

Figure 22 illustrates Equation (18). When the damping is small, maximum force transmitted to equipment is very nearly  $kd_{\max}$ .

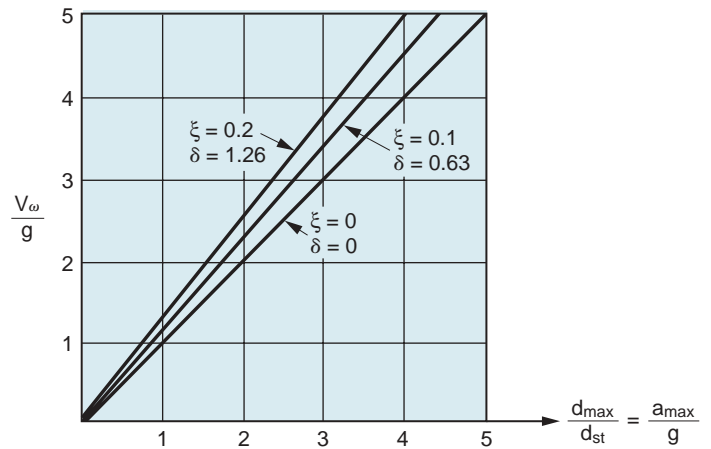


Figure 22 Shock Effect at Different Damping Values

### 3.3.2 Sudden Impact on Equipment [3]

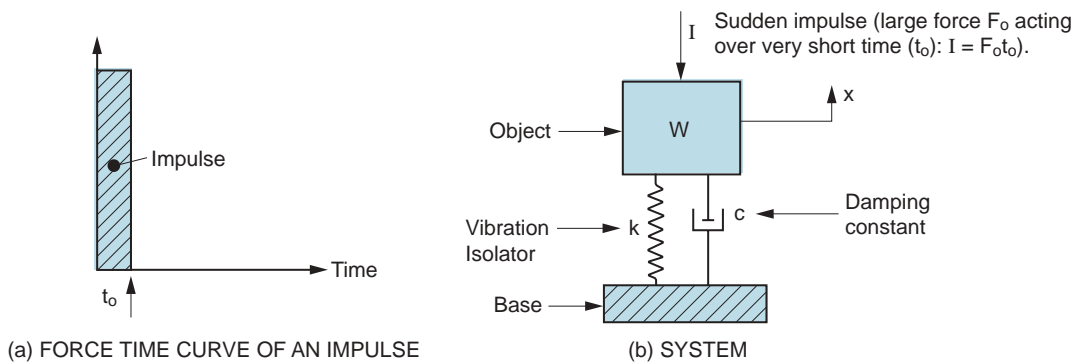


Figure 23 Vibration Isolation System of Object W (b) Subjected to Sudden Impact on the Object with Time History (a)

Sudden impact, or a sharp blow is characterized by a large force ( $F_0$ ) acting for a short period of time ( $t_0$ ) as shown in Figure 23(a). For practical purposes, suddenness is taken to mean that  $t_0$  is small in comparison with the natural period of vibration of the system in Figure 23(b). The *impulse*,  $I$ , is defined as the area under the force-time curve; i.e.,

$$I = F_0 t_0 \text{ lb-sec or kg m/sec} \quad (19)$$

Application of impulse  $I$  results in a sudden downward velocity  $V$  of the object,

$$V = Ig/W. \quad (20)$$

The maximum isolator deflection and the maximum acceleration of the object can be obtained by substituting  $V$  into Equation (18).

## 4.0 NONLINEARITIES

The equations previously given for transmissibility (Section 3.1) make certain assumptions which may not always be valid. For example, it is assumed that the damping is viscous or *linear* (resistance to relative motion is proportional to the relative velocity). The assumption greatly simplifies the analysis. However, the damping provided by wire mesh is a combination of localized frictional losses by individual wires and hysteresis in the cushion itself. Damping in elastomeric materials has similar characteristics. In practical terms, this means that the damping is a function of displacement in addition to velocity, and the terms describing the damping in the equations of motion are *nonlinear*. At resonance, where the displacement is large, the damping is high. In the isolation band, where displacement is small, the damping is negligible. This condition gives the best of both worlds as damping is only desirable under resonance conditions. Thus, the idealized curves in Figure 10 are on the conservative side since they show deterioration of isolation in the high frequency (after resonance) range.

A second assumption is that the flexible members or mounts behave as linear springs. This again is not strictly true as many mounts behave as hardening springs to a lesser or greater extent, depending on material of their flexible elements (e.g., proportion of mesh cushion in the wire-mesh mounts) and/or on design features of rubber flexible elements. As the term suggests, the stiffness increases with load/displacement. This property has the useful effect of increasing the dynamic load-carrying capability of the mounts. Consider the Equation (3) for the natural frequency of a simple spring-mass system. As can be seen, increasing the weight load (mass) of the isolated object reduces the natural frequency. But if the stiffness is increasing as well (as in the case of a hardening spring) then the ratio  $k/m$  is less dependent on the mass of the object and the mount can be used in a wider load range. Some vibration isolators are designed with their stiffness proportional to the weight load,

$$k = AW = Amg, \tag{21}$$

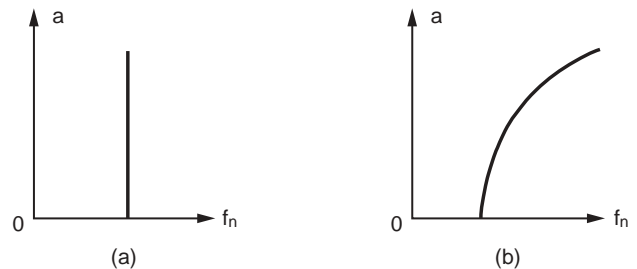
where  $A$  is a proportionality constant. For such mounts the natural frequency is

$$f_n = \frac{1}{2\pi} \sqrt{\frac{kg}{W}} = \frac{1}{2\pi} \sqrt{\frac{AWg}{W}} = \frac{1}{2\pi} \sqrt{Ag} = \text{const.} \tag{22}$$

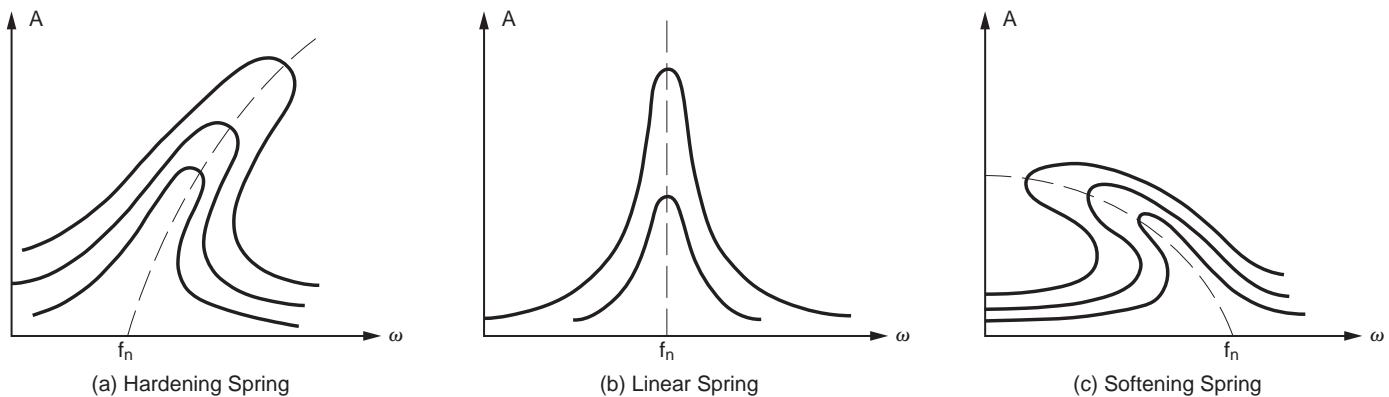
Accordingly, such vibration isolators are called *CONSTANT NATURAL FREQUENCY (or CNF) ISOLATORS*. This means that a mount will give the same degree of isolation for a broad load range, with the ratio of upper load limit and lower load limit up to and exceeding 20:1 [1]. An example of a CNF isolator is Ring Mount V10Z47M in this catalog.

Besides the convenience of using the same isolators for widely different objects, CNF isolators have many other advantages. The tolerance on stiffness of constant stiffness (linear) isolators with rubber flexible elements is usually about  $\pm 17\%$ . Such wide tolerance leads to a need for greater safety factors in order to achieve the required degree of isolation, and thus to softer isolators. The soft isolators are undesirable since they may result in a shaky installation. CNF isolators, on the other hand, are very robust and variation of rubber hardness due to production tolerances do not influence the natural frequency significantly [1]. Other advantages of CNF isolators are addressed below in Section 6.0.

The other way in which a stiffening spring affects the dynamic performance of a system is to make the natural frequency "input sensitive". As the amplitude increases, so does the displacement. Consequently, that stiffness increases as well. The natural frequency ( $f_n$ ) increases also. Figure 24 [5] shows a comparison between the way frequency  $f_n$  changes with amplitude for a linear spring (a) and a hardening spring (b). As can be seen, with a hardening spring,  $f_n$  increases with amplitude. Without going into the mathematical treatment, it should be appreciated that the actual responses for various inputs will be as shown in Figure 25 [5]. It can be seen that the resonant point actually changes with different inputs. A softening spring is added for comparison.

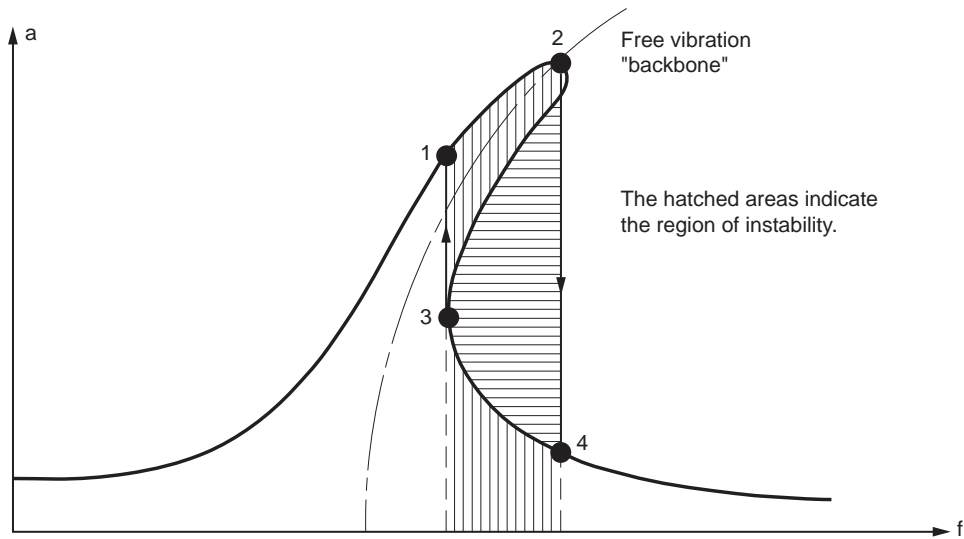


**Figure 24** Amplitude of Linear (a) and Hardening (Nonlinear) (b) Springs as a Function of  $f_n$



**Figure 25** Typical Resonance Curves for Various Levels of Excitation

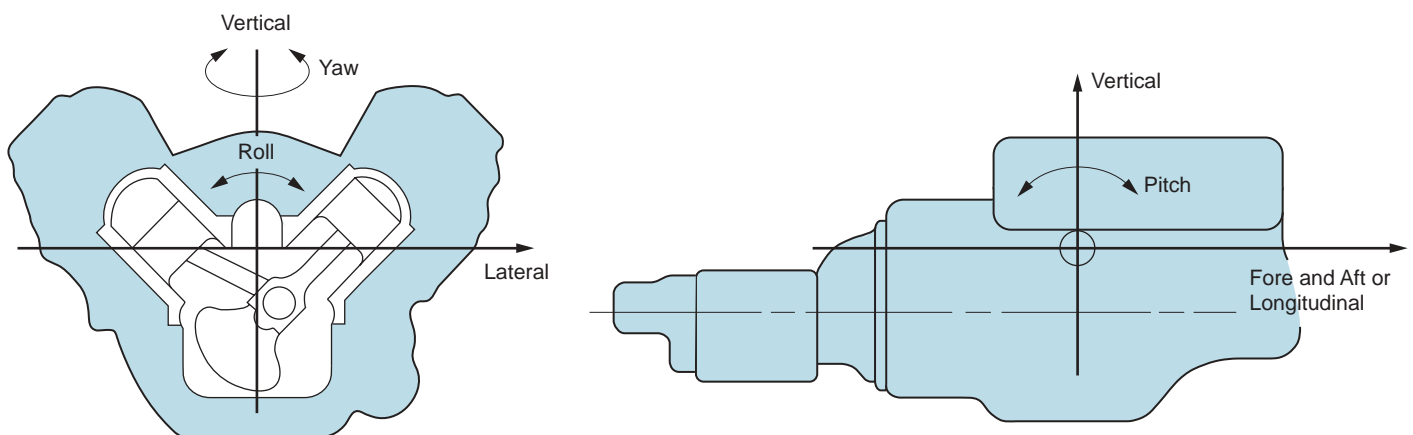
Another property of mesh mounts is demonstrated by Figure 26 [5]. As can be seen, in practice there is a sudden sharp drop from the resonant point, ensuring that isolation is achieved almost immediately. However, it is again safer to assume that isolation does not begin until  $\sqrt{2} f_n$  is achieved.



**Figure 26** Theoretical Frequency Response Curve for a Hardening Spring Type Resonant System

### 5.0 MULTIDEGREE OF FREEDOM SYSTEMS, COUPLED MODES

Figure 27 demonstrates that there are six independent ways in which a body can move; i.e., it has SIX DEGREES OF FREEDOM. The reader must be aware from this that there is a potential of six independent natural frequencies, as well as possible coupled modes of vibration.



**Figure 27** Degrees of Freedom of a Solid Body