WHAT'S NEW IN PRODUCT TESTING FOR DISTRIBUTION

Presented at ISTA Con 99 April 8, 1999 Orlando, Florida
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ABSTRACT

Although the obvious connection between product fragility and package performance is common sense (rugged products need less performance, fragile products need more), fragility testing of the product is required to quantify and optimize this relationship. Damage boundary protocols have been on the books for over 25 years – what's new? This paper will discuss the application of shock response spectrum (SRS) analysis and fatigue considerations to damage boundary testing, and resonance search with random vibration.

SRS ANALYSIS AND DAMAGE BOUNDARY TESTING

The Damage Boundary

The Damage Boundary concept was first proposed by Dr. Robert Newton of Monterey in 1968[1], and validated in 1969 and 1970 at Michigan State University. A few years later it was incorporated by ASTM (American Society for Testing and Materials) into D3332 – "Standard Test Methods for Mechanical Shock Fragility of Products, Using Shock Machines"[2]. For the first time, the packaging industry was afforded a practical tool for determining the fragility of commercial products – information that could then be used to actually *engineer* the design of protective packages.

A brief, and simplified, review: the Damage Boundary is a means of describing the shock fragility of a product or component – what shock pulses will damage it, and what pulses will not. It is generally expressed as a plot of peak acceleration vs. velocity change, as shown in Figure 1. The vertical line, critical velocity (V_C), represents the velocity change (can be related to drop height) below which no damage will occur regardless of the peak pulse acceleration. The horizontal line, critical acceleration (A_C), represents the acceleration at which the product will be damaged, if velocity significantly exceeds V_C. The Damage Boundary is determined in a laboratory by subjecting the product to controlled and specific increasing-severity shock pulses using a shock test machine, plotting the points on a Damage Boundary graph, and noting where damage occurs. Half sine pulses are used to find the critical velocity line (at which point the product breaks and must be repaired or replaced), and square wave pulses are used to find the critical acceleration line (breaking another product). Since the critical lines are known to be vertical and horizontal respectively, one point determines each line and only two products need be broken to determine the Damage Boundary (for a single axis and direction). In general, it can require as many as 6 different Damage Boundaries to describe fragility, one for each direction of each orthogonal axis of the product.

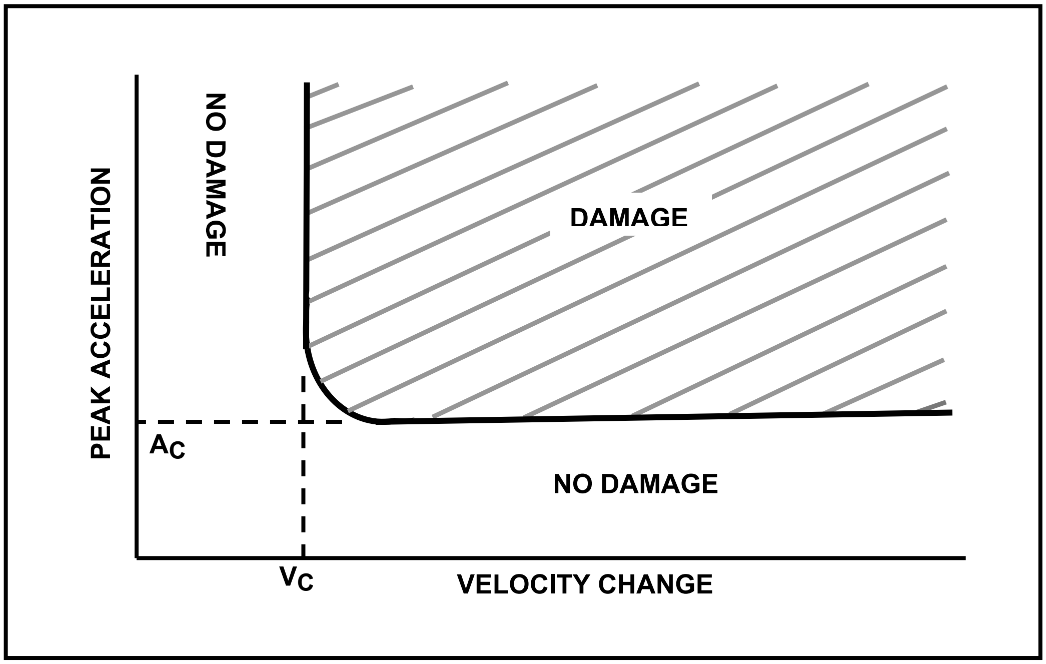

FIGURE 1: THE DAMAGE BOUNDARY

The Damage Boundaries for a product lead directly to an appropriate protective package design. If the critical velocity, when converted to equivalent free-fall drop height, is more than the design drop height, little or no protective package is needed. If the critical velocity is less than the design drop height, a protective package is required. In this case, package performance must be such that, when dropped from the design height, less than the critical level of acceleration is transmitted to the product.

D3332 has now been on the books for over 25 years, and is widely accepted. Many companies and organizations have written the concepts into their internal packaging standards, packaging schools have incorporated them into their curricula, and numerous papers, case studies, and success stories on the subject have been published. The Damage Boundary approach is taught and practiced in various forms worldwide.

Conservatism of the Damage Boundary

In traditional Damage Boundary testing, the critical acceleration (A_C) is determined with square-wave pulses for two reasons – first, because the square wave critical acceleration is an easily-defined horizontal line, making its value independent of velocity change and drop height (as long as the critical velocity is significantly exceeded); and second, because the square wave *envelopes* the damage potential of all other pulses of the same peak acceleration; i.e., no other waveshape can produce damage at a lower acceleration level. Since it's not possible to know beforehand the waveshapes that will be produced by a cushioned package (at the time of product fragility testing, the cushion material hasn't been selected and the package hasn't been designed yet!), covering all possible waveshapes was acknowledged to be the best approach.

But along with extensive use of the Damage Boundary came the realization that package designs based on critical acceleration are often quite conservative. That is, in many cases it may be possible to design the cushion to transmit a higher acceleration than A_C, yet still not cause damage to the product. This is because of the differences in pulse shape and characteristics between the fragility test and the package cushion performance test. While we don't know beforehand what waveshape will be transmitted by the cushion, it's essentially *never* a square wave, and therefore designs based on A_C will always be from slightly to significantly conservative. A small "safety factor" is probably good, but too much conservatism is costly and wasteful.

Why not use a different pulse type for Damage Boundary testing, one more like those produced by actual cushioned packages? One problem is that critical acceleration boundaries produced by non-square pulses are neither smooth nor horizontal; one point does not determine such a curve, meaning that dozens of products would have to be broken during test. Another problem is that actual cushion pulses can have widely *varying* waveshapes, depending on material, thickness, configuration, manufacturing methods, etc. – and any arbitrary test waveshape might *overstate* the product's ruggedness, leading to excessive damage in shipment. At least one always knows that with a square wave the fragility estimate will be "safe"; i.e. conservative. It's just that we don't want it to be *too* conservative.

So there is an obvious need for an improved approach to relate product fragility and package performance.

Shock Response Spectrum

The use of Shock Response Spectrum (SRS) analysis may provide such an approach. Briefly stated, SRS analysis calculates the responses of a large number of theoretical, single-degree-of-freedom spring-mass systems to a given shock pulse. An SRS plot is a graph of the absolute value of the peak response accelerations of each spring-mass system, plotted at their various natural frequencies[3]. Thus SRS provides an estimate of the response of an actual product and its various components to a given input shock pulse. And since it's the *response* of a product to shock, not the input shock pulse per se, which causes failure or breakage, an estimate of that response should be useful in predicting damage. Figure 2 is an example SRS, the plot of a nominal 30G 11 millisecond half sine pulse from a shock test machine.

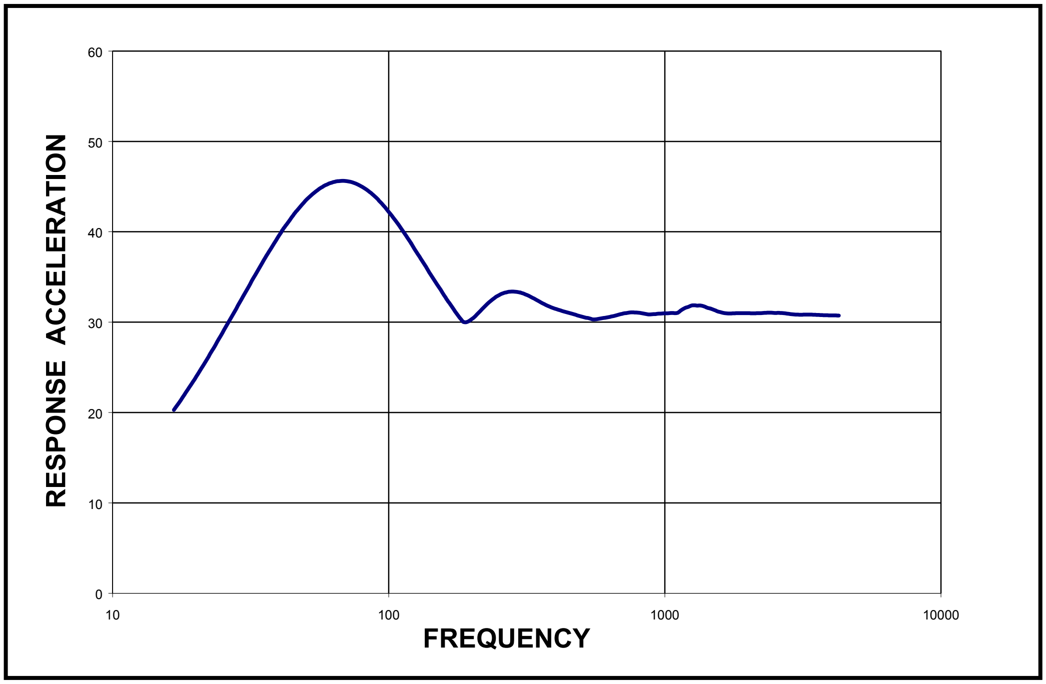

FIGURE 2: SHOCK RESPONSE SPECTRUM

SRS Analysis and Product Fragility

At the time of this writing, ASTM is near approval of an annex to D3332 which relates to the potential usefulness of SRS in fragility testing and package design. What is discussed is a procedure whereby a standard damage-boundary-type acceleration test is conducted using a square wave input shock pulse (the square wave is still used because it's the most severe, or most damaging, waveshape). But for the input (shock table) pulse that causes damage to the product, an SRS is calculated rather than just recording the pulse acceleration. This calculated response spectrum is called S_C, the "critical" SRS. The idea is that this estimated level of product response vs. frequency, regardless of what caused it, will result in damage. Then S_C, rather than A_C, becomes the design target for protective packaging: instead of designing the package to transmit no more than the critical acceleration A_C, it's designed to transmit a shock pulse with an SRS of less than S_C (lies below S_C at every frequency on the SRS plot). This largely compensates for the effect of varying input pulse waveshapes, since the design is based on the product's <u>*response*</u> rather than on the input pulse acceleration. And it often turns out that the peak acceleration of the cushion pulse exceeds the acceleration of the Damage Boundary pulse by 25% or more.

A further refinement is possible if the natural frequency of the product's fragile component is known (from a vibration test or through some other means). In this case, the SRS of the shock pulse transmitted by the cushioning need only lie below S_C in the frequency region of the fragile component's natural frequency (from perhaps 0.5 to 2 times the component's f_N). In other frequency regions the cushion SRS may exceed S_C.

It's interesting to note that the original Damage Boundary theory was based on SRS analysis. Newton's 1968 paper includes a lengthy discussion of shock spectra. So why didn't he recommend its use? On page 7, Newton states "A realistic appraisal of the data requirements makes evident the impracticality of using a fully rational version of shock spectrum analysis for routine package design. A simpler, and somewhat less accurate, procedure is needed." In other words, in 1968 Bob didn't have a PC and SRS software!

No such restrictions apply today. Several computer-based data systems are now on the market which incorporate fast and accurate SRS analysis. With the new annex to D3332, this advanced approach should get more attention and use, and result in more effective and efficient protective packages.

A Missing Link

Cushioned package design based on the current standard protocol is relatively straight-forward: determine the product's A_C from a Damage Boundary test, then examine shock cushion curves (which give transmitted G's for a specific material, thickness, and drop height as a function of static stress loading) to find a material and configuration which will transmit less than A_C. See Figure 3.

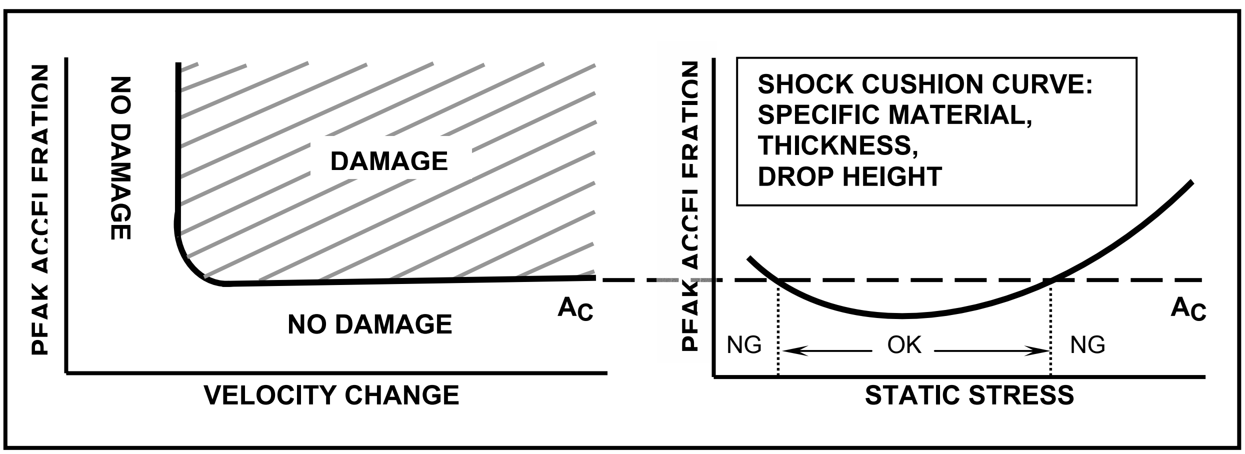

FIGURE 3: CUSHION DESIGN BASED ON A_C

But there currently is no cushion data based on SRS. So if one obtains S_C, the critical SRS for a product, it cannot be used directly to choose a cushion material and configuration. Some amount of trial and error must still be employed to design the best package. The advantage is that, using SRS techniques, there is a well-defined target for final package performance, and an ability to know what the limits are.

There is definitely a need for SRS-based cushion information, so that the process can be optimized. A possible approach: cushion data could be presented not as a 2-dimensional curve of acceleration vs. static stress, but as a 3D _surface_ of response acceleration, static stress, and frequency (see Figure 4). Projection of each individual curve on the acceleration-frequency plane would be the SRS of that particular cushion pulse (or the average SRS of several pulses); projection of the peaks of all curves onto the acceleration-static stress plane would give something like a traditional cushion curve, except that it would plot the calculated peak _responses_ to the cushion pulses, rather than the average of the peaks of the pulses themselves.

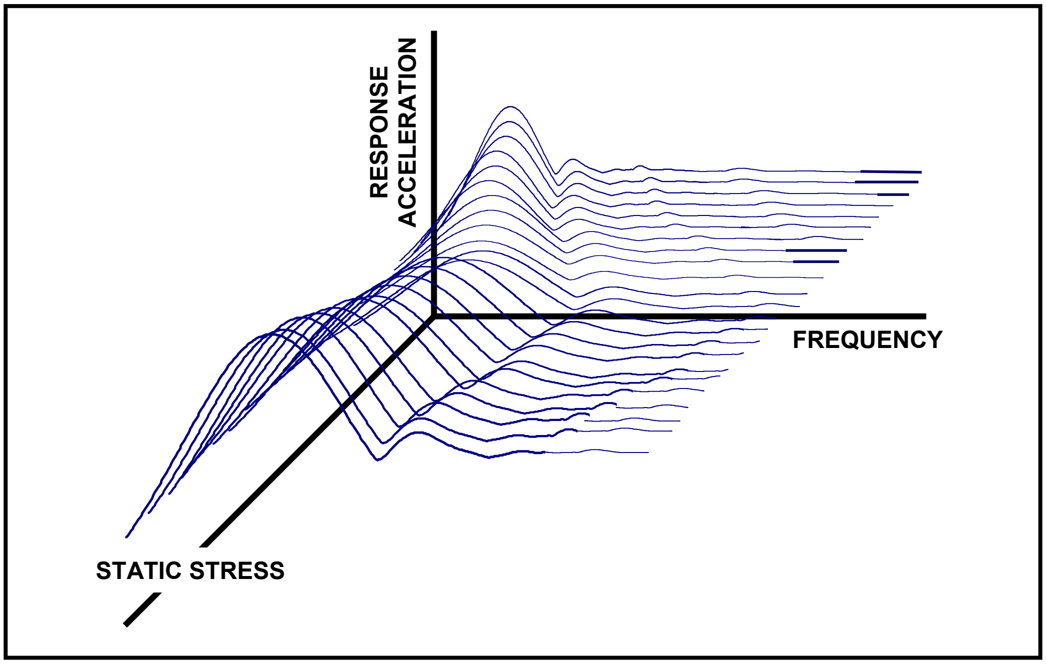

FIGURE 4: CUSHION DATA OF THE FUTURE?

Such cushion data would allow identification of cushions and loadings which produce SRSs below the target, S_C. Certainly it would not be as straightforward as comparing A_C to cushion performance as in Figure 3, but if both S_C and 3-dimensional cushion data were available in digital form, a suitable computer program could conduct frequency-by-frequency and loading-by-loading comparisons to find the suitable materials, thicknesses, and static stress ranges.

CUMULATIVE DAMAGE, FATIGUE

Brittle and Ductile Failures

Many materials like glass, hard plastics, and tempered steel fail in what is called a "brittle" mode; i.e. fracture occurs quickly and at a specific stress level, with little or no deformation beforehand. Repeated stresses below the fracture level cause essentially no degradation, but a single stress application above the critical level results in failure. Prior stress history has basically no effect on the critical level.

On the other hand, "ductile" materials such as soft metals and soft plastics fail more gradually; i.e. they become noticeably stretched, dented, or deformed before failure occurs. Applied stresses below the failure level may not initially cause damage, but they degrade the materials and reduce their ability to withstand further stress. Multiple applications of the same or relatively low stresses may eventually cause damage. Thus failure is determined by the cumulative effects of both stress level and number of stress applications.

Traditional Damage Boundary methodology assumes brittle failure, and in fact many real products do fail in a "brittle" mode. But many other products fail due to cumulative damage or fatigue, and this is not currently covered (D3332 does contain an annex which discusses the "Effect of Multiple Shocks", but this is focused primarily on determination of a value for the single shock application which will always result in failure; i.e., *elimination* of cumulative effects). Since in real-world distribution a product may experience a fairly large number of relatively low-level shocks, some means of determining cumulative effects and taking them into account would be useful.

The Fatigue Damage Boundary

Dr. Gary Burgess of Michigan State's School of Packaging has been thinking and writing about the effects of fatigue on fragility testing since at least 1988[4,5]. His latest work on the subject was in the form of a draft version of D3332, sent to ASTM subcommittee D10.15 (Fragility Assessment) for consideration. Work on this draft and method is currently under way.

What Burgess proposes is that the Damage Boundary's critical velocity (V_C) and critical acceleration (A_C) data be related to a third parameter, the number of impacts (N). In other words, failure would be defined not only in terms of V_C and A_C, but also in terms of N. Burgess shows that the basic form of the Damage Boundary would be unchanged (i.e., a vertical line for the critical velocity and a horizontal line for the critical acceleration), but that each of these would have a dependence on N.

To find the Fatigue Damage Boundaries, the procedure first involves setting up a standard laboratory "critical velocity" (short-duration half sine) shock test. But instead of starting at a low drop height and increasing the height until damage occurs, that first low-intensity shock is repeated *many times* until damage occurs, keeping track of the number of tests to failure. The idea is to find a (low) velocity change which requires a fairly high number of drops (N) to eventually cause damage. [Of course, the initial drop height may be too low to *ever* cause damage; Burgess recommends that if failure hasn't occurred in 20 drops, to raise the drop height and start over again.]

The results of the first portion of the procedure will be a V_C associated with a particular N; call it V_{CNx}, where x is the number of drops. The drop height is then raised and the testing repeated (with a new or repaired specimen), resulting in the determination of another V_{CNx}. And so on, until damage occurs in (ideally) one drop, determining V_{CN1} (Burgess' procedure can extrapolate to V_{CN1} even if actual damage occurred in two or three drops). Naturally, the number of different drop heights used will depend on how many specimens are available for test (a specimen is damaged at each drop height), but at least three is recommended.

Next, a standard laboratory "critical acceleration" (long-duration square wave) shock test is configured, at a velocity change of 2 or more times V_{CN1}. But instead of starting at a low acceleration level and increasing the acceleration until damage occurs, that first shock is repeated *many times* until damage occurs, keeping track of the number of tests to failure. Here, the idea is to find a (low) acceleration which requires a fairly high number of drops (N) to eventually cause damage. The result will be an A_C associated with a particular N; call it V_{ANx}, where x is the number of drops. The acceleration level is then increased and the testing repeated (with a new or repaired specimen), resulting in the determination of another V_{ANx}. And so on, until damage occurs in (ideally) one drop, determining V_{AN1}.

Typically, the number of tests to failure for the critical velocity data will not correspond to the number of tests to failure for the critical acceleration data. To be useful, the information must be presented in terms of complete Damage Boundaries (V_C and A_C) as a function of N, so it is necessary to adjust the data for matching values of N. Burgess shows how this can be done graphically, by linear interpolation/extrapolation, or with curve fitting calculations or software.

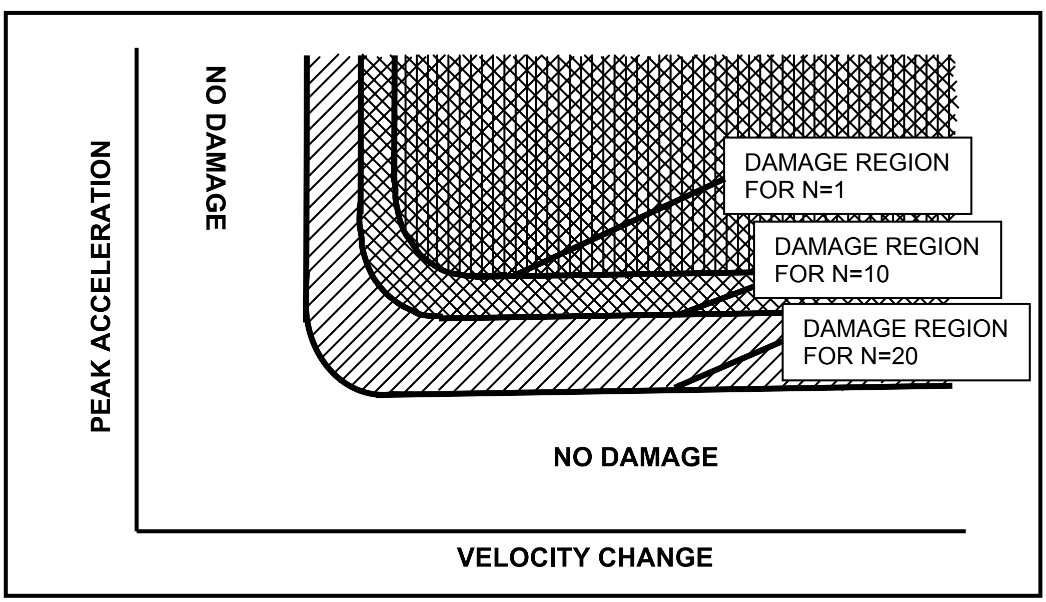

FIGURE 5: FATIGUE DAMAGE BOUNDARY

Significance

Fatigue Damage Boundary represents a general procedure, and covers the situation of brittle failure as a special case. For example, if the specimen were made of glass, the FDB procedure would find that there is *only* an N=1 damage area; attempts to find damage at lower levels and greater N's would prove fruitless. For the glass specimen, the current version of D3332 would produce exactly the same curve (and with fewer tests). But for products which fail in a ductile mode, D3332 would *not* find the curves corresponding to greater values of N, and FDB would. The more general Fatigue Damage Boundary procedure produces *complete* data on product fragility, and therefore has the potential of leading to better product and package designs.

If a standard D3332 test procedure is performed with a product which actually fails in the ductile mode, a potential over-estimate of the real fragility may be reported. In other words, multiple shocks lower in level than V_C or A_C could damage the product. Burgess' 1996 paper[5] shows that shocks down to 50% of A_C, in sufficient quantity, could produce failure. Considered in this way, the traditional Damage Boundary is potentially quite *non* -conservative!

The best situation, of course, would be to have solid statistical data on the distribution of drop heights and orientations that a particular package will experience in actual transportation, then combine that with FDB and package performance information. A number of transport environment measurement studies have been conducted[6,7] and more are currently underway[8]. All pieces of the puzzle are falling into place.

One is tempted to think about combining the SRS and FDB techniques described here into what could become the most accurate and powerful method of describing product fragility. Indeed, significant work has already been done in this area[9]. If actual drop height distribution data were also available and used, the result could be the most thorough and efficient overall methodology. Perhaps something along those lines will be the subject of future research projects and technical papers.

Applicability

There are several inherent drawbacks to this new approach. Obviously more testing is involved – the shock tests go rather quickly, but diagnostic procedures to determine damage can be quite time-consuming for some products. More after-test data manipulation is required with the Fatigue Damage Boundary procedure, but this could be overcome by suitable computer programs or possibly spreadsheet macros. A bigger issue may be the availability of test specimens to be damaged. More ductile-failure-mode products will ultimately be broken than brittle-failure-mode, but it's generally not possible to determine the mode beforehand, so enough specimens have to be obtained to cover either case.

Probably the best application of Fatigue Damage Boundary would be to moderate-value, high volume products – where test specimens are readily available, and where the payoff for improved knowledge of product fragility would easily justify the added time and expense involved in the testing process.

RESONANCE SEARCH USING RANDOM VIBRATION

Resonance and Damage, Resonance Search and Dwell Tests

It is generally accepted that product vibration damage is most likely to occur at the natural (resonant) frequencies of critical components. These are the frequencies where equivalent spring-mass systems within the product over-respond to input vibration. As a result, accelerations and displacements are amplified to the point of potential damage. Such behavior can often be observed visually, seen with the aid of a stroboscope, audibly identified, or measured and recorded with appropriate instrumentation. In the latter case, data is usually presented in the form of a transmissibility plot, as shown in Figure 6.

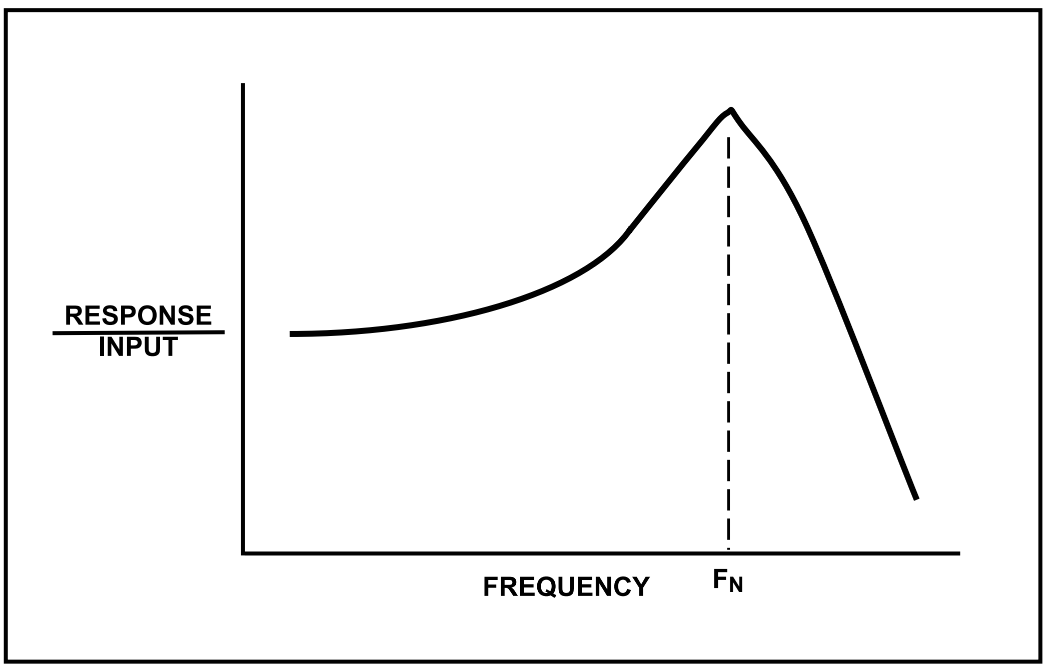

FIGURE 6: TRANSMISSIBILITY PLOT

The peaks of the transmissibility curves (the maximum responses) occur at the observed or measured components' natural frequencies, F_N; these are identified during a _resonance search_ test as being potentially critical, then subjected to _dwell tests_ (constant frequency) to ascertain if damage will, in fact, occur.

ASTM D3580

ASTM D3580 – "Standard Test Methods for Vibration (Vertical Linear Motion) Test of Products" [2] – covers product resonance search and dwell testing, and has been in existence for a number of years. Until its most recent revision, the method employed sine testing for the "search" portion, with a recommended ¼ - ½ G sweep from 3 to 100 and back to 3 Hz. at a maximum sweep rate of 1 octave per minute. The test conducted in this way (at the 1 oct./min. rate) takes approximately 10 minutes – about 5 for the up-sweep and 5 for the down-sweep. [The governing formula is $F = F_0 \, x \, 2^{RT}$, where F_0 is the starting frequency, and F is the frequency after sweeping at octave rate R for time T]. In 1994, it was suggested that a resonance search using random vibration could be conducted more quickly and would yield similar results. The D3580 Task Group began investigating this idea, first by surveying a number of leading testing organizations which had experimented with the approach, then by conducting a controlled series of feasibility tests using various models and products. The indications were positive, so draft revisions of the method began, as well as an extensive series of round-robin tests. The purpose of the round-robin series (multiple tests, multiple labs) was not only to thoroughly validate the new approach, but to furnish data to meet ASTM's requirements for a definitive and well-founded Precision and Bias statement.

The final result of this effort was the 1995 revision to D3580, which incorporates resonance search using random vibration. But it's interesting that the revision contains this note: "The two test methods (*sine and random*) are not necessarily equivalent and may not produce the same results". What does this mean, and what are the ramifications?

The Round-Robin Test Data

Answers to these questions can be obtained from examination of the round-robin tests and data[10]. Six different laboratories were involved in the test series, and a total of 52 separate tests were run over a 3 month time period. The test equipment varied, with 5 different types of hydraulic actuators, 4 different table sizes and types, and 3 different kinds of instrumentation and control systems. The test specimen was a "combustion blower" furnished by a leading U.S. furnace and air conditioner manufacturer. While certainly a real product, it was a relatively simple spring-mass system dynamically, with the motor/fan assembly affixed to the housing with three equally-spaced steel springs. The unit was mounted to a rigid L-shaped fixture, which in turn was mounted to the vibration systems' tables as shown in Figure 7. An accelerometer was attached to the end of the motor, with the responses measured and plotted as transmissibility wherever possible (some controllers couldn't record transmissibility directly, so it was calculated or otherwise derived). The same test specimen and fixture was shipped between the various laboratories and used for all the tests, but each lab furnished their own accelerometers, cables, signal conditioners, and associated instrumentation.

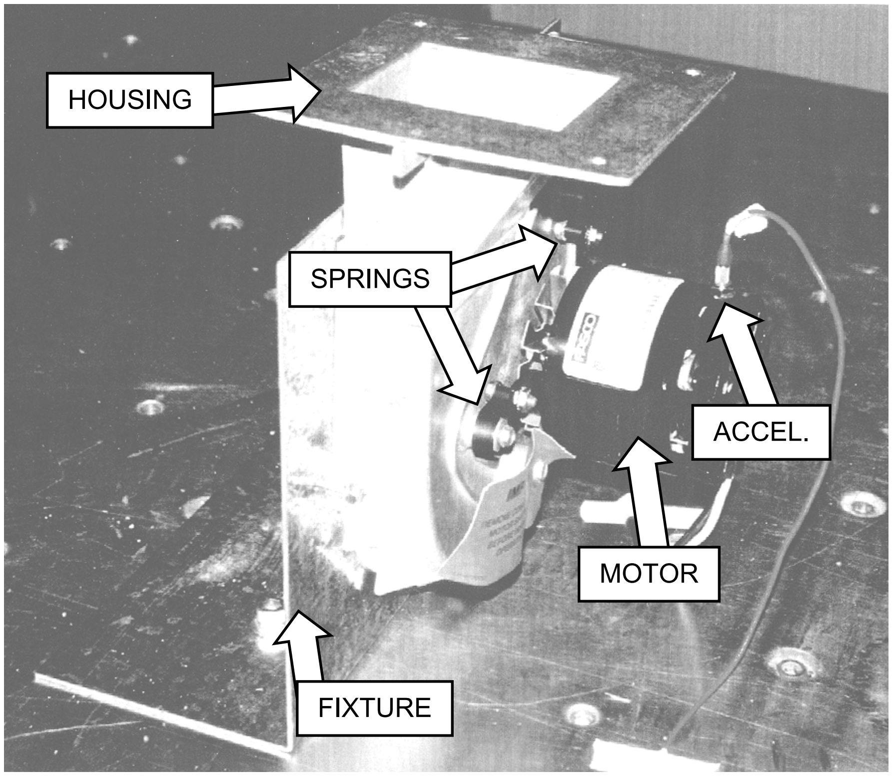

FIGURE 7: "COMBUSTION BLOWER" TEST SPECIMEN

A series of sine sweep tests in accordance with D3580 were performed as a control. Eight of these tests were run by 5 laboratories, using ½ G sweeps. The results are shown as Figure 8.

TEST #	LAB	F1	F2	F3	F4	F5	F6
2	LAB "B"	27.33			73.94		145.16
6	LAB "C"	27.33		64.60	73.94		
10	LAB "D"	30.24			72.70	84.62	145.16
14	LAB "E"	27.44			72.13		143.2
23	LAB "B"	27.33	42.38		72.70		142.74
30	LAB "B"	27.33	42.38		72.70		145.16
37	LAB "F"	27.80		64.60	72.70		145.16
44	LAB "F"	27.80		64.60	73.94		145.16

FIGURE 8: RESULTS OF SINE TESTS

The “Test #” column indicates the position of the sine tests in the overall test series; the important point is that these tests were not run back-to-back, but were sprinkled throughout the larger program. The columns labeled “F1”, “F2”, “F3”, etc. indicate the significant product resonant frequencies (with transmissibilities exceeding 2:1) which were identified by each lab and test. Notice that the nominal 28 Hz. resonance was identified every time, as was the nominal 73 Hz. resonance. The 145 Hz. resonance was not recorded by Lab C, and Labs B and C recorded frequencies not identified by other labs. So even the sine “control” tests were not entirely consistent.

Figure 9 shows results of the random tests.

TEST #	LAB	SPECTRUM	F1	F2	F3	F4	F5	F6
1	LAB "A"	BROADBAND	28.00		63.75	75.50		NOTE
3	LAB "B"	RAIL	27.97			75.02		144.96
4	LAB "B"	TRUCK	26.70			73.75		144.96
5	LAB "B"	AIR	27.97			73.75		144.96
7	LAB "C"	RAIL	27.97		64.85	73.75		
8	LAB "C"	TRUCK	27.97		64.85		80.11	
9	LAB "C"	AIR	27.97			71.21		144.96
	LAB "D"	RAIL	30.52			72.48	91.55	
	LAB "D"	TRUCK	30.52			71.21	91.55	
13	LAB "D"	AIR	30.52			71.21	91.55	
5	LAB "E"	RAIL	28			71		145
	LAB "E"	TRUCK	28			71		145
	LAB "E"	AIR	27			71		145
8	LAB "A"	BROADBAND	27.25	39.25	60.25	72.75		NOTE
9	LAB "A"	BROADBAND	27.25			73.00		NOTE
	LAB "A"	BROADBAND	30.00			74.00		145.00
	LAB "A"	BROADBAND	30.50			73.50		144.50
	LAB "A"	BRDBND 5	29.50			72.50		144.00
24	LAB "B"	RAIL	27.97			73.75		144.96
	LAB "B"	TRUCK	26.70			72.48		144.96
26	LAB "B"	AIR	27.97			71.21		142.42
7	LAB "B"	FLAT	26.70			71.21		142.42
28	LAB "B"	FLAT - DIP	26.70	40.69		72.48		142.42
9	LAB "B"	FLAT - B. DIP	26.70	40.69		73.75		143.69
	LAB "B"	RAIL	26.70			72.48		144.96
32	LAB "B"	TRUCK	26.70			71.21		144.96
	LAB "B"	AIR	27.97			71.21		142.42
34	LAB "B"	FLAT	26.70			71.21		143.69
5	LAB "B"	FLAT - DIP	26.70	40.69		72.48		143.69
36	LAB "B"	FLAT - B. DIP	26.70	39.42		72.48		142.42
38	LAB "F"	RAIL	29.25		66.12		87.74	143.69
9	LAB "F"	TRUCK	27.97		64.85	71.21		143.69
40	LAB "F"	AIR	27.97			71.21		143.69
1	LAB "F"	FLAT	29.25		66.12		95.37	143.69
42	LAB "F"	FLAT - DIP	29.25		64.85	73.75		143.69
43	LAB "F"	FLAT - B. DIP	29.25		64.85	73.75		143.69
45	LAB "F"	RAIL	29.25		66.12	73.00	87.74	
46	LAB "F"	TRUCK	27.97		64.85		92.82	143.69
47	LAB "F"	AIR	27.97			71.21	92.82	142.42
48	LAB "F"	FLAT	27.97		64.85		94.10	143.69
49	LAB "F"	FLAT - DIP	29.25		64.85	73.75		143.69
50	LAB "F"	FLAT - B. DIP	29.25		64.85	73.75		144.96
51	LAB "A"	BROADBAND	30.50			72.00		145.50
52	LAB "A"	BROADBAND	31.00			72.00		145.50

FIGURE 9: RESULTS OF RANDOM TESTS

Several different random spectra were used, as indicated in the “Spectrum” column. The “Truck”, “Rail”, and “Air” spectra are taken directly from ASTM D4169, using Assurance Level II in all cases. Lab A drove their vibration system with a flat random signal (called “Broadband”) and did not otherwise control the resultant spectrum shape. For test 22 they experimented with a higher-voltage-level signal; for tests 1, 18 and 19 their spectrum only extended to 100 Hz. The “Flat” spectrum was a constant 0.002 G^2/Hz. from 3 to 200 Hz.; the “Flat – Dip” spectrum was similar but with a -10 db section that extended from 10 to 80 Hz.; the Flat – Big Dip” spectrum was similar but with a -20 db section.

Using random, all labs and tests again identified the nominal 28 Hz. resonance. All *labs*, but not all *tests*, identified the 73 Hz. resonance. All labs usually (but not always) recorded a 145 Hz. resonance – except for Lab D, which *never* reported 145 Hz. Frequencies F2, F3, and F5 were indicated by more than one lab, but not often enough to be deemed significant.

Amplifications at resonance (commonly called “Q”) were measured during the tests. These were not included in the report (that would have been beyond our scope), but the data is interesting as it shows a large variation in measured Q’s. For example, just for the nominal 28 Hz. resonance the sine test Q’s ranged from 16.9 to 43.2 while the random test Q’s ranged from 11.1 to 36.5. The lower Q values with random are probably to be expected (less resonant amplification buildup with random than with sine), and perhaps some Q variation in random can be explained by product component non-linearities. But the large Q range with the standard ½ G sine sweep was unexpected and difficult to explain.

Resonance Search Conclusions

From a packaging standpoint, the fact that the lowest-frequency resonance was always identified, both in sine and random, is sufficient. If a package were designed to properly protect for this resonance, all higher-frequency resonances would be automatically be taken into account[11]. But in terms of describing product characteristics, the inconsistencies in identifying critical frequencies could be troubling. The source of these inconsistencies was not investigated as part of the round-robin series, but obviously could be due to differences in the actuators, vibration tables, instrumentation, and control systems.

The conclusion would be that, for increased accuracy and data confidence, replicate tests should be conducted – ideally with different test systems and instrumentation. This of course doesn’t just apply to resonance searches and vibration testing, but is always recommended for any critical testing program.

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