# Shock Machines for Testing Miniaturized Products

By

George Henderson
GHI Systems, Inc.
Published in Evaluation Engineering, April 2002.

## Introduction

The rapid evolution of technology has lead to miniaturization of products. These changes have dictated a shift in the design of shock machines used to test such products. The differences are reflected in new test specifications for a wide range of product classes. Historically, the defense industry set shock test specifications for products that were large and bulky. The old tried and true specifications, such as 50 g's amplitude and 11 msec duration using clean geometric waveform shapes were the gospel. Now, it is not uncommon to encounter requirements for several thousand g's peak at durations less than 1 msec, and in some cases, without a defined shock profile. In some instances such as pyroshock, amplitudes as great as 10E+4 g's are seen with time history shapes and durations which can't be measured by older traditional methods.

These changes raise several issues, some related to test machines and some to analysis methods. This paper discusses both.

## Hardware Issues

The changes in product response dynamics and hence test specifications brought on by miniaturization now require higher performance from shock machines.

Product design dictates the relationship between the dynamics of response and the specifications for the test shock. Reduced to it's simplest elements, when a component of a product is caused to resonate at it's basic modal frequency by a shock, the highest potential for damage will occur when the driving shock's frequency matches that of the resonant component. In other words, if we assume an imaginary product with a major component resonance at or near 500Hz, a shock pulse with a duration of 0.002 sec would force it into potentially destructive response.

It follows that as test items become miniaturized, the decrease in component masses results in much higher resonant frequencies. For example a new 1 inch format computer hard disk "microdrive" may have a stack modal frequency perhaps 10 times higher than it's 3.5 inch predecessor. In order to accomplish the same type of shock test on this new product, a shock machine capable of high amplitude shocks at 1/10th the duration of the older machine would be used. Where previously a 2 msec shock duration was acceptable, it may now require a duration of 0.2 msec. In addition, in order to obtain the velocity changes required, the pulse amplitude must also be higher.


**Figure 1**. GHI Systems, Inc. LSM Shock machine designed for testing miniature products. A 10" x 10" table is provided and the machine is unique in that it produces shocks in the X-Y plane.

Such short duration, high amplitude shocks are the domain of the mechanical shock machine. While electrodynamic shock machines are programmable over wide ranges of duration, they ultimately become limited by the response bandwidth of their control and actuation components.

A new type of shock machine used to produce high amplitude, short duration shocks is shown in Figure 1. It is a small horizontal motion, stored energy machine designed specifically for testing miniaturized products. Energy is accumulated in driving springs which are compressed by an air cylinder. Pulse amplitude and duration are user programmed by the identical methods used for falling table shock machines. This machine is capable of 250 in/sec $\Delta V$ shocks.

**Shock Specifications**.

For a particular shock machine of either gravity accelerated or stored energy operation, the relationship between available shock amplitudes and durations is primarily set by its ability to produce a certain velocity change ($\Delta V$). Obviously, in order to have a high $\Delta V$, the initial impact velocity must be high. The shock $\Delta V$ magnitude is the sum of the impact and the rebound velocities, and because they are additive, the sum can be higher than the impact velocity. To program the impact, i.e., set the deceleration and rebound, some form of impact pad is used. Variance in $\Delta V$, and hence shock amplitudes and durations, can be achieved by different resilient modular elastomer pads (MEP's) or even sheets of felt or paper. A machine driven by gravity alone is ultimately limited to $\Delta V$'s of less than twice the velocity of free fall. The theoretical limit of twice the impact velocity would be met using a programmer with a coefficient of restitution equal to 1, however, this would result in an impossible rebound velocity equal to the impact velocity, a condition for perpetual motion. For practical reasons, gravity driven shock machines are usually limited to $\Delta V$'s that are around 1.5 times the impact velocity.

The above limitation is overcome by using stored energy shock machines that do not rely on gravity for obtaining high initial impact velocities. Gravity assisted vertical shock machines are modified by the addition of elastic "bungee" cords that, when stretched, aid gravity by further accelerating the test table to obtain higher impact velocities.

By using stored energy devices, (springs, bungees, pressure accumulators, etc.), it is possible to produce a shock machine of small size and relatively low mass, as pictured in Figure 1, that can achieve high impact velocities resulting in higher $\Delta V$'s. For this reason, these types of machines are ideal for testing smaller new generation products, such as MEMS, and other miniaturized electronic and mechanical items. Since gravity assistance is not used, these machines can also produce horizontal shocks for products that must operate in a vertical gravity environment. For example, automotive crash sensors must sense a shock in the horizontal X-Y plane. An array of such devices is shown in Figure 2.

The shock pulse specification for the crash sensors shown in Figure 2 deals more with the expected operational environment than with the product's response dynamics. For this reason, even though these products are borderline "miniature," they are not tested at a high amplitude or short duration, rather they are tested at relatively low frequency, hence the orange MEP that produces 7.5 msec, 40g shocks. The critical element of this test is that they are tested in a horizontal plane.


**Figure 2.** Table of shock machine for testing miniaturized products. On the table are car crash fuel shut-offs. Operation is also monitored.

**Setting Shock Test Specifications**

A full discussion of the subject of setting specifications for all categories of shock testing is complicated and beyond the scope of this article. However, there are some basic relationships that have been used for environmental threat related testing. For example, it may be desired to produce a shock that would result if a product is dropped from a certain height onto a particular surface and be capable of maximum damage. Using some common assumptions, if a rigid product is dropped 36 inches onto a relatively hard surface with a coefficient of restitution of 0.5, the velocity change, $\Delta V$, would be equal to 1.5 times the impact velocity, or approximately 250 in/sec assuming a non-restricted rebound contribution. ($\Delta V = V(i) + V(r)$, where Vi is impact and Vr rebound velocities respectively). For this example, V(i) would be 166 in/sec, and the rebound velocity would be $0.5V(i) = 83$ in/sec.

Since the area under the shock pulse, $\Delta V$, is equal to the product of g's and time, we can work out several possible combinations of shock amplitude and duration that would meet a shock machine limit of 250 in/sec $\Delta V$. To accomplish this, we will assume that the shock pulses are roughly half sine shaped and that the coefficient of restitution is 0.5. The following table lists some of the possibilities for shock amplitude and duration that can be produced within the limits of a 250 in/sec $\Delta V$ machine.

| Peak Acceleration - g's | Duration - msec | ΔV - in/sec |
|---|---|---|
| 1500 | 1.0 | 112 |
| 2900 | 0.5 | 215 |
| 14500 | 0.1 | 250 |

A change in MEP coefficient of restitution would result in a completely different set of parameter possibilities. For very short duration shocks at high amplitudes, thin sheet programmers are used, such as felt, paper, or combinations. Since the “stopping distance” when using thin felt or paper programmers can be very small, they are close in performance to metal-to-metal impacts. Performance of this type of programmer would fall into the bottom row of performance values given in the above table.

**Shock Analysis**

For some time, shock machines with metal-to-metal contact surfaces or even fast burning explosive excited plates have been used to produce the very short duration high amplitude shocks that certain products require. Examples of these products are space electronic hardware, such as semiconductors, subjected to explosive events - stage separation, solar panel deployment, fuel tank diaphragm rupture, etc. Testing of munitions components such as fuses, sensors, and micro electro-mechanical systems, (MEMS), that are designed to impact hard surfaces are other examples of special test requirements being met by special shock machines.

Figure 3. shows the time history of a typical shock intended to test high velocity impact survivability of a military device. This recording was made on a machine similar in operation to that shown in Figure 1. The basic shock parameters of peak amplitude = 6500 g’s and duration = 200μsec can be determined in Figure 3. This type of shock is sometimes referred to as a “pyroshock” although pyrotechnic devices
were not used in its creation.

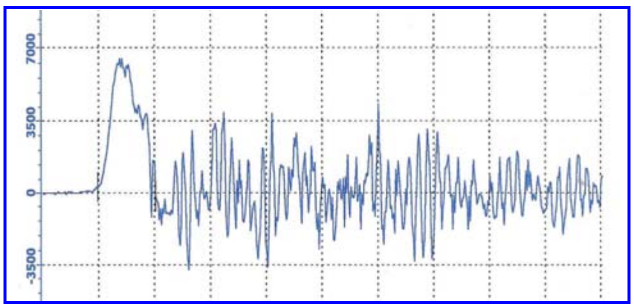


**Figure 3.** Shock amplitude is 6500g’s, and the duration of the primary pulse is 200μsec. Ringing to the right of the primary is self resonance of either the fixture or the product itself.

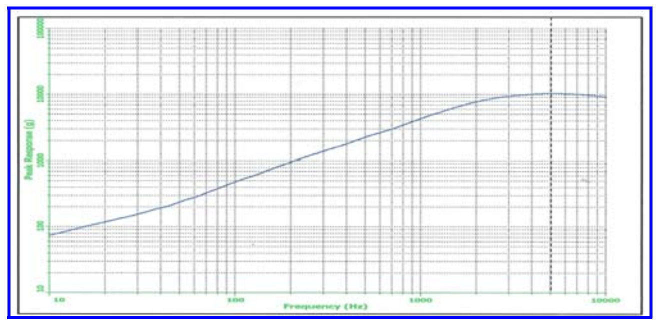

**Figure 4.** SRS of shock pulse seen in Figure 3. This shape is indicative of a classical half sine geometry shock.

It can be seen that the shape of the shock pulse is not a pure geometric fundamental, i.e., not a half sine, trapezoid, or terminal sawtooth. This lack of fidelity does not negate the test, but rather complicates the determination of its validity because simple methods of evaluating the shock pulse shape can not be easily applied. Instead the shock pulse can be processed with a analytic routine which plots the response of an infinite number of progressively “tunned,” single degree of freedom, spring mass resonators to the shock. This analytical tool is known as Shock Response Spectrum, (SRS), and is usually performed on a fast digital computer [1].

Starting with Mil-Standard 810-C in the early 1980's, the SRS has been the preferable method of characterizing a shock [2]. This is because a particular shock has a unique SRS signature. The specific shape signature combined with tolerance bars is used to define fidelity of the shock test to a specification. This specification is usually given as a set of minimum SRS amplitude tolerance bars [3]. Any deviation in amplitude of the actual shock test SRS below the tolerance limits may be considered a “failed test.”

Figure 4 shows the SRS from our example shock shown in Figure 3. Since the mechanical ringing of the product fixture was determined to be irrelevant in this specific case, the residual ringing trailing the primary pulse was truncated. The SRS was then computed from this adjusted time record. Although the time history shown in Figure 3 is not a perfect geometric half sine shape, the resulting SRS in Figure 4 is almost indistinguishable from the SRS of a classic half since shock pulse.

**Conclusion** As products to be tested have become miniaturized, requirements for shock machines and analysis methods have changed. Starting with shock durations needed to match product fundamental resonances while maintaining typical environmental ΔV values, shock amplitudes must increase. Increased ΔV capability is provided by miniaturized, acceleration aided, shock machines.

An additional benefit of the miniaturized machine is that it can be “stiffer.” This stiffness shifts the machine’s self resonances to higher frequencies, most probably out of the range that would overlap the resonances of miniaturized products. On the other hand, large drop shock machine table designs exhibit high self resonances over a broad range of frequencies when attempting high amplitude, short duration, shocks and are thus limited when testing miniaturized products unless extensively modified.

The above does not consider product fixtures, which due to materials selection and design can be self-resonators and complicate fidelity of the test and in addition, data analysis.

SRS is a solution to the data analysis part of this problem. In the presence of both machine and fixture resonances, SRS analysis can determine test adequacy, i.e., the product being subjected to the desired excitation. Because of this capability, and its test-to-test fidelity, SRS has become a standard method of test verification in many product test applications.

For the typical extreme short duration shocks used for miniaturized products, SRS is the preferred analysis tool. However, SRS can not overcome inherent machine performance limitations.

**References:**

1. Smallwood, D. O., “An Improved Recursive Formula for Calculating Shock Response Spectra”, Shock and Vibration Bulletin, No. 56, Part 1, pp. 279-287.
2. Military Standard 810-F, “Environmental Engineering Considerations and Laboratory Tests,” Department of Defense, United States of America.
3. Henderson, G.R., “A Proposed Method of Standardizing Shock Machines Using SRS Analysis,” Journal of the Institute of Environmental Sciences, July/August 1994, pp. 40-45.