD.

While making notes for this editorial, I experienced this sort of time history that many readers have also experienced. I was driving on a highway (though not while I was making notes) when an automobile pulled out a short distance ahead of me, so I hit the brakes hard to slow down. When I braked more lightly as I caught up to the vehicle, a stick slip vibration was felt. Hence, I felt the road noise non-stationary random vibration along with the intense periodic stick-slip vibration. Our problem is to isolate the short term intense periodic vibration from the long term random vibration for test purposes.

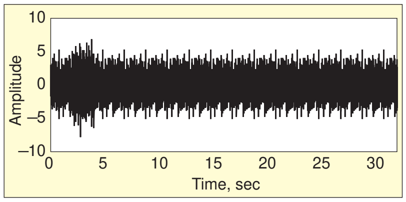

Figure 1. Combined periodic and random time history. The periodic signal occurs in the 2-4 sec time window.

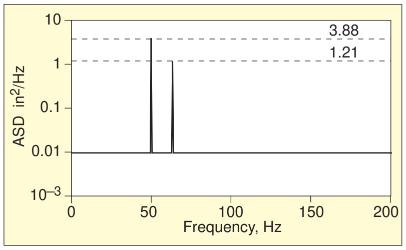

Figure 2. Auto Spectral Density of 2-4 sec time history segment.

The solution was to use an analysis method similar to that described by Mohamed Khalid Abdel-Hamid[3] where he examined the ASD of each window of data and sorted the results based on the RMS level in order to determine those blocks of data that include the intense periodic and random signals compared to those that were only a much lower random vibration. When this is done, we should be able to identify those blocks of data that are primarily low level random, and those blocks that contain both and are therefore of the most interest. Then, if we are careful and thoughtful, we can create a random frequency ASD spectra that shows a good estimate of the periodic spectra. In this way, we can see the at least near-true character of the periodic spectra.

The best way to explain the problem at hand is to use an illustration where a short periodic time history is combined with a long random time history. For this exercise, I selected two sinusoids, one at 50 Hz with an amplitude of 2.0 in. and the other at 63 Hz with an amplitude of 1.0 in., which produces a time history with a 1.582 in. rms amplitude, a maximum amplitude of 3.0 in., a minimum value of –3.0 in., and a mean value of zero. The random signal is generated using pseudo-random concepts. The ASD was uniform with an amplitude of 0.00978 in^2/Hz and a zero mean over the 0.5 to 256 Hz frequency range with a $\Delta f = 0.50$ Hz. The corresponding rms amplitude is also 1.582 in.. The corresponding time history has max and min values of 5.35 in. and –5.10 in., respectively.

The single 2 sec periodic signal is zero padded to create a 32 sec time history; i.e., one 2.0 sec non-zero block out of 16 total 2 sec blocks. The effective rms value for the 32 sec block becomes 0.395 in. or ¼ of the original 1.582 in. rms value. This clearly shows what happens when you perform ASD averaging with a frequency analyzer – the short time periodic values decrease with increased averaging time.

In contrast, when 16 (2 sec) pseudo random blocks are added end to end, the rms value as well as the max-min values remain the same as for a single block. Why? We are adding 16 equal inputs to be averaged over a period that is 16 times as long. Hence, there is a big difference between the short periodic signal's behavior and the continuous random signal's behavior when averaged over long time periods.

Now, add the two time histories together as shown in Figure 1. The periodic signal is in the 2-4 sec time block where a slight bulge occurs. For this combined signal, the maximum signal is 6.91 in. and the minimum signal is –7.85 in. The combined signal's RMS value has increased from 1.582 in. to 1.629 in. or 3%, a value that is hard to detect. However, if we examine the 2-4 sec time histories' ASD as shown in Figure 2 for $\Delta f = 0.50$ Hz, we find the random ASD values of 0.00978 in^2/Hz from 0.5 to 256 Hz. The periodic components stand out at 50 Hz (3.875 in^2/Hz) and at 63 Hz (1.207 in^2/Hz). These periodic components have peak values of 1.968 in. vs 2.0 in. originally at 50 Hz and 0.853 in. vs 1.0 in. originally at 63 Hz. Hence, the frequency analysis of the time block that contains the periodic components has a good chance of revealing these periodic components. The ASD for all of the other time blocks are the same as Figure 2 without the periodic components. Hence, when these blocks are averaged, the random part remains at 0.00978 in^2/Hz while the two periodic components are reduced to approximately 0.250 in^2/Hz and 0.0846 in^2/Hz, respectively.

So the bottom line is, "How can I find randomly spaced short term periodic signals that are buried in a long random signal?" The most useful methodology that I have found is to first save the time history so it can be analyzed in a number of different ways by using different length time windows. Second, analyze the signal with a given time window and save each calculated ASD and its corresponding rms value. Third, repeat the ASD and rms calculations with a shorter window and compare those rms values to the previous rms values. When the time window includes a significant portion or all of the short periodic record, its rms value should stand out as higher and the corresponding periodic ASD components should stand out as well. Eventually, we should begin to understand the unsteady characteristics and the periodic portion of the vibration environment. Only then, can we begin to apply a reasonable loading to test the widget.

A methodology similar to that described was applied in the case of my former student's widgets. The result was a significantly larger periodic excitation at frequencies near one of the widget's resonances. When these frequencies were included in the controller's signal, the widget's failures began to show up with reasonable times to failure where there had been no failures during previous tests.

Remember that test standards often contain compromises and assumptions that are easily hidden by the wording. Just assuming that the signal is 'random' is like saying that I bought a 'car.' It is not until I give a brand name, model and color that you have a good idea of what the car looks like, how it should perform, etc. So beware when you use a "standard test of the industry" without checking out just what may be different in your application when compared to the norm that is assumed in the standard. You might be in for a great disappointment (or at least a phone call to a former professor) if you do not do your homework.

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2. ASD (Auto Spectral Density) is the preferred name over the common misnomer of PSD (Power Spectral Density).
3. Abdel-Hamid, Mohamed Khalid. "Digital Analysis and Simulation of Nonstationary Service Loads," Ph.D. Thesis, Department of Engineering Mechanics. Iowa State University, 1981.

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