PACKAGING DYNAMICS #6 of 5
EXTRA CREDIT – TRICKS OF THE TRADE

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Oct 2015
Packaging Dynamics Webinar Series

All available at [http://www.westpak.com/page/resources/webinars](http://www.westpak.com/page/resources/webinars)

#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  DONE !

#6 Extra Credit: Tricks of the Trade – October 2015
Agenda

- **Brief**  Review of Packaging Dynamics Webinars #1 – #5
- Who Does the Best Protective Package Design Work?
- Vibration Attenuation Rules of Thumb
- Conservative Nature of the Damage Boundary Test
- Shock Pulse Filtering
  - Waveform Morphology
  - Frequency Domain Analysis
- Input vs Response Measurement in Package Testing
- Coefficient of Restitution, $e = \frac{V_r}{V_i}$
- Non-linear Cushion Dynamics; Deformable Shape Cushions
- Herb’s Super Secret Seven Protective Package Design Steps
Review of Webinars 1 - 5

• 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
Review of Webinars #1 - #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
Review of the “Bar Chart”

PROTECTIVE PACKAGE: That device which limits environmental input to a level below product fragility
Who does the best Protective Package Design Work?

Almost always the people who sell the material or the service (often the same folks).

Why? Mainly because:

• They know the material
• They know the processes
• They know the potholes
• They normally want to sell you the best system
Tip # 1: Protective Package Design

Can I design the package myself?
YES!! Absolutely!! But don’t expect to do your best work the first time….

Can I trust package vendors to give me the best deal?
Look at the inscription on the back side of the dollar bill…..
When designing cushion systems for larger products (60 Kg and up), ALWAYS pay more attention to vibration attenuation than to impact or shock protection. WHY?

- Impacts occur infrequently for heavy products
- Vibration during distribution is a certainty
- Most heavier products are vibration sensitive
- Heavier products are more closely coupled to the vehicle and get more vibration “content”
Tip #2: Vibration Attenuation Rules of Thumb

Continued….

• Product reliability suffers more from vibration input than from impacts
• By optimizing a larger pkg system for impact protection, you can create a package that actually destroys the product
• Many larger or heavier products have resonances in the range of highest input from over-the-road trucks (10-18Hz)
Continued....

- Vibration attenuation is easy once you know the numbers
- A properly attenuated package design normally uses less material and is more economical
- Most “hidden damage” during distribution results from poor vibration attenuation in the package
Tip #3: Shock Pulse Filtering

When measuring mechanical shock (during fragility assessment, package drop testing, etc), remember the following:

• The transducer will pick up broadband signals
• Includes the low(er) frequencies we want
• Higher frequencies also (ringing, harmonics, chatter, “noise”)
Electronic filtering is a method of keeping the low(ER) frequencies we want and reducing the high(ER) frequencies we don’t want.

- But it must be done “correctly”
- Unfiltered pulses are sometimes unreadable
- Over-filtered pulses give distorted data
- Under-filtered pulses don’t tell the true story
- Properly filtered pulses give the best view of any shock test
Tip #3: Shock Pulse Filtering

Filter (low-pass) shock pulses at no lower than 10 times pulse frequency.
Tip #3: Shock Pulse Filtering

Filter (low-pass) shock pulses at no lower than 10 times pulse frequency.

**Example:**

Pulse duration = 2 msec  
Pulse period = 4 msec  
Frequency = 1/period  
Frequency = 1/.004 sec  
Frequency = 250 Hz  
$f_f = 10 \times f_p$  
= 2500 Hz
Tip #3: Shock Pulse Filtering

The goal here is to more accurately “see” what’s happening without distorting the data.

• Filtering at $10 \times f_p$ will reduce pulse amplitude less than 10% on average (depending on HF noise)

• Over-filtering can drastically reduce pulse amplitude (make it look better…)
Tip #3: Shock Pulse Filtering

Here is the same pulse we saw previously but properly filtered.
Tip #4: Shock Pulse Filtering

How can you tell if a shock pulse has been over-filtered?

• It’s “too smooth”....
• The filter level was less that 10 X \( f_p \)
• The filtered pulse has a “tail” on it
Tip #5: Damage Boundary is Conservative

Shock Fragility of Products Determined by the Damage Boundary Test Method Tends to be Very Conservative. WHY?

- The “square wave” pulse (actually a trapezoidal pulse) used for the critical acceleration produces the maximum response of a spring/mass system of any pulse with the same amplitude and duration.
Tip #5: Damage Boundary is Conservative

That’s what the normalized SRS plot tells us:

SRS, SDOF SPRING-MASS
MAXIMUM RESPONSE
UNDAMPED SYSTEM

\[ \frac{A_r}{A_i} \]

\[ f_r \div f_i \]

2

1

1/6

1/2

SQUARE WAVE

HALF SINE

TRAPEZOIDAL PULSE
OK… What are the practical realities of this?

- A product with a 50G fragility determined with a trapezoidal pulse will likely withstand a 55 or 60G half sine shock pulse.
- Most shock pulses delivered to a product during a package drop test, for example, are “half-sine-ish” in shape. You’ll never see a trapezoidal pulse in a package drop test.
- Also, a typical DB test will involve perhaps six or more shock inputs before failure occurs.
- This “shock fatigue” results in a lower $A_c$ than would otherwise be the case. Result: conservative.
Tip #5: Damage Boundary is Conservative

If this is the case, why do we use a trapezoidal pulse in the first place?

• We use the trapezoidal pulse for fragility analysis because it’s the best overall choice in spite of its drawbacks.
• It gives us an absolute number regardless of pulse frequency or pulse shape.
• It’s much easier to program than half-sines or saw tooth pulses.
Time for Questions
Tip #6: The Secrets of the Shock Waveform

The shock pulse from a monitored pkg drop test is as unique as your fingerprint, every one is different.

- A properly loaded cushion will normally produce a symmetrical waveform ($T_r = T_d$)
Continued…

• An over-loaded cushion will normally produce a skewed waveform with the rise time greater than the decay time ($T_r >> T_d$)
Continued…

- An under-loaded cushion will normally produce a skewed waveform with the rise time much shorter than the decay time ($T_r \ll T_d$)
Tip #7: The Secrets of the Shock Waveform

Bottoming of the cushion will show up as a discrete spike on the waveform. If the spike is near the start of the waveform, the cushion is severely over-loaded.

If the spike is at the midpoint or later, the cushion is only slightly over-loaded.
It’s virtually impossible to measure package shock input during a package performance drop test. That is, this line is VERY difficult to properly place.
Tip #8: Shock Input vs Response

The reason is that monitoring a product during a package drop always results in a combination of package (cushion) input and product response.

Here’s the situation schematically:

Result is always a combination of cushion input and product response.
Tip #8: Shock Input vs Response

So what do we do about this problem???

- Measure both input AND response during the product fragility testing!!
- I call this “Simultaneous Input & Response Measurement”, SIRM for short….
- It’s easy to do but prone with “issues” because most people don’t have a clue about what to do with the data…..
Tip #8: Shock Input vs Response

**S I R M....**

During product fragility testing, measure BOTH shock input here...... and product Response here....... They will be different!

- Use the shock input number to design the package.
- Use the product response number for pass/fail in the package drop test.
When a cushion (spring) deflects in response to a shock input, it stores energy – up to nearly the full amount of the input. It then “gives back” some of that energy to the product (mass). That is the total “energy” dissipated during the event.

We call it “$e$”

\[ e = \frac{V_r}{V_i} \]

(rebound velocity divided by impact velocity)

Recall that total Velocity Change ($\Delta V$) = $V_i + V_r$

and that $\Delta V$ can be thought of as the “energy” content of the event........
Tip #9: The Coefficient of Restitution is Your Friend

Our goal is to limit the TOTAL impact energy delivered to the product, not just the peak deceleration. Thus:

A cushion that limits $\Delta V$ during an impact (lower $e$ value) is more desirable than one that doesn’t.

These systems are generally referred to as non-rebounding cushions or deformable shape cushions.
Tip #9: The Coefficient of Restitution is Your Friend

EXAMPLE:
Package drop height = 30 in.

\[ V_i = \sqrt{2gh} = (2 \times 386 \text{ in/sec}^2 \times 30 \text{ in})^{.5} \]

= 152 in/sec

If \( e = .8 \), then total \( \Delta V = (1+e) \sqrt{2gh} = 274 \text{ in/sec} \)

[common for PE foam materials]

If \( e = .2 \), then total \( \Delta V = (1+e) \sqrt{2gh} = 182 \text{ in/sec} \)

[common for molded pulp & other crushable shape designs & materials]

Which would you rather have, 274 or 182 in/sec?
Tip #10: Non-Linear Cushions are the Best

What in the world does this mean???
Start with a linear cushion (spring):

\[ k = \frac{F}{D} \]
\[ \Delta = \frac{W}{k} \]
How about a non-linear cushion (spring):

The non-linear hardening spring gives high deflection at low force levels making it ideal for vibration (where force levels are low) and good for shock where force levels are much higher and the spring resists deflection before bottoming out.
Tip #10: Non-Linear Cushions are the Best

Continued….

Non-linear cushions:

• Usually require a computer to design
• Are often expensive
• Often found in reusable crating systems
• Have been extensively investigated by large computer companies
• The benefits can be approached by the use of ribs on traditional materials
Tip #10: Non-Linear Cushions are the Best

Non-linear cushion example:

Ribbed (non-linear) design  Rectangular (linear) design
Tip #11: Follow Herb’s Super Secret Seven

Protective Package Design Steps

1. Establish the required deflection for shock protection.
2. Establish the required cushion thickness from cushion efficiency data.
3. Determine cushion static stress loading that is optimum for vibration.
4. Design for fabrication efficiency for the chosen material, process, and locations. Use ribs whenever possible. Avoid void corners.
5. Fabricate the prototype package system.
6. Document the prototype package design.
7. Test the design for vibration performance first, then for impact. Test to failure for impact (margin). Use SIRM data.
Tip #11: Follow Herb’s Super Secret Seven

• Other people do their design work differently. So be it. Viva la différence!

• I believe the margin testing is important. Don't skip it.

• It is extremely rare that a package design meets all requirements the first time around. Redesign and retesting is almost always required.
### Questions

| 1. How much headsleave or margin is best in a protective package design? |
|-----------------|------------------------------------------------|
| **Answers**     | I shoot for zero margin. The shock test procedures are so conservative that there is more than adequate margin built into them. |

| 2. What steps do you use for designing a crushable cushion system? |
|-----------------|------------------------------------------------|
| **Answers**     | I used the same general procedures outlined previously. I simply adjust the stiffness and depth of the ribs based on test results. |

| 3. Why don't cushion material suppliers furnish vibration data? |
|-----------------|------------------------------------------------|
| **Answers**     | Likely because we as consumers don't demand it often enough. |
### Questions

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<thead>
<tr>
<th>Questions</th>
<th>Answers</th>
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<tr>
<td>4. How does one determine maximum product deceleration levels and resonant frequency information?</td>
<td>Refer to webinar #3. Those topics were covered in depth during that session.</td>
</tr>
<tr>
<td>5. Does the weight of the product affect test parameters, particularly the use of a trapezoidal shock pulse for critical acceleration testing?</td>
<td>No. The weight of a product does not affect the test procedures at all. Product weight will have a pronounced effect on the equipment utilized for the test.</td>
</tr>
<tr>
<td>6. What do you mean by &quot;void corners&quot;?</td>
<td>To me, void corners implies that there is no material, only airspace, between the corner of the product in the corner of the shipping container.</td>
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### Questions

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<td>7. Some of the rib shapes you showed seem to be fairly narrow. Are you concerned about buckling?</td>
<td>Yes, column buckling is always a concern when the height of a cushion system exceeds the length or width.</td>
</tr>
<tr>
<td>8. Where does one find reliable cushion curves and vibration data for cushion materials?</td>
<td>The material supplier should provide that information as a minimum. Demand it from them!</td>
</tr>
<tr>
<td>9. I’d like to see a webinar that discusses all of Westpak’s test devices and their capabilities.</td>
<td><strong>Thanks!! Visit our website at <a href="http://www.westpak.com">www.westpak.com</a> then call us to arrange a tour. We’d be happy to show you around.</strong></td>
</tr>
<tr>
<td>10. Where did you get all this information about Packaging Dynamics?</td>
<td>It comes with the grey hairs and wrinkles….. And we make it our business.</td>
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QUESTIONS??
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Please feel free to Contact Us with any questions or assistance with your testing needs.

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