

DYNAMIC PACKAGE TESTING
TECHNIQUES TO OPTIMIZE DATA COLLECTION

PREPARED BY

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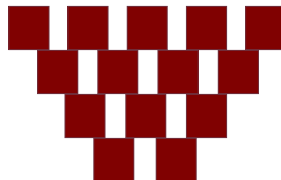
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DYNAMIC PACKAGE TESTING

The purpose of this paper is to define certain techniques which can be useful to the package engineer in determining package system performance; that is, how well does the package protect the product. A protective package is a device or material placed between a fragile product and a potentially harmful environment, the purpose of which is to protect the product from the effects of the environment. Although there are many potentially harmful environmental inputs, we will concentrate on the effects of shock (or impact).

Most protective package systems use cushion materials designed to deflect in response to induced forces. This deflection transforms the relatively high acceleration short duration shock pulse experienced when two rigid surfaces collide (such as a product dropping on the floor) into a lower G, longer duration event such as that shown in Figure 1.

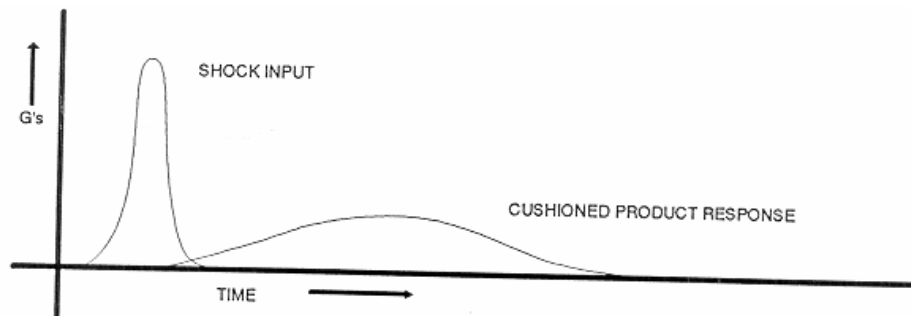
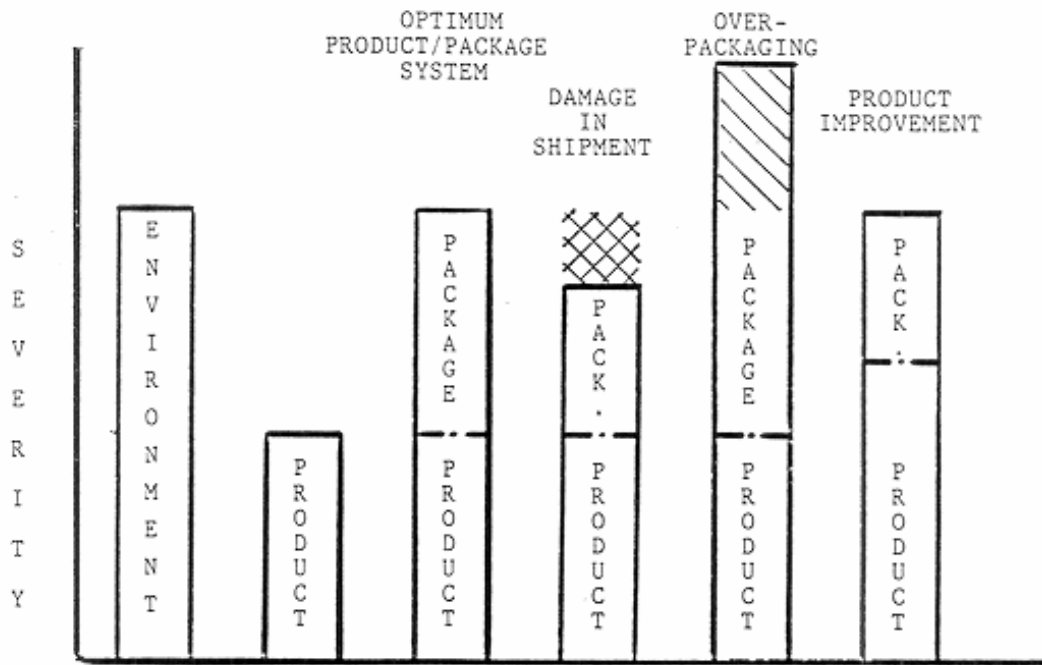


Figure 1
Shock Input and Cushioned Response

Although it is not the main focus of this paper, the process of designing a protective package system must be given significant attention by responsible packaging engineers. There is a logical step by step process helpful in the design of a cushioned package. If the proper engineering procedures are not used, the design process becomes little more than trial and error. This may result in a significant waste in materials through over-packaging. Many professionals in the field today consider over-packaging to be more significant economically than damage in shipment. The bar chart in Figure 2 shows that the optimum package design avoids both over- and under-packaging.



Protective Package – That device which limits environmental input to a level below product fragility

Figure 2

It is interesting to note that most package test specifications use either pass/fail criteria or have a maximum acceleration level as the passing criteria for the package. The bar chart suggests that it may be feasible to specify both an upper and a lower acceleration limit for package performance.

For verification of package shock performance, most test procedures simply call out a series of freefall impacts (drop tests) ala NSTA. In some cases companies will specify that the product be monitored during the impact to measure the acceleration transmitted through the cushion material. While this is a quantum leap forward from the pass/fail procedures, there are problems in collecting accurate data and making good judgments from that data.

The following is a discussion of techniques for monitoring the response from a package during a drop test. In all cases these techniques use existing technology to help the engineer better understand the dynamics of the package system under test.

THREE AXES MONITORING

This technique uses the three channels of instrumentation to monitor the acceleration in all three mutually perpendicular axes during an impact. The purpose is to determine if there are significant responses of the packaged product in axes other than the impact direction. This can occur, for example, in a system comprised of a symmetrical cushion and a product whose center of gravity is significantly removed from the geometric center of the product. There are oftentimes responses in the "side" axes that go unnoticed if a single axis only is monitored. The author has seen cases where the cross axis direction registered a higher acceleration level than the input parallel to the impact direction. This technique can also help determine the flatness of a drop which may be very important for later analysis.

The equipment required for this approach includes a triaxial accelerometer or three single accelerometers and the associated cables and amplifiers. Also required is a readout device capable of storing and displaying three axes of information simultaneously. This can be done on a computer screen with the appropriate software (Figure 3), or the information may be displayed on an oscilloscope such as has been the custom for 20 years or more.

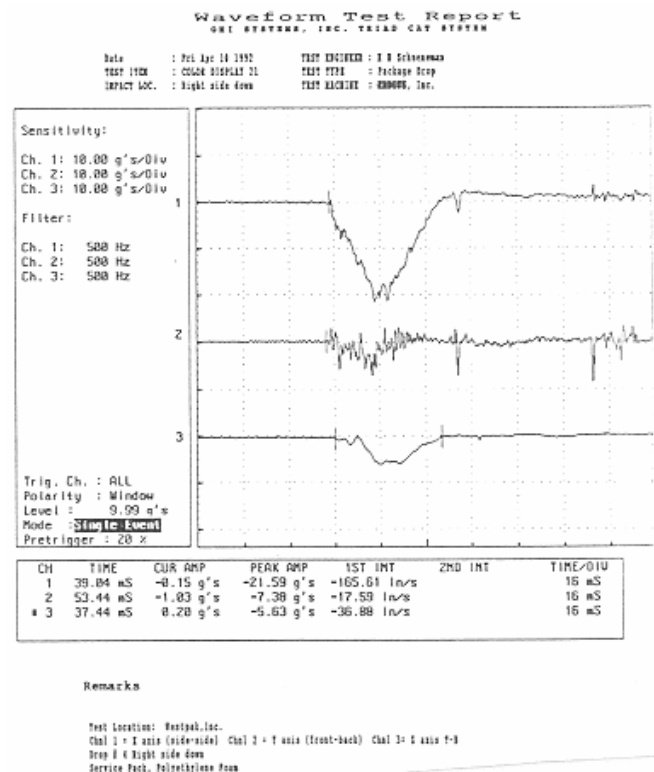


Figure 3
Simultaneous Three Axes Monitoring

Using the computer approach, the information is stored immediately after the event takes place. Following this, more tests can be run or the existing data can be massaged in a variety of different fashions. The flexibility of this approach is enormous due in large part to the software based nature of the analysis.

One of the primary disadvantages of this approach is the cost of the equipment necessary, generally about double the cost of a single axis system.

Perhaps a more significant drawback is the judgment necessary on the part of the test operator, especially in placing a triaxial accelerometer in a position which will accurately record the package response in all three axes. Rarely is it that the accelerometer placement correct for one axis will result in usable data from the other two axes. As we shall see later on, the placement of the accelerometer has a significant bearing on the overall results of a package response test. However, in spite of its drawbacks, this approach offers vast improvements over single axis monitoring. This approach gives a much more complete picture of total package response than any single axis approach can offer.

SIMULTANEOUS INPUT AND RESPONSE MONITORING (SIRM)

Most fragile products can be analyzed as a series of suspended masses, each of which has its own characteristic response to a dynamic input. Depending on the natural frequencies of these components and the frequency of the dynamic input, these components can respond at acceleration levels far greater than the input. This characteristic is displayed graphically and schematically in Figure 4. This figure shows the acceleration response amplification that can be expected from a spring/mass system as a function of its natural frequency and the frequency of the input (shock pulse). In particular, the graph shows that a linear spring/mass system which is lightly damped can be expected to generate a response acceleration more than 30 times the input if the frequency of the input coincides with the natural frequency of the spring/mass system.

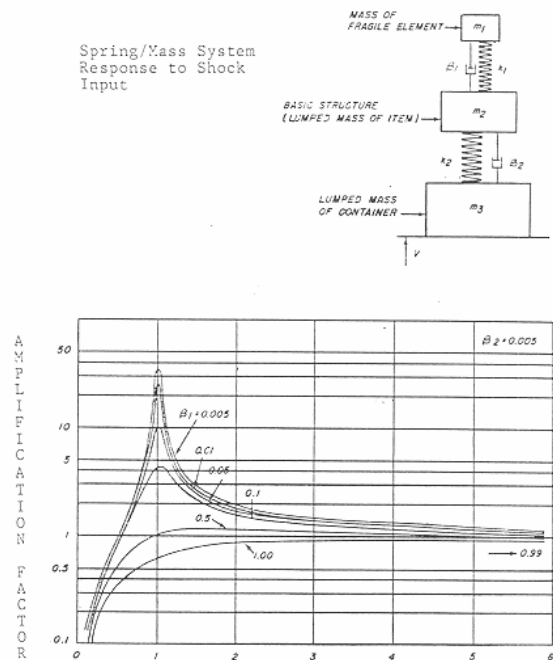


Figure 4
Response / Input Frequency Ratio

A real life system which demonstrates this characteristic very graphically is a rigid Winchester disc drive mounted inside a personal computer (processor). The rigid disc amounts to a fairly massive component suspended on a low frequency shock mounting system within the product. The natural frequency of this spring/mass system often coincides with the frequency of a shock pulse transmitted through a protective package system. This results in amplification of the shock pulse as monitored on the disc drive. Thus it is not unusual for a package system to deliver 25 G's to the processor, but have the disc drive respond at a level of 3 to 4 times that amount.

The SIRM technique is an attempt to determine the difference between **package input** and **product response**. Even though this seems like a fairly academic question and one that should be easily resolved, many engineers (especially in high tech companies) are struggling with this issue. The use of this technique may offer the information and tools necessary to help resolve the dilemma.

To use this technique, it is most desirable to generate fragility data using both an input and a response accelerometer. This deviates from the recommended practice for Damage Boundary testing in that normally only the input is monitored and the last non-failure input acceleration pulse is considered to be the fragility limit of the product. Using the SIRM approach, however, both the input to the product and the response of a critical component (such as a disc drive) would be monitored. This is shown schematically in Figure 5.

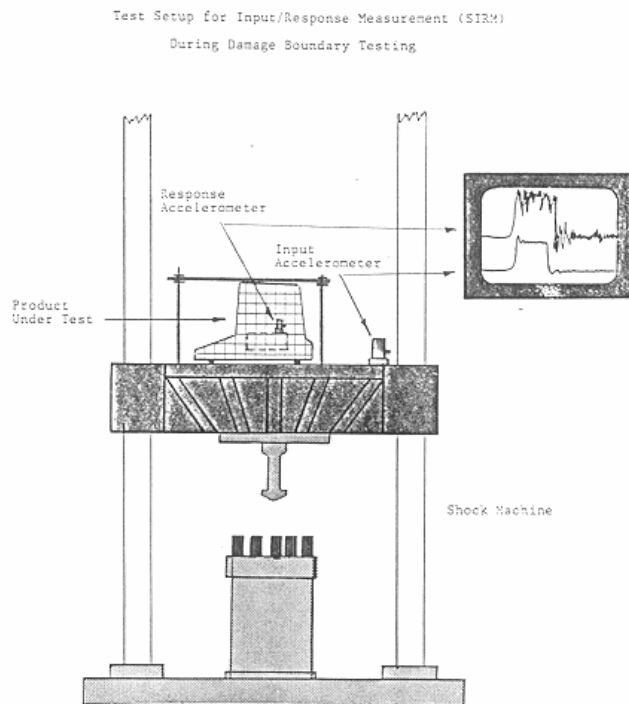


Figure 5

When the product is placed in the package system for package response testing, the acceleration response is monitored on both a rigid portion of the product and on the same flexible component monitored during the Damage boundary testing. A word of caution is in order here: The high frequency ringing and other responses typical of this

type of testing will make the data look very noisy and difficult to interpret. Filtering techniques, explained later, are helpful in a situation like this. Frequency domain analysis (Shock Response Spectrum) can also help.

Many interesting and useful things can be learned from the SIRM technique. In most cases this technique should resolve the issue of package input vs. product response. It may result in significant cost savings from over- designed package systems for high technology products.

Another significant advantage is that product and package vibration response can be estimated. For example, most packaging engineers know that it is potentially disastrous to design a cushion system which has a natural frequency at or near the critical frequencies of the components within the product. These critical frequencies can usually be estimated from product response data collected during a Damage Boundary test. Vibration transmissibility data on cushion materials can be obtained from the cushion manufacturers or can be estimated using static compression data. It should be emphasized that this results only in an estimate of the natural frequencies involved in the product and package system and that accurate response data should be obtained from vibration transmissibility tests.

The disadvantages of this approach include the requirement for two channels of response instrumentation both during product fragility testing and package performance testing. Another disadvantage is the complex nature of the response data and potential difficulties in properly interpreting the data. However, with better understanding of the dynamics involved and better tools such as the computer, this disadvantage should prove easy to overcome.

COMPUTER ASSISTED DATA ANALYSIS

The analytical power of a small computer has opened up new areas for the analysis of protective package systems. In its simplest form, the hardware required consists of the traditional accelerometer, cable and amplifier together with an analog to digital converter, a high speed storage device such as a transient memory and a processor/analyzer (computer). It should be emphasized that the appropriate software is an absolute necessity in order to enjoy the advantages this approach can offer. The

computer hardware is only as useful and beneficial as the instructions (software) allow it to be.

The various components of this system work as follows: The accelerometer senses the shock pulse and transmits it along the cable. The amplifier provides proportional boosting of the signal. The analog to digital converter takes the analog signal and changes it into a series of digital pulses which can be stored in a high speed memory device, typically solid state memories. The signal is then fed into the processor/analyzer where various functions are performed depending on the software written for the particular program.

Some of the capabilities available with this system include the following:

1. Reduction of instrumentation triggering problems.
2. Digital filtering of shock pulse, operator selectable.
3. Improved accuracy in reading response data.
4. Additional analytical capability including calculation of velocity change, deflection, coefficient of restitution, damping characteristics, etc.
5. Frequency domain analysis using SRS software.

1. **Eliminating Trigger Problems**

One of the biggest problems encountered in traditional drop testing has been devising an accurate, repeatable and easy to use system for triggering the instrumentation prior to package impact. Previously this was done with a tripwire, light beam, time delay or some other device that proved less than desirable. Current digital systems eliminate this problem by using Pulse Level Triggering. This allows the operator to select a level and polarity of signal which will automatically trigger the instrumentation system using the shock pulse itself. It is a relatively easy matter to select a threshold which will not trigger on normal transients and yet will capture the desired shock pulse repeatably.

2. Digital Filtering

Once a shock signal has been captured in its broad band format, the signal can be filtered using digital filtering techniques in which the high frequency cutoff is operator selectable. This is an incredibly useful tool which allows the test operator to filter out unwanted high frequency superimposed noise while retaining the bulk of the useful data. This also helps eliminate "human filtering" or fairing which normally occurs with a noisy response pulse. The operator can also avoid the trap of overfiltering the response pulse in which serious data distortions can occur. Figure 6 shows an example of a broad band and a filtered pulse using this technique.

The same shock pulse broadband (top) and post-filtered (lower) using a digital transient recorder and processor/analyzer

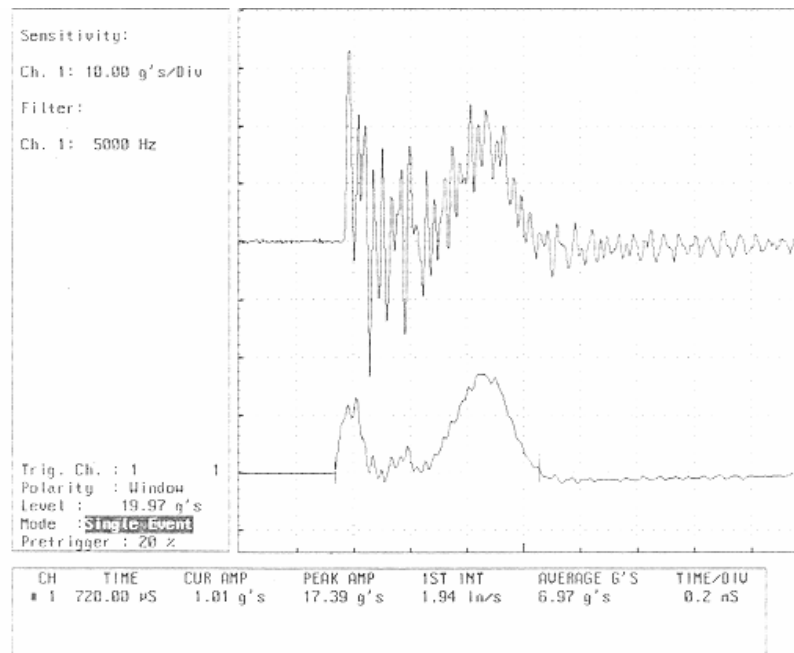


Figure 6

The same shock pulse broadband (top) and post-filtered (lower) using a digital transient recorder and processor/analyzer.

Many engineers have not been exposed to the broad band response of a packaged item during a drop test and it may be beneficial for them to see the degree of superimposed "noise" that normally exist during package response testing. It would be particularly useful for an engineer to attempt to determine

the lowest natural frequency in an unfiltered waveform without benefit of an analytical tool. For this exercise, it would also be beneficial to selectively filter the pulse in ratios of its lowest component frequency starting with .5 times this frequency and then going on to 1.0, 2.0, 5.0 and 10 times the frequency. During this exercise, the effect of filtering would become readily apparent.⁽¹⁾

3. Improved Test Accuracy

Through the use of cursors on the x and y axes of the computer screen, both the peak and the duration of a shock pulse can be very accurately determined. In addition, the peak and duration of secondary or superimposed waveforms can also be accurately determined. This is shown in Figure 7.

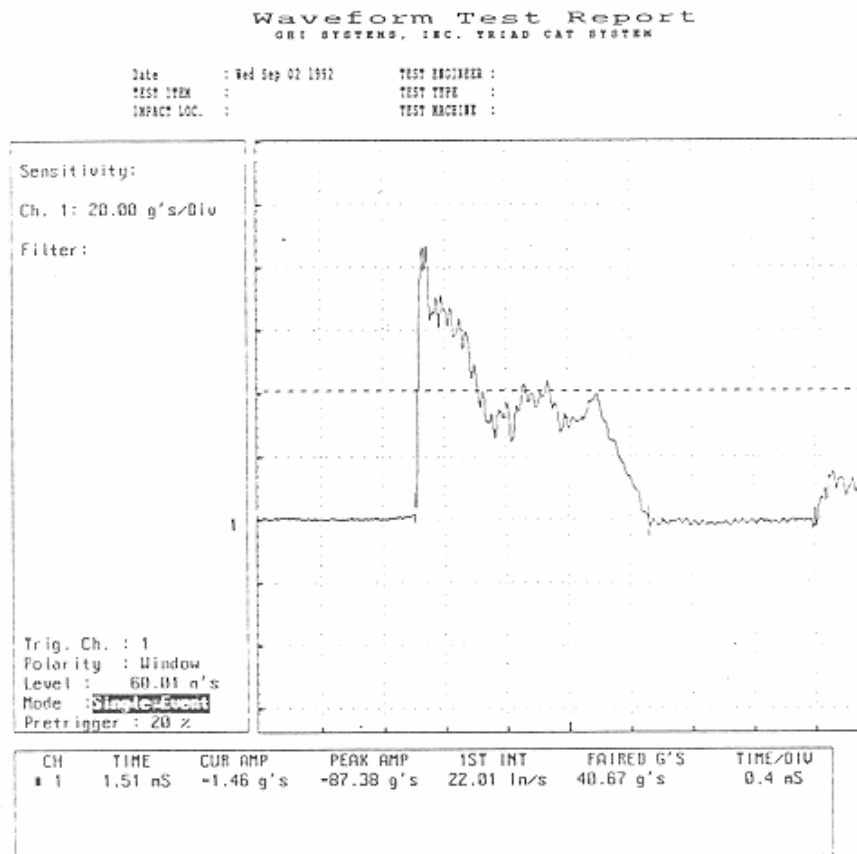


Figure 7

Another related technique involves fitting a response pulse within a certain tolerance band such as called out in MIL standards, such as MIL Std 810. Tolerance bands on a shock pulse of $\pm 15\%$ of peak amplitude are typical. With the proper software, these amplitude bands can be inserted in the program and

superimposed on top of a response waveform. It is then an easy matter to determine whether or not the shock pulse satisfies the criteria. See Figure 8 for an example.

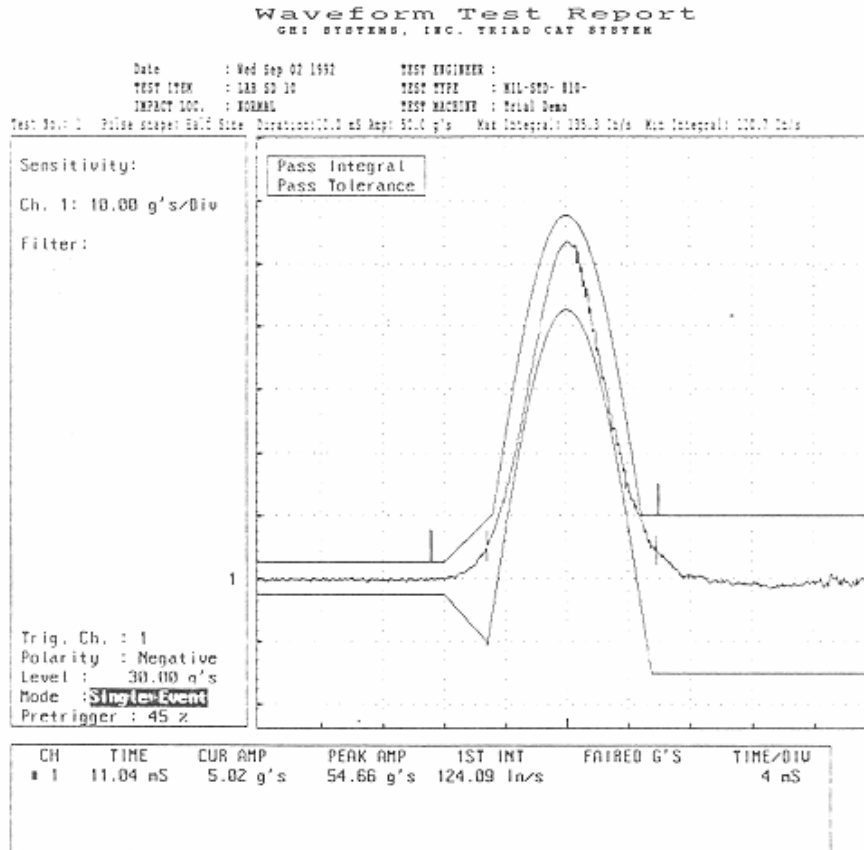


Figure 8

4. Analytical Capability

Once the shock pulse has been stored in memory, a number of analytical exercises can be performed on the waveform depending once again on the software instructions.

One of the most common analyses is a determination of velocity change which is obtained by integrating the acceleration vs. time pulse. If that information is integrated a second time, the displacement or deflection of the cushion system may also be approximated. This information can be plotted in phase with the acceleration pulse, producing the acceleration velocity and displacement profile shown in Figure 9.

Waveform Test Report
GSI SYSTEMS, INC. TRIAD CAT SYSTEM

Date : Wed Sep 02 1992 TEST ENGINEER :
TEST ITEM : TEST TYPE :
IMPACT LOC. : TEST MACHINE :

Drop Height = 4.0 In

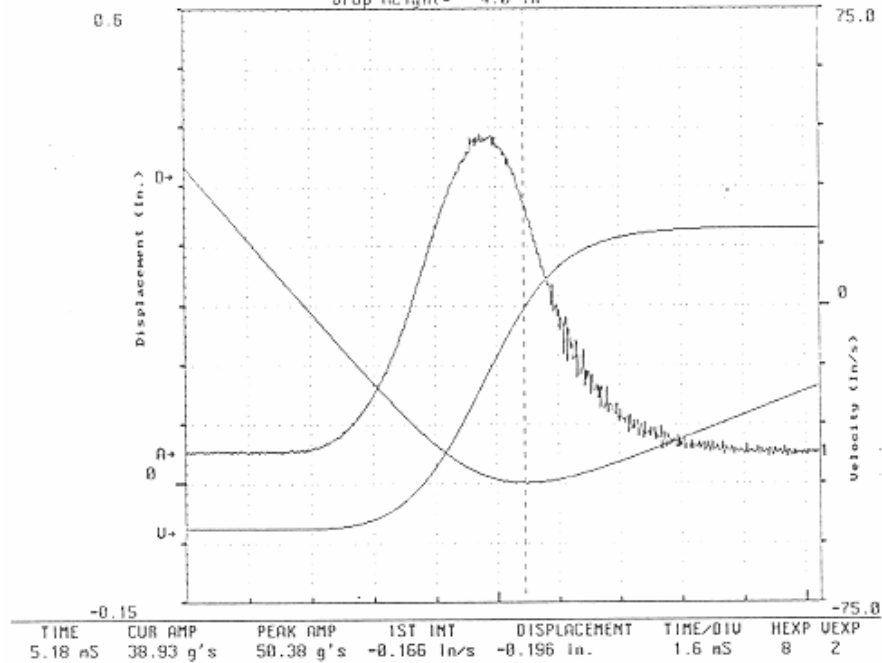


Figure 9

A variety of other analytical possibilities also exists including a determination of the coefficient of restitution of the cushion material and its damping characteristics. Once again, these are functions of the software built into the analysis system.

5. Frequency Domain Analysis

Using this technique, the acceleration vs. time (time domain) signal is stored and then reprocessed using Shock Response Spectrum (SRS) software which displays peak amplitude in G's as a function of frequency in Hz. Thus, it is called frequency domain analysis rather than the traditional time domain analysis. An example of a half sine pulse in the time domain and the resulting frequency domain, SRS plot, is shown in Figure 10.

SRS Test Report
GHI SYSTEMS, INC. TRIAD CAT SYSTEM

Date : Wed Sep 02 1992 TEST ENGINEER :
 TEST ITEM : TEST TYPE :
 IMPACT LOC. : TEST MACHINE :

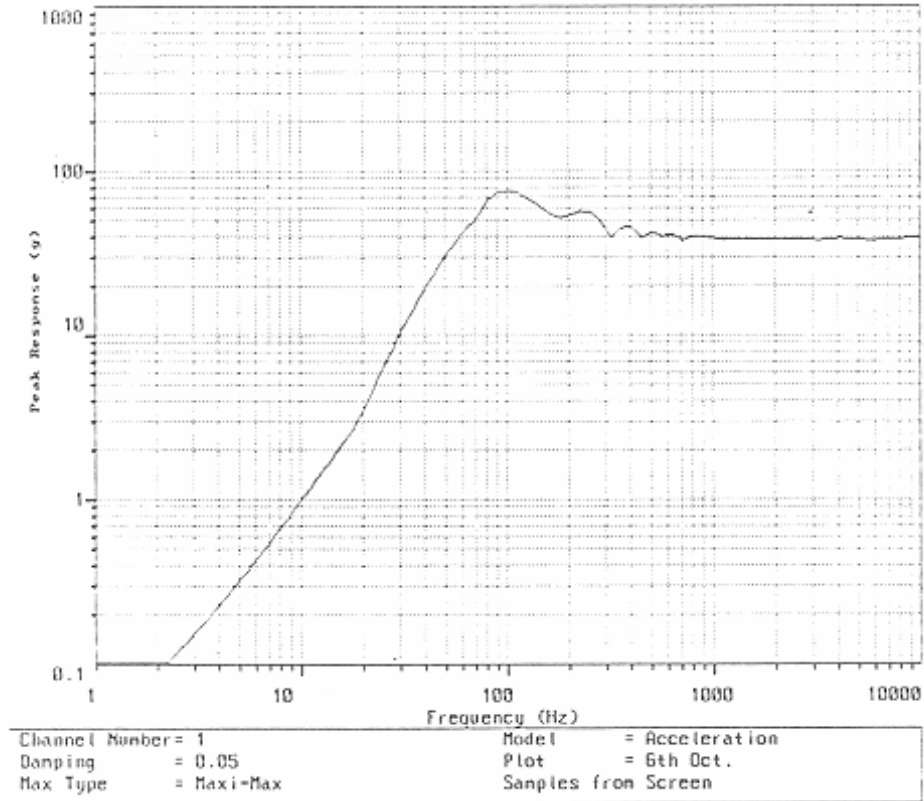


Figure 10

In the SRS all frequencies are present and their various response levels are clearly shown. Typically, SRS plots are clean looking and avoid the cluttered appearance of high frequency time domain data. Normally the lowest frequency response shown on the SRS is the cushion system and the peak acceleration level can be determined.

This technique holds promise for future analysis of package response tests once it is better understood by most packaging engineers.

Certainly other uses are available for micro processors in the packaging analysis laboratory. When combined with a printer, the computer has the capability of generating an instant report on the test results. In itself, this is a tremendous improvement in both accuracy and economy from older systems.

In addition, a large amount of data can be stored with a computer, either on removable media such as a floppy disc or as a printout on paper.

The computer can also be integrated into other data collection and analysis techniques such as drawing a Damage Boundary on laboratory data. The fragility of the product (ideally in all 3 axes) can be stored in the computer memory and can be used to assist in the package design process.

Cushion response characteristics such as transmitted deceleration levels and vibration characteristics can be stored and plotted using the appropriate software.

Once the packaging engineer is able to use these tools efficiently, the package design process should become simpler, even for more complex products. More significantly, the packaging engineer is able to accumulate much data which is potentially very useful for product design or redesign purposes. For example, if the response of a particular component is excessive, that component can be identified and strengthened, resulting in net package cost savings and a more rugged product.

It would appear to many that the design and testing of a protective package system is becoming more complex. The tools of the trade are indeed changing, but the package design function remains basically the same; namely to provide optimum protection at reasonable cost. We can anticipate that further changes will occur in the manner in which we do our job and the tools used to perform that function. However, the "human-ness" of the engineer will always have a place in the development process and package engineering is no exception. The overall worth of an engineer to an employer and to society is in part a function of his/her ability to use the best tools available. We have attempted to explain some of those new tools, what they are, and how to use them to advantage. With creativity, imagination, and the best analytical tools, the packaging engineer can help lead our economy to improvements in the efficient distribution of products.

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1. Mr. George Henderson, President
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Monterey, CA

Reference

- (1) "To Filter or Not to Filter", that is the Question"; Westpak, Inc., 1992