

Shock Control For Portable Electronics

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Introduction

Portable electronics continue to evolve, with technology diminishing their size while adding features. Most notable are cell phones, PDA's and notebook computers. A fundamental problem still remains for all such devices: their owners often drop or bump them. When this happens, a shock event occurs. Shock is a major cause of damage and failure of portable electronic devices. Presented here is a discussion of this problem and the solutions that are available from E-A-R Specialty Composites.

What Is Shock?

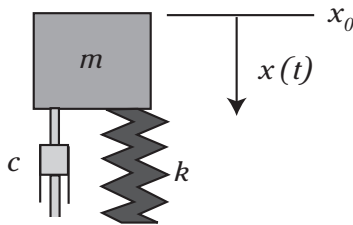


Figure 1 Simple spring-mass-damper system

Shock is typically considered a short-duration event with large-magnitude acceleration. The most common source of shock in portable electronics is a drop to the floor or bump against a hard surface. There are a few important factors that determine how this shock event is transmitted to the electronic device. The primary variables are drop height, type of floor surface and materials used in the electronic device. Often a one-degree of freedom model (1dof) of a spring-mass-damper is used to describe the effects of shock. This allows simple and straightforward solutions. The chassis is assumed to be infinitely rigid, and the shock pulse is transferred directly into the component

of concern. A diagram for such a system is shown in Figure 1.

Drop Shock: Freefall Condition

The primary cause for damage to any electronic device is the G level it experiences. The primary factor that determines G level in freefall is the drop height H . The next consideration is rebound. Rebound R characterizes how the dropped object changes velocity at the moment of impact. For full rebound $R=2$, partial rebound $1<R<2$ and with no rebound $R=1$. Since most objects do not exhibit behavior at the extremes, using a partial rebound value of $R=1.5$ is quite appropriate for most pieces of equipment.

Here are the steps taken to calculate the G level. The following equation is used to calculate the change in velocity ΔV at the moment of impact from a freefall drop

$$\Delta V = R\sqrt{2gH}$$

In the above equation, g is the gravitational constant 386.1 in/s^2 or 9810 mm/s^2 . (Note: A consistent set of units must be used.) Next, using the common assumption that the shock pulse is a half sine wave, the following formula holds for acceleration.

$$A = \frac{\pi\Delta V}{2t} = \frac{\pi R\sqrt{2gH}}{2t}$$

The time duration t of the shock input must be known before the above equation can be solved. Another common assumption is that the time duration for an impact into a hard surface is 0.002 seconds (2ms). To convert the acceleration value to Gs, A is divided by the gravitational constant g .

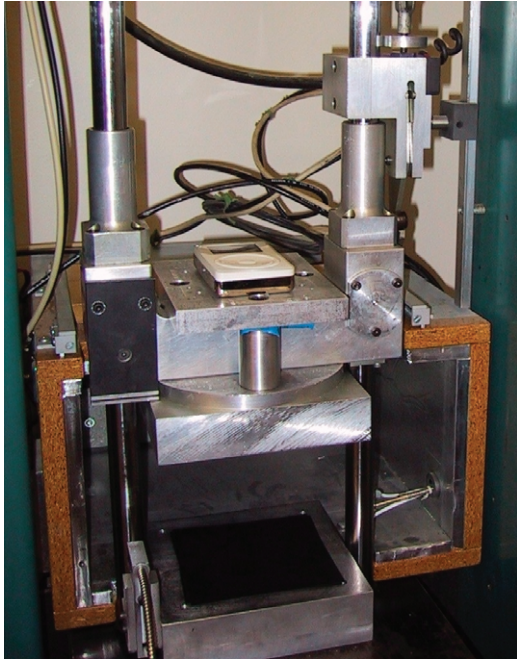


Figure 2: Drop Shock Table

Acceleration Pulses

A benefit of using the half sine pulse to approximate a drop shock is that a very reliable drop table, such as the one in Figure 2, allows for accurate and repeatable results. This is especially the case when the device is clamped to the drop table. The duration and shape of the shock pulse is adjusted by changing impact pads under the drop table.

As mentioned, a typical shock input duration used with portable electronics is 2 milliseconds. The graph in Figure 3 demonstrates the Acceleration vs. Time response of a 100G, 2 ms shock pulse on a one-degree of freedom system (1dof) with low damping and a natural frequency of 160 Hz. The response indicates a low-damped system. The advantages of high damping will be demonstrated later.

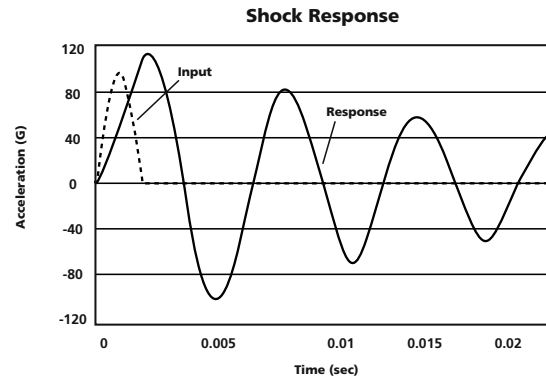


Figure 3: Response of 1dof system to acceleration pulse

Shock Transmissibility

The Response shown in Figure 3 is dependent upon the natural frequency of the system and the level of damping present. If one were to test the system with various natural frequencies and levels of damping using a half sine input, the graph in Figure 4 would be produced called the Shock Transmissibility. The graph shows the shock transmissibility for a 1dof system as a function of natural frequency of the system multiplied by the effective duration of the shock pulse.

The effective duration τ_r of a shock pulse is dependant upon its shape and duration. For a half-sine pulse, the effective duration is equal to

$$\frac{2}{\pi} t$$

where t is the total duration of the pulse.

Natural frequency ω_n is given by

$$\omega_n = \sqrt{\frac{k}{m}}$$

The shock transmissibility graph can be used as a design tool that indicates how pulse duration and system natural frequency offset peak G levels transmitted to the suspended mass. (Note the damping shown in the graph is for hysteretic damping called *loss factor* or η .)

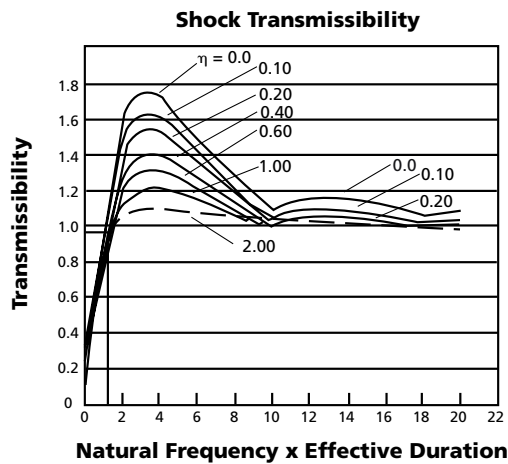


Figure 4: Shock transmissibility spectrum for half sine input and hysteretic damping (Graph adapted from Harris' Shock and Vibration Handbook, 4th Edition, p. 31.23)

Types of Damping

The damping used in almost all simulations is viscous damping c found in the 1dof differential equation

$$m\ddot{x} + c\dot{x} + kx = F(t)$$

Viscous damping is velocity dependent. Damping ratio (ζ) is commonly used to describe viscous systems and it is related to the fraction of critical damping in the system.

$$\zeta = \frac{c}{c_{cr}}$$

Critical damping c_{cr} is that damping level that will return a disturbed mass to equilibrium in the shortest amount of time.

Elastomeric materials used for shock isolation do not display viscous damping. Instead they exhibit hysteretic damping, which is a displacement dependent term usually called loss factor (η) or $\tan \delta$. The differential equation now becomes

$$m\ddot{x} + k^*x = F(t)$$

$$\text{where } k^* = k'(1 + i\eta)$$

There is, however, no closed form solution.

The rule of thumb used to equate viscous damping to loss factor is

$$\eta = 2\zeta$$

This relationship is most accurate for low damping levels, but out of necessity it must be used for modeling high damping levels as well.

Effects of Damping on Shock Response

The presence of damping has a beneficial effect on systems subjected to shock. As damping increases, there is a reduction in sway space requirements and the G level experienced. A plot of acceleration versus

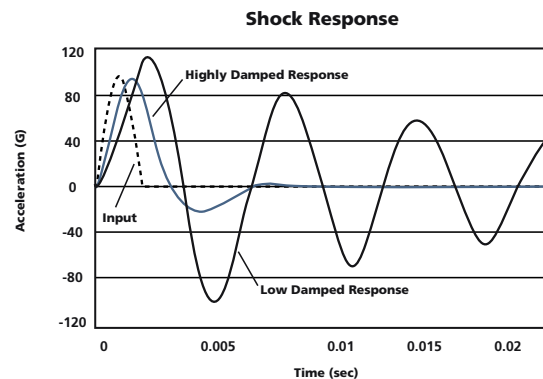


Figure 5: Comparison of 1dof shock response, light vs. heavy damping

Sway Space vs Natural Frequency (400G @ 2.0ms half-sine pulse)

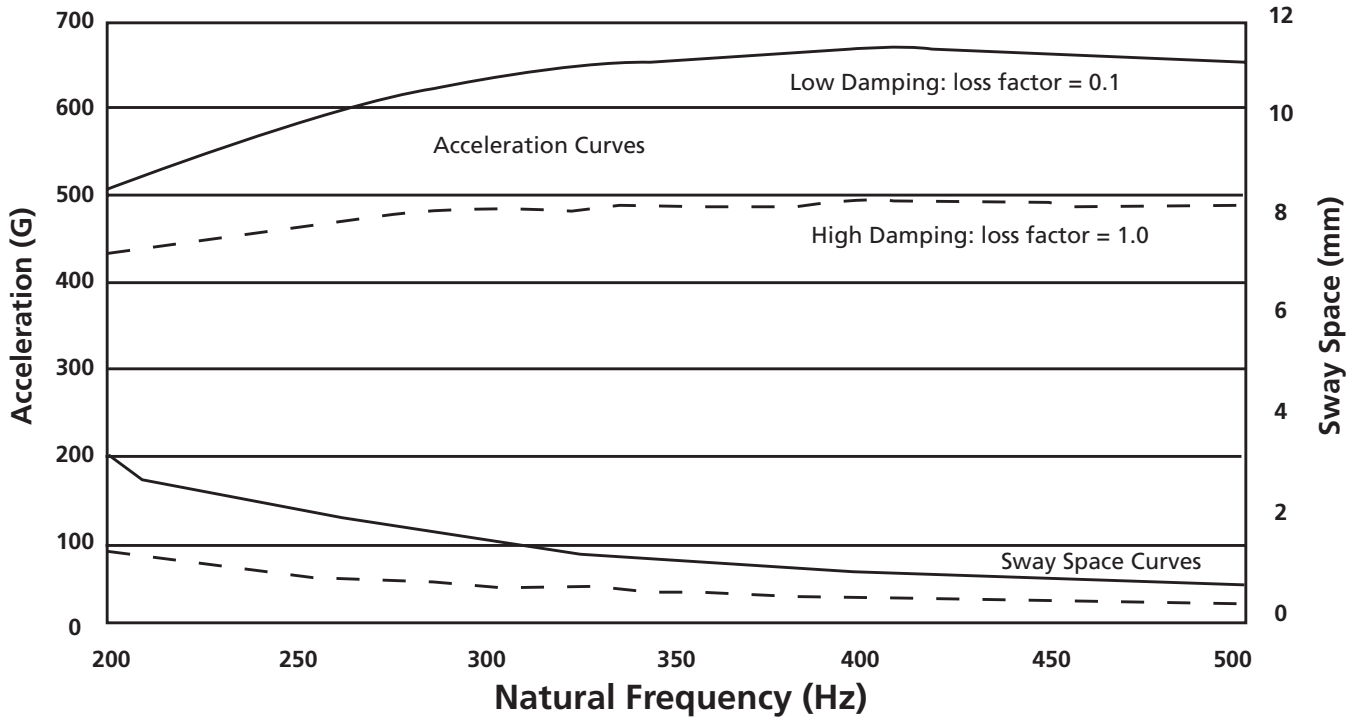


Figure 6: Sway Space and G level as a function of natural frequency

time is shown in Figure 5. The damped response has a lower amplitude and quicker settling time than the low damped case.

Any sensitive electronic device will need to return to its original state quickly so it can resume its intended function. The use of high damping elastomers can allow this to happen.

Figure 6 is a shock response spectrum or SRS. It shows sway space requirements and G levels for two different damping conditions as a function of natural frequency (governed by mass and stiffness for a fixed pulse shape and duration). It is clear that adding damping to the system reduces G levels and reduces sway space requirements. Both of these properties are beneficial when designing small electronic devices.

E-A-R Solutions

This section will address some applications involving shock reduction techniques typically employed by E-A-R Specialty Composites. The solutions typically involve the use of highly damped elastomers in the form of grommets, snubbers, sleeves, as well as the use of our highly damped CONFOR® foams.

Hard Drive Isolation

In Figure 7, a 3.5-inch hard drive is isolated from the chassis by using ISODAMP® grommets. These grommets act like the spring and damper discussed in the 1dof example.



Figure 7: ISODAMP grommet isolators

LCD Protection

E-A-R's CONFOR foam can help to cushion and protect the liquid crystal display (LCD) in a personal digital assistant (PDA), as shown in Figure 8. The foam allows the LCD to displace with a damped response, thus helping to prevent cracking. The foam acts not only as the spring and damper but also as a constrained layer damper for flexural vibrations of the LCD.



Figure 8: CONFOR foam LCD cushion

Bumpers

E-A-R Specialty Composites can mold bumpers into many shapes and sizes. The high damping of E-A-R materials ensures that the shock transferred into the case is minimized. The bumpers act as the spring and damper. Materials available include ISODAMP thermoplastics, VersaDamp™ TPEs and ISOLOSS® urethanes. Figure 9 shows two bumpers attached to the sides of a tablet PC. These bumpers allow for shock protection in all directions—all edges and faces—without interfering with functionality. The bumpers also make good handles, adding even more value.

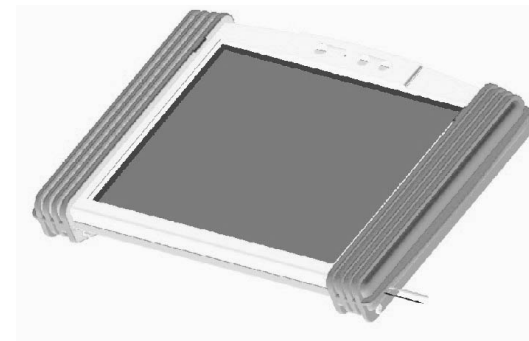


Figure 9: VersaDamp bumpers

Design Advice

When designing a shock isolation system, it is important to consider the support structure used to hold the shock mount(s). When a mount is placed into a soft bracket, its ability to damp shock and vibration is compromised. As shown in Figure 10, a shock mount placed in a frame equates to two springs in series. The relationship of two springs in series is:

$$K_s = \frac{K_f K_m}{(K_f + K_m)}$$

Where K_s is the effective system stiffness, K_m is the stiffness of the mount and K_f is the stiffness of the frame. What this equation shows is that when the frame stiffness is low, the effective spring rate is significantly reduced. The effective damping is also reduced as is indicated in the following equations:

$$\eta_s \approx \left(\frac{K_s}{K_m}\right)\eta_m + \left(\frac{K_s}{K_f}\right)\eta_f \text{ for } \eta_m < 0.5$$

$$\frac{\eta_s}{1 + \eta_s^2} = K_s \left[\frac{\eta_m}{K_m(1 + \eta_m^2)} + \frac{\eta_f}{K_f(1 + \eta_f^2)} \right] \text{ for } \eta_m > 0.5$$

A good rule of thumb is to have the frame stiffness at least 10 times the isolator stiffness. When this condition is met the isolator has the dominant effect and controls the motion of the mass.

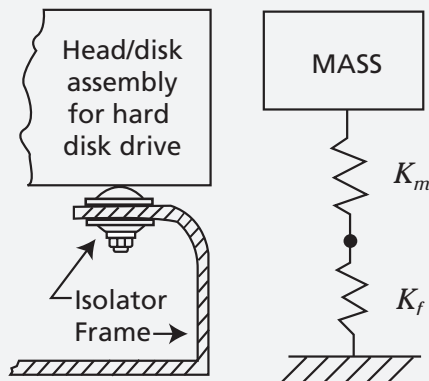


Figure 10: Frame-Isolator-Mass system, sketch and model

About E-A-R Products

E-A-R Specialty Composites manufactures a complete range of materials—the broadest selection offered by a single source—for noise and vibration control applications. E-A-R's proprietary vinyl and urethane formulations can be produced as foams and solid materials, in sheet, roll and bun form, as die-cut and molded parts, and in multi-layer composites.

Mechanically strong and durable, ISODAMP® and ISOLOSS® brand sheet damping and isolation materials, and VersaDamp™ molding materials effectively address impact noise and structureborne vibration under diverse physical and environmental conditions. As standard and custom-molded parts—grommets, bushings and stud mounts, for example—these highly damped materials virtually eliminate unwanted energy from a system, ensuring precision, shock protection, noise control and vibration isolation.

E-A-R's TUF COTE® acoustical foams, barriers and composites offer exceptional performance, durability and versatility for a wide variety of noise and vibration control applications. The foams are manufactured by a proprietary thin-sheet casting method that affords superior processing control. It also allows economical in-line, adhesive-free bonding with barrier and damping materials to form multi-function composites and with backings, facings and reinforcements.

Assistance with specific applications, technical questions or design problems is available from E-A-R's Applications Engineering Department. Product literature and samples also are available by contacting the Customer Service Department toll free at (877) 327-4332 or by faxing (317) 692-3111. EAR's Website address is www.earsc.com, the electronics Website is www.earshockandvibe.com, and the e-mail address is solutions@earsc.com.



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