PACKAGING DYNAMICS #5 of 5
Protective Package Design, Testing, & Evaluation

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Sept 2015
Westpak’s 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 – September 2015
Agenda

- Brief Review of Webinars #1 – 4
- Protective Package Design Steps
- Testing Procedures Commonly Used
  - Stimulation vs Simulation
- Look at Packaging Diagnosis
- Logistics and Cube Utilization
Review of Webinars 1 & 2

- History and Terminology of Packaging Dynamics
  - Single degree of freedom spring mass system
- Common Packaging Dynamic hazards
- 5-Step Procedure for Protective Package Design & Testing
- Step #1: Environmental Quantification
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
Review of Webinars 3 & 4

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
Webinar 5

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
In Webinar #3, we quantified this bar.

PROTECTIVE PACKAGE: That device which limits environmental input to a level below product fragility.
Cushion Test & Design #4

In Webinar #4, we quantified this bar.

PROTECTIVE PACKAGE: That device which limits environmental input to a level below product fragility.
In this Webinar, we will focus on these 3 bars

PROTECTIVE PACKAGE: That device which limits environmental input to a level below product fragility
The Package Design Process

Steps:

1. Determine the cushion deflection necessary for impacts:
   \[ \Delta X = \frac{2h}{(A-2)} \]
   if \( h=30 \text{ in} \) & \( A=50 \)
   Then \( \Delta X \) or cushion deflection = 1.25 in.

2. Select the desired cushion and determine the required thickness. This comes from the “cushion efficiency”:
   
   \[ EPS = 40\% \]
   PE foams are about 60\%
   Many urethane foams are about 75\%
   The exact number isn’t important. It will get you into the ballpark. Don’t just use a cushion curve and select one of the thicknesses given. Wasteful.
Selecting Cushion Thickness

Assume the cushion material behaves as a linear spring and look solely at the total deflection necessary to achieve the required deceleration from the design drop height. This deflection is estimated by:

\[ \Delta x = \frac{2h}{(A - 2)} \]

where:

\[ \Delta x = \text{cushion deflection in cm (or inches)} \]
\[ h = \text{drop height in cm (or inches)} \]
\[ A = \text{the required deceleration level (G's)} \]
... A little background...

- $\Delta x$ gives the theoretical deflection necessary, not the overall cushion thickness.
- In general, cushion materials such as expanded polyethylene foam will compress approximately 50 to 60% of total thickness before "bottoming out" starts to occur.
- More flexible materials such as polyurethane foam will compress up to 75% before bottoming out.
A product has a fragility of 50 G's and a design drop height of 90 cm. (35 inches).

The theoretical deflection is calculated from the formula:
\[ \Delta x = \frac{2 \times 90}{50 - 2} = 3.75 \]

The resulting theoretical deflection is 3.75 cm. Total cushion thickness necessary for the individual materials is:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>OPTIMUM STRAIN %</th>
<th>TOTAL THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPS foam</td>
<td>40%</td>
<td>9.4 (3.75/.4)</td>
</tr>
<tr>
<td>PE foam</td>
<td>55%</td>
<td>6.9 (3.75/.55)</td>
</tr>
<tr>
<td>Polyurethane foam</td>
<td>75%</td>
<td>4.5 (3.75/.75)</td>
</tr>
</tbody>
</table>
OK, Back to the Steps...

Steps:

3. Divide the required deflection by the cushion efficiency to obtain your optimum thickness:
   - For PE foam: $\Delta X = 1.25''$ and PE foam is 55% efficient thus required thickness $= 1.25/0.55 = 2.3''$

4. Determine the optimum loading (weight/area of cushion) from the:
   A) cushion vibration data sheet (amplification/attenuation plot), and
   B) cushion impact curve for the design drop height

For that type and thickness of material....
Designing the Optimum Cushion System

Static Loading Determination

Impact (shock)

![Graph showing deceleration vs. static stress for different cushion thicknesses and maximum loading for shock protection.]

Vibration

![Graph showing frequency vs. static stress with zones for amplification, unity, and attenuation.]

Minimum loading for vibration protection = 68 g/cm^2

Lowest product natural frequency = 37 Hz

Product fragility = 28.9

Maximum loading for shock protection = 86 g/cm^2

2 cm thick cushion
Designing the Optimum Cushion System

**Static Loading**

**Determination**

Vibration
Fn = 70 Hz

Range: Range > 0.80 psi

Impact (Shock)
Ac = 70 G’s

Range: 0.66 psi < Range < 1.33 psi

Combined Range
0.80 psi < RANGE < 1.33 psi
Design Goals

Foam Loaded and Designed at 1.0 psi

Combined Range
0.80 psi < RANGE < 1.33 psi

Test Input | Goal
---|---
Vibration | Attenuation at or before 70 hz
Drops | Deceleration < 70 G’s
What if there isn’t a single loading that satisfies BOTH impact & vibration??

Here’s what we recommend:

1. Use the vibration loading that comes closest to the required impact value. Why? Vibration is 100% certain, impact are a probability function.

2. Use ribs on the cushion and design the rib peak for vibration loading and the 25% deflection level for impact loading.
A. At the “peak” or top of the rib, the cushion area should give a loading value (weight/area) that satisfies (or exceeds) the vibration “Amplification/Attenuation” plot value.

B. At 25% total deflection the loading should be approximately equal to that which would give the optimum “cushion curve” value.
Designing the Optimum Cushion System

Static Loading Determination

Impact (shock)

At 25% deflection, the loading on the rib should satisfy this value.

Vibration

At the rib peak the loading should satisfy this value.
Designing the Optimum Cushion System

Points to remember!!!

• Don’t ignore vibration. It’s 100% certain and can be very destructive.

• Sometimes the Vibe & Impact loadings don’t overlap. In this case, use the Vibe loading value.

• The procedure used for running cushion curves may have a significant effect on the usefulness of the data.

• The use of ribs in the cushion design can have a very positive result on the design effectiveness.
Designing the Optimum Cushion System

The Use of Ribs (non-linear cushions)

Ribbed (non-linear) design

Rectangular (linear) design
Other Issues:

FACTOR ISSUES

FABRICATION FACTORS

• Sustainability: don’t glue foam to corrugated, etc.
• Highest yield = lowest cost
• Package suppliers of the have the best ideas for this

NESTING

• Cushions are bulky. Nesting is vital for shipping & storage.

CORNER PROTECTION

• Most impacts in distribution are on the corners of shipping containers. Void corners are a big source of damage during shipment for otherwise well designed product/package systems.
QUESTIONS??
Package Vibration Test & Validation:

- Not necessary to simulate the distribution environment.
- The only requirement is to excite the spring/mass system consisting of the product (mass) on its cushion (spring).
- The resulting package resonance should be ½ the frequency of the lowest product resonance.
- When this happens the cushion system will attenuate vibration input at all product critical frequencies (resonances).
- Typical excitation methods include random vibration (flat or shaped spectrum), sine vibration, impacts, etc.
Package Test & Design Verification

Package Vibration Test & Validation:

- Mass
- Your Product
- Package Cushion

Remember this??
Package Test & Design Verification

Typical PRODUCT Vibration Test Results
Package Test & Design Verification

Typical PACKAGE Vibration Test Results
Package Test & Design Verification

Here is what we want them to look like:

- Package resonance = 12.7Hz
- Separation between Product and Package resonances is greater than 1 octave.
- Lowest product resonance = 29 Hz
Package Impact Test & Validation:

• Package impact tests should verify that the transmitted deceleration levels are below the critical deceleration ($A_c$) in all axes.

• Measure deceleration levels on a rigid portion of the product, not on the “critical component”.

• Flat drops are used for this. (Highest deceleration levels because all the energy is dissipated in one axis.)

• Corner & edge impact are conducted to verify the integrity of the package design.

• Corner & edge impacts are the most likely during distribution.
The ISTA 10-Drop sequence has become the accepted standard for package impact verification.

<table>
<thead>
<tr>
<th>Sequence Number</th>
<th>Orientation</th>
<th>Drop Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most fragile face-3 corner</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shortest edge radiating from the corner tested</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Next longest edge radiating from the corner tested</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Longest edge radiating from the corner tested</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>One of the smallest faces</td>
<td>81</td>
</tr>
<tr>
<td>6</td>
<td>Opposite small face</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>One of the medium faces</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Opposite medium face</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>One of the largest faces</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Opposite large face</td>
<td></td>
</tr>
</tbody>
</table>
Package Test & Design Verification
Transmitted deceleration levels should be **BELOW** product fragility levels in all axes.
Deceleration waveforms can tell us a lot about the package cushion system. (waveform morphology)

When the waveform is symmetrical (rise time = decay time), the cushion is properly loaded.

When the rise time < decay time, the cushion system is under-loaded; it’s too stiff.

When the rise time > decay time, the cushion system is over-loaded; too much weight or too little cushion.
## Drop Test Results per ISTA 2A

### GOAL: Maximum Deceleration < 70 G’s

<table>
<thead>
<tr>
<th>Drop Orientation</th>
<th>Maximum Transmitted Deceleration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corner 2-3-5</td>
<td>20</td>
<td>Pass</td>
</tr>
<tr>
<td>Edge 2-5</td>
<td>17</td>
<td>Pass</td>
</tr>
<tr>
<td>Edge 3-5</td>
<td>18</td>
<td>Pass</td>
</tr>
<tr>
<td>Edge 3-4</td>
<td>15</td>
<td>Pass</td>
</tr>
<tr>
<td>Front Side 5</td>
<td>65</td>
<td>Pass</td>
</tr>
<tr>
<td>Back Side 6</td>
<td>75</td>
<td>Fail</td>
</tr>
<tr>
<td>Right Side 2</td>
<td>50</td>
<td>Pass</td>
</tr>
<tr>
<td>Left Side 4</td>
<td>52</td>
<td>Pass</td>
</tr>
<tr>
<td>Top Side 1</td>
<td>45</td>
<td>Pass</td>
</tr>
<tr>
<td>Bottom Side 3</td>
<td>47</td>
<td>Pass</td>
</tr>
</tbody>
</table>
# Vibration Test Results per ISTA 2A

## GOAL: Attenuation at or before 70 hz

<table>
<thead>
<tr>
<th>Vibration Orientation</th>
<th>Attenuation At:</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Down</td>
<td>50</td>
<td>Pass</td>
</tr>
<tr>
<td>Top Down</td>
<td>60</td>
<td>Pass</td>
</tr>
<tr>
<td>Side Down</td>
<td>45</td>
<td>Pass</td>
</tr>
<tr>
<td>End Down</td>
<td>50</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Decisions, Decisions...

• If your engineered package “passes” its designated package performance test:
  – You can theoretically ship your package through its distribution environment with little worry of product damage

OR!

– You can perform margin testing to determine how much packaging waste is present in your package
Reasons for Shipping “as is”

• Time constraint
  – Builds are ramping up

• Relatively high-dollar product
  – Acceptable to have additional protection

• Borderline or barely acceptable test results
  – Packaging reductions are unlikely
Reasons for Margin Testing

• Have time to engineer / source a package redesign
• Results are significantly better than anticipated
• Reduce overall costs
  – Materials costs
  – Supply chain costs

HUGE Potential!!
Logistical Expense Breakdown

From Supply Chain Strategies (p. 170) by Frazelle, 2001, New York
Transportation Cost

Source: http://www.prioritylogistics.net/blog/
Reducing your Package Size will...

• Reduce your overall “cube”
  – Fit more units on a pallet
  – Fit more units on an ocean container
  – Drastically decrease your transportation costs
This is Accomplished with:

- Specialized Palletization Software (Examples)
  - Total Optimization Packaging Software (TOPS)
  - Cape Pack Software

- Auto palletizes and containerizes your packages based on specified dimensions
Package and Pallet Specifications

**Shipcase Parameters**
- **Case**
  - New
  - Fixed
  - Database
- **DataBase**
  - All
  - Multiple
  - Select
- **Material**
  - Corrugated
  - Other
- **Dimensions**
  - Inside
  - Outside
- **Units**
  - English
  - Metric

**Description**
- User Defined

**Mix Tray**
- None

**Style**
- RSC (FEFCO 0201)

**C.A.S.Y. Style**
- None

**Flute**
- C Flute

** Slack**
- 10.0000

**Vert**
- 0.0000

**Length (in)**
- 10.0000

**Width (in)**
- 10.0000

**Height (in)**
- 10.0000

**Max Weight (lbs)**
- 1000.000

**Use Tare weight**
- None

**Tare weight (lbs)**
- 0.000

**Round to nearest 1/16**
- None

**Sizing**
- Min Count
  - 1
- Max Count
  - 1000

**Units**
- English

**UnitLoad Parameters**

**Pallet**
- Single
- Pallet Style: GMA (NOTCHED)
- Slave Pallet: Slave GMA (NOTCHED)

**Number of Slaves**
- Two

**Maximum Height (incl. Pallet)**
- (in) 54.000

**Maximum Weight (incl. Pallet)**
- (lbs) 2500.000

**Load Offset**
- Length (in)
  - 0.000
- Width (in)
  - 0.000

**Maximum Overhang**
- 0.000

**Maximum Underhang**
- 15.000

**Packaging weight**
- (lbs) 0.00

**Limit to Max**
- Layers
  - 0
- Items/layer
  - 0
- Total Items
  - 0

**Pallet Size**
- (in) 48.000 X 40.000 X 5.000
Automated Results
### Case Study

- Difference between different foam thickness designs of a toaster with the following packaging dimensions.

<table>
<thead>
<tr>
<th>Package</th>
<th>Dimensions (in)</th>
<th>Reduction (each side)</th>
<th>Increase in Efficiency</th>
<th>Annual Freight Transportation Costs ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (60 / Pallet)</td>
<td>16.43 x 9.35 x 9.35</td>
<td>None</td>
<td>None</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Proposed 1 (90 / Pallet)</td>
<td>15.43 x 8.35 x 8.35</td>
<td>-1 inch</td>
<td>150%</td>
<td>666,667 (33% Reduction)</td>
</tr>
<tr>
<td>Proposed 2 (147 / Pallet)</td>
<td>13.62 x 6.85 x 6.85</td>
<td>-2.5 inch</td>
<td>245%</td>
<td>408,000 (59% Reduction)</td>
</tr>
</tbody>
</table>
# Current Design

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</table>
# Proposed Redesign 1

<table>
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<tr>
<th>Package</th>
<th>Dimensions (in)</th>
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</table>
## Proposed Redesign 2

<table>
<thead>
<tr>
<th>Package</th>
<th>Dimensions (in)</th>
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About WESTPAK, INC.

Two Locations:

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83 Great Oaks Boulevard
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San Diego Laboratory
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San Diego, CA 92121
858-623-8100

www.westpak.com

Contact Us
THANK YOU!

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

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