Designing Test Fixtures for Vibratory Accelerated Life and Screening Tests

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Abstract:

A well-designed vibratory Accelerated Life Test (ALT) will ensure the acquired data can be used to characterize the dynamic parameters of a product as well as screen its endurance capacity. Dynamic characterization enables decision makers, using correlated structural models, to assess the product's fitness for service, significantly compressing the time to market compared to employing testing alone.

In optimizing a design; avoiding both an overdesigned product or one which has too high of a risk exposure; good dynamic characterization is essential. A well-designed test fixture facilitates recovering response data for characterization of a product as well as ensuring the screening requirement of the ALT has been met. Test fixture design considerations are the focus of this brief.

Background:

The types of vibratory Accelerated Life Tests (ALT) traverse the continuum from broadband random to narrowband harmonic spectrums. Each type of test has characteristics which lend themselves to meeting specific goals of a reliability program.

Typically, broadband random inputs are produced by employing a shaker table imparting motion at the base of the test article using an electrodynamic actuator. Figure 1 is an example of such a device.

Figure 1- Shaker Table

The electrodynamic actuator is used in a closed loop feedback system to produce the specified motion over a desired frequency range. Random motion is defined by the profiles of Power Spectral Density (PSD) curves. The units are g^2/Hz with the motion normalized to frequency so that the profile is the same regardless of the spectral line resolution and defined in terms of power since there is no phase relationship maintained across the spectrum. The square root of the integrated curve is the RMS level input. Since the mean input is zero, the RMS value equals the standard deviation (1σ) of the spectrum.

Employing PSD excitation for vibration screening became prominent during the early U.S. Space Program. The NAVMAT spectrum, in Figure 2, became a de facto standard for vibratory endurance screening.

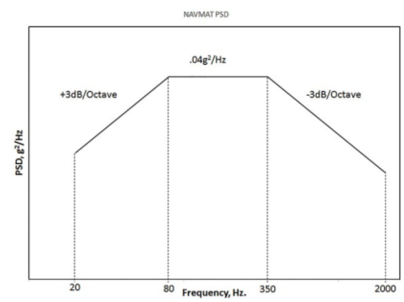

Figure 2 - NAVMAT

In addition to random testing, electrodynamic actuator systems are also used for sine sweeps, dwells and shock. The closed-loop system enables a high level of precision in control of the motion imparted to the test article regardless of the type of vibratory input.

Unidirectional input is a limitation of electrodynamic shaker tables. Each test is done on a per axis basis. Another approach, which addresses the unidirectional limitation, is the repetitive shock table. Figure 3 is an example of such a system.

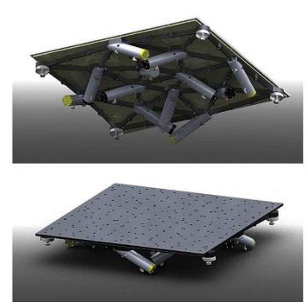

Figure 3

Pneumatic actuators are used to produce motion in all six degrees of freedom, three translational and three rotational axes. The motion is pseudo-random. No closed loop control is involved and, therefore, the spectral content is not controlled in real time. The primary use of this type of testing is to quickly identify the weakest feature in the component by driving it to failure with a specific highly accelerated screening test.

Compressing Development and Testing Time:

In bringing a product to market, the value of ALT can be multiplied significantly when coupled with analytical models. Using models to develop data acquisition plans and then using the data for correlating the models compresses the time in bringing a product to market. The time compression is actualized by reducing uncertainty. Models help identify not only the weakest link in the system but also enable the identification of other features which will become the weak links once the initial limiting feature has been addressed. The design process becomes parallel rather than serial.

By properly locating both strain gages and accelerometers on the test article, the responses during a PSD test can provide information to correlate dynamic models. The structural model is employed to develop a data acquisition plan and the acquired data is then used to correlate the natural frequencies, damping and vibratory patterns with the empirical data.

Due to *a priori* knowledge provided by the model, relative accelerometer measurements can be used to easily identify elastic modes in the test article. Employing two types of measurements; strain gage and accelerometer measurements; provides a means for analytical falsification eliminating the potential of a circular process. The use of both motion and strains enables confidence in correlating models which are not self-referencing but have predictive power.

By cross correlating narrowband pass filtered strain measurements at the natural frequencies, the signs of the cross-correlation coefficients enable vibration patterns to be assessed. Damping can be estimated from auto-spectrums of the accelerometer measurements using the half power method. For more information on the half power method, reference Estimating Damping Values Using the Half Power Method. Analysis leading design creates relatively little overhead and simultaneously provides a wealth of information to reach market goals.

Ensuring Test Compliance:

For the test to be meaningful, the motion imparted into the test article is required to be at the levels defined by the governing specification. One way this objective can be defeated is by the fixture, securing the test article to the table, having mass-elastic participation in the frequency range of the test. This problem occurs frequently and it is insidious in that it often occurs without it being identified. It not only defeats the primary objective of the test but it also complicates the effort of correlating a model. Proper design of test fixturing is essential to ensure both testing and correlation are productive activities.

When mass-elastic participation of the test fixture occurs in the test frequency range, it distorts the motion imparted to the test article from the shaker. The test article's mass participation in the fixture mode increases the impedance between the fixture and test article. At higher frequencies, this reduces the body forces carried by the test article.

A simple 2 DOF model, in Figure 4, is used to illustrate this behavior.

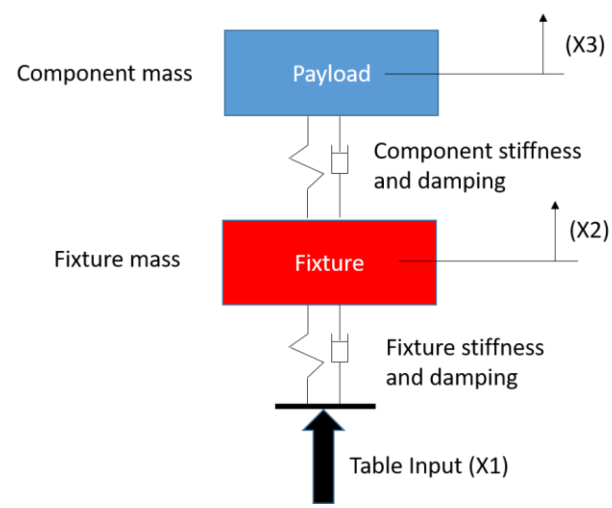

Figure 4

The motion imparted by the shaker is transferred into the test article (payload) without distortion (i.e., X1=X2) if the fixture acts as a rigid body in the frequency range over which the test is conducted. If the fixture has an elastic mode in the frequency range, however, the mass participation of that mode will distort the motion transferred.

In this simple example, the test article's weight is 100 lbs., has a damping value of 2 percent (i.e., Q=25), and a fundamental frequency at 50 Hz. A sine sweep of 0.01 g is imparted by the table across a 100 Hz frequency range. A properly designed fixture, with a 0.01 g input, will result in a load carried by the test article of 25 lbs. at resonance. This is shown with the orange curve in Figure 5.

The blue curve is the load carried by the test article with a fixture mode at 6 Hz. The peak value is less than the maximum of 25 lbs. and occurs at the lower frequency resulting in significantly less accumulated damage than a test with a properly designed fixture.

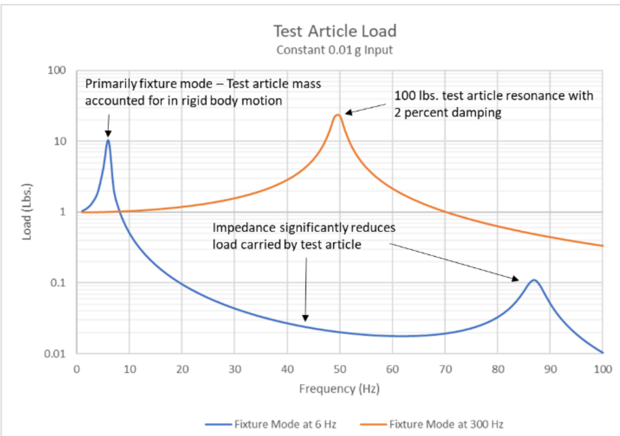

Figure 5

Guidelines in Test Fixture Design:

- Stiffness to Mass Ratio:

The stiffness to mass ratio of test fixtures should be maximized and have its first natural frequency; accounting for the payload mass; at least 3 times higher than the maximum test frequency range. Maximizing the fixture's stiffness to mass ratio will minimize the mass overhead on the shaker table, maximizing its utilization potential.

- Eliminate Flexural Load Paths:

To maximize the fixture's stiffness, the load path from the test article through the fixture and into the table should be primarily carried by direct or shear stresses. Flexural load paths should be avoided due to the inherent flexibility of such features.

- Fundamental Frequency Target:

Prior to testing, the fixture should be modeled with the connection points to the shaker table grounded and the payload accounted for with a mass element located at its center of gravity and accounting for its complete mass properties.

The mass element should be connected to the fixture at the appropriate interface points with workless constrain equations. These are typically referred to as RBE3 elements. Kinematic constraint equations should not be employed since they artificially stiffen the fixture. A modal analysis is executed to ensure that the first fundamental mode of the fixture is at least 3 times greater than the highest frequency in the test range.

Conclusions:

For a vibratory test to be meaningful, it is imperative the motion imparted into the test article is not distorted by the test fixture. Considering the expense of testing and more importantly the opportunity costs associated with using compromised data, modeling the test fixture to ensure its fundamental frequency is out of the test range should be considered a minimum requirement in any durability program.

Reducing uncertainty in the design process is how correlated models compresses time to market. To achieve this objective, using analysis to lead data acquisition plans and using the empirical data to correlate them should always be considered. Correlated models provide both explanatory and predictive power as design alternatives are considered in developing a product. Using analysis to lead a program rather than having it play an ancillary role provides significant efficiency gains and superior design results.