# **PRODUCT SHOCK FRAGILITY TESTING:**

## ACQUISITION AND USE OF CRITICAL VELOCITY CHANGE DATA

PREPARED BY

HERBERT H. SCHUENEMAN, CP-P/MH AUGUST, 1993

PRESENTED BY

WESTPAK, INC. 83 Great Oaks Blvd., San Jose, CA 95119 (408) 224-1300 FAX (408) 224-5113 www.westpak.com



## PRODUCT SHOCK FRAGILITY TESTING: ACQUISITION AND USE OF CRITICAL VELOCITY CHANGE DATA

#### ABSTRACT

Product fragility is often determined using the Damage Boundary test procedure described in ASTM D3332.(3) Part of that procedure requires determination of the critical velocity change of the product under test. The duration (half period) of the shock pulse used to conduct the velocity change test is crucial. It must be very short relative to the natural period of the "fragile element" within the product. Some implications of this and recommendations on testing procedures are explored.

#### <u>SYMBOLS</u>

#### DESCRIPTION

**COMMON UNITS** 

An	Peak pulse acceleration (input)	m/s², G
Ar	Peak acceleration response	m/s², G
e	Coefficient of restitution, $V_r/V_i$	dimensionless ratio
f	Frequency, cycles per second	Hz
f <sub>i</sub>	Frequency of an input (shock pulse)	Hz
f <sub>r</sub>	Natural frequency of the responding spring/mass system	Hz
g	Acceleration of gravity at sea level	9.8 m/s², 386 in/s²
G	Dimensionless multiple of g, a/g	
р	Period of a shock pulse=(2)t	ms
ť	Duration of pulse measured at .1 An	ms
Vi	Impact velocity	m/s, in/s
Vr	Rebound velocity	m/s, in/s
DŻ	Velocity change, V <sub>i</sub> + V <sub>r</sub>	m/s, in/s
DV <sub>c</sub> (Vi +Vr)c	Critical velocity change	m/s, in/s

#### I. INTRODUCTION

The Damage Boundary theory, as originally proposed by Dr. Robert Newton (1), is a simplification of shock response spectrum (SRS) analysis widely used in architectural and civil engineering and other fields for studying the response of large structures to shock inputs. The SRS (figure 1) tells us that mechanical components (characterized as spring-mass systems) respond differently to various types of shock pulses. In particular, the response of a single degree of freedom (SDOF), undamped spring-mass system to a very short duration shock pulse ("short" relative to the natural period of the SDOF system) is largely a function of the velocity change (integral of acceleration) of the input shock pulse. This type of event is often called a "velocity shock".



Figure 1

For longer duration shock pulses, the response of that same spring-mass system is a function of the peak acceleration of the input shock pulse as well as its waveform (the shape of the shock pulse). By studying the SRS in figure 1, it can be seen that a square wave produces the highest primary response of a spring-mass system, and this response is independent of pulse duration for  $f_r > .5f_i$ . For other types of waveforms, such as half sine or terminal peak sawtooth pulses, the acceleration response of a spring-mass system depends on the relationship between the pulse frequency,  $f_i$ , and the natural frequency of the spring-mass system,  $f_r$ .

The value of the Damage Boundary concept was that it simplified the procedure for determining the response of a spring-mass system (such as a mechanical product) so that two waveforms could "envelope" its response to all potential shock inputs. A short duration "velocity shock" pulse would be used to determine the response of the product in the high frequency range (short pulse duration), and a longer duration pulse would be used to determine the response of the product to lower frequency (longer duration) shock pulses.

A half sine waveform is generally used to determine critical velocity change. The reasons are that it is easy to program on most shock test machines, and the response of spring-mass systems in this frequency region is independent of shock input waveform. (See figure 1).

To determine the critical acceleration of a product, a square wave is the normal choice because the spring-mass response is a maximum. This results in a conservative estimate of the fragility of a mechanical product in the Damage Boundary test. However, it is physically impossible to program a perfect "square" wave because the required rise and decay times of the pulses are infinitely short. Mechanical systems such as shock test machines always produce shock pulses with some finite rise and decay time. Thus the waveform actually used more resembles a trapezoidal pulse than a square wave. This results in a slightly less conservative estimate of fragility when using the Damage Boundary method (see figure 2). However, this is not considered significant because the likelihood of the product ever experiencing a "square wave" (or even a trapezoidal pulse) during its life cycle is extremely rare.



Figure 2 Damage Boundary Representation for Various Waveforms

Thus it was that the original Damage Boundary theory proposed using a short duration half sine pulse to determine critical velocity change, and a longer duration trapezoidal pulse to determine critical acceleration. It can be seen from figure 2 that the Damage Boundary plot closely resembles an inverted SRS plot. This was done on purpose in order to minimize the confusion between the two. (2)

#### II. THE NATURE OF THE VELOCITY CHANGE TEST

It was stated earlier that the shock pulse used to program critical velocity change must have a very short duration relative to the natural period of the spring-mass system (product) under test. For a single degree-of-freedom undamped spring-mass system, the requirement is that the input pulse have a period 1/6 or less the natural period of the spring-mass system. For pulses longer than this, the spring-mass system begins to respond to the acceleration and waveform of the input shock pulse, not just the velocity change. It should also be noted that once the period of the input shock pulse reaches 1/2 the natural period of the responding spring-mass system, the full effect of the waveform and its peak acceleration content are seen in the responding system. (See figure 1)

It follows from the above that one must have knowledge of the natural frequency of critical components within a tested product prior to running a Damage Boundary test. Specifically, one must know the lowest natural frequencies of critical components in order to determine the maximum duration of the shock pulse used to run the velocity change test. The original Damage Boundary theory and early versions of test standard ASTM D3332 suggested that a 2 or 3 msec duration pulse was adequate for most "velocity shock" test purposes.(3) However, if one uses the above criteria for determining maximum pulse duration, it can be shown that spring-mass systems with natural frequencies above 42 or 28 Hz respectively\* are no longer in the "velocity shock" response mode but are starting to respond to peak acceleration and waveform too. The experience of the author has been that many electronic products have critical components with much higher natural frequencies.

\* For a .002 sec pulse, natural period = (2)(.002) = .004 sec

f = 1/p = 1/.004 = 250 Hz. (1/6)(250 Hz) = 42 Hz = highest product natural frequency for which a 2 msec shock pulse can accurately determine critical velocity change. For a 3 msec pulse, highest  $f_r$  = 28 Hz

It should be noted that the 2 or 3 msec duration normally specified for velocity change tests has its origin in the limitation of shock test equipment on the market at the time. Shock machines of higher payload capacity tend to be unable to produce very short duration pulses; their structures will simply not allow it. However, this does not mean that it is prudent to ignore the requirement of the shock response spectrum to program a short duration pulse for true velocity change testing.

This does mean that vibration testing should be conducted on a product prior to conducting a Damage Boundary velocity change test in order that the natural frequency of responding systems be known. This practice makes good sense from a practical standpoint as well. This testing is often done on prototype or expensive products where the availability of testable specimens is normally very restricted. Since vibration testing is rarely destructive by its very nature, it is prudent to conduct vibration testing on scarce sample products prior to the potentially destructive Damage Boundary test. Of greater significance, of course, is the fact that the natural period can be determined easily from this test.

#### **III. CASE HISTORY**

Over the past 10-15 years much testing has been conducted on electro-mechanical products associated with the computer industry, particularly Winchester disk drives (so-called hard drives). These products were initially very sensitive to shock input and were normally considered the weak link (fragility wise) in a personal computer. More recent products, especially the smaller format disk drives, have shown an amazing increase in their ruggedness and ability to withstand shock input. Acceleration sensitivity of 150 G's is not uncommon and 300+ G products have been tested. In addition the velocity sensitivity of these products is likewise increasing. Critical velocity changes in excess of 2.5 m/s (100 in/s) are considered the norm.

As product size decreases and ruggedness increases, the natural frequency of critical components within the product tends to rise. Some products show primary resonances well above 300 Hz. In a case like this the typical 2 msec half sine pulse is far too long to determine critical velocity change of the product. It merely subjects the product to a half sine waveform acceleration test. The reason for this is the 2 msec pulse is very long in comparison to the natural period of the product. In order to determine the true velocity sensitivity of a product such as this, a pulse of about

200 microseconds duration is necessary. The programming of such pulses requires specialized equipment that is very limited in its size and weight capacity.

Vastly different results can be anticipated from velocity change testing using a nominal 2 msec half sine versus a shock pulse with a period less than 1/6 the natural period of the product. In the case of the Winchester disk drive product mentioned previously, the velocity change test conducted with a 2 msec half sine produced a critical velocity change in the neighborhood of 2.8 m/s (110 in/s). The peak acceleration of this waveform is about 300 G. The same product subjected to a 200 microsecond pulse with a peak acceleration above 1000 G's showed the true velocity sensitivity to be approximately 1.8 m/s (70 in/s).

Thus it can be concluded that the first test was not a "velocity change" test at all but merely a "peak acceleration" test using a half sine waveform. When this same product was tested for peak acceleration using a trapezoidal pulse, a 180 G sensitivity was determined.

### IV. THE PRACTICAL USE OF VELOCITY CHANGE DATA

After the true velocity sensitivity of the product has been obtained, what is the engineer to do with this data? Of what significance is the determination of critical velocity change?

In general there are three practical uses for this data. The first is to determine whether or not a package system is required for the product. Secondly, the data gives a good indication of the ruggedness of the product for the "in-use" or unpackaged environment. Finally, engineers use the critical velocity change number in programming the shock pulse used to determine critical acceleration. The criterion generally applied is that the critical acceleration pulse should have a velocity change at least double that of the critical velocity change. The reason for this is to avoid programming the critical acceleration pulse in the "knee" of the Damage Boundary. See Figure 2 for more details.

#### IS A CUSHIONED PACKAGE REQUIRED?

If the critical velocity change determined in the Damage Boundary test is greater than the impact velocity likely to be experience by the product in distribution, then it can be concluded that a cushioned package (one that limits peak acceleration to the product) is really not required. A practical example of this occurred when testing some of the early computer systems, those that consisted primarily of a keyboard and a printed circuit card. In one particular case, the critical velocity was determined to be in excess of 7.5 m/s (288 in/s). Since the product weighed approximately 7 kg (16 lbs.) and was approximately the size of a small typewriter, the design drop height was determined to be 1.1 m (42 in.). The impact velocity from a 1.1 m freefall is approximately 4.5 m/s (180 in/s). Thus, the coefficient of restitution, e, of the impact would have to be nearly 1 before the product would experience 7.5 m/s (288 in/s) or more given a 1.1 m (42-in.) freefall. For a situation like this, the product did not require a protective package, but merely one that would avoid physical scratching, scuffing or other aesthetic damage. It was not velocity sensitive in the range of inputs likely from the distribution environment.

### PRODUCT "IN-USE" RUGGEDNESS

The second major use of the velocity change data is in determining the ruggedness of the product for the "in-use" or unpackaged environment. If a product is unstable and likely to tipover during its manufacture or use, then the velocity change sensitivity would give a good indication of whether or not damage was likely during that event. Similarly, if a product, like a hand-held calculator, has a low critical velocity change, then it is likely to receive damage in its normal "in-use" environment.

### THE "GLASS JAW" CALCULATOR

An interesting case occurred with the manufacturer of a well-known hand-held calculator. The typical place of use for this particular product was on a desktop surface. Testing had shown that the product could not withstand the velocity change associated with a free-fall impact from desktop height. Since this was later determined to be a "reasonable environment" for product operation, it was therefore expected that the product should in fact be able to withstand this impact. This

product was later recalled and replaced with a more rugged product at considerable expense to the manufacturer.

#### THE UNINSTALLABLE HDA

A large format disk drive system was found to have velocity sensitivity of the head/disk assembly (HDA) of approximately 1.1 m/s (43 in/s). The product had a terrible history of damage during shipment, and enormous effort was placed in the redesign of the protective package to reduce the incidence of damage. However, it was discovered that more elaborate and expensive packaging had little or no effect on the incidence of damage in the field.

It was then that the critical velocity change data was examined more carefully. In particular, it was determined that the installation of the HDA into its driver mechanism produced a shock pulse with a velocity change greater than the critical velocity determined earlier during damage boundary testing. Furthermore, the design of the unit made the shock pulse unavoidable because of close tolerances between alignment members of the product. Thus, the critical velocity change data showed that the product could not be assembled without producing shock pulses known to cause damage to the product. In this case, product redesign was the only feasible answer.

### V. CONCLUSIONS

It is important to recognize that the Damage Boundary test procedure is not a cookbook for robotic technicians, but rather a guideline to assist the engineer in setting up the test procedure to properly determine critical velocity change and critical acceleration for the product under test. It is necessary that the engineer understand both the product and the nature of the test in order to correctly conduct the test and properly interpret the test results.

This paper focused on the necessity of understanding the natural period of the spring mass system (product) under test and that the engineer have sufficient knowledge of the natural period of critical components prior to conducting the Damage Boundary critical velocity change test.

Without this understanding, the engineer is likely to conduct a test whose outcome may be misleading for package design or product ruggedness evaluation purposes. It is only by understanding the nature of the test and the nature of the product that accurate and reliable results can be obtained. The engineer is encouraged to investigate these areas and to modify test procedures and specifications if warranted.

### REFERENCES

- 1. Robert E. Newton, *Fragility Assessment Theory and Test Procedure,* Monterey Research Laboratory, Inc., Monterey, California, 1968.
- 2. Conversation with R. E. Newton, May, 1983.
- 3. American Society for Testing and materials, Standard ASTM D3332-72, Philadelphia, Pennsylvania