PRODUCT & PACKAGE SHOCK TESTING

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What’s This All About?

• Why, how, and when do we mechanically test products and package systems for shock sensitivity?

• What do we expect to learn from this?

• What test procedures should we use?

• What should we do with the information?
Agenda

• Background, terminology, etc.
• Shock Testing Dynamics
  – Drop vs. Shock: What’s the Difference, Velocity, Velocity Change
  – Fragility, SRS, SDOF, Pulse Shapes, Damage Boundary
  – Product Improvement and Ruggedization
  – Sources of Input, Different Approaches to Shock Testing, Myths, etc.
  – Cushion Shock Dynamics
Shock Dynamics - Background

- Mechanical Shock is a term for non-repetitive excitation (one can define the beginning and the end)
- Vibration and shock are both time domain events
- Shock is a *vector quantity* with units of acceleration (rate of change of velocity)
- The unit G represents multiples of the acceleration of gravity and is conventionally used.

• A shock pulse can be characterized by its duration, peak acceleration, and the shape of the shock pulse (half sine, triangular, trapezoidal, etc.)

- Frequency domain is the inverse of the time domain
- The Shock Response Spectrum (SRS) is a method for further evaluating a mechanical shock
Shock Dynamics - Background

- Shock occurs during transit, delivery, and in-use
- Delivering a quality product to your customer demands knowledge of product ruggedness

- To test or not to test is **not** the question. The product **will be** tested - the distribution environment will make sure of that!
- The only question remaining is who will see the results first; you or your customer?
Today's marketplace demands ruggedized products

*Global distribution* puts more stress on the product, both shock and vibration-wise

Smaller and lighter weight products are handled more severely and must endure a higher shock environment than previous generation equipment

These trends will continue!
To start the process of studying mechanical shock, we return to our old buddy, the spring/mass system.

It turns out there are two primary types of response of our Spring/Mass system to a shock input...
**Type 1 Response:**

- This shock pulse is very short relative to the natural period of the Spring/Mass system.
- The pulse is over and done with before the S/M system can respond.
- This is called a “Velocity Shock” response. It is dependent only on the velocity change of the input pulse.
- The response is independent of the input wave shape.
- The mass oscillates at the fn of the S/M system.
**Type 2 Response:**

- This response is highly dependent on the shape of the input pulse.
- The amplitude of the response can be double (or more) the amplitude of the input.
- The period of the input pulse is one half or greater the period of the responding system.
- This type of event is referred to as an “acceleration” response.
- The response is complex with a high component of the fn of the responding system.
Shock Response of SDOF

Input & Response might look like this for a sawtooth pulse:
Other Pulse Shapes

\[ R = \frac{f_s}{f_p} \]

SQUARE WAVE PULSE

HALF SINE PULSE

mass \( m_p \)
Characteristics of SRS

Shock Response Spectrum analysis (SRS)

• Responses for all wave shapes when the $f_s/f_p < 1/4$ are nearly identical.

• As the $f_s/f_p$ approaches $\frac{1}{2}$, the response reaches its max for all wave shapes.

• As $f_s/f_p$ becomes larger, the step pulse (square wave) maintains its max response.

• The sawtooth and half sine pulses show diminished responses.
Actual Wave Shapes
If we take our trusty S/M model and plot its response to various shock inputs, frequency & wave shape, we get these results...
SRS Plot

Or a composite that might look like this:

![SRS Plot Diagram]

- **Velocity shock region**
- **Acceleration shock region**

**SRS, SDOF SPRING-MASS**
MAXIMUM RESPONSE
UNDAMPED SYSTEM

- $\frac{A_r}{A_i}$
- $f_r / f_i$
- SQUARE WAVE
- HALF SINE
- TRAPEZOIDAL PULSE

- Mass $m_p$
- Spring $K_p$
- Acceleration $A_i$
- Velocity $A_r$
The purpose of shock testing is to determine the fragility of products.

- Ruggedness is a desirable product characteristic.
- A certain amount of ruggedness is necessary for the product’s proper functioning.
- Manual handling during distribution normally will “exceed” product ruggedness so protective packaging is usually required.
- Shock testing can be useful to improve the ruggedness of designs and add value to the product.
Fragility Testing

• Traditional shock fragility testing used SRS techniques because we lacked knowledge of what inputs were likely.

• SRS was well established in architecture and the building industry.

However ...

• SRS was very complex and time consuming to run.
Recognizing the complexity of SRS, Dr. Robert Newton suggested the Damage Boundary theory to simplify things and provide accurate fragility data.

- **Type 1 Response**
  - A short duration half sine pulse would be used to determine the velocity shock region of the SRS.

- **Type 2 Response**
  - A longer duration square wave pulse would be used to determine the acceleration region of the SRS.
A short duration half sine pulse would be used to determine the velocity shock region of the SRS.

A longer duration square wave pulse would be used to determine the acceleration region of the SRS.
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.
Damage Boundary

- The critical velocity change (ΔVc) tells us max drop height (closely related to ΔV) the BARE product can withstand before product damage (as you define it) occurs.

\[ ΔV = (1 + e) \times \sqrt{2gh} \]

where  
- \( e \) = coefficient of restitution of the impact surfaces  
  \[ e = \frac{Vr}{Vi} \]

  thus \( 0 \leq e \leq 1 \)

- \( g \) = the gravitational constant \( (9.8\,\text{m/s}^2,\ 386\,\text{in/s}^2) \)
- \( h \) = the drop height

- The critical acceleration value (Ac), is the design criteria for an optimal protective package system.
Other Approaches

MIL STD 810
ASTM D3331
IEC 60068-2-27, 75
EIA TP-27B
ANSI-VITA 47-2006
CUSTOM SPECS
CUSTOMER’S SPECS
Shock Testing: End Results

- Highly reliable and more robust product
- Identify and correct design deficiencies
- Facilitate world-wide shipment and delivery of a high-quality product
- Better able to meet customer demands and warranty claims
- Reduce costs and create profit!!
This is a destructive test. Products are taken to the failure level, that is, until they break.

A rigorous test would require 12 specimens; 6 for the $\Delta V_c$ test ($+X$, $-X$, $+Y$, $-Y$, $+Z$, $-Z$ axes), plus another 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 $\Delta V_c$ and Ac numbers are INPUT numbers.

The only quantities available from a package performance test are RESPONSE values which may be quite different than the INPUT.
Lots of mechanical shock tests specify an 11 msec pulse, varying amplitudes, normally $\frac{1}{2}$ sine shape.

Why 11 msec????
Why not 10 msec?
Or 2 msec?
Or 20 msec?

Where does 11 msec come from? Who likes it? Why?
What’s the real value of using a half sine pulse for mechanical shock testing?

- Easy-to-program
- Often seen in the environment
- Has a pleasing appearance

What’s wrong with the half sine?

- It excites only odd harmonics within the product
- It doesn’t represent the worst case input for the same peak and duration
What’s the real value of using a sawtooth pulse for mechanical shock testing?
• It has almost zero rebound

What’s wrong with the sawtooth?
• It excites only even harmonics within the product
• It doesn’t represent the worst case input for the same peak and duration
What’s the real value of using a square or trapezoidal pulse for mechanical shock testing?

• It’s easy to program
• It’s nearly 100% rebounding
• It represents the worst case for a given peak and duration

What’s wrong with the square wave?

• It’s conservative
• Difficult to achieve high acceleration levels
Shock Test Equipment
This characteristic is measured using instrumented impacts resulting in a cushion curve.

Typical procedures include:

- ASTM D1596
- ASTM D4168
- MIL STD 26514E
This curve describes the peak deceleration level (or more correctly, acceleration) transmitted through a material of given thickness as a function of static stress (loading) on the cushion and the drop height.

**TYPICAL CUSHION CURVE**

75 cm (30 in.) DROP HEIGHT
The cushion curve shows:

- **peak acceleration** on the vertical axis and static stress on the horizontal axis (static stress = weight/bearing area)
- Each curve is drawn from a minimum of 5 test points (static stress levels)
- Each test point is the average of the last 4 of 5 acceleration readings (impacts) of the cushion material
Cushion Shock Dynamics

- It is desirable to use cushions in the lower portion ("belly") of the curve where performance is optimum.
- When the product critical acceleration, weight and design drop height are known, the usable static stress range of cushion area can be determined for a given material and thickness.
Here’s how the data is used:
Static Cushion Loading Must Satisfy BOTH Requirements

Impact (shock)

Vibration
Questions?
Questions?

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Riveting Revisions of Medical Device Package Test Procedures

Presenter: Katie Tran
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