

Damping Effects on Shock Response Spectra

Part 1: 2.5-inch Disk Drives

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INTRODUCTION

This is the first in a series of papers that discuss the effects of shock on small portable hard disk drives, a topic especially critical for portable electronics that require large amounts of memory. Here we focus on the 2.5-inch hard disk drive (HDD), it is the largest form factor of the currently available portable HDDs. Part 2 in this series covers 1.8-inch hard drives, and Part 3 discusses 1-inch hard drives. The aim of this white paper series is to provide guidance for engineers as they design shock protection schemes for HDDs in their products.

Half-Sine Acceleration and Modeling the System

Shock calculations were conducted utilizing computer algorithms for simulating half-sine acceleration shock pulses. The half-sine acceleration pulse was chosen since it is the most common one used in the electronics industry and is easily simulated with a drop table. Several elastomeric springs were evaluated based on their various loss factors and their effect on G levels and sway space. The shock load applied to the 2.5-inch HDD was a 1000G half-sine acceleration pulse of three durations: 0.0005 sec, 0.001 sec and 0.002 sec. The mass of the hard drive is considered to be 0.1 kg. Three levels of damping were included in the analysis: loss factor $\eta = 0.1, 0.5$ and 1.0 . The $\eta = 0.1$ value would correspond to elastomers such as natural rubber or neoprene, and the $\eta = 1.0$ value corresponds to E-A-R Specialty Composites' ISO-DAMP[®] material. The hard drive isolation system is assumed to be a single

degree of freedom system (1DOF). The HDD and mounting foundation are assumed to be infinitely rigid. The model for this system is shown in Figure 1.

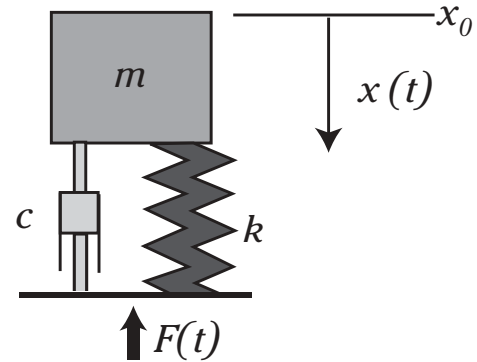


Figure 1: Single Degree of Freedom System

The variable m represents the mass of the hard drive and $F(t)$ represents the forcing function. For a half-sine acceleration pulse of duration T :

$$F(t) = F \sin\left(\frac{\pi t}{T}\right) \text{ for } 0 \leq t \leq T \quad \text{and}$$
$$F(t) = 0 \text{ for } T < t$$

$\ddot{x}(t)$ represents the displacement across the spring and damper. Computer algorithms are used to monitor $\ddot{x}(t)$, which is the acceleration experienced by the hard drive, usually in units of Gs ($1G = 9.8 \text{ m/s}^2$). The maximum displacement experienced by the hard drive, called *sway space*, also is monitored. The variable c traditionally represents viscous damping provided by a dashpot, and k represents the spring stiffness. In an elastomeric spring used for shock protection, c and k combine to form a complex stiffness: k^* .

The damping in the material, called loss factor η , represents the relationship between the real and imaginary components of that complex stiffness. The computer algorithms utilized cannot account for complex stiffness, so viscous damping is used. The variable used to represent viscous damping in the algorithms is ζ , which is called the critical damping ratio. Equating ζ to loss factor η can be achieved with the following expression:

$$\zeta = \frac{c}{2\sqrt{km}} = \frac{\eta}{2}$$

This relationship is accurate for low levels of damping. Out of necessity, it must be used for high levels of damping as well, because only the differential equations of motion dealing with viscous damping are readily solvable with a closed-form solution. They can be solved numerically, i.e., via non-linear solution techniques.

The equations of motion for the 1DOF system is:

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2x = F \sin\left(\frac{\pi t}{T}\right) \text{ for } 0 \leq t \leq T$$

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2x = 0 \text{ for } T < t$$

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

The time domain response of the two equations above can be solved utilizing the Laplace transformation. The solution is a bit lengthy and is outside the purpose of this paper. Once solved, the resulting equations can be used in a

computer algorithm, the time domain response can be plotted and maximum displacement—velocity or G level—can be determined. When enough simulations of the HDD response have been conducted and the maximums determined, the graphs found in this report can be generated.

A typical acceleration time response for this system is shown below using a system natural frequency of 100 Hz. To illustrate the effect of damping on the time response, two curves are shown. The dashed curve reflects a lightly damped system, and the solid curve reflects a highly damped one.

G Level vs. Time 1000G 2 ms half-sine pulse, 0.1 kg mass

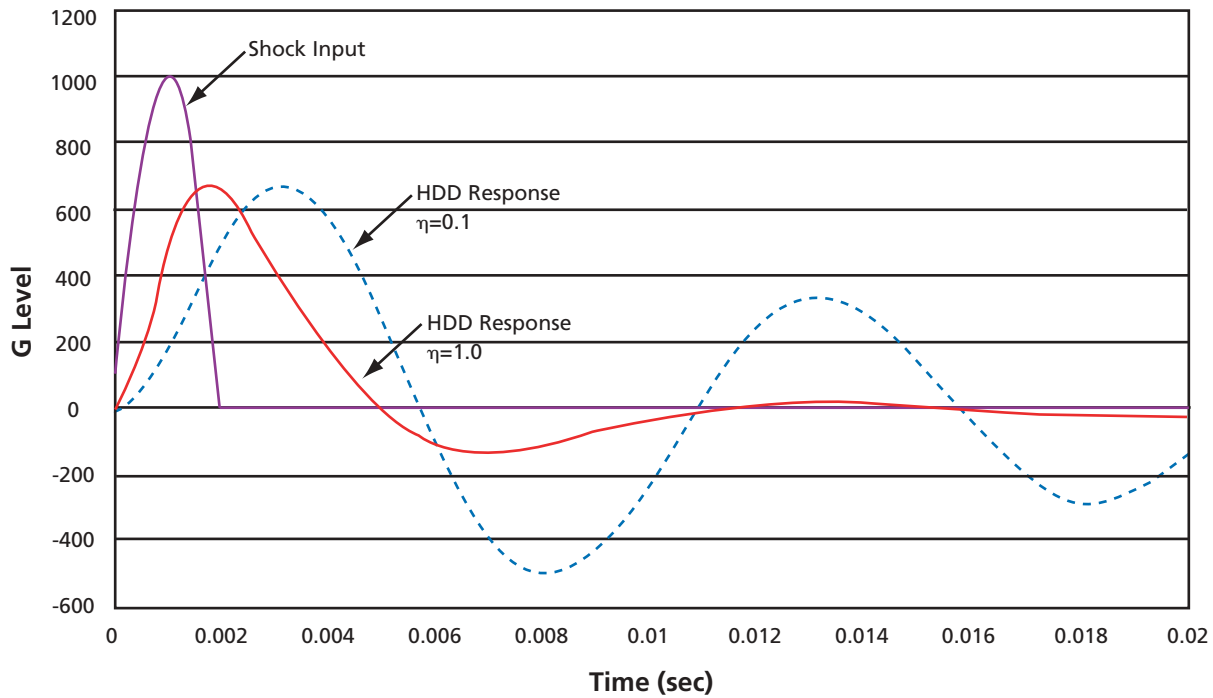


Figure 2: Time domain response, 1DOF system subjected to half-sine pulse

Figures 3 through 8 on the following pages depict the shock response spectra for three different half-sine shock pulse durations: 0.0005 seconds, 0.001 seconds and 0.002 seconds. For each pulse duration, the peak transmitted G level and deflection are plotted versus system natural frequency. Since the mass is always the same, system natural frequency really represents changing stiffness.

Shock Spectrum Results

Shock duration of 0.0005 seconds

G Level vs. Natural Frequency: 0.0005 sec duration

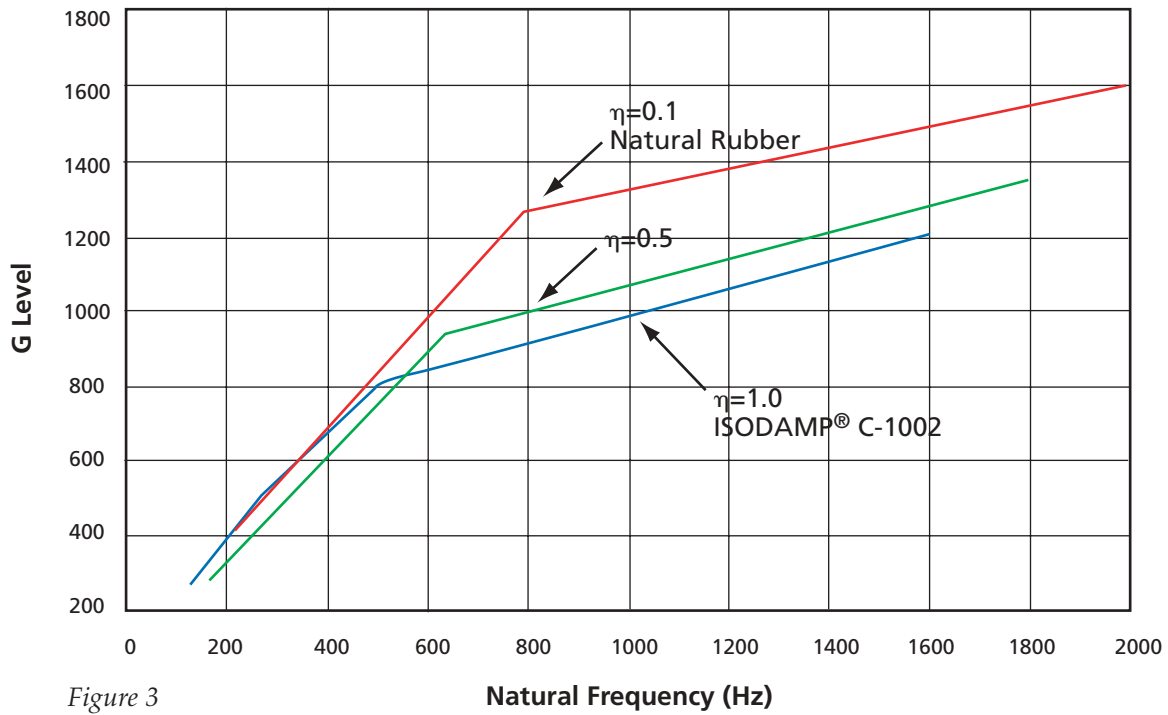


Figure 3

Sway Space vs. Natural Frequency: 0.0005 sec duration

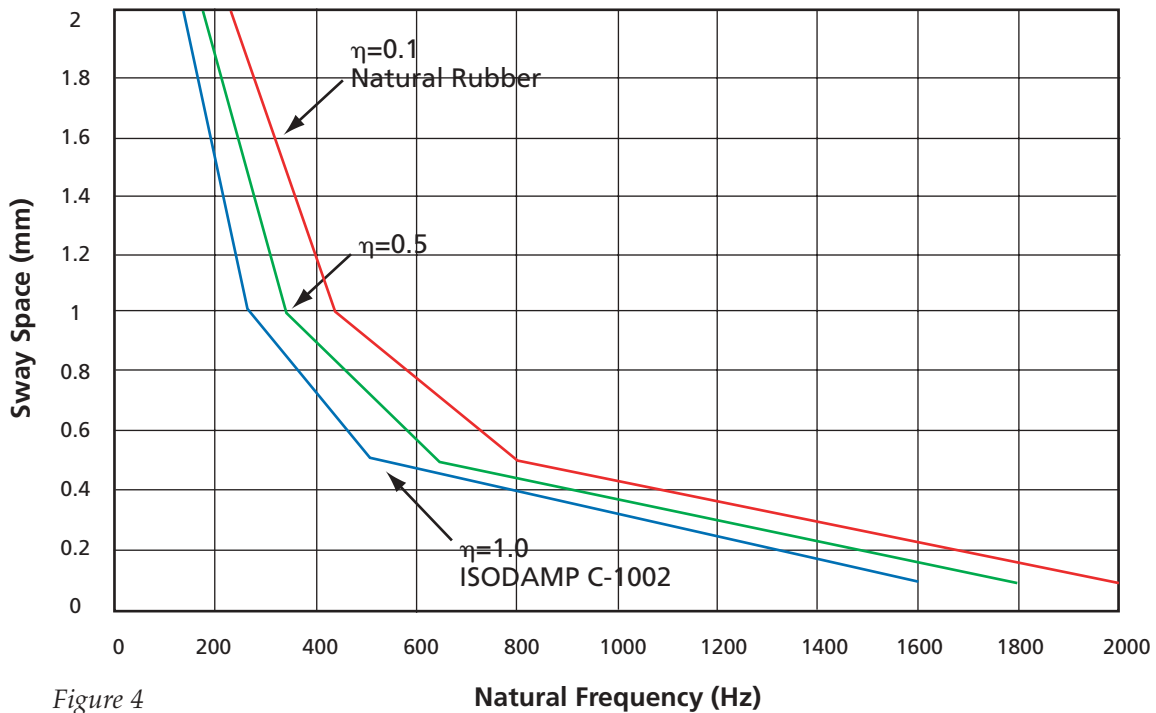


Figure 4

Shock duration of 0.001 seconds

G Level vs. Natural Frequency: 0.001 sec duration

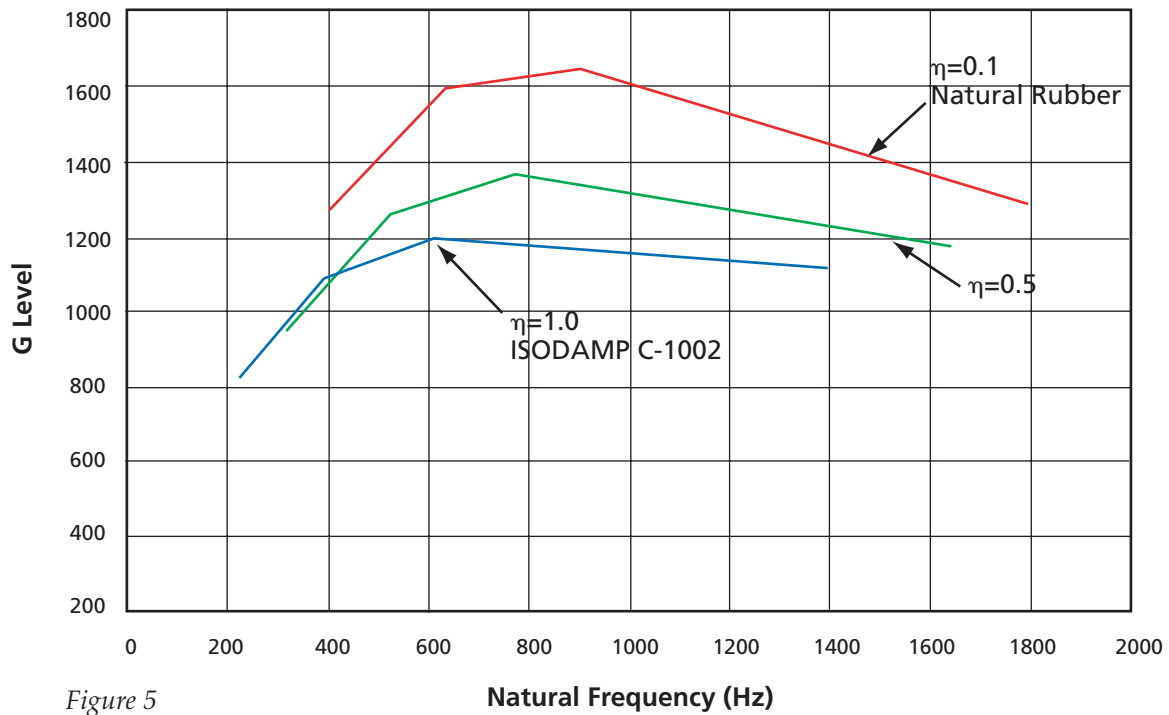


Figure 5

Sway Space vs. Natural Frequency: 0.001 sec duration

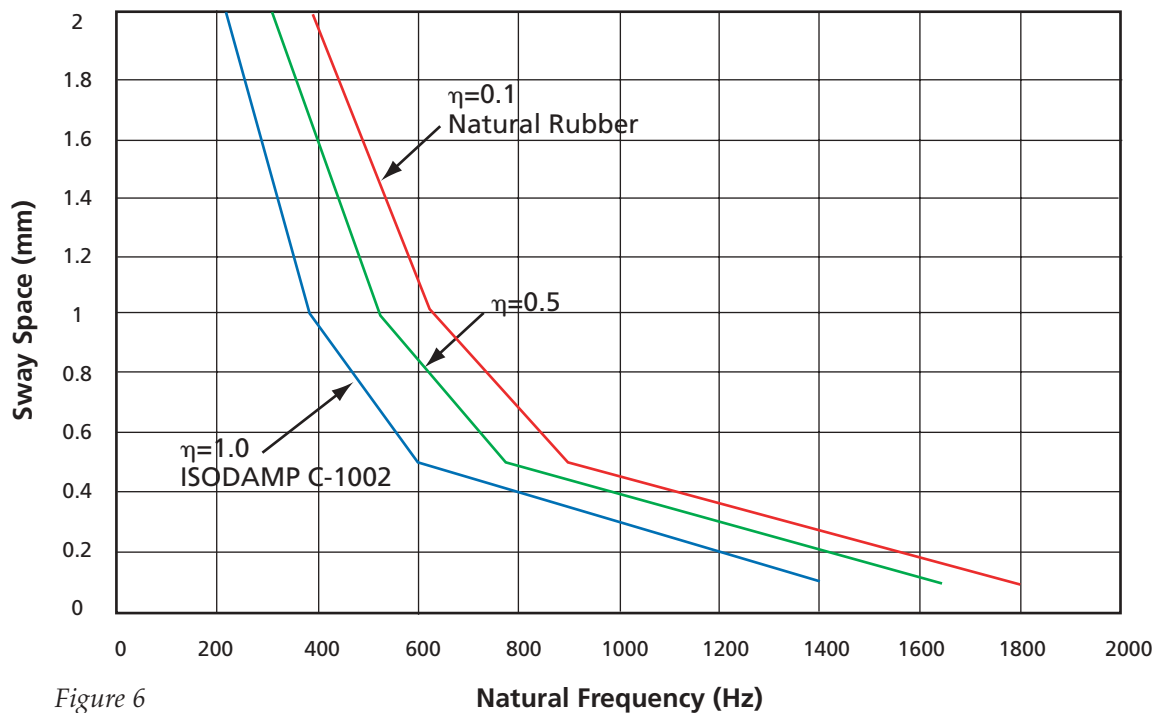


Figure 6

Shock duration of 0.002 seconds

G Level vs. Natural Frequency: 0.002 sec duration

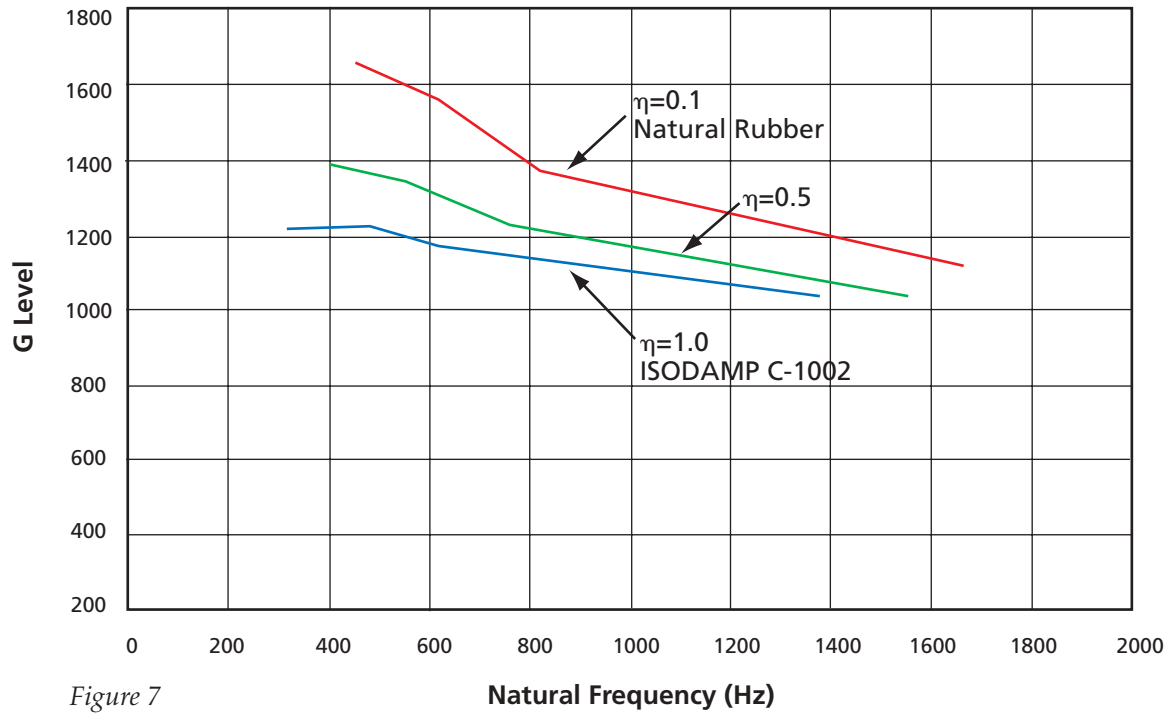


Figure 7

Sway Space vs. Natural Frequency: 0.002 sec duration

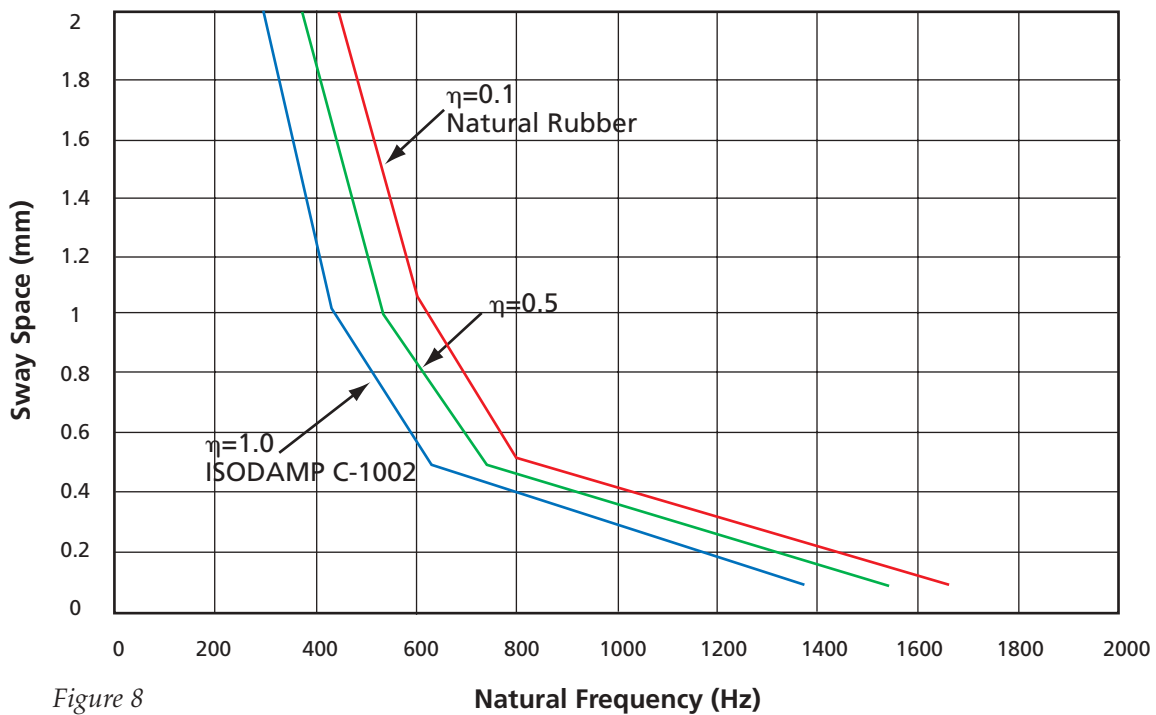


Figure 8

The high damping response curves shown in the graphs indicate that for a given natural frequency, i.e., stiffness, a system requires less sway space and will obtain a lower G level than with a material with low damping. Note how much the system response changes when the shock duration changes. An optimal solution for one acceleration pulse is not necessarily optimum for another duration pulse (nor for another pulse shape such as a triangular pulse or versed-sine pulse).

Solutions Available

E-A-R Specialty Composites' shock protection solutions typically involve the use of energy-absorbing elastomers such as ISODAMP or VersaDamp™ in the form of grommets, snubbers and sleeves and/or the use of E-A-R's highly damped CONFOR® CF-EG foam.



Figure 9: E-A-R Specialty Composites' grommets for 2.5-inch hard drives



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E-A-R Specialty Composites offers a variety of grommets that provide isolation and high damping. (See Figure 9.) Custom designs are available as well.

There often is little available space for any isolation solution. When this happens, CONFOR CF-EG foam often provides a viable solution. CONFOR CF-EG foam is highly damped and can be cut as thin as 1.5 mm. CONFOR CF-EG foam can be compressed to 50 percent of its thickness without a dramatic impact on its stiffness properties. Figure 10 shows a pad of CONFOR CF-EG foam cut to cushion a 2.5-inch hard drive.



Figure 10: CONFOR CF-EG foam cushion for 2.5-inch hard drive.

See also:
Damping Effects on Shock Response Spectra.
Part 2: 1.8-inch Disk Drives
Part 3: 1.0-inch Disk Drives