An Introduction to Vibration Isolator Selection

The Purpose of Isolators.

a) To reduce the transmission of forces from the mounted equipment to the supporting structure.
b) To protect sensitive equipment from the motion of the supporting structure.

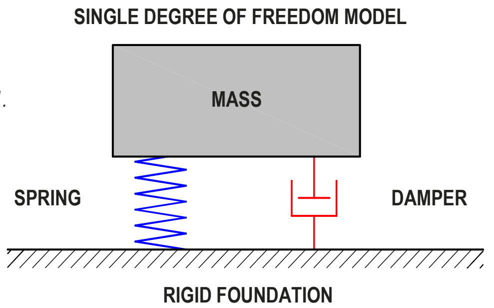
Disturbances may be steady state oscillations, non-repeating transients or a combination of both.

How Vibration Isolators Work.

At present virtually all isolators are passive using steel springs, rubber mouldings or air bellows to form the flexible elements. They absorb energy in one part of an oscillation and give it back in another. Thus energy is not dissipated except for a small amount of heat generated by internal (or material) damping. The force transmitted is that required to dynamically deform the isolators.

A real machine on flexible mounts may be idealised as shown in Figure 1.

Figure 1.



BEWARE : This only works in two dimensions (up/down and time).

Force transmissibility is the ratio of the peak force required to dynamically deflect the isolator to the force required to accelerate the mass during each oscillation. Damping forces are usually small and are ignored for the moment.

This simple equation may assist.

$$T = 1/\sqrt{(1-\omega^2.m/k)^2}$$

Where:

ω^2 = square of forcing frequency (rad/sec^2)
m = isolated mass (kg)
k = stiffness (N/m)

Viscous damping may be incorporated in the equation using a damping ratio (C) as follows:

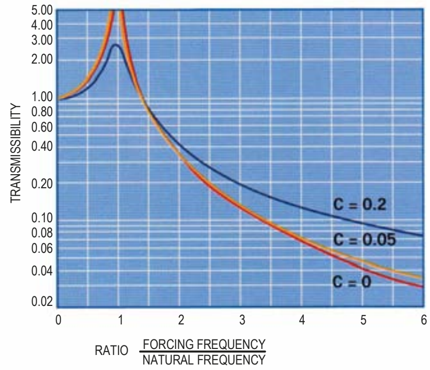
$$T = 1/\sqrt{(1-\omega^2.m/k)^2 + 4.C^2.\omega^2.m/k}$$

Natural rubber materials show internal friction which may be approximated to viscous damping with a ratio of C = 0.05. If C = 1 there is a condition known as Critical Damping, when a mass if displaced and released will just not overshoot equilibrium.

This equation can be plotted as shown in Figure 2 and it may be seen when ω^2 = k/m force transmission becomes infinite.

This is known as the state of resonance when the oscillation amplitude would also be infinite without any damping. The other curves shown on this plot show the effect of adding damping such as provided by natural rubber or fluid filled dampers.

Figure 2.



Rather than transmissibility it is common to quote isolator efficiency which is given by :

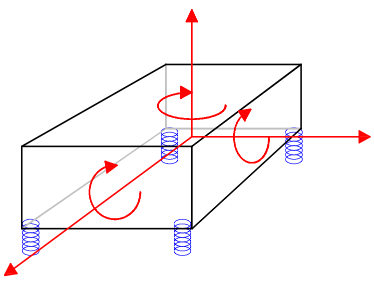
Efficiency = (1 - T) x 100 %

The efficiency appears to approach 100% as the forcing frequency increases but in the real situation other factors such as flexibility in the supporting structure and isolating material standing waves result in a practical limit of about 97 - 98% for most types of isolator.

Natural Frequency and Static Deflection.

If displaced from equilibrium and released, an isolated mass will oscillate freely at its natural frequency. In a theoretically undamped system, this oscillation will continue indefinitely. A rigid mass freely suspended on an isolator system will in reality have six natural frequencies, one for each degree of freedom of motion as shown in Figure 3.

Figure 3.



These frequencies are not usually apparent on most machines unless excited during start-up or shutdown. A proper design should ensure that normal operating speeds and harmonics avoid resonant conditions.

BEWARE : Many engineers may only analyse motion in the vertical mode. Can you be sure that other natural frequencies are not lying in wait? If the body itself is not truly rigid, then the whole body motion may be affected by internal resonances within its own structure.

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For a single degree of freedom system of Figure 1, the natural frequency is a function of the static deflection under the weight due to gravity. Figure 4 shows this relationship.

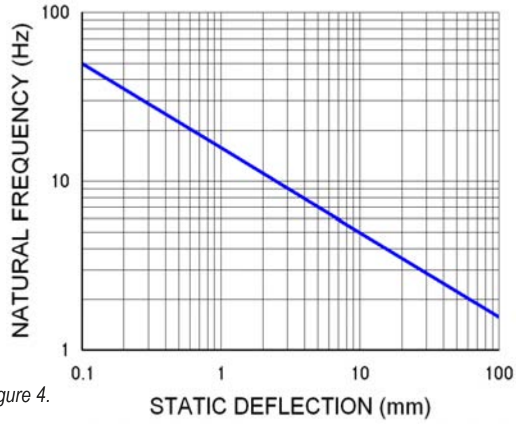

Figure 4.

BEWARE : Real isolating elements may change stiffness with varying deflection, temperature, vibration amplitude and frequency. Dynamic stiffness is the rate of change in spring force with a change in deflection during the oscillation.

The natural frequency plot should be used with an equivalent static deflection based on the dynamic stiffness for the particular operating condition being considered.

Three Dimensions, Coupled Modes and Higher.

For all but the simplest of applications, the more complex systems benefit from consideration of the various modes of motion and the effects of multiple forcing excitations, any one of which can impair operation.

Consider a hydraulic power unit mounted on four springs beneath its base being excited by the deck moving horizontally due to some transient condition e.g. collision. See Figure 5.

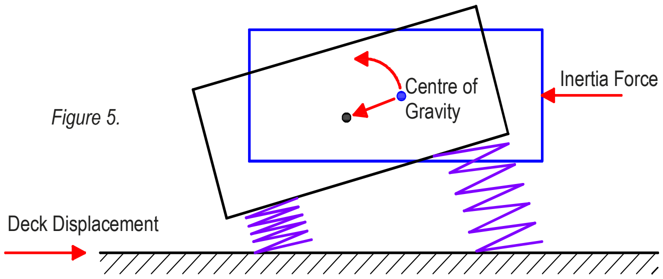

Figure 5.

Initially, the springs will shear creating a horizontal force on the unit base. A rotation will be induced as the acceleration of the centre of gravity forms a couple with the force and if small asymmetries exist other rotational motions may start. Soon, the motion of the unit will be a complex mixture of oscillations in each of the three orthogonal planes and directions.

The creation of motion in one mode from that in another is termed "coupling" and is a property of the mechanical system. It is independent of the excitation.

By the use of symmetry it is possible to design systems whereby some modes can be decoupled or coupled in pairs permitting a simpler mathematical analysis and a more easily manipulated design.

Computers are used to model and calculate the responses of such systems which may include a number of masses connected by many flexible elements.

The Effect of Mass.

Why do we sometimes add inertia bases or other extra mass when isolation efficiency is mainly a function of isolator deflection ? See Figure 6.

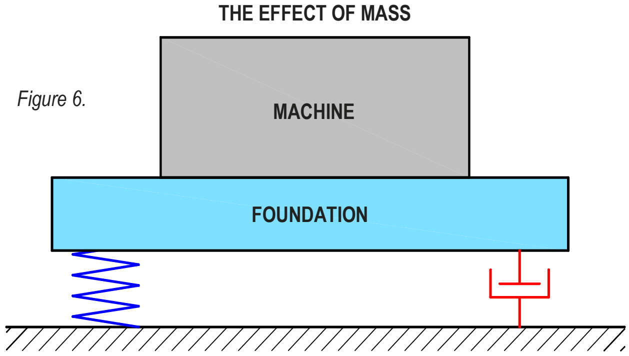

Figure 6.

a) **For Static Stability.** A lightweight machine on soft springs may suffer unacceptable displacement due to the action of external forces, e.g. water pump pipe pressure or manual operation of an isolated micro-balance.

b) **To Reduce Vibration Amplitudes.** For many machines, the internal forces would create large oscillating displacements or accelerations capable of damaging the machine or its flexible connections, for example, reciprocating air compressors and power station diesel generating sets.

c) **To Increase Stability under Shock.** Tall narrow devices exhibit much coupling of rotational and linear modes of motion giving rise to large displacement responses to earthquake or explosive inputs. A lower centre of gravity can greatly reduce such responses, for example electrical cabinets, chillers, bunk beds.

When is Simple Theory Enough ?

a) **Experience and Good Practice.** If the application is straight forward and the isolator and similar machines have been mounted on similar flexible mountings many times, then it is a waste of the engineer's time and the client's money to reinvent the wheel every time.

b) **Simple Problems.** If a machine is inherently stable, runs at a speed more than three times its vertical natural frequency and is well away from a critical area, few difficulties should arise from a more basic development method.

BE AWARE : Our computer analysis methods permit relatively inexpensive calculation of many factors giving much more confidence in the final installation than is possible with basic selection methods. For many applications, data is not available initially for analysis or the specification may be imprecise but this should not necessarily preclude proper consideration and many factors other than vibration characteristics may be present in the design. We would expect to consider the effects of fatigue, corrosion, creep, ease of installation and maintenance, low and high temperature properties and the life expectancy of the isolation materials.

Efficient Vibration and Shock Isolation results in:

- Longer life of structures.
- Lower installation and foundation costs.
- Increased production.
- More efficient plant layout.
- Less operator fatigue.
- Reduced maintenance costs.
- Improved quality of work.
- Better environment.

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