

Shock Pulse Filtering Evaluation on Package Size and Cost

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ABSTRACT

Distribution packaging design often relies on cushion curves to determine required material thickness needed for product protection during shipment. The material thickness chosen based on cushion curves establishes overall package size, a key determiner of logistics costs. Cushion curves are constructed by dropping a mass onto a cushion, and interpreting the resulting shock pulse deceleration. The reported deceleration can be highly influenced by applying a “filter” to the shock pulse, a useful standard practice that removes unwanted high frequency elements superimposed on top of the basic shock pulse shape. Standard test methods for generating cushion curves generally do not require reporting what filter was used, or whether the filter influenced the resulting cushion curve information. This paper demonstrates quantitatively how shock pulse filtering influences cushion curves and cushion thickness, which in turn affects logistics costs.

KEYWORDS: *Shock Pulse, Filter, Package Size*

1.0 INTRODUCTION

Traditional distribution packaging design takes into consideration several important factors to help ensure the right balance of cost and protection. Too little packaging increases the risk of damaged product, upsetting customers and damaging brand reputation. Too much packaging increases costs throughout the value chain and is at odds with good environmental stewardship. For many years ISTA (International Safe Transit Association) has

advocated a concept of “just right packaging,” to minimize the amount of packaging while still meeting product protection requirements [1]. Traditionally, choosing the right amount of packaging for distribution environments requires a knowledge of at least three important factors. First are supply chain hazards: the shock, vibration, compression, and environmental conditions typically found in the physical supply chain. Second is the maximum deceleration limit the package must provide, which is determined through fragility

testing of the most sensitive components that need protection during distribution. And third, identifying the correct test protocols that best match the expected supply chain hazards. ISTA has a long, successful history developing test protocols that help members find the right balance between cost and product protection. In addition to these three standard components for developing “just right” packaging, the purpose of this paper is to suggest another element to consider when determining the right amount of packaging to use. The additional element is filtering of shock pulses captured during the creation of cushion curves, or captured in

product freefall drop tests, which can materially affect package size and logistics costs, and lead to over or under designed packaging.

2.0 BACKGROUND

Shock pulse analysis is important in two different steps of packaging design. First is in the development of cushion curves, outlined in ASTM D1596 [2]. Cushion curves are constructed by dropping a mass onto a cushion, and interpreting the resulting shock pulse deceleration. Second is the deceleration interpretation from the shock pulse captured

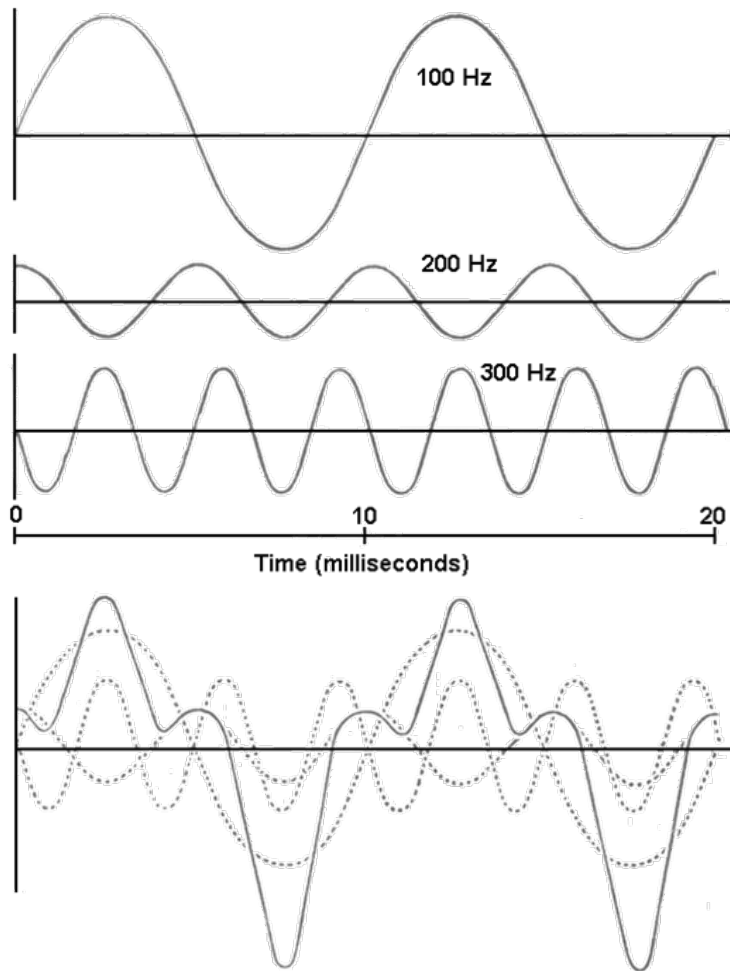


Figure 1. Resultant Pulse Composed of Multiple Sine Wave Components [6].

during packaged free fall drop, where the accelerometer is mounted on the product. In either case, the impact generates an electrical signal captured by the accelerometer and digitally converted and displayed for interpretation. The shock pulse is a curve, deceleration (expressed as the dimensionless unit G) on the vertical axis, and time (milliseconds) along the horizontal axis. The area under the curve is considered to be the total energy transmitted to, or absorbed by, the component affixed with the accelerometer. By analyzing this shock pulse curve, cushion curves are constructed describing the shock absorbency of a given material, and determine if shock transmitted to the product is below damage thresholds. The deceleration values from a product free fall drop test are used in conjunction with the cushion curves to systematically adjust cushion thickness to achieve the desired deceleration level. In both cases, the reported deceleration can be highly influenced by applying a “filter.” Filtering the shock pulse is a standard practice, a useful tool when the shock pulse is “noisy,” or difficult to determine the underlying pulse duration, shape, or deceleration, because of high frequency elements superimposed on top of the basic pulse shape. High frequency

noise can come from a variety of sources, such as electromagnetic interference, cable movement, or test fixture movement. Several sources are available for a more thorough treatment of shock pulse filtering practice and theory [3-5]. For purposes of this paper, a basic conceptual understanding of filtering will suffice to illustrate how packaging design and logistics costs can be affected. Simply put, filtering means removing sine wave frequency components from the pulse. As shown in Figure 1, a pulse can be thought of as a combination of multiple sine waves. Choosing a filter frequency of 100 Hz means removing all sine wave components 100 Hz or higher. In practice, there may be various approaches employed by software and hardware to remove unwanted noise, but the essential basis of filtering is the removal of frequency components.

Choosing the correct filter frequency is critical when determining the true peak deceleration. If a product component must be protected below 30G, and the shock pulse captured during a free fall drop test is filtered as shown in Figure 2, only the 50Hz filter pulse meets the criteria, even though all three pulses represent the same drop event. If the 270Hz filter was chosen, the deceleration dis-

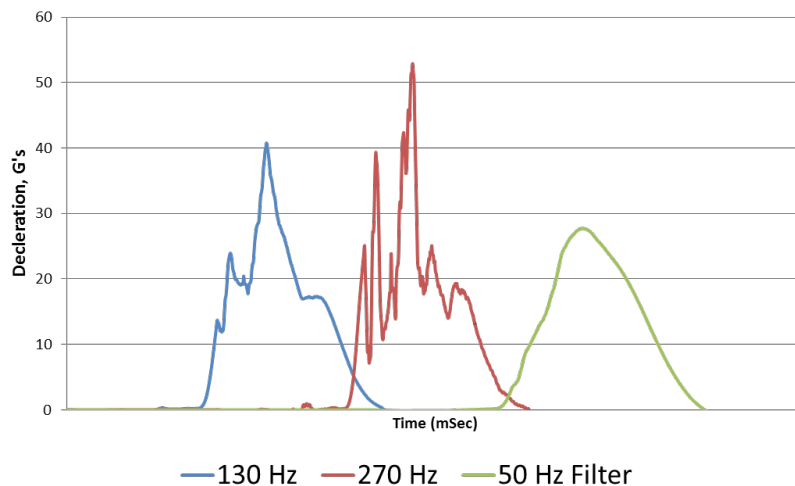


Figure 2. Deceleration Values Change With Filtering.

played would require more cushion material to reduce deceleration below 50G. In a similar way, if the cushion curves were created using the 270 Hz filter, it would imply requiring a cushion twice as thick compared to using a 50 Hz filter, as depicted in Figure 3.

Clearly then, the filter frequency chosen can play a significant role in whether the cushion thickness, and as a result, packaging size, is over or under designed. Up to now, we have only observed it is possible to affect packaging size based on shock pulse filtering. To quantify this observation, data were collected and analyzed to measure the effect shock pulse filtering had on packaging size and logistics costs.

3.0 EVALUATION METHOD

To quantify the observation that shock pulse filtering can significantly alter packaging size, the following approach was used. First, shock pulse data

were collected using ASTM D1596, using corrugated board cushion samples. The data were then filtered using three different settings. Next, cushion curves corresponding to the three filter settings were constructed. Finally, using the same product assumptions, cushion thickness was chosen based on the three different cushion curves, and the resulting package size and shipping costs were calculated.

4.0 TEST SETUP

C-flute corrugated board with an Edge Crust Test (ECT) value of 32 lbs/in was used as the cushion material. Outside liner basis weight was measured at 34 lbs, with the medium basis weight at 24 lbs. All samples were made by gluing eleven layers together in sample sizes of 4 x 4 inches, 5 x 5 inches, or 6.5 x 6.5 inches. Samples were pre-conditioned at 73F/50% RH. Conditions in the lab during testing were 72F/47% RH. Drop height and weight were varied to create nine different test lev-

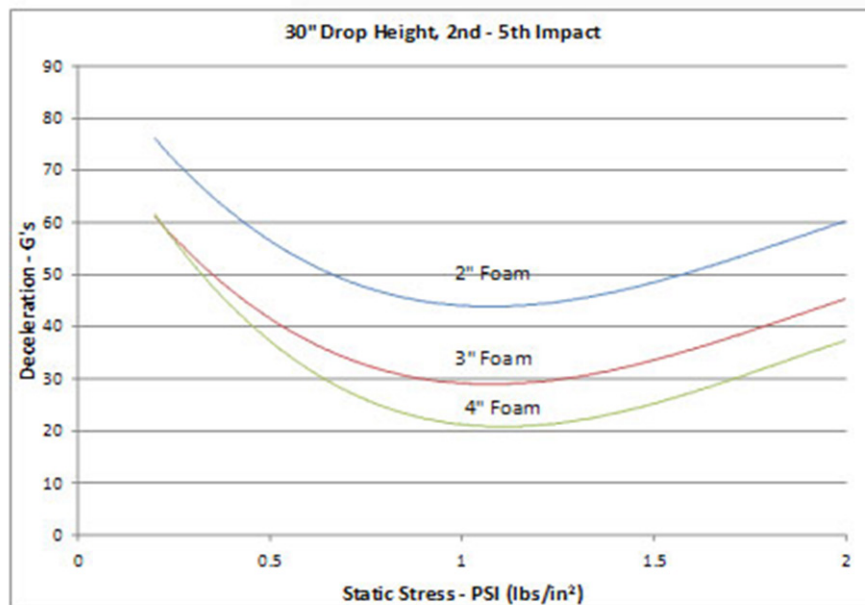


Figure 3. Foam Thickness Required To Limit Deceleration.

els, per the stress-energy method for constructing cushion curves [7]. Drops were then made onto the corrugated samples, perpendicular to the facings (flat crush mode). Using ASTM D1596, the first drop data were captured, three repetitions for each sample. A Lansmont Model 23 cushion tester instrumented with a PCB ICP® piezoelectric accelerometer, and Test Partner 3 data acquisition software was used with the following settings: Pre-trigger 20%, Double Pole RC, Half-Sine Auto Filter Ratio of 5x (this was the baseline “Auto pre-filter” setting), and a trigger threshold of 9.43 g. A 1 MHz sample rate was used, and the pulses were filtered with the following: 5x pulse frequency (pulse frequency multiplied by 5) using the “Auto with pre-filter” setting; a filter frequency of 1000 Hz; and 50 Hz. The 1000 Hz filter was chosen to simulate a user that defaults to a standard filter default option found in some software packages. The 5x pulse frequency was chosen as a generally recognized industry best-practice, a minimum recommended value [5]. The 5x pulse frequency filter was applied using the Auto Pre Filter setting, which works by applying a high frequency filter to

the raw data, then analyzes the pulse to determine its duration, then applying the 5x pulse frequency filter to the raw data. These settings were made in the Advance Setup dialog box in Test Partner. The 50 Hz filter was chosen as an extreme value that might be chosen to ensure a clean pulse shape, and was manually set. The test setup details are summarized in Table 1.

5.0 RESULTS

Deceleration values from each drop, expressed in dimensionless G, are summarized in Table 2 (page 46). Note the 50 Hz filter always gave the lowest deceleration values, while the 1000 Hz filter as expected always gave the highest deceleration values, since that filter level removes the least number of sine components from the original shock pulse.

The deceleration values were used to create the Dynamic Stress Energy Curves, one each for the three different filter settings. The Stress-Energy method uses the data collected from ASTM D1596 to create one governing equation that describes the

Table 1. Test Sample Setup.

Energy Level	Sample Number	Cushion Area (in ²)	Thickness (in.)	Weight (lbs.)	Drop Height (in.)	Static Loading (psi)
1	1-3	42.3	1.6	12.8	4.1	0.3
2	4-6	42.3	1.6	12.8	6.0	0.3
3	7-9	42.3	1.6	19.2	10.0	0.5
4	10-12	25.0	1.6	19.2	10.0	0.8
5	13-15	16.0	1.6	12.0	16.0	0.8
6	16-18	25.0	1.6	32.0	12.0	1.3
7	19-21	16.0	1.6	19.2	18.0	1.2
8	22-24	16.0	1.6	25.6	16.1	1.6
9	25-27	25.0	1.6	51.2	14.0	2.0

Table 2. Summary of Deceleration From Filtered Shock Pulses

Energy Level	Sample Number	5x Pulse Frequency		1000 Hz Filter		50Hz Filter	
		(G)	Filter (Hz)	(G)	Filter (Hz)	(G)	Filter (Hz)
1	1	87	595	120	1000	30	50
	2	65	424	94	1000	32	50
	3	69	362	97	1000	31	50
2	4	136	781	159	1000	35	50
	5	63	463	100	1000	32	50
	6	105	490	129	1000	39	50
3	7	88	253	222	1000	42	50
	8	66	278	254	1000	36	50
	9	36	207	192	1000	25	50
4	10	36	180	103	1000	21	50
	11	78	543	205	1000	14	50
	12	28	170	115	1000	22	50
5	13	28	120	81	1000	24	50
	14	32	125	133	1000	21	50
	15	41	130	128	1000	28	50
6	16	50	658	74	1000	14	50
	17	18	92	46	1000	16	50
	18	25	98	151	1000	18	50
7	19	26	108	77	1000	21	50
	20	30	167	66	1000	22	50
	21	61	472	123	1000	16	50
8	22	52	148	74	1000	30	50
	23	53	158	91	1000	28	50
	24	72	490	81	1000	28	50
9	25	103	379	137	1000	35	50
	26	153	521	224	1000	36	50
	27	106	463	114	1000	35	50

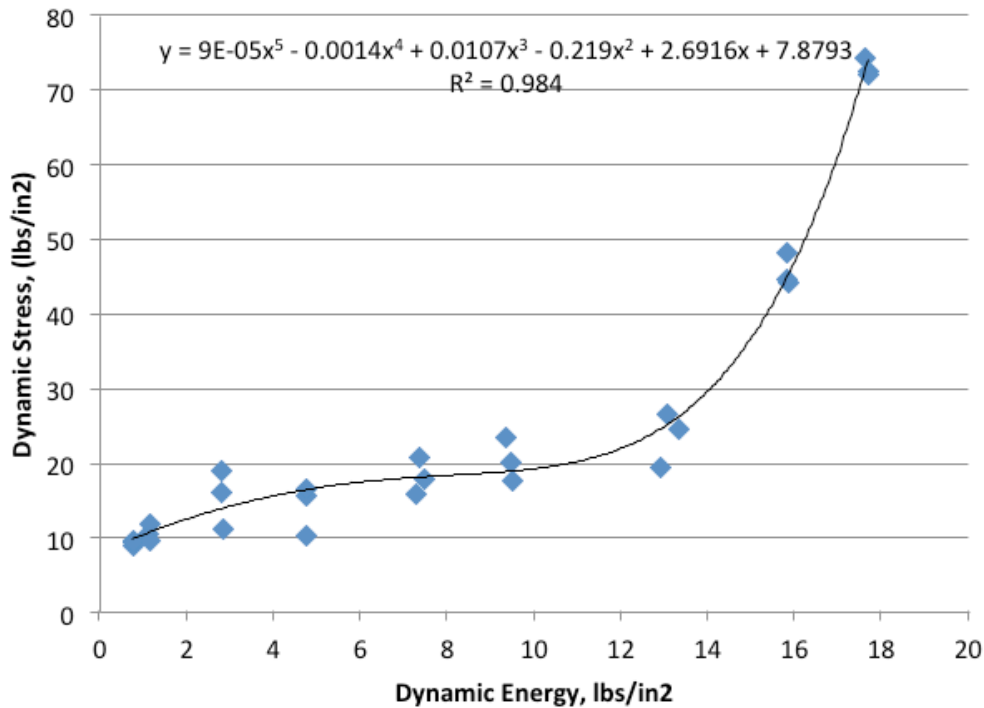


Figure 4. Dynamic Stress-Energy Curve Using 50 Hz Filter Frequency.

cushioning behavior of the material [7,8]. Figure 4 (page 47) shows the stress energy curve generated from the pulses filtered at 50 Hz.

To demonstrate filter frequency impact on deceleration, cushion curves were then constructed, [9] one each for the three filtering levels. Figure 5 (Page 48) shows the curves overlaid using the same test conditions of a 3 inch cushion, 12 inch drop height, and a static loading of 4.25 psi. Typically the highest static loading with the target deceleration level will be chosen to minimize the size of the cushion (recall static loading is weight of the product divided by the area of the cushion in contact with the product). Filtering results in deceleration ranging from 13G to 52G, and even greater disparity at other static loadings.

A more helpful analysis would show how cushion

thickness varies to obtain the same deceleration value, and then calculating package size and the resulting logistics cost difference. Using the stress energy curves and evaluating predicted deceleration at the same static loading, Figure 6 (page 48) was constructed to demonstrate the difference in cushion thickness needed to obtain the same deceleration value. At the same 12 inch drop height and 4.25 psi static loading, the deceleration values corresponding to the filtered pulses result in estimated cushion thickness ranging between 2.5 inches and 3.25 inches.

Using the information from Figure 6, analysis was then made to determine if the cushion thickness difference resulting from different filtering would make a material difference in package size and logistics costs. The product was assumed to be similar in size to a small tablet-like device and its

accessories, needing protection at or below 30G. Other assumptions included a standard GMA (48 inch by 40 inch) size pallet, a 40 foot high cube reefer ocean container with 21 pallet locations, 16 boxes per layer, and a cost per container of \$4000 USD, Hong Kong to Long Beach, CA. Results are summarized in Table 3 (page 49). Compared to the 1000 Hz filter, using the filter 5x the pulse frequency resulted in an 8% increase in number of units per pallet due to increased number of layers. Assuming 700 containers per year, savings would

be approximately \$233,000. Savings are three times greater using a 50 Hz filter.

Although potential cost savings might be realized using a 5x pulse frequency filter compared to 1000 Hz, there is also a danger that filtering too much can understate the deceleration, and actually result in higher damage rates from cushioning that is too thin. This could especially be true when using an aggressive filter like 50 Hz.

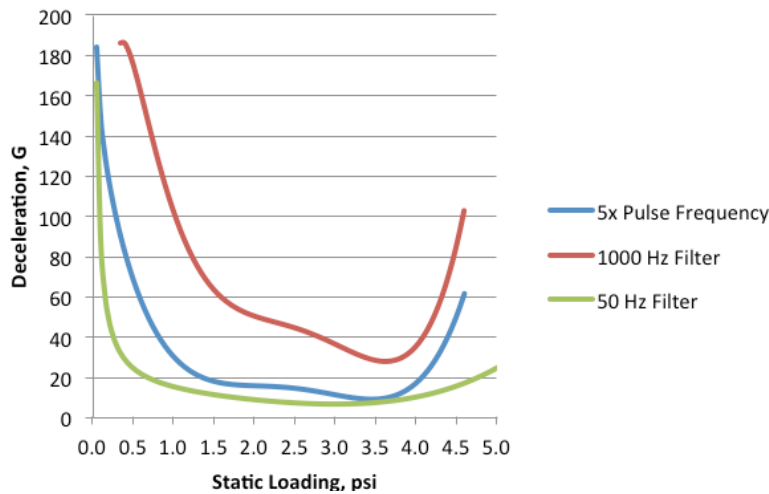


Figure 5. Filter Frequency Changes Cushion Curves. 3 inch Cushion, 12 inch Drop Height.

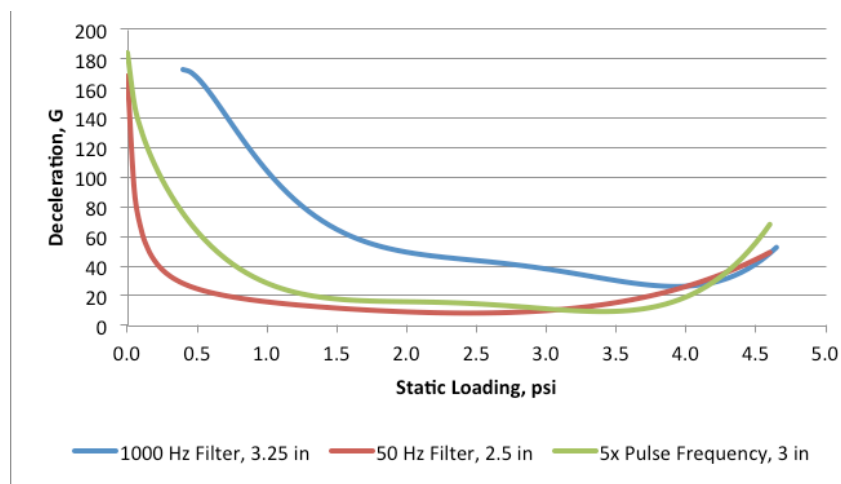


Figure 6. Cushion Thickness Varies Depending on Filter Frequency.

Table 3. Logistics Costs Resulting From Changing Filter Frequency

40' Ocean Container	1000 Hz Filter	5x Pulse Freq Filter	50 Hz Filter
Max stack height, in	100	100	100
Box height, in	8	7.5	6.5
Box length, in	12	11.5	10.5
Box width, in	10	9.5	8.5
Number of layers	12	13	15
Boxes per pallet	192	208	240
% increase		8%	25%
Freight/unit	\$0.60	\$0.54	\$0.46
Savings/year		\$233,000	\$700,000

6.0 SUMMARY

There are many resources available for understanding shock pulse filtering, and at a minimum any packaging engineer involved in making cushion choices should familiarize themselves with the theory and practice of filtering. Second, the filtering chosen for any application (generation of cushion curves, or shock from free fall product drop test) should be stated. Standards such as ASTM D 1596 should require stating the filter frequency used. Generally, a filter of not less than 5x the pulse frequency should be used, to keep the integrity of the pulse shape, deceleration and total energy, per industry best practice. And finally, it is worth the time to evaluate cushion thickness differences using different filtering, calculating potential savings or risk.

7.0 FURTHER STUDY

The use of deceleration as the determining factor for cushion thickness and packaging size presumes the product has some critical component that fails at or above a critical deceleration value. This assumption is a condition of the single degree of freedom spring mass model [10]. For compo-

nents that are not simple single degree of freedom spring mass systems, deceleration alone may not be sufficient to determine whether damage will occur. Instead, more complex models should be used that include fatigue cycles, for example [11,12]. In those cases, filtering of the pulse may be less important, or not important at all. Determining pass/fail criteria beyond simple deceleration needs further exploration so that application is not limited to single degree of freedom spring mass models.

REFERENCES

- [1] "ISTA's Responsible Packaging by Design Guide (RPbD)," (ISTA.org), [online] 2014, Accessed 25 March 2014). [Link](#)
- [2] ASTM D1596-97 (2003), "Standard Test Method for Dynamic Shock Cushioning Characteristics of Packaging Material," Annual Book of ASTM Standards, ASTM International, West Conshohocken. [Link](#)
- [3] Schueneman, H., and Escobedo, M. "The Do's and Don'ts of Package Impact Performance Testing." *Westpak*. Web. 31 March 2014. [Link](#)
- [4] Harris, C.M. "Shock and Vibration

- Handbook.” McGraw-Hill Companies, Inc., New York, NY. [Link](#)
- [5] Kipp, B., “Signal Filtering Part 2, Practical Application,” (lansmont.com), [online] 1995, (Accessed: 25 March 2014). [Link](#)
- [6] Mannell, R., “Speech Acoustics Adding Waveforms and Phase,” (MacQuarie University, Faculty of Human Sciences), , (Accessed: March 2014). [Link](#)
- [7] Burgess, G. Consolidation of Cushion Curves. *Packaging Technology and Science* Vol 3, 189-194 (1990). [Link](#)
- [8] Daum, M. “Simplified Presentation of the Stress-Energy Method for General Commercial Use.” *Journal of Testing and Evaluation*. Volume 36, Number 1. January 2008. [Link](#)
- [9] Daum, M., Darby, D., Batt, G., and Campbell, L. “Application of the Stress-Energy Method for Generating Corrugated Board Cushion Curves.” *Journal of Testing and Evaluation*. Volume 41, No. 4. March 2013. [Link](#)
- [10] Brandenburg, R.K., Ph.D., and Lee, J.J.L., Ph.D., *Fundamentals of Packaging Dynamics*, L.A.B., Skaneateles, NY
- [11] Daum, M. “Shock Response Spectrum and Fatigue Damage: A New Approach to Product Fragility Testing.” *Dissertation for the Degree of Ph.D.*, Michigan State University, 1999.
- [12] Daum, M. “Combining a Fatigue Model With a Shock Response Spectrum Algorithm.” *Journal of Testing and Evaluation*. Volume 32, Issue 5. September 2004. [Link](#)