



THEORY: SINE SWEEP VS RANDOM VIBRATION TESTING

Sine sweep vibration tests are used much more for research than for acceptance testing. They are used to determine certain natural frequencies in structures, which should not coincide with excitation frequencies from the environment or the device. If the frequencies do coincide, then an endurance test can be conducted at the natural frequencies found. An endurance test is a form of fatigue testing. Lloyds Register, Germanische Lloyd, and other classification societies use these.

In a sine sweep test, we attempt to simulate real world situations by increasing and decreasing the vibration level. Some vibration standards which require a sine sweep vibration test give the user/designer free reign in choosing the vibration level (with suggestions based on possible applications).

However, in reality, the excitation is usually not a sine wave, but a much more complex signal. Unlike in a sine sweep test, some frequencies are of a much higher level than others. Excitation of these different frequencies typically occurs in parallel and not one after the other, as in a sine sweep test. A random vibration test is therefore a much better reflection of reality because it features the specific frequencies that can occur from, for instance, trains, cars, aircraft, etc., as well as near railroad tracks, and they also occur simultaneously. This interaction between such a varied and complex excitation and the natural frequencies and vibration forms in a device or system can result in a completely different pattern of damage. Incidentally, this does not mean that a sine sweep test is useless. It is quite useful when you are aware of its limitations and the possibility of overtesting and undertesting in certain frequency ranges.

A frequently used (military) standard, the MIL-STD-810, prescribes random vibration spectrums almost exclusively (as do, for instance, the ASTM standards for transport simulations, see ASTM D 4728). These spectrums are based on measurements. Where field measurements are not available, a standard PSD spectrum is required for a random vibration test as an acceptance test.


Sine sweep vibration tests (and related standards) came about in part because in the early days of formulating vibration requirements, a sine (sweep) vibration test was (practically) the only thing a vibration table could do. Modern electronics with software is much better suited for complex random vibration tests, especially when it comes to random-on-random or sine-on-random. For this reason, there is currently a movement underway to switch to random acceptance vibration tests.

Duration and vibration level

In a vibration test, duration plays a more important role with respect to fatigue. Almost all standards require an endurance test of at least one hour, and often up to a maximum of three hours. For endurance tests for two or more frequencies in a device, a total time limit is usually placed on the tests, e.g. 4 hours per direction.

For a random vibration test, in which the entire spectrum is excited at the same time, a timeframe is applied of at least 1 hour and up to maximum of 3 to 4 hours. Sometimes we look at the total product life that a device must be operational. To avoid extremely long vibration times, we can increase the vibration level.

If a measured vibration spectrum is expected to occur for 1000 hours over the operational life of a device, it would be a costly affair to carry out a vibration test of this kind. For three directions, you would have to run vibrations for 3000 hours. MIL-STD-810, among other standards, gives a method for reducing vibration time by increasing vibration level.



Increasing the PSD spectrum by a certain factor enables us to either reduce the vibration time or simulate a longer vibration time. The equivalent vibration time is the product of the “standard” vibration time and the fourth power of the ratio between the increased PSD level and the one from the norm. Or expressed as a formula:

Tequivalent = (selected PSD level : standard vibration level)⁴ x testing time

Example: A PSD level multiplied by 2 gives us a simulated duration that is 24 times the original vibration time for the test. Theoretically, you can set the vibration level so high that it reduces a vibration time of one hour down to, say, 1 minute. In practice, a minimum of 1 hour and a maximum of 3 hours are typically applied per direction as a general rule. If we reduce the vibration level by a factor of 2, then we will have to extend the vibration time by a factor of 16 (= 2⁴).

Note: The fourth power (as a conversion factor) is an average value. It varies between approx. 2-6 depending on the materials or products being tested.

Ageing/fatigue:

For devices, housings, or components, you could theoretically simulate the entire product life in a single vibration test using the above method. One requirement for this is that a reliable vibration spectrum be available. It is also a question of whether this is necessary, and if so, what conversion factor should be used.

For fatigue, we generally assume a maximum of 10⁶ to 10⁷ changes because in excess of that amount the delta peak-to-peak value for fatigue does not change. If you include this in the sine vibration requirements and compare it with these values, you will never get this number of changes.

Example:

In a sine sweep test with a speed of 1 octave per minute, we vibrate at 16 Hz (as natural frequency of a component in the device) for around 6-7 seconds. This corresponds to 7x16 ≈ 110 changes per sweep. So, at 10 sweeps up and down (around 1 hour of vibration), the device will only get a total of 2x10x110 = 2,200 changes at that frequency. Yet this is only a fraction of the expected product life or of the 10⁶ changes in fatigue tests. At higher frequencies, the duration per frequency decreases (logarithmically), which means the number of changes only increases slightly. At lower sweep speeds, such as 0.5 oct/min, the number of changes may well double, but this is quite different from a real fatigue test.

In a sine seep vibration test, time as a factor plays a very limited role when it comes to ageing. Thus, a sine sweep vibration test is often used to pinpoint critical natural frequencies for or in a device, followed by an endurance test for the frequencies found in the area of interest. An endurance test of one hour at a frequency of 16Hz is equivalent to 3600x16 = 57,600 changes, which is significantly more than with the sine sweep test.

Conversion of a sine seep test into a random vibration test
The frequently used MIL-STD-810 standard states that a 1-to-1 conversion of a sine sweep test to a random vibration test is not possible and that a measured vibration level is the best basis for formulation of vibration requirements.