

# A Primer on Vibration Isolation

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A vibration isolator functions as a mechanical filter, but it doesn't work like an on-off switch. The efficiency of a vibration isolator varies with frequency. But the vibration isolation efficiency is also dependent on the natural frequency of the isolation system. The natural frequency of an isolation system is the frequency at which it will resonate. This is a function of the stiffness of the isolation system, as well as the mass being supported by the system. Figure 1 shows a transmissibility curve. Transmissibility is the ratio of the output vibration divided by the input vibration – if the ratio is greater than one, vibration is amplified, and if the ratio is less than one, the vibration is reduced, or attenuated. The maximum transmissibility occurs at the natural frequency of the isolation system. The skill is in selecting the natural frequency of the isolation system to be well below the driving frequency of concern. If the natural frequency of the isolation system coincides with the driving frequency, amplification may occur, perhaps dramatically. Transmissibility also varies with damping in the isolation system.

Consider the desired function of the isolation system. Are we trying to isolate the environment (say, an office space) from the equipment? Alternatively, we may be trying to isolate equipment from the environment (say, a truck cab from road vibrations). In isolating rotating equipment, we should determine if we need to isolate the rotational frequency or harmonics. Equipment with a low operating speed requires an isolation system with a lower natural frequency, and this may limit the available options for isolation systems. Isolating equipment from the environment presents a different challenge. The direction of excitation may also be significant, and this may be a factor in determining the installed orientation of an isolator.

The weight distribution of the supported equipment needs to be determined. This is necessary in selecting vibration isolators. If the distribution of load is extremely uneven, isolators should have different stiffnesses to provide approximately equal deflections at each location. With elastomer isolators, this could be accomplished by selecting mounts with different hardnesses; with elastomer pads, length and width can also be varied to match the stiffness; with helical springs, different wire diameters can be selected within a given housing to match the stiffness. None of this is possible if the weight and load distribution are not known.

So, let's say that we know the operating speed of the equipment, the amount of vibration isolation desired at that frequency, as well as the load distribution.

Are there any external loads applied across the mounting system? Belt loads, such as drive belts, which cross the isolation system invariably require some compromise in vibration isolation. Experience has shown that wherever possible, equipment which include drive belts or flexible couplings should be mounted to a rigid skid, and the skid isolated for vibration. Rotating equipment imparts a torque to the system which must be resisted by the isolation system. This increases the forces on one side of the system, and decreases the forces on the other side, possibly unloading the isolation system. Since the system must function under either extreme, these conditions need to be evaluated. To prevent total unloading, a suitable restraint system may be required. Does the isolation system need to resist thrust loads imparted by pumps moving water or fans moving high velocity air? Individual isolators may need to be oversized to accept these loads, or a separate thrust restraint may be required to accept the loads.

**Support Structure Stiffness.** For an isolator to perform its function, it must be able to deflect. If the support structure, and/or the supported structure are relatively soft, they will deflect rather than the isolators, and the isolators will not function as intended. Besides obtaining inadequate isolation, this may result in fatigue of the structure. The common rule of thumb is that the structures should have a stiffness ten times that of the isolators. This will ensure that the isolators are providing 90% of the required deflection, and that the structure is providing 10% of the required deflection.

**Structural Resonances.** Every structure has numerous frequencies at which it will resonate. The frequencies at which the parts of the structure vibrate are referred to as structural resonances, and are a function of the material, dimensions, shape and end conditions (method of support). On a transmissibility curve, they could appear as individual sharp peaks or as a broad region of numerous peaks, resulting in transmissibility higher than would be predicted based on theory. Stiffening the structure may help, but more often the selective application of damping materials seems more effective.

**Rocking Modes.** For horizontal excitation of an isolation system, there are two possible vibration modes generated: a longitudinal mode and a pitch mode. These modes are said to be coupled when a vibrating force at the frequency of one mode causes vibrations to occur at the frequency in the other mode. Considering the entire system, there are six rigid body modes of vibration – three in translation and three in rotation. Rocking modes decrease the efficiency of an isolation

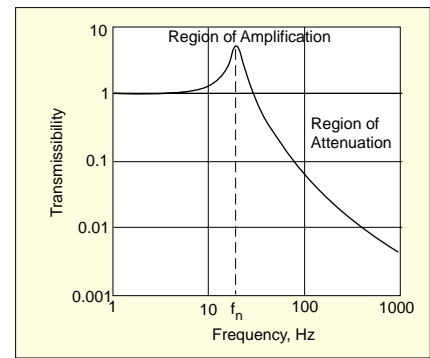


Figure 1. Theoretical transmissibility for a system with a natural frequency of 20 Hz.

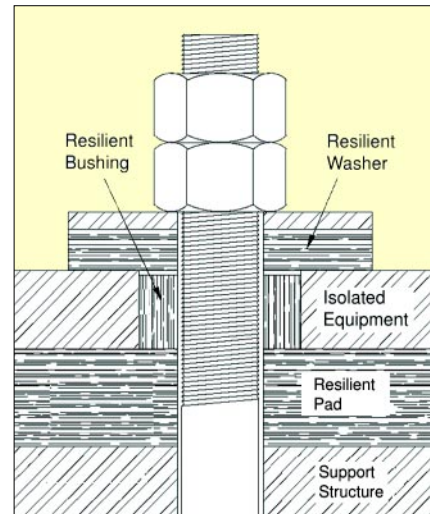


Figure 2. Recommended method of installation for a pad isolation system.

system, so to improve isolation, the system must be decoupled. This means that the elastic center of the isolated mass coincides with the center of gravity of the isolated mass. This can be accomplished by locating the isolators on the same horizontal plane as the center of gravity of the isolated mass. A second method of decoupling is to focalize the isolation system to project the elastic center to the center of gravity.

**Standing Waves.** Every material has frequencies at which it can behave almost as if it is transparent (a window) to vibrations. This means that the material will transmit vibrations at certain frequencies even though the transmissibility curve shows that little vibration would be transmitted. In springs, these frequencies are referred to as surge frequencies. Surge frequencies are typically counteracted by combining the spring with an elastomer pad, breaking the transmission of high frequency vibration. Standing waves can also occur in elastomers, but damping in elastomers is generally sufficiently high that standing waves are seldom identified as significant problems.

**Sound Shorts.** Any type of mechanical element which crosses from one side of an isolation system to the other represents a potential sound short, creating a short cut for the vibration to be transmit-

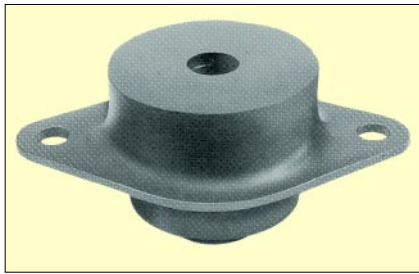


Figure 3. Elastomer isolator.

ted around the isolation system. Piping and ductwork that crosses the system should have a flexible connection, a flexible loop, or should itself be isolated for some distance beyond the equipment. Electrical conduits should similarly include flexible loops or be isolated. Rotating drive elements which must cross the isolation system should have some form of a flexible coupling. Equipment isolated by elastomer pads should not be bolted directly to the structure, but should have resilient washers and bushings to prevent metal to metal contact, which would effectively short-out the pad system. Figure 2 shows an effective method to prevent metal to metal contact with a pad isolation system.

Now that we know what can go wrong, how do we determine what type of isolator would be appropriate for a given application? Let's start with the simplest form of isolation – pads. Pads are available in numerous elastomers, and also in cork and felt. They are available in many thicknesses and lengths, and are convenient because they generally can be cut to any given shape. A single layer of pads is not too likely to provide a very low natural frequency, but some manufacturers have the capability of bonding multiple layers of pads to tailor the stiffness for the application. With this approach, pad systems with vertical natural frequencies as low as 6 Hz can be achieved.

Elastomeric isolators have many desirable features which result from the fact that rubber is essentially an incompressible material. By varying the configuration of the molded product, and by properly locating rigid steel components, an infinite range of stiffness can be achieved in every direction. There are numerous families of elastomer types which can be used based on the intended use and environment. Operating temperature and fluid exposure are two critical environmental parameters which should be considered in selecting the elastomer types. Different formulations can provide varying amounts of damping, which can affect vibration isolation. Consult the manufacturer to learn the amount of damping, and how it affects vibration isolation in your frequency range of concern.

Figure 3 shows a common elastomeric isolator which consists of a neoprene elastomer bonded to steel components. This particular design has a stiffness which is approximately equal in all direc-

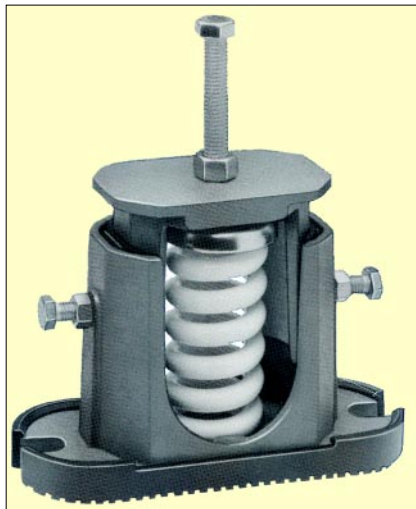


Figure 4. Housed spring isolator.

tions. For this design, installing an appropriately sized steel washer below the mount with a nut and bolt, the system becomes captive. This means that the interlocking metal components will keep the equipment captive, even if the elastomer or elastomer-to-steel bond should fail. This is a desirable feature for isolators used on mobile applications, or for stationary applications involving a significant uplift. Elastomer isolators can be used in stationary applications, but are also ideal for mobile type applications because of the flexibility in design. In mobile applications, many designs are effective in isolating engines, motors, compressors, cabs, radiators and related equipment.

For applications requiring a lower natural frequency than can be obtained with elastomer isolators, a frequent isolation choice is a coil spring mount. Many manufacturers offer a standard line of coil spring isolators which provide a static deflection of up to 5-inches, which is equivalent to a natural frequency of 1.4 Hz. Where are these used? Cooling tower fans generally run at very low speeds (~300 RPM), and a very soft system is necessary to provide isolation at 300 RPM. Where improved isolation is required, generator sets (generally operating at 1800 RPM) frequently utilize springs with 1/2-inch to 1-inch static deflection. Large air handling units on the roofs of buildings are frequently isolated by 1-inch to 3-inch deflection spring isolated curb units. High static deflection spring isolators are used where exceptional mid-frequency vibration isolation is desired, or where the support structure may not be sufficiently rigid for a stiffer isolation system. What features are required in a coil spring mount?

- Static deflection should be based on known weight and load distribution, and should be approximately equal at each location
- To minimize the effect of surge frequency, and to isolate high frequency vibration, an elastomer pad should be



Figure 5. Pneumatic isolator.

placed between the spring and the support structure

- If the isolator is a free standing spring, the design must be stable to prevent the spring from buckling, and the equipment from toppling
- If there are significant uplift forces, or if there are seismic requirements, the spring should be housed with an integral restraint mechanism
- Springs have very little inherent damping. If damping is desired, standard designs are available which incorporate friction damping, hysteretic damping or viscous damping

Large static deflections associated with springs can create problems with piping, so standard designs have evolved which allow these deflections to be contained within the isolator, while only requiring about 1/4-inch movement of the isolated equipment.

Figure 4 shows a housed spring isolator which incorporates many of the features discussed above. Note the rubber pad below the casting. The side bolts provide adjustable damping by applying a compression load to an elastomer pad internal to the isolator. A relatively constant loaded height is obtained by loading the spring via a compression plate below the top adjustment bolt.

Finally, what does one do with a piece of equipment, such as a Coordinate Measuring Machine, which is sensitive to frequencies so low that even a soft helical spring cannot provide sufficient isolation? The logical choice is a pneumatic isolation system which can provide natural frequencies as low as 0.5 Hz.

A pneumatic isolation system uses a gas, such as air, to provide vibration isolation. Pneumatic isolators do not require a large static deflection, because the gas can be compressed to support the load while providing the low stiffness necessary to provide vibration isolation. The air spring consists of a sealed pressure chamber, with plumbing for filling and releasing the gas, and a flexible diaphragm to permit relative motion. One advantage of the pneumatic isolation system compared to a mechanical coil spring system is the large load carrying capacity for a given low natural frequency. Standard designs are available with load capacities up to 120,000 pounds. A sec-

ond advantage is that natural frequency is essentially independent of static load.

Figure 5 shows a standard pneumatic isolator which provides a vertical natural frequency of approximately 2.5 Hz. Softer systems are obtained by varying the volume of the chamber and the effective area of the diaphragm. Damping is achieved by directing air through a lami-

nar flow restrictor. Systems with pneumatic isolators require a source of clean, dry gas, with pressures ranging from 60 psig to 120 psig, depending upon the isolator and the application.

As with all isolation systems, stability is critical to the performance of a pneumatic isolation system. The rule of thumb is that the height of the center-of-gravity

should be less than 1/3 the smallest distance between isolators. If it is impractical to increase the distance between isolators, a saddle can be used to effectively lower the height of the center-of-gravity.

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