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Materials Design:
Vibration Isolation and Damping, the Basics

Vibration management should always be considered in any engineering design. Applications that have effectively incorporated vibration management surround us every day, from buildings to rail cars. Even the mirrors on our cars have to pass a vibration test to ensure visual clarity at high speeds. Designs that neglect to properly address vibration often result in malfunctioning components and, in some cases, catastrophic failure.

There are two facets of vibration management: isolation and damping. Isolation is the prevention of vibrations from entering a system. Damping is the absorption of the vibration energy that is entering the system and dissipating it by changing the kinetic energy of vibration into a different form of energy. The two forms of vibration management are different from each other, but often are used in conjunction to achieve the desired performance.

Transmissibility

In order to understand what isolation and damping are and how to apply them, we must first understand transmissibility and natural frequency.

Transmissibility is a measurement used in the classification of materials for vibration management characteristics. It is a ratio of the vibrational force being measured in a system to the vibrational force entering a system.

$$T = \left|\frac{A_o}{A_i}\right| = \sqrt{\frac{1 + \left(2\varsigma \frac{f_d}{f_n}\right)^2}{\left[1 - \left(\frac{f_d}{f_n}\right)^2\right]^2 + \left[2\varsigma \frac{f_d}{f_n}\right]^2}}$$

A_o = Amplitude of the Vibrational Response
A_i = Amplitude of the Vibrational Input
ς = Damping Ratio
f_d = Driving Frequency
f_n = Natural Frequency

Equation 1.0

If a vibration isolator pad has a transmissibility of 80%, it means that 80% of the vibrating force is being transmitted through the pad and is being measured on the other side. This can be seen in Figure 1.0 below.

Transmissibility is more easily defined as the percent of vibrational energy that is being transmitted through a structure.

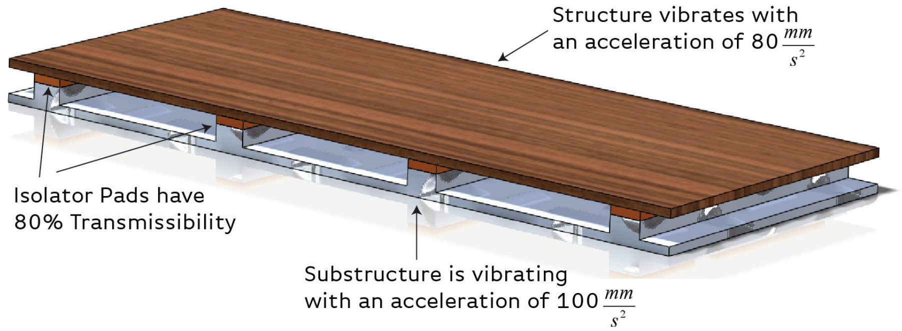

Figure 1.0
Illustration of isolator pads in a vibrating system with corresponding input and output accelerations.

The vibration characteristics of materials are typically represented by a graph of transmissibility versus frequency. Figure 2.0 is a typical plot of a material's transmissibility curve.

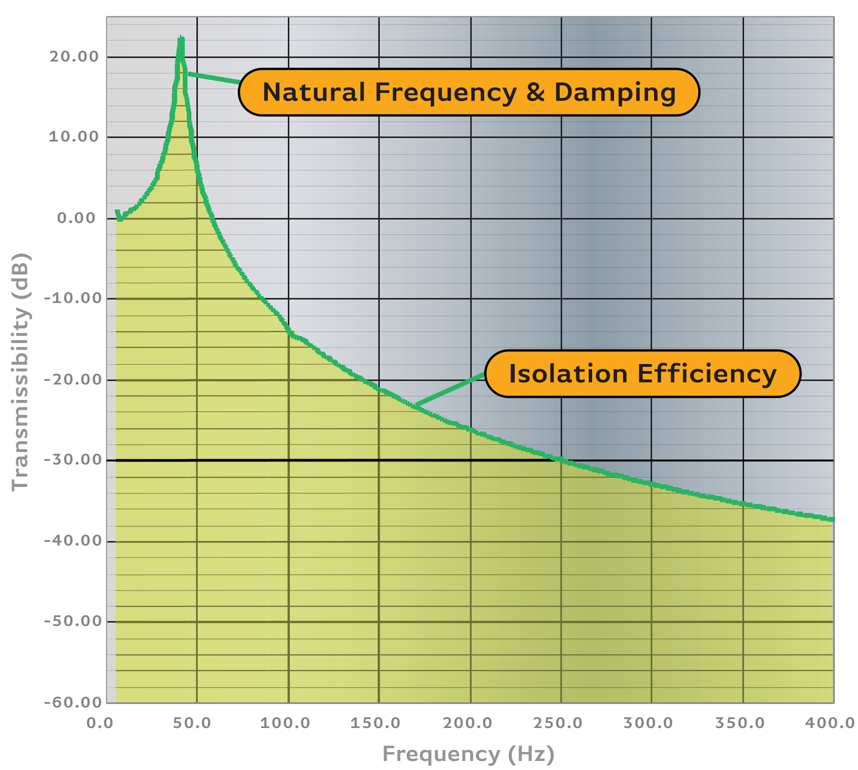

Figure 2.0
Rogers' BISCO® L3-2540 material transmissibility curve. Information such as natural frequency, damping ratio, and isolation efficiency can be extracted from this curve.

Frequency is plotted on the X-axis in Hertz (Hz) and transmissibility is plotted on the Y-axis in decibels. The Equation for converting the ratio into decibels is below.

$$dB = 10LOG(Ao/Ai)$$

Equation 2.0

Using this curve (Figure 2.0) engineers can extract useful information about the material's properties in regard to vibrations, including natural frequency, damping ratio, and isolation. The peak on the curve at around 35 Hz is representative of that material's natural frequency. Using this peak and some math, engineers calculate the amount of damping in a material. When the curve crosses the Y-axis into negative values (at approximately 60 Hz on the plot above.), the material begins to isolate vibrations. As frequency increases, the amount of energy transmitted from vibrations is reduced (i.e. isolation performance increases).

Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.

Natural Frequency

Also known as resonant frequency, is the specific frequency at which a material will naturally vibrate. If unaffected by outside forces, a material vibrating at natural frequency will vibrate forever; this is Newton's first law of motion.

In the real world, there is always some force that acts on the vibrating object to remove energy and eventually dissipate the vibration; this is damping.

Knowing, understanding, and designing around natural frequency are critical to any engineer in the modern world. When systems or structures are forced to vibrate at natural frequencies, the oscillations develop very large amplitudes of deflection. This results in excessive shaking, component wear, and, ultimately, failure of the structure or component.

In the simplest form, using a Single Degree of Freedom (SDOF) system, we can define natural frequency as a function of mass and stiffness.

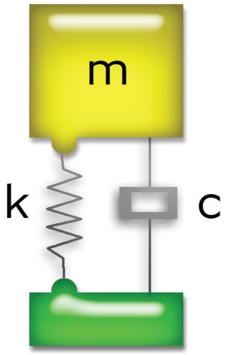

Figure 3.0
SDOF system

$$natural\ frequency\ (\omega) = \sqrt{k/m}$$

(Eq. 3.0)

$m = mass$

$k = stiffness$

$c = damping\ coefficient$

$$k = \frac{AE}{L}$$

Equation 3.0

Every system will have numerous natural frequencies. This is due to the fact that materials in the system all have different natural frequencies. The stiffness of the materials varies as well. A steel plate can have vertical, horizontal, rotational, and bending stiffnesses. Using Equation 3.0 above would yield four individual natural frequencies for one steel plate. The easiest way for engineers to identify the natural frequencies in their systems is to use finite element analysis software to run a modal analysis.

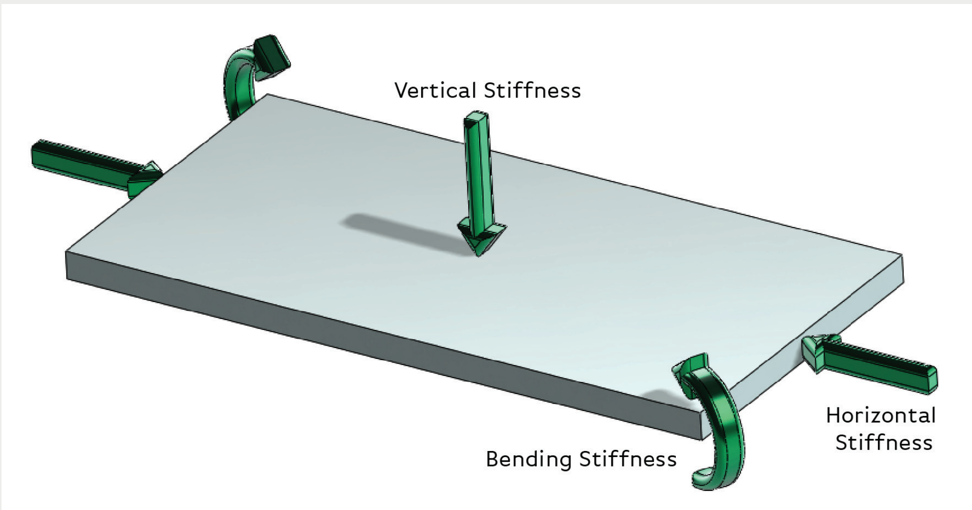

Figure 4.0
Steel Plate illustrating various stiffnesses of the material

Isolation

Earlier we defined isolation as the prevention of vibrations from entering a system; we also defined transmissibility as the percent of vibrational energy that is being transmitted through a structure. Mathematically these two terms are simply related.

$$\%\ Isolation = 1 - \%\ Transmissibility$$

Equation 4.0

Looking at the Figure 5.0 and recalling Equation 2.0, it can be seen that for any Y-value greater than zero decibels the transmissibility percent is greater than 100%. In this region there is no isolation; this is known as the region of amplification. Also take note that this region of amplification is centered around the natural frequency where, as we mentioned earlier, large amplitudes of deflection occur.

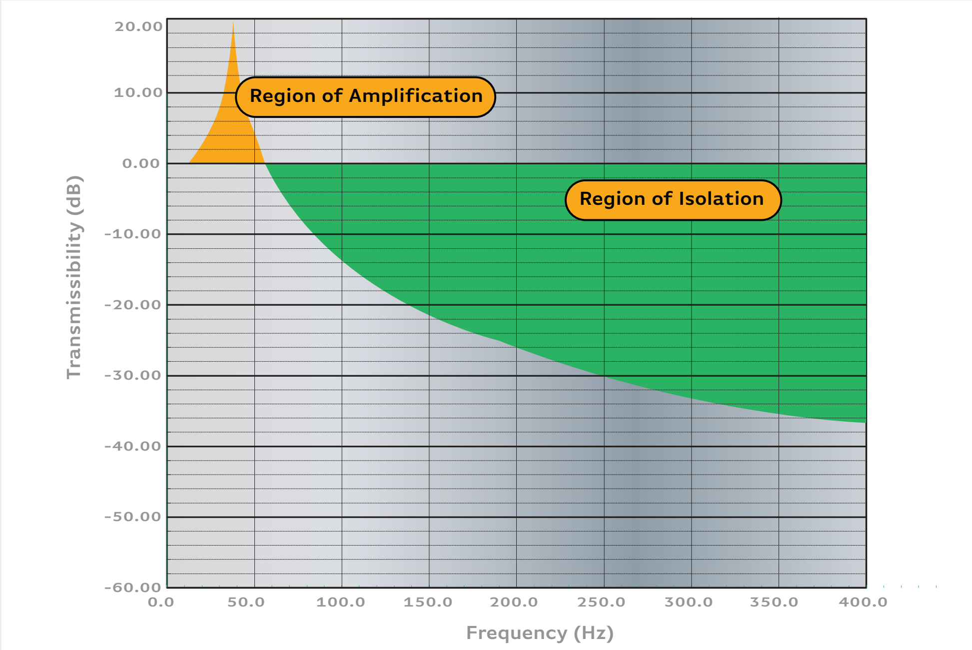

Figure 5.0
Rogers' BISCO® L3-2540 material transmissibility curve with region of amplification and isolation illustrated.

The opposite is true for negative Y-values. Any portion of the curve that has a negative decibel value is isolating. In this region the transmissibility ratio is less than one which indicates that a material is isolating vibrations in this range of frequencies. Exact percent of isolation performance is calculated using the ratio of transmissibility and Equation 4.0, above.

Damping

is the process of dissipating energy from a system by changing kinetic energy into heat. There are three types of damping: viscous, coulomb, and structural/solid damping. Viscous damping is dependent on velocity of the movement. Coulomb damping is dependent on surface friction and the pressure between surfaces. Structural damping, also known as hysteresis, is internal friction within the material; all materials exhibit some amount of hysteresis.

Springs have very low internal damping of 0.5%, where foams can have damping ratios as high as 20%. Figure 6.0 illustrates how the damping ratio affects how quickly the system returns to equilibrium.

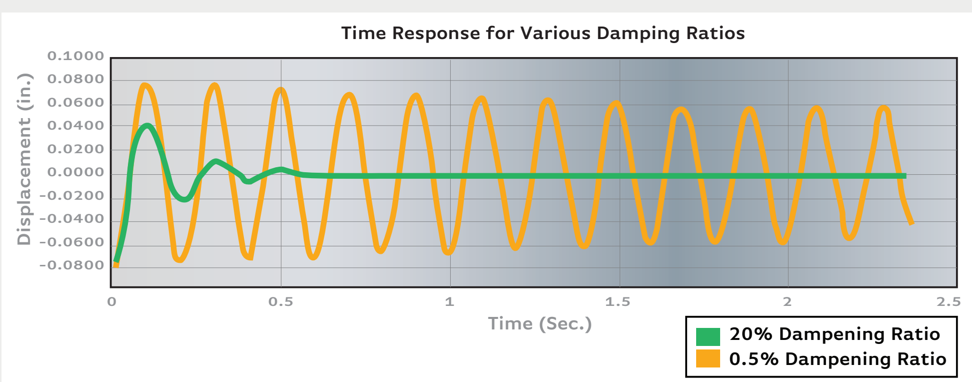

Figure 6.0
Time Response graph for a 0.5% damping system (Spring) and a 20% damping system (Foam)

Damping can be calculated using the transmissibility curve in Figure 7.0 using a method called the Half Power Bandwidth Method.

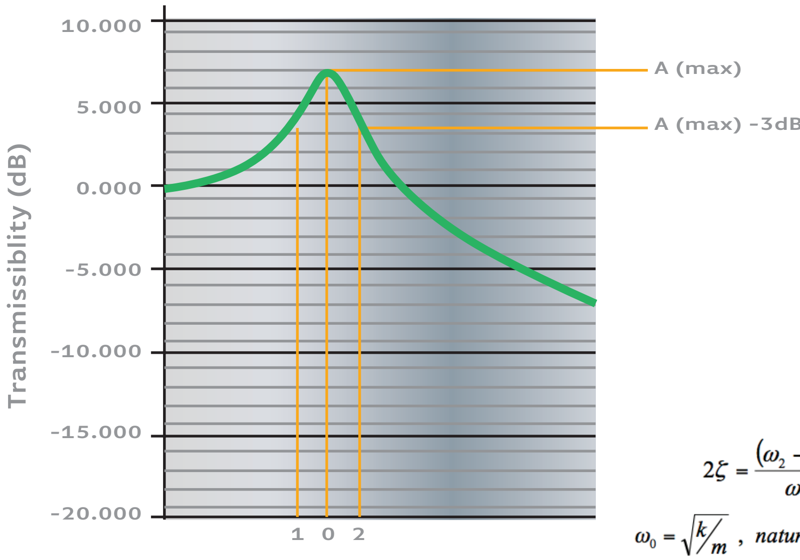

Figure 7.0
Half Power Bandwidth Method

$$2\zeta = \frac{(\omega_2 - \omega_1)}{\omega_0}$$

Equation 5.0

$$\omega_0 = \sqrt{k/m} \text{ , natural frequency}$$

Equation 5.1

Damping can also be measured using standard test methods such as Dynamic Mechanical Analysis (DMA) to obtain the mechanical loss factor for the material.

$$\text{mechanical loss factor} \quad \eta = 2\zeta$$

Equation 6.0

Application

Damping and isolation are very different approaches to vibration management, but are often used interchangeably in conversations and specifications. It is important to recall the definitions mentioned above and understand that isolation and damping have different effects on the system. In fact, having a large amount of damping has a negative effect on isolation and vice versa. In Figure 8.0, it can be seen that as the damping ratio increases the region of isolation decreases.

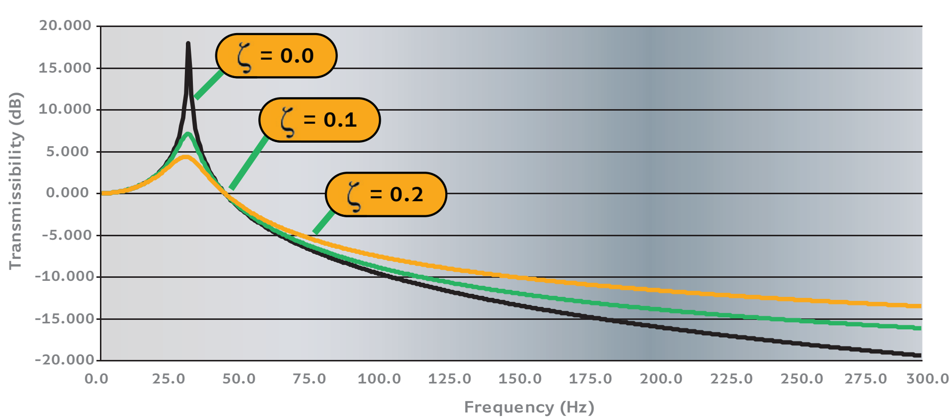

Figure 8.0
Transmissibility curve illustrating the effect of increasing damping on isolation performance.

The easiest way to determine whether a damper or an isolator is needed is to identify the frequencies that are of concern. Selecting the correct isolator will shift the natural frequency lower and move the frequencies of concern into the region of isolation, preventing them from penetrating the system. When the system's natural frequency can not be shifted lower and the frequencies of concern are located near or at the natural frequency, damping is the appropriate method of vibration management.

Rogers Corporation: High Performance Foams Division

Rogers Corporation specializes in engineered polyurethane and silicone based foams designed specifically for vibration and shock management.

Rogers' PORON® materials are polyurethane based foams used in applications that demand high performance under normal operating conditions. BISCO® silicone foams offer the same vibration management solutions as PORON materials, but are designed to handle extreme operating conditions.

Acknowledgements

Rivin, Eugene I. Passive Vibration Isolation. New York: ASME Press, 2003. Print.

Irvine, Tom. "The Half Power Bandwidth Method for Damping Calculation" Isolation. (2009) www.vibrationdata.com. Web. 30 Aug. 2011.

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