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

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Sept 2015
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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
Review of Webinar #2

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.
In Webinar #4, we quantified this bar.
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 \( h=30 \) in & \( A=50 \)
   Then \( \Delta X \) or cushion deflection = 1.25 in.

2. Select the desired cushion and determine the required thickness. This come 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:
- \( \Delta x \) = cushion deflection in cm (or inches)
- \( h \) = drop height in cm (or inches)
- \( A \) = 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:

$$\Delta x = 2 \frac{(90)}{(50-2)} = 3.75$$

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></td>
<td></td>
<td>cm</td>
</tr>
<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>
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 $= \frac{1.25}{0.55} = 2.3”$

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)

Vibration
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

Combined Range
0.80 psi < RANGE < 1.33 psi

Foam Loaded and Designed at 1.0 psi

<table>
<thead>
<tr>
<th>Test Input</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td>Attenuation at or before 70 hz</td>
</tr>
<tr>
<td>Drops</td>
<td>Deceleration &lt; 70 G’s</td>
</tr>
</tbody>
</table>

![Amplification / Attenuation Curve (3" Foam)]

![36" Drop Height Cushion Curves (Average 2-5)]
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.
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:

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 $\frac{1}{2}$ 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
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 face</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
Sensitivity:

Ch. 1: 40.00 G's/Div
Ch. 2: 40.00 G's/Div
Ch. 3: 40.00 G's/Div

Filter:

Ch. 1: 500 Hz
Ch. 2: 500 Hz
Ch. 3: 500 Hz

Trig. Ch.: ALL
Polarity: Window
Level: 9.96 G's
Mode: Single Event
Pretrigger: 25%

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><strong>Back Side 6</strong></td>
<td><strong>75</strong></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

<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>

GOAL: Attenuation at or before 70 hz
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/](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
- Description: User Defined
- Mix Tray: None
- Style: RSC (FEFCO 0201)
- C.A.S.Y. Style: None
- Flute: C Flute
- Material: Corrugated, Other
- Dimensions: Inside, Outside
- Units: English, Metric
- Max Weight (lbs): 1,000,000
- Use Tare weight
  - Tare weight (lbs): 0.00
- Round to nearest 1/16"*

UnitLoad Parameters
- Pallet
  - Single Pallet Style: GMA (NOTCHED)
  - Slaves Pallet: GMA (NOTCHED)
  - Number of Slaves: Two
- Multi Pallets: Select Pallets
- Maximum Height (incl. Pallet) (in): 54.00
- Maximum Weight (incl. Pallet) (lbs): 2,500.00
- Load Offset
  - Maximum Overhang (in): 0.00
  - Maximum Underhang (in): 15.00
- Packaging weight (lbs): 0.00
- Limit to Max
  - Layers: 0
  - Items/Category: 0
  - Total Items: 0
- Pallet Size (in): 48.00 × 40.00 × 5.00

*Note: Round to nearest 1/16"*
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>
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</table>
## Proposed Redesign 2

<table>
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<tr>
<th>Package</th>
<th>Dimensions (in)</th>
<th>Reduction (each side)</th>
<th>Increase in Efficiency</th>
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Contact Us
Please feel free to Contact Us with any questions or assistance with your testing needs.