VIBRATION TESTING OF

PRODUCTS AND PACKAGE SYSTEMS

PREPARED BY

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I. INTRODUCTION

Before the job of the production and engineering groups at any company is completed, a product must be manufactured **and delivered** to the ultimate customer and be put into useful service. While this may seem like a simple and straightforward concept, it implies strongly that the product must pass through **and survive** the distribution environment. Of particular note is the fact that a substantial amount of vibration exists in the distribution environment; probably more than in any other separate element of the product life cycle.

The vibration content of the distribution environment is known to be potentially harmful to nearly all products. This can range from a very small amount of potential harm to a near destructive capability a high percentage of the time. Much of this is dependent on the product and package **response** to vibration input.

The approach normally recommended for protecting products from vibration in the distribution environment involves the following steps:

1. **Define the likely inputs from vehicles in the distribution environment.**

2. **Define product sensitivities to vibration input.**

3. **Determine the vibration characteristics of commonly used cushion materials.**

4. **Design and test the package system that will properly attenuate vibration input at product "critical frequencies".**

II. DEFINING THE DISTRIBUTION VIBRATION ENVIRONMENT

Defining the vibration distribution environment amounts to defining the characteristics of vehicles in which products are likely to travel because this is the primary source of the vibration input.

The job is accomplished by placing accelerometers or other sensing devices on various parts of vehicles and measuring the amount of vibration present at that particular point. By monitoring a large number of vehicles in various load configurations (empty, moderately loaded, heavily loaded) over different road conditions, a good summary or average input can be determined. Truck, rail and aircraft are characterized in the same basic manner.

Much of this work has been previously accomplished and has been summarized in manuals such as the FPL22 report generated by the Forest Products Laboratory in 1979 (1). The normal format for the data is a **power spectral density** (PSD) plot which shows the acceleration density level over the frequency band of interest. Because the input from distribution vehicles is complex and random in nature, this winds up being the best way to present the information.

A summary of the envelope plots typical of various types of vehicles is presented in figures 1-4. These show truck, rail, and aircraft spectrum and a composite spectrum such as that found in ASTM D4728,(2) the random vibration test procedures for packages. (See Figure 5)

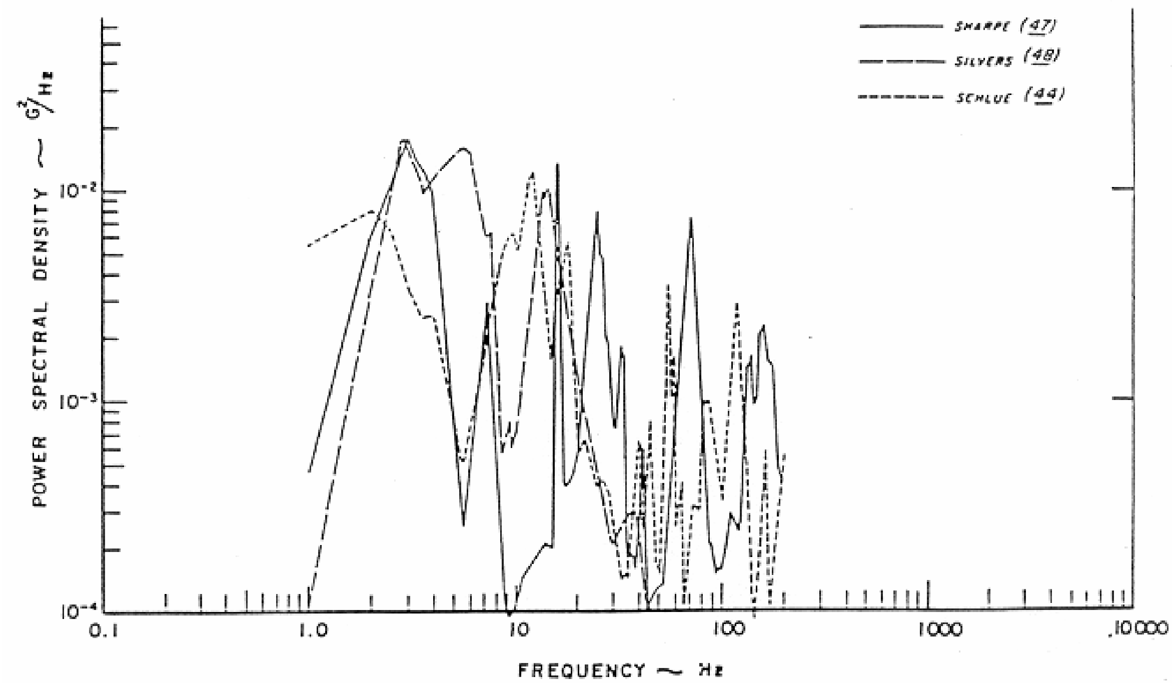

Figure 1
Truck Frequency Spectra, Summary of 3 Studies, source (1)

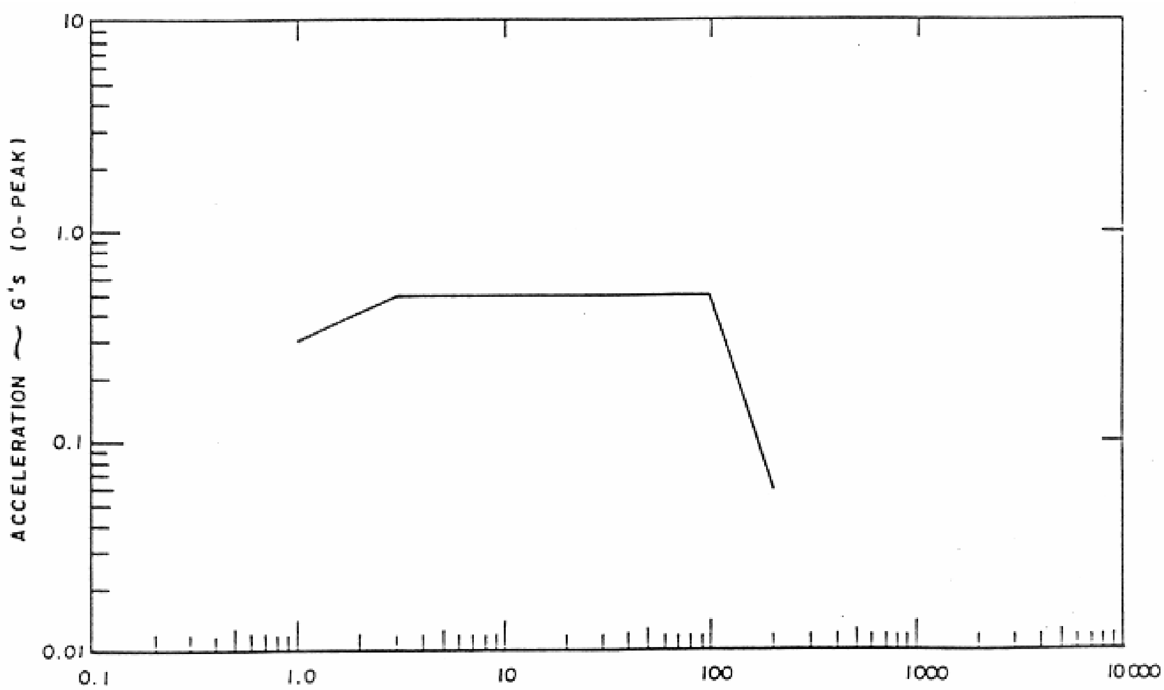

Figure 2 – Truck Vibration "Envelope" Spectrum, source (1)

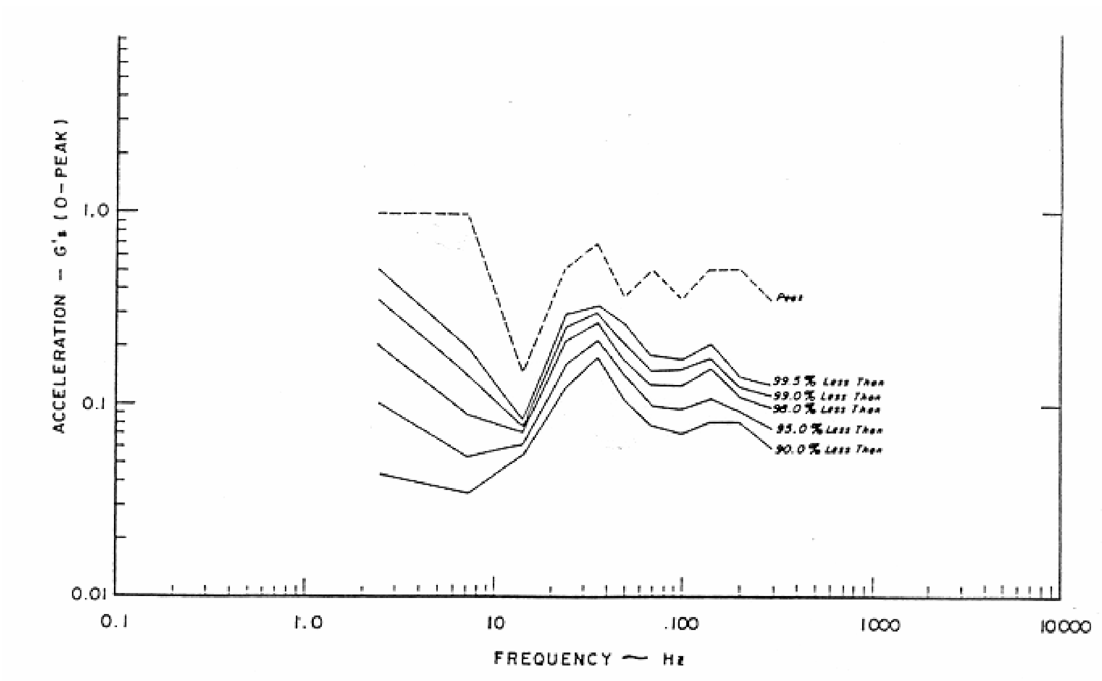

Figure 3 – Rail Frequency Probability Spectra, source (1)

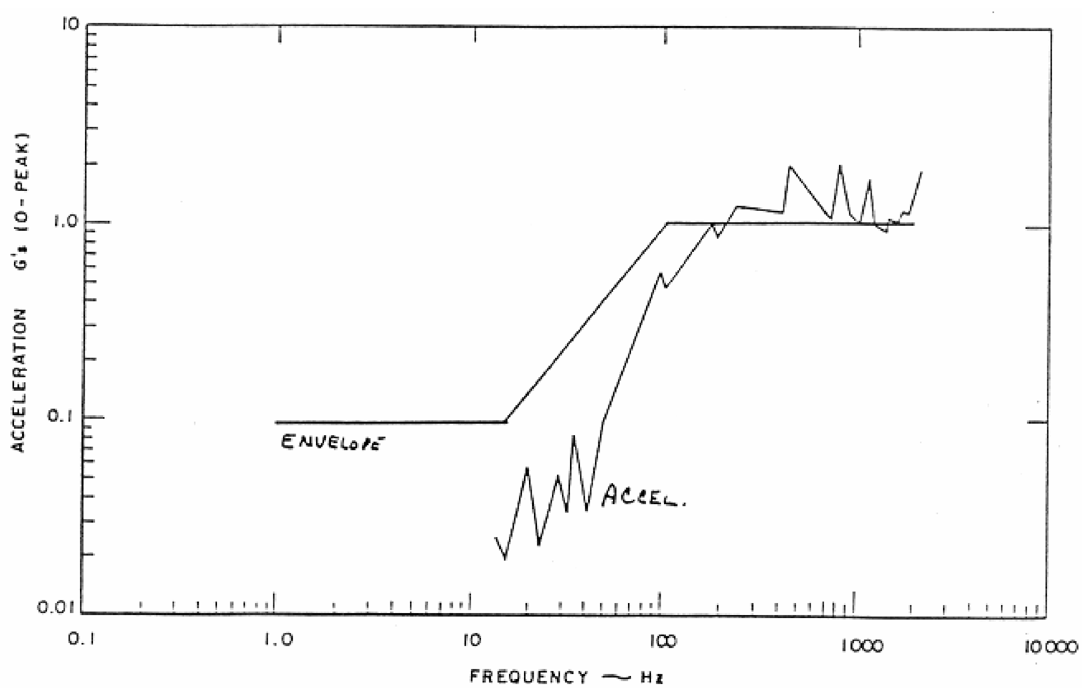

Figure 4 – Turbojet Aircraft Acceleration Spectrum and Envelope PSD, source (1)

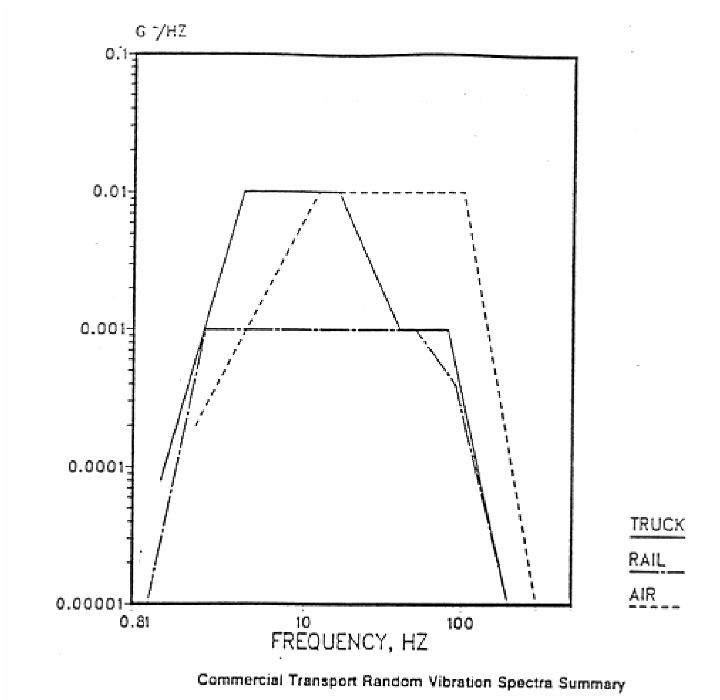

Figure 5 – Composite Envelope Spectra, source (2)

Other specialized vibration components of the distribution environment include lateral side sway on railcars and the rolling and pitching motion of ocean-going vessels. Those will not be dealt with at this time, although one should recognize that any product sensitive to this type of motion should be investigated and tested.

Truck transit is considered the most severe of any input likely in the distribution environment. Here's what FPL-22 concluded:

> (The data) shows, for example, that trucks impose the severest vibration loads on cargo with the railcar next, followed by ship and aircraft. The jet aircraft shows high vibration levels at high frequencies, but these are not considered damaging to general cargo. Many transportation vehicles and systems remain to be defined... However, the environment appears to have been described for the severest condition, i.e., **truck transport,** which is present in almost every distribution cycle. source (1)

III. PRODUCT VIBRATION SENSITIVITY TESTING

Product vibration sensitivity results from exciting critical components within the product at their natural or resonant frequencies, resulting in scuffing, fatigue and stress failure. As a general rule, products will not be damaged as a result of non-resonant loading caused by vibration typical of the distribution environment. The acceleration levels of most vehicles are relatively low when compared to the critical acceleration levels of most products. It is only when a component of a product is excited at its natural frequency that damage is likely.

The traditional method for vibration sensitivity testing was a sinusoidal resonant search test as described in ASTM D3580. To run this test, a monitored product was subjected to a vibration sweep over the frequency range of interest, typically 3 to 300 Hz. Resonances within the product were monitored and plotted for future study. The transmissibility plot that resulted described the natural frequency and amplification level of various components (see Figures 6 & 7).

This test procedure may result in significant overstressing and therefore a distorted quantification of product vibration response. Random vibration (rather than sinusoidal) may be a much better approach. It has been used extensively by military and aerospace test engineers. Significantly it allows for the natural interaction of spring/mass systems within a product to occur as they would in normal distribution. In general, the response of a product to random vibration will be less extreme than for single frequency sinusoidal inputs, especially at component resonance.

A product resonant search test using random vibration input has gained substantial popularity in the past several years. The reason for this popularity includes the availability and lowering prices of P C based analyzers necessary to properly interpret the data as well as the recognition that the random vibration test is possibly more accurate and a better predictor of actual vibration performance of a product.

When excited or vibrated in the distribution environment, the input is almost always of a quasi-random nature. This means that all harmonics within the product are simultaneously excited at various amplitude levels. The random vibration test attempts to duplicate this type of excitation and the product response to it. By analyzing product responses to this random vibration input, a more realistic characterization of the product sensitivity can be determined.

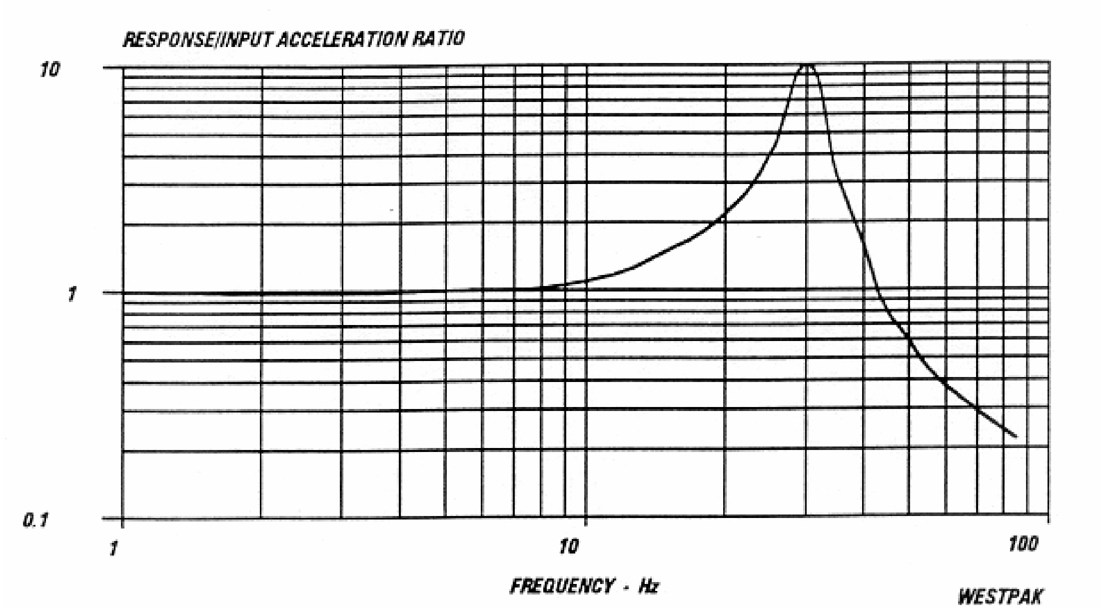

Figure 6 – Theoretical Product Transmissibility Plot, source - Westpak

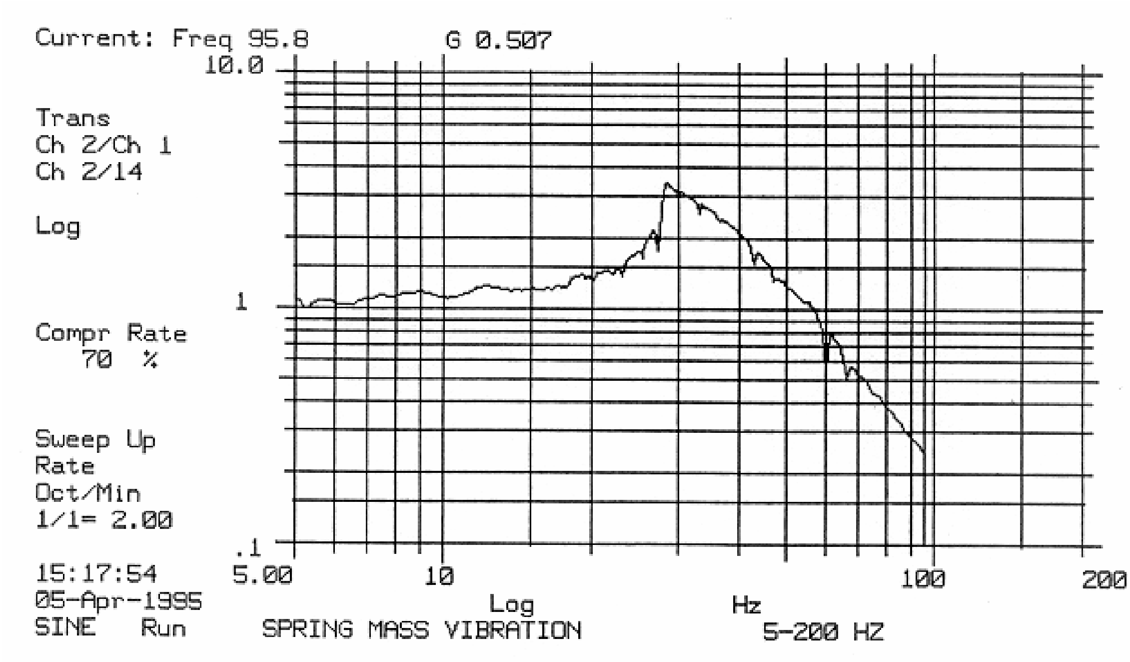

Figure 7 – Actual Product Vibration Response Data, source - Westpak

While no "offically sanctioned" procedure exists for running the test, the generally accepted and followed practice starts with monitoring flexible or sensitive components of the product with accelerometers. The product is then fastened to the table of a suitable vibration test machine and subjected to a random vibration profile with a "reasonable" acceleration content. Reasonable in this case would normally mean a .5 G rms random vibration spectrum is normally used. (See Figure 8)

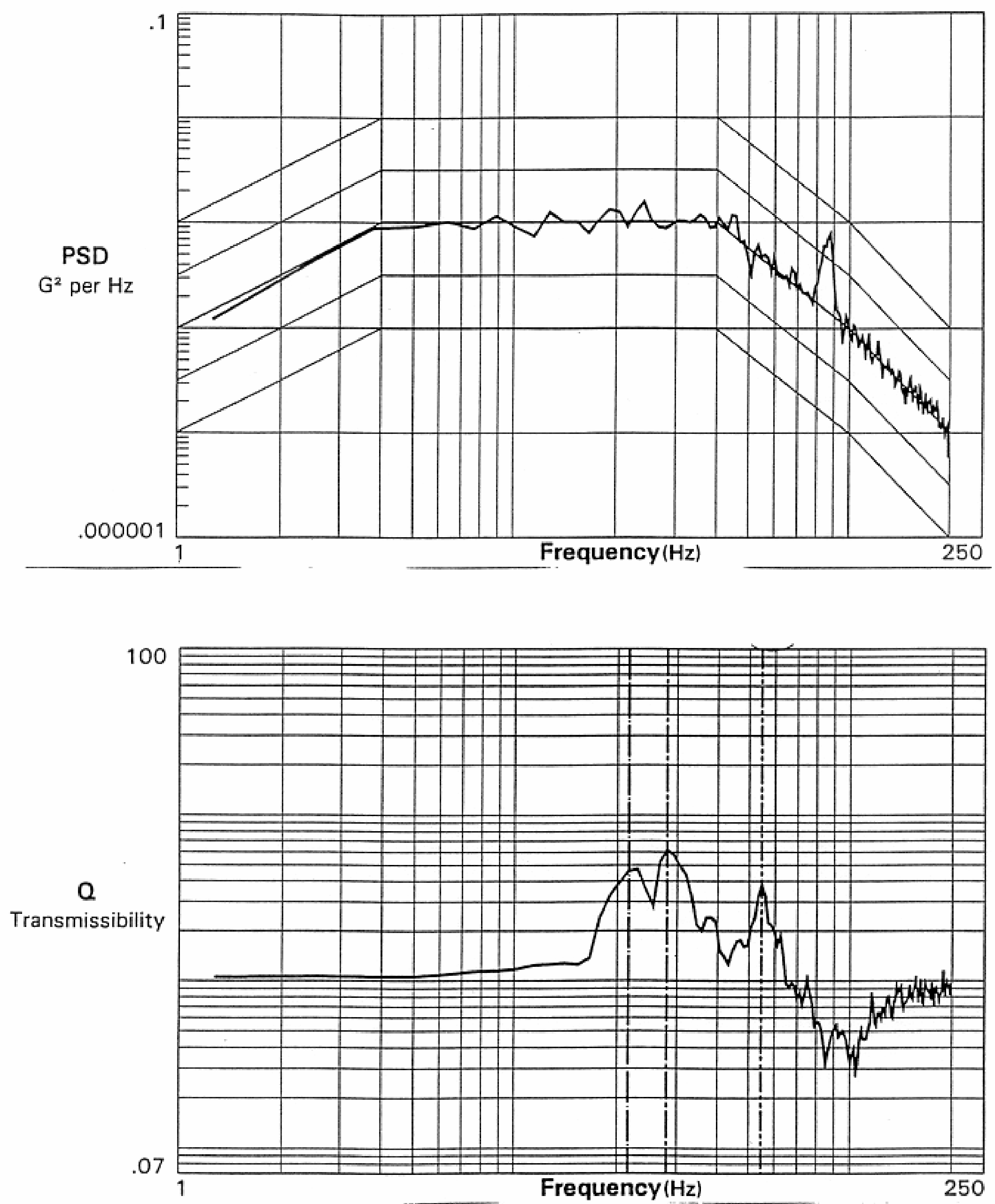

Figure 8 – Product Response to Random Vibration Input (top) and Resulting Transmissibiity Plot
source - Westpak

IV. CUSHION VIBRATION PERFORMANCE

The vibration characteristics of cushion materials are determined by subjected them to vibration inputs over the frequency range typical of the distribution environment. The procedure involves placing a test block on top of a cushion to form a spring-mass system. The resonant frequency of this system is determined by placing it on the table of a vibration machine programmed to produce a sine input of coISTAnt acceleration of 1/2 G, while the frequency is slowly changed (or swept) from low to high, typically 3-300 Hz. The response/input ratio is plotted as a function of frequency, producing the transmissibility plot shown in Figure 9.

Resonance is that characteristic of all spring-mass systems where, at a given frequency, response acceleration is greater than the input. The resonant or natural frequency is the point where maximum response of a spring-mass system to forced input occurs. The test setup to produce these data is shown schematically in Figure 10.

The mass of the test block is changed in order to vary the static loading on the cushion, and the test is repeated. Different plots are obtained in this fashion, as shown in Figure 11. A series of five sweeps is recommended to plot the amplification/attenuation (A/A) plot shown in Figure 12. (Actual test data shown in Figure 13)

The A/A plot shows frequency on the vertical axis and static stress loading on the horizontal axis. The center portion is that combination of frequency and loading that results in amplification of vibrational input. This is called the **amplification zone**. At lower static stress loadings and frequencies, there is a zone where the response/input ratio is approximately 1. This is the unity zone where the cushion material neither amplifies nor attenuates the input. At higher frequencies and static loading levels, the cushion material will attenuate (reduce) vibration input. This area is called the **attenuation zone**.

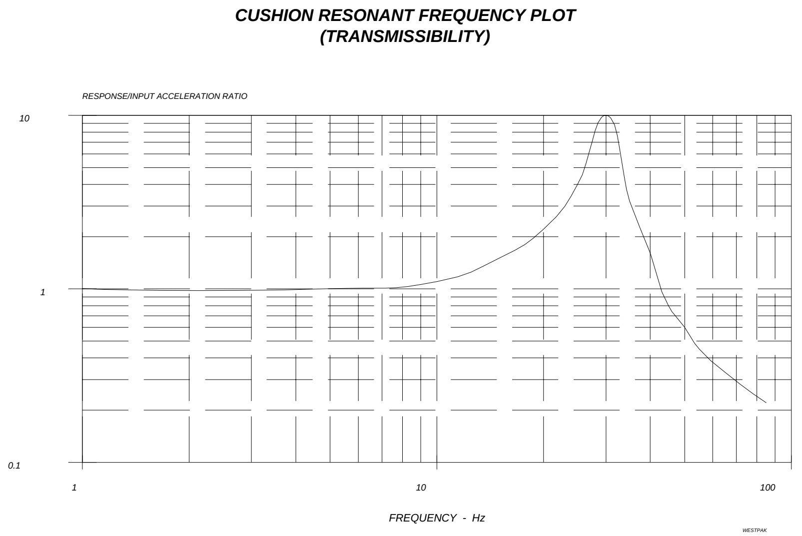

Figure 9 – Cushion material transmissibility plot for one static stress loading and one thickness, source - Westpak

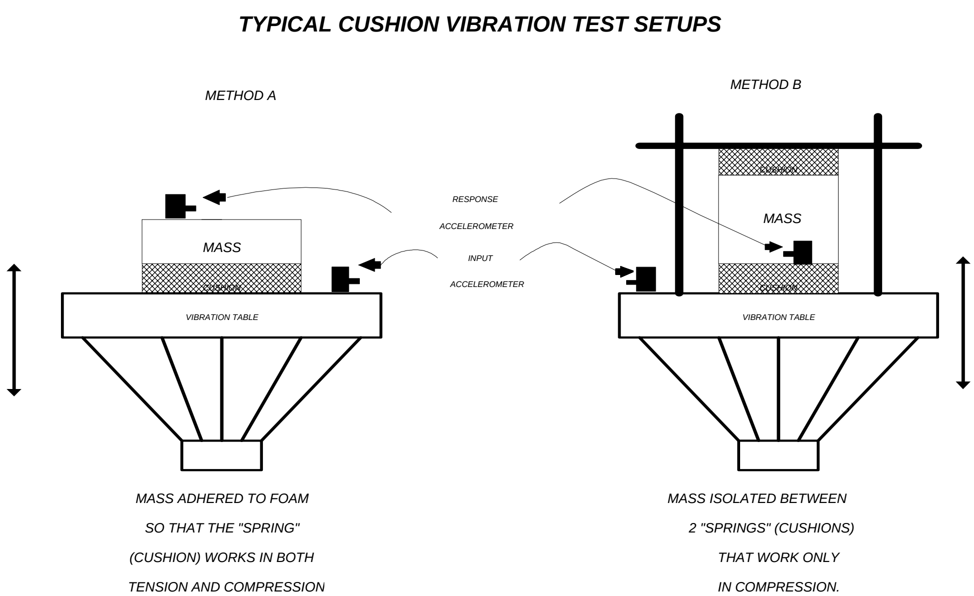

Figure 10 – Vibration test setup, source - Westpak

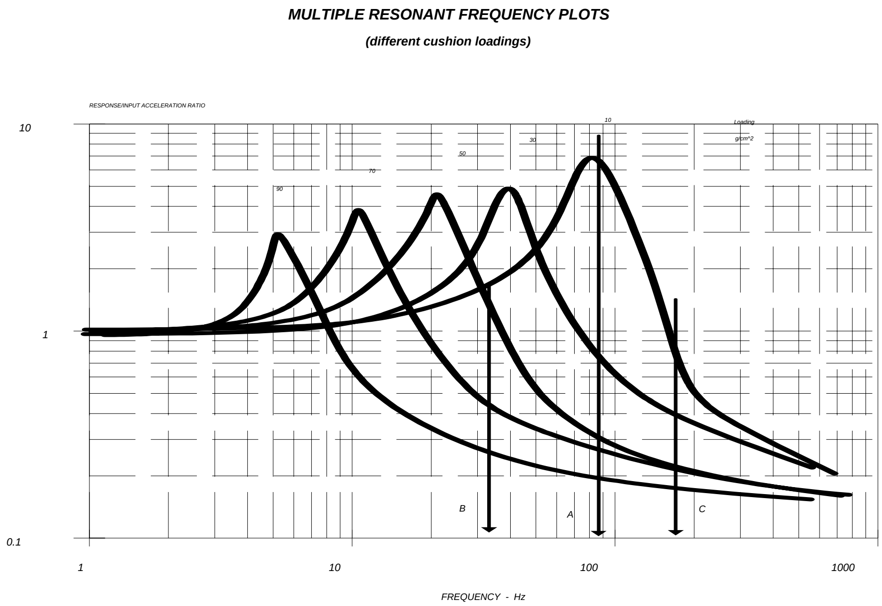

Figure 11 – Multiple transmissibility plot, source - Westpak

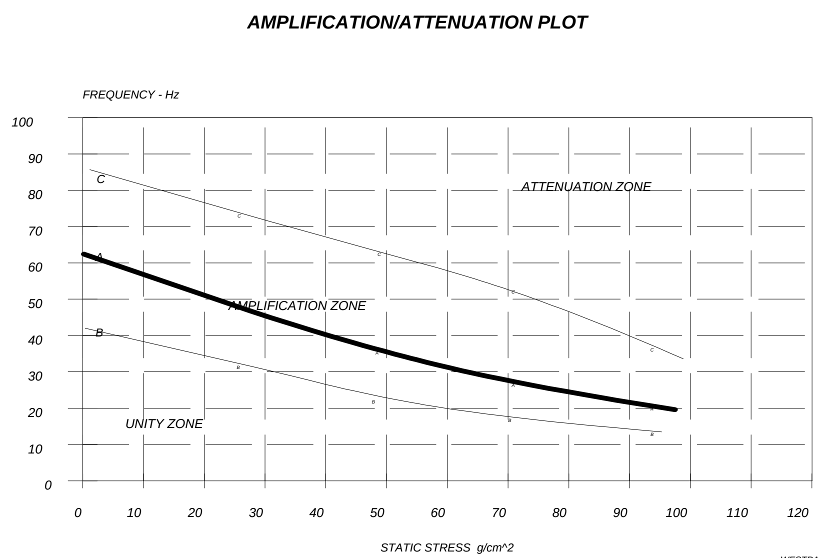

Figure 12 – Amplification/attenuation plot, source - Westpak

The plot in Figure 12 may be interpreted as follows. For a given frequency, the lower static stress loadings result in the same acceleration transmitted to the product as the input. In other words, the response/input ratio is approximately 1. As the static loading level increases, there is a range in which the cushion material amplifies the vibration input. At higher static loading levels, the cushion material attenuates vibration input and the response/input ratio is less than 1.

At the present time there is no recognized standard governing the procedure for running cushion vibration tests. Much of the data currently published were produced using the Fixture Method. This fixture is a device for restraining a test block in two axes while allowing it free movement in the vertical axis. A cushion sample is placed above and below the block and the entire fixture is mounted on the table of a vibration test machine. The remainder of the procedure is identical to that described earlier. Other procedures, including the use of the Enclosed Test Block as described in ASTM D4168 are also commonly used.

Random vibration may also be used in place of sinusoidal vibratin and may result in more accurate and reliable data.

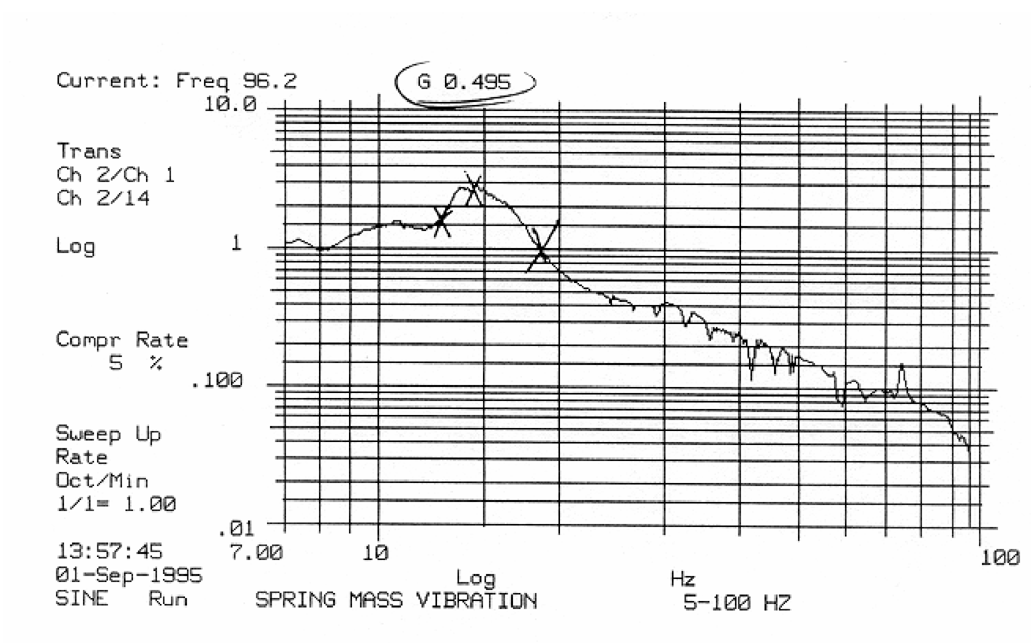

Figure 13 – Actual cushion vibration test data, source

V. PACKAGE DESIGN AND TESTING FOR VIBRATION

When analyzed as a mechanical spring, the job of the package is to filter out or attenuate those frequencies from the distribution environment that are harmful to the product. This is accomplished most effectively when the natural frequency of the package/cushion system is 1 octave less than the lowest product critical frequency. The reason this approach is normally successful is that the lower frequency bands are generally not an area of high sensitivity to the product. Also, package cushion attenuation will normally occur at product critical frequencies if the cushion resonance is well below product resonances.

The situation can also occur with stiffer cushion materials where package resonance at higher frequencies represents a good design compromise. This is especially true for heavier products that are rigidly mounted and do not display high amplification at resonance. Cushion materials for which this design parameter makes sense include expanded polystyrene (EPS) and molded pulp cushions.

When the cushion vibration characteristics are presented in an amplification/attenuation plot, it's easy to determine a static stress loading that will result in the proper vibration characteristics for the package. This is especially true if the vibration testing on the cushions was accomplished using a random vibration input. Experience has shown that this results in a more accurate design criteria and better results during the package testing itself.

Package system testing in the past has taken many different forms including sinusoidal resonant search and dwell tests, repetitive bounce tests (ISTA style), and similar procedures.

What probably makes the most sense is to conduct the package response testing using random vibration input. For this test, the input spectrum should be that called out in ASTM D4728(2) or something similar. A minimum of two response channels should be included in the test. The first channel should be connected to a rigid portion of the product in order to determine the natural frequency of the cushion material itself. A second channel should monitor one of the flexible components earlier characterized in the product testing. The criteria for this channel should be a response level which is less than the responses noted during the product testing.

The criteria recommended by NASA during the 1980's was a six decibel reduction in response amplification at the product natural frequencies using a random vibration input.

It's important to remember that a "protective package" can actually destroy a product if the cushion is loaded to resonate at the same frequency as the product "critical components" also resonate.

VI. CONCLUSIONS

Vibration in the distribution environment is a certainty.

The harmful effects of vibration input can be disastrous on a product.

Trucks represent the worst vibration environment in transit.

Testing for product vibration sensitivity is easy, simple, and non-destructive.

Random vibration testing probably makes more sense than sinusoidal tests.

Cushion vibration testing is also relatively easy, simple, and straightforward.

Random vibration testing for cushion vibration characteristics also makes sense.

Package design and testing for vibration input is likewise relatively straight-forward.

Why would anyone call themselves a package designer or packaging engineer without investigating this area?

References:

1. Ostrem, Fred E. and Godshall, W. D., "An Assessment of the Common Carrier Shipping Environment", General Technical Report FPL22, Forest Products Laboratory , Forest Service, U. S. Department of Agriculture, Madison, WI, 1979.

2. ASTM D4728 - 91, "Standard Test Method for Random Vibration Testing of Shipping Containers".

3. Westpak Test Data.

4. Bakker, Marilyn, "The Wiley Encyclopedia of Packaging Technology", John Wiley & Sons, New York, 1987.

5. MIL-HDBK-304B, "Package Cushioning Design", Packaging Evaluation Agency (AFALD/PTPT), Wright-Patterson AFB, OH.