PACKAGING DYNAMICS #3 of 5
Product Shock & Vibration Sensitivity Assessment

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Agenda

• Review of Webinars #1 & 2
• Stimulation vs. Simulation
• The concept of RESONANCE
• Vibration Sensitivity
• Shock Fragility – How Things Break
• Damage Boundary Theory & Test Procedure
• Instrumentation Requirements
• Q & A (hopefully...)

WESTPAK, INC. Excellence in Testing
Review of Webinar #1

• History and background of Packaging Dynamics
• Terminology and Lingo
  – Time domain Vs frequency domain
  – Single degree of freedom spring mass system
• Common Packaging Dynamic hazards
  – Vibration
  – Impact (shocks and drops)
  – Compression (static and dynamic)
Review of Webinar #1: Shock Input and Response
Step 1 • Define the Environment
Step 2 • Define Product Fragility (or Sensitivity)
Step 3 • Cushion Material Performance Evaluation
Step 4 • Package Design
Step 5 • Test the Product/Package System
Define the Distribution Environment by QUANTIFYING all the Hazards Capable of Causing Damage to our Product.

- **Impacts**: determine the anticipated drop height range, number, and orientation of the likely impacts
- **Vibration**: Determine the vibration spectrum that envelopes all the vehicles in which the product will likely travel
- **Temperature & Humidity**: Determine extreme levels and likelihood of occurrence.
- **Top Load Compression**: Quantify the max stack height and duration in distribution and storage.
- **Altitude**: Determine the maximum altitude exposure (minimum pressure) for both truck and aircraft shipment.
Review of Webinar #2

**SOURCES of INFORMATION:**

- Direct Measurement of the Distribution Environment
- Literature Search and Historical Records
- Observation
- Damage Claims

**Other Concerns**

- Cost of Data
- Validity of Data
- Time to Collect Data
Product Fragility Assessment

Step 1
• Define the Environment

Step 2
• Define Product Fragility (or Sensitivity)

Step 3
• Cushion Material Performance Evaluation

Step 4
• Package Design

Step 5
• Test the Product/Package System
Product Fragility Assessment

We’d like to QUANTIFY this bar.

PROTECTIVE PACKAGE: That device which limits environmental input to a level below product fragility.
Define the Terms

“Fragility”

“Sensitivity”

“Ruggedness”

All mean the same thing: “How much can the product take before damage or failure occur?”.

Think of it this way:

Fragility is an innate product characteristic, just like color, mass, & physical dimensions are all product characteristics.
Define the Terms

What constitutes “Damage” or “Failure”? 
• Varies from product to product 
• Varies from company to company 
• Varies from place to place

Shipping pacemakers? 
Not even a hint of damage tolerable...

Shipping jigsaw puzzles? 
10 – 15% cosmetic damage is OK
Define the Terms

Westpak recommends that “damage” be defined as any condition or defect that you would not want your best customer to experience.

• This may be as minor as a slightly misaligned flange or minor scuffed finish.
• Or it may be an electronic product that’s DOA.
• It’s your choice but it needs to be defined **BEFORE** sensitivity testing begins.
Why is vibration important?

• It 100% certain to occur (impacts are a probability function only)
• The negative effects of vibration can be disastrous
• If the product and the package have the same natural frequencies, fatigue damage is likely
• Global distribution of products will result in a theoretically large increase in vibration exposure
Product Vibration Sensitivity

Vibration Sensitivity testing consists of identifying the product resonant frequencies – and amplification levels - in the bandwidth of distribution vehicles.

Trucks & Rail: 1-200 Hz
Aircraft: 5-300 Hz
What is “Resonance?”

Resonance is that characteristic of all structures (analyzed as spring/mass systems) wherein the response to a vibration input is greater than the input itself.

Response > Input

You have likely experienced that annoying rattle in the car or buzz in a rotating piece of machinery. Those are examples of resonance.
Spring/Mass Systems

All products can be characterized as a spring/mass system.

The simplest system is a single degree of freedom (SDOF) spring/mass system (without damping).

\[ f_n = \frac{1}{2\pi} \sqrt{\frac{Kg}{W}} \]
Spring/Mass Systems

Other Spring/Mass systems...

FIGURE 1.4 Single-degree-of-freedom systems.

FIGURE 1.5 Two-degree-of-freedom systems.
Spring/Mass Systems

Products are normally pretty complex and a multiple degree of freedom (MDOF) model is more appropriate, but also very much harder to analyze.
Spring/Mass Systems

• When excited at its natural or resonant frequency, the system shows its maximum response and this is precisely where damage is likely to occur.

• The transmissibility plot shows the response/input ratio on the vertical axis as a function of frequency on the horizontal axis.
The whole purpose of product vibration sensitivity testing is to determine the critical or natural frequencies of the product so that these frequencies can be properly attenuated by the package cushion system.

Non-resonant vibration induced loading of a product is rarely damaging because of the low acceleration amplitudes of transportation vibration.

It is only when product natural frequencies are excited by the vehicle, the package cushion system, or both, that damage is likely to occur.

This damage can be catastrophic but often shows up as fatigue related bending of components, loosened screws and fasteners, scuffing and abrasion, misalignment of critical components, and similar.
1. The test is conducted by fastening the product to the table of a suitable vibration test machine with response transducers mounted to critical components within the product.

2. The system is then subjected to low level sinusoidal or (preferably) random vibration input and the response of the monitored components is monitored and recorded as a function of frequency.

### Example

<table>
<thead>
<tr>
<th>Direction</th>
<th>Component A</th>
<th>Component B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral (X)</td>
<td>None</td>
<td>35 Hz</td>
</tr>
<tr>
<td>Longitudinal (Y)</td>
<td>25 Hz</td>
<td>33 Hz</td>
</tr>
<tr>
<td>Vertical (Z)</td>
<td>18 Hz</td>
<td>None</td>
</tr>
</tbody>
</table>
Vibration Testing Summary

• Test all orientations where vibration input is possible.
• Monitor all elements suspected of being vibration sensitive.
• The mass of the response transducer must be very much less than the mass of the monitored component.
• Fixture the product to the vibration machine rigidly and in a manner similar to how the package cushion system might contact the product.
• Follow the general guidelines of ASTM D-3580.
• Sinusoidal, random, or complex excitation can be used for this testing. If conducted properly, all should give the same (or very similar) results.
Vibration Testing Results

The end result of this testing should be:

1. A clear identification of the natural frequencies within the product in all shippable orientations
2. Lowest “structural” resonance in each orientation
3. Amplification (Q) levels associated with each component fn.

![Graph showing vibration testing results](image)
This test should be relatively easy and quick to run. It is non-destructive.

Random vibration is recommended over sinusoidal excitation because it excites all frequencies and harmonics simultaneously so the effects of constructive & destructive interferences between components are taken into account.

- Sine excitation can result in an over-test.
- Dwell testing at resonance is not recommended. (This is not a fatigue test, only an identification of critical frequencies.)
The purpose of the test is to stimulate the product (spring/mass system) so that it’s natural frequencies can be identified, not to simulate any kind of vehicle.
QUESTIONS??
Background:
1. Fragility is simply another product characteristic like size, mass, color, etc.
2. The “traditional” method of fragility assessment used Shock Response Spectrum (SRS) analysis to determine the sensitivity of the product to both short duration (velocity shock) and longer duration (acceleration) inputs.
3. Dr. Robert Newton simplified this process in 1968 with his Damage Boundary test procedure (ASTM D3332).
   • It uses a short duration pulse to determine “velocity” sensitivity and a longer duration pulse to determine acceleration sensitivity.
Shock Response Spectrum (SRS) is the most basic method of fragility determination because it is concerned only with the response of the structure or product to any type of input.
Recognizing the complexity of SRS, Dr. Robert Newton suggested the Damage Boundary method to simplify things and provide accurate fragility data.
The real genius of Newton’s approach consisted of using a simple 2 msec half sine pulse for velocity change determination and a simple trapezoidal pulse for critical acceleration assessment. Combined with a straightforward protocol for testing (ASTM D3332), this resulted in a brilliant method for product fragility assessment.
START

Shock the unit at determined level

Inspect for physical damage and functionality

Increment Shock Level

Document the damage and shock level

Additional Units Available?

Retest at same orientation
Or change orientation

END
Here is how the test is conducted:

ΔVc (Critical Velocity Change)
Damage Boundary Test Procedure

Mechanical Shock Testing
End Result of Running This Test

• The critical velocity change, \((\Delta V_c)\), tells us max drop height (closely related to \(\Delta V\)) the BARE product can withstand before product damage (as you define it) occurs.

\[\Delta V = (1 + e) \times \sqrt{2gh}\]

where \(e\)=coefficient of restitution of the impact surfaces
\(g\) = gravitational constant (9.8m/s\(^2\), 386in/s\(^2\))
\(h\) = drop height

• The critical acceleration value (\(A_c\)), is the design criteria for an optimal protective package system.
Product Fragility Assessment

That’s how we quantify this bar.

PROTECTIVE PACKAGE: That device which limits environmental input to a level below product fragility
• This is a destructive test. Products are taken to the failure point, that is, till they break.

• A rigorous test would require 12 specimens; six (6) for the ΔVc test (+X, -X, +Y, -Y, +Z, -Z axes), and six (6) for the Ac test.

• Fixturing of the test specimens to the shock test surface is critical for good test results.

• The use of a trapezoidal pulse for Ac tests is conservative and results in a worst case level.

• The ΔVc and Ac numbers are INPUT numbers. The only quantities available from a final package test are RESPONSE values. They may be quite different...
QUESTIONS??
Next Webinar: Packaging Dynamics Series

#1: Overview and Definition of Terms – Jan 2015  **DONE !**

#2: Defining & Quantifying the Distribution Environment Through Which All Products Must Travel – March 2015  **DONE !**

#3: Determining the Vibration Sensitivity & Shock Fragility of Products; Test Methods, End Results, and Significant Insights – **DONE !**


#5: Design and Testing of the Protective Package System; How We Know When the Job Was Done Correctly– Oct 2015
THANK YOU!

Please feel free to Contact Us with any questions or assistance with your testing needs.

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