# Viscoelastic Damping 101

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One's knowledge of damping, or lack thereof, is often judged solely on the basis of what word is used to refer to it – damping or dampening:

**damp·en** / ´dæm-pen / vt 1. To make damp or moist. 2. To check or diminish the activity or vigor of: deaden (also **damp**).

Although technically both words are used interchangeably, it is commonly understood that when one needs to dampen a structure, he or she should reach for the nearest garden hose. But if it is the conversion of mechanical energy into thermal energy for the purpose of reducing the mechanical vibration of a structure, damping is what you need. That there is confusion over this rather trivial grammatical point suggests a basic lack of understanding on the subject of damping among technical professionals.

**What is Damping?** A structure subject to oscillatory deformation contains a combination of kinetic and potential energy. In the case of real structures, there is also an energy dissipative element as some of the energy is lost per cycle of motion. The amount of energy dissipated is a measure of the structure's inherent damping. In simple terms, damping is the conversion of mechanical energy of a vibrating structure into thermal energy, which is then lost to the structure's environment.

**What are the Different Forms of Damping?** There are many forms of damping: Coulomb friction, fluid viscosity, air damping, particle damping, joint damping, magnetic hysteresis and piezoelectric damping, to name a few. The most common form of damping employed to solve noise and vibration related problems is passive-based material (or viscoelastic) damping, usually in the form of add-on treatments applied to a structure.

**What is Viscoelasticity?** Viscoelastic materials encompass a broad range of materials, including, but not limited to, pressure sensitive adhesives, epoxies, rubbers, foams, thermoplastics, enamels and mastics. Their common characteristic is that their modulus is represented by a complex quantity, possessing both a stored and dissipative energy component. This complex modulus reveals the material's stiffness and damping properties as a function of temperature and frequency, and is usually represented by the SDOF (single degree of freedom) hysteretic model of Figure 1 and Equation 1. The hysteretic model is used instead of the classic viscous damping model because it is a better representation of the true behavior of viscoelastic materials in which the damping is proportional to strain and independent of rate.

$$E(T,f) = E_1 + iE_2 = E_1(1+i\eta) \qquad (1)$$

where:
$E_1$ = Young's storage modulus
$E_2$ = loss modulus
$\eta$ = loss factor = $E_2/E_1$.

## Measures of Damping

Several techniques are used to quantify the level of damping in a structure:

**Half-Power Bandwidth Method.** For the SDOF structure defined by Equation 2, the structure will possess a classic compliance response as shown in Figure 2. The level of damping can be subjectively determined by noting the sharpness of the resonant peak at $\omega_o$: the more rounded the shape, the more damping present in the structure. For a quantitative measure of damping, the half-power bandwidth method can be employed. As defined in Equation 3, the damping of the structure $\eta$ can be determined from the ratio of $\Delta\omega$ to $\omega_o$ with $\Delta\omega$ determined from the half-power point down from the resonant peak value, $A_{max}$ (equal to the inverse of the amplification factor $Q$). On a decibel scale, this corresponds to a –3 dB drop from the peak. For that reason, this damping measurement technique is also referred to as the 3 dB method.

$$m\ddot{x}(t) + k^* x(t) = F(t) \qquad (2)$$

where:
$k^* = k(1+\eta i)$
$F(t) = F_0 e^{i\omega t}$
$x(t) = e^{i\omega t}$
$\dot{x}(t) = i\omega X_0 e^{i\omega}$
$\ddot{x}(t) = -\omega^2 X_0 e^{i\omega t}$

$$\eta = C\frac{\Delta\omega}{\omega_0} \qquad (3)$$

where:

$$C = \frac{1}{\sqrt{n^2-1}} \text{ or } \eta = \frac{\Delta\omega}{\omega_0} \text{ for } n = \sqrt{2} \text{ (half-power)}$$

**Amplification Factor Method.** Another representation of damping for the SDOF system of Figure 1 is the amplification factor $Q$ which is the ratio of the response amplitude at resonance $\omega_o$ to the static response at $\omega = 0$. The amplification factor relates to the hysteretic loss factor $\eta$ through Equation 4.

$$Q = \sqrt{(1+\eta^2)/\eta} \qquad (4)$$

**Log Decrement Method.** Another measure of damping can be made from the transient response of the system in Figure 1. The log decrement method computes damping from the rate of decay of the system response in the time domain. Computing the damping by this method is illustrated in Figure 3 and is defined in Equation 5.

$$\delta = \frac{1}{m}\ln\frac{x_n}{x_{n+m}} \qquad (5)$$

**Hysteresis Loop Method.** Yet another estimate of damping can be achieved by calculating the energy loss per cycle of oscillation due to steady-state harmonic loading. Again assume the complex spring element of Figure 1 is subjected to the cyclic stress $s(t)$ resulting in a strain response of $e(t)$. By plotting the instantaneous stress versus strain for a given cycle of motion, the elliptically shaped hysteresis curve of Figure 4 is generated.

The area captured within the hysteresis loop $D$ is equal to the dissipated energy per cycle of harmonic motion. For reasonable levels of damping, the loop area can be used to calculate damping, as shown in Equation 6.

$$\eta = D/(\pi\sigma_0\varepsilon_0) \qquad (6)$$

**Damping Interrelationships.** For low levels of damping and within the linear region of the viscoelastic material, the various methods of damping estimation can be related as shown below:

$$\eta = \frac{1}{Q} = 2\xi = \frac{\%C_r}{50} = \tan\phi = \frac{\delta}{\eta} = \frac{D}{2\pi U} = \frac{\Delta\omega_{3\text{dB}}}{\omega_0} \qquad (7)$$

where:
$\eta$ = loss factor
$\phi$ = phase angle between cyclic stress and strain
= $\Delta t \times \omega$
$Q$ = amplification factor
$\xi$ = damping ratio
$\delta$ = log decrement of a transient response
$\%C_r$ = percent of critical damping
= $100\% \times \xi$)
$D$ = energy dissipation per cycle
$U$ = stored energy during loading

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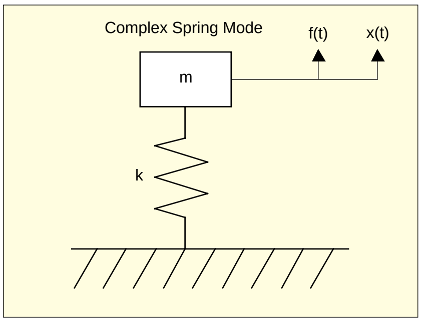


*Figure 1. SDOF hysteretic model.*

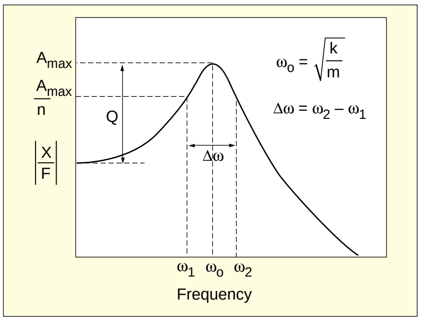


*Figure 2. Compliance transfer function for a SDOF system.*

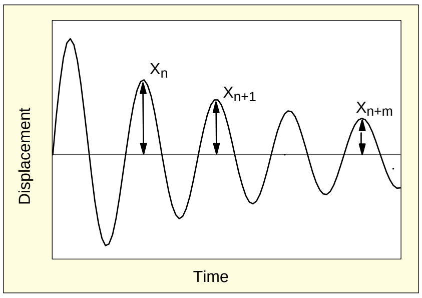


*Figure 3. Transient response of a classically underdamped system.*

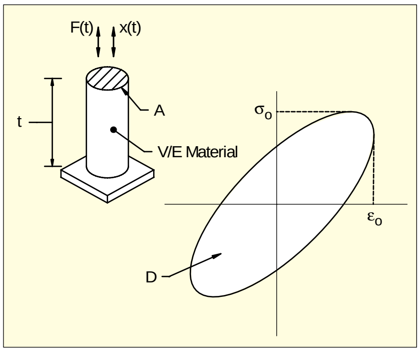


*Figure 4. Typical hysteresis loop for force-excited SDOF system.*