# THE MEASUREMENT OF DAMPING CAPACITY

by

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# NOMENCLATURE

| | |
|---|---|
| $b$ | decay of amplitude per half cycle |
| $c$ | coefficient of viscous damping |
| $c_c$ | critical damping coefficient |
| $f$ | frequency in cycles per second |
| $f_n$ | resonant or natural frequency in cycles per second |
| $f_1$ | frequency at amplitude 0.707 that of amplitude at resonance, and it is smaller than $f_n$ |
| $f_2$ | frequency at amplitude 0.707 that of amplitude at resonance, and it is larger than $f_n$ |
| $F$ | force |
| $F_o$ | magnitude of forcing function |
| $k$ | elastic spring constant |
| $K$ | constant for elastic system |
| $m$ | mass |
| $n$ | number of cycles |
| $Q$ | damping factor of damped forced vibration |
| $t$ | time |
| $W$ | total vibrational energy |
| $\Delta W$ | energy dissipated per cycle |
| $x$ | displacement of mass from rest |
| $X$ | amplitude of steady-state oscillation |
| $\dot{x}$ | velocity |
| $\ddot{x}$ | acceleration |
| $x_o$ | initial amplitude |

## NOMENCLATURE (concl.)

| | |
|---|---|
| $\Delta x$ | decay of amplitude per cycle |
| $X_n$ | amplitude at resonance |
| $\gamma$ | solid damping coefficient |
| $\delta$ | logarithmic decrement |
| $\phi$ | angle of lag between displacement and force, arbitrary constant |
| $\omega$ | frequency in radians per second or circular frequency |
| $\omega_o$ | damped natural frequency |
| $\omega_n$ | undamped natural frequency |
| $\xi$ | damping factor of viscous-damped free vibration |

# INTRODUCTION

All bodies possessing mass and elasticity are capable of vibration. Therefore vibration problems are often encountered by the engineer in connection with the design of almost every type of machine or structure.

In all real vibrating systems, anybody, sooner or later, comes to rest if energy is not supplied to it. In other words, energy is dissipated during each cycle in the interchange between potential and kinetic energy of vibration. The various mechanisms by which this dissipation of energy occurs are collectively termed "damping capacity," "internal friction" (of solids), or "mechanical hysteresis effect" [19].

The term "damping capacity" was proposed by O. Foeppl [19] in 1923, who defined it as: "Damping capacity is the amount of work dissipated into heat by a unit volume of the material during a completely reversed cycle of unit stress." For comparison between materials of different moduli of elasticity, the "logarithmic decrement" of a damped vibration or the "damping factor" is often used.

A high damping capacity is of practical engineering importance in limiting the amplitude of vibration at resonance conditions, thereby reducing the likelihood of fatigue failure. High damping is considered desirable in turbine blades, crankshafts, aircraft propellers, etc. Damping capacity is also taken into account in acoustical problems. For example, a zinc-base die casting of high damping capacity has been used in electric shavers because it makes operation less noisy [8].

Besides its various practical applications in engineering, damping capacity is used as an indirect measure of other properties of solids. Changes in damping are used as an indication of changes in mechanical properties of a material induced by a given set of testing conditions, and as an indication of the presence or absence of certain material characteristics; damping capacity measurements are used to study the internal structure and mechanical behaviour of materials by studying their inelastic response to cyclic loads under which this structure remains unaffected by the test [6].

Many techniques for measuring damping capacity have been investigated. Most of them fall into one of the following six types:

1. Determination of the amplitude decay in free vibration,
2. determination of the resonance curve during forced vibration,
3. determination of the hysteresis loop in the stress-strain curve during forced vibration,
4. determination of energy absorption during forced vibration,
5. determination of mechanical impedance during forced vibration, and
6. determination of sound wave propagation constants.

Since methods 1 and 2 are the most used, and since their precision is high, they are described in detail in this report [12].

# SUMMARY OF DAMPING THEORY

## Types of Damping

Damping in practical systems is usually one of the following three types or combinations of them:

Viscous Damping. This type of damping occurs when the force resisting motion is due to viscous resistance in a fluid medium, and it is therefore called viscous damping. In theoretical analysis, the viscous-damping force is usually indicated by an ideal dashpot $c$ (Fig. 1), where $c$ is a proportionality factor and is called the coefficient of viscous damping. The total viscous damping force at any time is $-c\dot{x}$, where $\dot{x}$ is the velocity of the mass from its rest position.

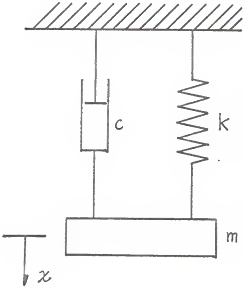



Fig. 1. Simple viscous-damped vibration system.

Coulomb Damping. This type of damping arises from sliding of dry surfaces. The damping force is a kind of kinetic friction force which is dependent on the nature of the surface and the normal pressure. Usually this damping is characterized by a constant dissipative force acting in a direction opposite to that of the velocity.

Solid or Hysteresis or Structural Damping. This is one of the most important forms of damping. The damping force is the internal friction within the material itself. It occurs in all vibrating systems with elastic restoring forces. It is proportional to the displacement and independent of frequency. Since strain is proportional to stress in the elastic range, the solid damping force is also proportional to the stress. Its magnitude is $\gamma kx$, where $\gamma$ is the non-dimensional solid damping coefficient, $k$ is the spring constant, and $x$ is the displacement of the vibrating mass from its rest position [1].

## Free Vibrations with Viscous Damping

A single degree-of-freedom system consisting of a mass supported by a spring and a viscous dashpot is shown in Fig. 1. When dynamically excited, the differential equation of motion is

$$m\ddot{x} + c\dot{x} + kx = 0 \qquad (1)$$

where

$m$ = mass of the vibrating system,

$c$ = coefficient of viscous damping,

$k$ = spring constant, and

$x$ = displacement of the mass from its rest or equilibrium position at time, $t$.

The general solution of this equation depends upon whether the damping coefficient, c, is equal to, greater than, or less than the critical damping coefficient, $c_c$, which is given by

$$c_c = 2\sqrt{km} = \frac{2k}{\omega_n} \tag{2}$$

where $\omega_n = \sqrt{\frac{k}{m}}$ is the natural (angular) frequency.

The ratio $\xi = c/c_c$ is called the viscous-damping factor. When $\xi > 1$ (supercritical damping) or $\xi = 1$ (critical damping), there is no oscillation. When $\xi < 1$ (subcritical damping), the damping of the system is less than critical, and the general solution of (1) is

$$x = x_o \, e^{-\frac{ct}{2m}} \cos \omega_o t \tag{3}$$

where $\omega_o = \left(\sqrt{1 - \xi^2}\right)\omega_n = \sqrt{\omega_n^2 - \frac{c^2}{4m^2}}$ is called the damped natural frequency. [1, 13].

The type of motion obtained with subcritical damping is shown in Fig. 2.

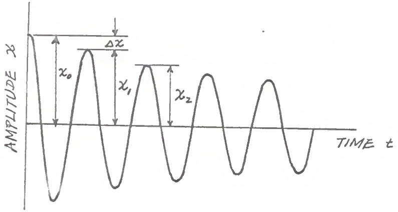



Fig. 2. Subcritical viscous-damped free vibration.

## Free Vibrations with Coulomb Damping

In a free vibrating system with Coulomb damping, the system is similar to Fig. 1 with the dashpot replaced by a dry friction damper. The damping friction force, F, is considered to be constant at all times. The differential equation of motion is

$$m\ddot{x} + kx = \pm F \tag{4}$$

The solution is

$$x = x_o \cos \omega_n t \pm \frac{F}{k} \tag{5}$$

which means that the frequency is equal to the natural frequency. The amplitude decreases by $\frac{4F}{k}$ for each cycle. The envelope to the displacement-time curve is a pair of converging straight lines. The mass comes to rest in an extreme position as soon as the displacement in such a position is less than $\frac{F}{k}$ , i. e., at which position the spring force is insufficient to overcome the static friction force.

In a damped free vibration where a combination of different types of damping are present, Coulomb damping generally predominates during the final stages of motion. During these final stages other types of damping, which are frequency-and amplitude-dependent, will become negligible, and the constant Coulomb damping will remain [1, 13].

## Free Vibrations with Solid or Hysteresis Damping

In a free vibration system with solid damping, the differential equation of motion is

$$m\ddot{x} + \gamma k \frac{\dot{x}}{|\dot{x}|} |x| + kx = 0 \tag{6}$$

where $|x|$ = absolute value of displacement, which shows the proportionality of the solid damping force to displacement without bringing any sign change into the equation, and

$$\frac{\dot{x}}{|\dot{x}|} = \text{ unit vector in the direction of the velocity}$$

of the mass.

From energy considerations, it can be shown that the decay of amplitude per half cycle, b, is a function of the material and the amplitude, i.e., $b = 2\gamma x.$ (7)

The decay curve has the same exponential envelope shape as one with viscous damping [1].

## Forced Vibrations with Viscous Damping

When the system shown in Fig. 1 is under the action of ...rmonic force $F = F_o \sin \omega t$, the differential equation of motion is

$$m\ddot{x} + c\dot{x} + kx = F_o \sin \omega t. \tag{8}$$

The transient solution of this equation is the same as the solution of viscous-damped free vibration, i.e., (3)

$$x = x_o e^{-ct/2m} \cos \omega_o t.$$

The steady-state solution is

$$x = X \sin(\omega t - \varphi) \tag{9}$$

where $\phi$ = phase angle by which the motion lags the applied force, and

$$X = \frac{F_o/k}{\sqrt{\left(1 - \frac{\omega^2}{\omega_n^2}\right)^2 + \left(\frac{2c}{c_c}\ \frac{\omega}{\omega_n}\right)^2}} \tag{10}$$

is the amplitude of steady vibration.

For small amounts of damping the amplitude is practically the same as for no damping, except in the neighborhood of

$$\frac{\omega}{\omega_n} = \frac{f}{f_n} = 1. \tag{11}$$

Maximum amplitude occurs when the induced frequency very nearly equals the undamped natural frequency. Therefore for most practical systems, it is necessary to consider only damping in the neighborhood of resonance.

The resonance curve for forced viscous-damped vibration is obtained by plotting X against f (Fig. 3) [1, 13].

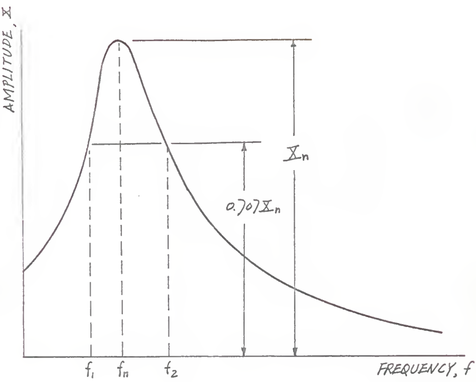



Fig. 3. Resonance curve of forced viscous-damped vibration of one degree of freedom.

## Forced Vibrations with Various Types of Damping

Since, in the case of forced vibrations with viscous damping, the resulting steady-state motions are harmonic and the phase angle is always 90 degrees at resonance, it is therefore assumed that in most practical systems of small amounts of damping, the phase angle is alwyas close to 90 degrees at resonance regardless of the type of damping and that the steady-state forced vibration is harmonic [13].

The equivalent viscous damping may be used to find the amplitude of a damped forced vibration in the neighborhood of resonance. It is the amount of viscous damping that would give the same amplitude as the damping force in question. The amplitude of equivalent damping needs to be considered only in the neighborhood of resonance. When the frequency ratio $f/f_n$ is considerably different from unity, the amplitude is so close to the undamped one that it is not necessary to consider the damping at all.

## Logarithmic Decrement

The degree of damping in a subcritical damped system ($\xi < 1$) may be expressed by the logarithmic decrement, $\delta$. It is defined as the natural logarithm of the ratio of amplitudes of two successive cycles of the damped free vibration (Fig. 2), i.e.,

$$\delta = \ell n \frac{x_o}{x_1} \tag{12}$$

It may also be expressed as

$$\delta = \frac{1}{n} \ell n \frac{x_o}{x_n} \tag{13}$$

where $n$ is the number of cycles between amplitudes $x_o$ and $x_n$ [1].

By making use of the logarithmic series for small damping, $\delta$ may be expressed as

$$\delta = \frac{\Delta x}{x} \quad . \tag{14}$$

From energy considerations, $\delta$ may be given as

$$\delta = \frac{\Delta W}{2W} \tag{15}$$

in which $\Delta W$ = energy dissipated per cycle of vibration,

and $W$ = total vibration energy at some time, $t$.

For forced vibration with small damping, $\delta$ may be obtained from the resonance curve (Fig. 3) using the approximate formula

$$\delta = \frac{\pi}{Q} = \frac{\pi(f_2 - f_1)}{f_n} \tag{16}$$

where $f_n$ = resonant frequency.

$f_1$ = the frequency lower than $f_n$ which has an amplitude 0.707 that of $f_n$,

$f_2$ = the frequency higher than $f_n$ which has an amplitude 0.707 that of $f_n$, and

$$Q = f_n/(f_2 - f_1) \tag{17}$$

is called the damping factor [1, 10, 13].

The great advantage of expressing the damping of a vibrating system in terms of logarithmic decrement, $\delta$, is that it is a dimensionless quantity and is thus the same whatever systems of units be used to express energy and length. It is easily measured, and it is readily found from the results of other investigators of vibration damping phenomena, however the results be set forth [10].

Energy Dissipation per Cycle (Hysteresis)

A hysteresis loop (Fig. 4) obtained by plotting stress against strain during one cycle is a measure of the amount of energy dissipated, $\Delta W$, during the cycle. The loop area is found by line integration, and is equal to $\pi c \omega x_o^2$, i. e.,

$$\Delta W = \pi c \omega x_o^2 \tag{18}$$

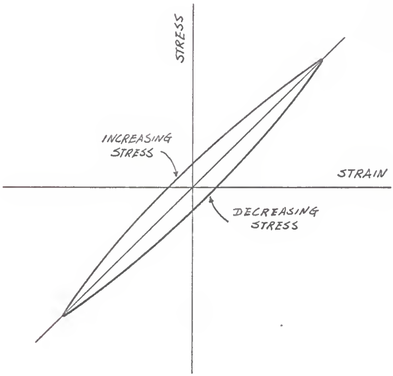



Fig. 4. Stress-strain (hysteresis) loop in damped vibration.

In forced vibration, the work done by the applied force during one cycle is

$$W = \pi X F_o \sin\phi \tag{19}$$

At resonance, $\phi = 90$ degrees; then

$$W = \pi X_n F_o \tag{20}$$

in which $X_n$ = amplitude at resonance.

This is the largest possible amount of work done per cycle, and it is equal to the energy dissipated per cycle at resonance [9, 10, 13, 18].

## MEASURING EQUIPMENT AND TECHNIQUES

### General Description

Of the many methods developed to measure damping capacity, two are widely used [12]:

Determination of the Amplitude Decay in Free Vibration. In this method, which is also called the damped free vibration method [19], the specimen performs free vibrations at its natural frequency, and it is damped only by the internal friction of the material. The amplitudes of successive cycles are determined to be used to calculate the logarithmic decrement according to (12).

This technique is the most suitable one for low stress. The apparatus is simple and easy to operate. The method is inconvenient, however, if frequency is to be a variable.

Determination of the Resonance Curve During Forced Vibration. In this method, which is also called the damped forced vibration method, the specimen is excited into forced vibration by an alternating force of variable frequency and the amplitudes are observed. The logarithmic decrement is calculated according to (16).

The equipment is simple and easy to operate, and can be used over a broad frequency range. It is not used if the damping capacity is frequency or amplitude dependent.

## Measuring Equipment

To measure damping capacity or logarithmic decrement by the damped free vibration method, the equipment consists of a vibration exciter, a vibration pickup, amplifiers, and a wave recording device. In the damped forced vibration method, a vibration exciter, a frequency counter, a vibration pickup, amplifiers, and an amplitude measuring device are required.

Vibration Exciters. A vibration exciter or generator is a device that transmits a vibrating force to the test specimen. It can be a purely mechanical device, or it can be a device based on electrodynamic, electrostatic, electromagnetic, eddy current, or other electrical principles, and powered by a variable audio frequency oscillator or signal generator.

Mechanical vibration exciters may be either direct-drive or reaction-type devices. They are suitable for use with low operating frequencies and large displacements.

An electronic oscillator or signal generator and a power amplifier supply alternating current power of variable frequency, variable voltage and single phase to vibration exciters using electrodynamic, electromagnetic, electrostatic, eddy current or other electrical principles. The frequency of the oscillator is fairly constant and determinable with great accuracy; it can be easily varied by means of a tuning capacitor. The power available is sufficient for most measurements, and the wave form is very close to a pure sine wave.

In one type of electrodynamic exciter, the output signal from the signal generator and power amplifier is used to operate a driving unit which is similar to a dynamic loudspeaker with a driving rod attached to it. In an electrostatic, eddy current or electromagnetic exciter, a method of excitation without direct contact may be employed, and the specimen is free to vibrate at its own natural frequency, since no physical contact exists between the specimen and the exciter [12].

Vibration Pickups (or Transducers). A vibration pickup is a device which converts the vibratory motion into an optical, a mechanical, or most commonly, an electrical signal that is proportional to a parameter of the experienced motion. Pickup devices fall into several classes, for example, those which act as variable resistors, inductors, or capacitors and those which act as variable batteries.

There are many pickups of the variable resistance class. A carbon microphone makes use of the change in conductivity of compacted carbon grains when pressure is applied. A strain gauge is another simple device. It is based upon the fact that the resistance of a very fine wire (about

0.001 inch in diameter [15] ) changes when it is strained. A photoelectric cell may also serve as a variable resistance pickup. Its resistance varies with the amount of light admitted through its window, and the admission of light can be controlled by the motion of a mirror attached to the vibration specimen, or by a mask or knife edge moving with some part of the specimen.

In a variable inductance pickup, a displacement of the vibration system causes a variation in the inductance of the magnetic circuit, such as a change in the air gap of an inductance coil; thus, the inductance of the coil is varied by the displacement. Variable inductance pickups are used most widely in displacement measuring applications, or as accelerometers at relatively low frequencies (below approximately 100 cycles per second). Their resolution is usually not adequate for very small displacements [9] .

In a variable capacitance pickup, the spacing between the plates of a capacitor is changed proportional to the displacement of vibration. This type of pickup has the advantage that the vibrating part is loaded only by the relatively small mass of the moving capacitor plate; it has high sensitivity to small displacements. The disadvantage is that relatively complex electrical circuitry is required particularly if high frequency carriers must be used to cover the normal vibration frequencies of interest.

Variable emission devices generate an electrical output signal which is proportional to some parameter of the vibration, without the use of an external power source or carrier voltage. These devices use the piezoelectric effect, electromagnetic induction, or photoelectric effect, etc.

In piezoelectric pickups, the piezoelectric element may be either a natural or synthetic crystal, or a ceramic material such as barium titanate or quartz, which has the property of emitting an electric charge when strained. This type of pickup is sensitive to small displacements and generates large output signals. Such pickups can be made extremely small size. They are most usable as accelerometers.

A velocity pickup is based on the principle of electromagnetic induction. An output current which is directly proportional to the velocity of vibration is generated in a coil moving through the field of a powerful magnet. The device is limited in low-frequency response by its natural frequency, often approximately 10 cycles per second. Its high-frequency limit of 500 to 2,000 cycles per second is determined by the usually small velocity values at high frequencies. It is relatively large in size [9].

A photoemissive cell can be used as a pickup. It produces a direct current which is proportional to the light entering through the window. The light intensity is proportional to the motion of the vibrating system.

Wave Recording Devices. Two types of wave recorders are usually used. The simplest one is a pen-and-ink recorder. Basically it is a pen mounted on an arm extending from the armature of a galvanometer. It has three disadvantages: 1. It is a vibratory system itself; 2. Due to the effect of moment of inertia, a signal of rather high strength is required for a given deflection; and 3. Friction exists between the pen stylus tip and chart paper strip. A mirror and a beam of light arrangement and a recording camera may be used to reduce these disadvantages.

The cathode-ray oscilloscope is a good recording device in common use. The popularity of this instrument in both visual and recording applications is mainly due to the all-electronic action of the cathode-ray tube. Since a virtually massless electron beam is used as the pointer, there is no mechanical natural frequency to limit its upper-frequency response [3, 9].

For convenience of photographic recording of waves displayed on the cathode-ray tube screen, some oscilloscopes are equipped with a sweep-lockout device which makes it possible to photograph transient signals by using the input signal to trigger a single sweep of the cathode ray. The camera lens should be the best available. Recommended minima are: f/4.5 for stationary recording, and f/2 or f/1.5 for moving films and single sweep [9].

Amplitude Measuring Devices. A simple dial indicator may be used to measure the amplitude of vibration, but it is limited in use to very low frequencies.

A voltmeter or ammeter is usually used to indicate the amplified signal voltage or current which comes from the vibration pickup and amplifier, and which is proportional to the amplitude of vibration. By proper calibration, the reading of the voltmeter may be converted to the magnitude of the amplitude. Among various types of voltameters the vacuum tube voltmeter is most widely used. It has very high impedance and may give resonably accurate readings over a wide range of frequencies extending up to several megacycles per second.

Voltmeters and ammeters usually indicate either the average or effective value of the quantity measured. For example, the voltmeter reads 0.707E for a voltage whose value is $e = E \sin \omega t$. To get an instantaneous value of the voltage, an oscilloscope may be used.

Frequency Counters. To measure the frequency of a vibrating specimen or a driving force, either a mechanical frequency meter or an electronic frequency counter may be used. A mechanical meter using the principle of the seismograph consists of a large number of reeds as resonators. It is limited in use to the low frequency range.

An electronic counter is one of the most convenient and accurate frequency meters. One type of electronic counter is called an events-per-unit-time (EPUT) meter (such as Beckman Model 7161 Preset EPUT Meter) which combines a high-speed electronic counter with an accurate, crystal controlled timing gate. It can automatically count and display in decimal form any number of events from 20 to 100,000 which have occurred during a precise one-second counting interval. The events may be optical, physical or electrical occurances translatable into voltage changes. Its basic accuracy is essentially $\pm 1$ cycle for any input frequency. It is connected to the vibration pickup or the signal oscillator through an amplifier to measure the frequency of vibration or driving force.

Amplifiers. Amplifiers are constructed on the principle that when a small alternating voltage is applied between the grid and the cathode, a relatively large change in plate current takes place. They are used to raise the voltage or power level, or both, available from a vibration pickup or signal generator. They should perform linear amplification without distortion; i.e., the output waveform should be a precise replica of the input signal but to a different amplitude scale. The output of a power amplifier is used to operate meters or recorders or to drive the vibration exciters.

To convert an alternating voltage representing a velocity-time wave into its corresponding displacement-time wave or acceleration-time wave, an integrator or differentiation circuit may be used. If most accurate results are wanted, instead of using electrical integration or differentiation, the required quantity may be obtained by dividing or multiplying the input voltage value by $\omega$ (known frequency) or $\omega^2$ as the case may be [3, 9, 16, 19].

## Measuring Techniques

Arrangement of Equipment. Figure 5 shows a block diagram of equipment arranged for a typical damping capacity measurement using the damped free vibration method. The specimen is supported at its nodes (0.224 length of the specimen from the end). A vibration pickup is attached to or installed near the center or end of the specimen, depending upon which type of pickup is used. The output of the pickup is fed through the amplifier to the oscilloscope. A camera is installed in front of the oscilloscope. A vibration exciter is placed to apply an exciting force at the center of the specimen. Since, in free damped vibration, the specimen is not continuously excited, the specimen can be excited by light impact with equally good results.

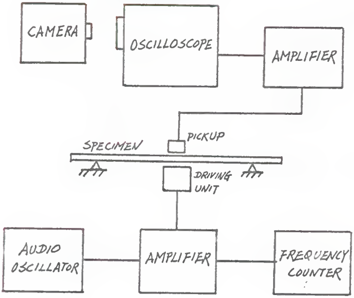


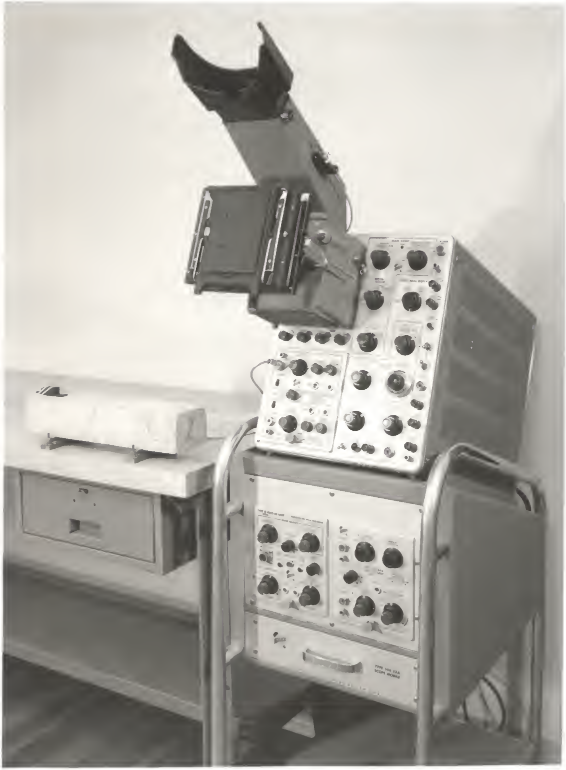

Fig. 5. A block diagram of apparatus arrangement for the damped free vibration method.

The impact may be a light blow with a plastic hammer or the impact of a steel ball dropped from a certain height. A photograph of a practical arrangement of equipment used in the Department of Applied Mechanics to measure damping capacity of concrete beams is shown in Plate I, and its block diagram is shown in Fig. 6 [1, 9].

EXPLANATION OF PLATE I

Photograph of a practical equipment arrangement for measuring the damping capacity of concrete beams. (A block diagram is shown in Fig. 6.)

PLATE I



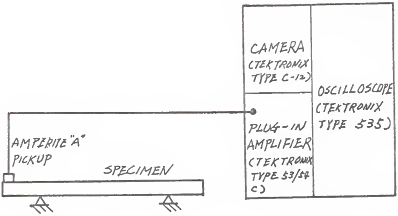



Fig. 6. A block diagram of equipment arranged to measure damping capacity of concrete beams. (See Plate I.)

Figure 7 shows a block diagram of equipment arranged for a typical damping capacity measurement employing the damped forced vibration method. The specimen supports and pickup installation are the same as that shown in Fig. 5. The output of the pickup is fed through an amplifier to a vacuum tube voltmeter. The vibration exciter consists of a signal generator and a driving unit. The output of the signal generator is fed through an amplifier to the driving unit and to the frequency counter. The driving unit is installed to apply the driving force at the center of the specimen [9, 14].

Among the various installation problems that one must consider are: 1. The effect of the added mass and the changes in the stiffness of the specimen which are introduced by the measuring instruments; 2. Electrical noise; and 3. External energy losses [8, 9, 12, 17].

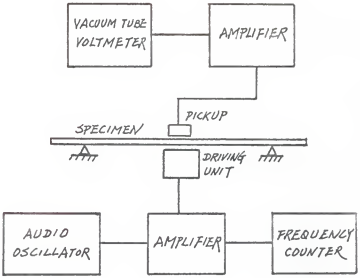



Fig. 7. A block diagram of equipment arranged for the damped forced vibration method.

It is important to choose equipment which will not affect the characteristics of the system under test. Thus, if a pickup is attached to the specimen, its mass must be small compared with the mass of the specimen. If special mountings are used, they should be so designed that they do not increase the stiffness of the specimen. The pickup itself may affect the vibration wave form or cause spurious resonances, if it is not securely mounted.

Electrical noise may be evident in the output of the measuring system even though no input signal is supplied. One of the most convenient methods to locate the source of noise is to check the equipment components one by one by using an oscilloscope under actual testing conditions. Another method is to use a small capacitor to short-circuit the signal path at various components in the system, one at a time, until the noise disappears. Sometimes electrical noise may be generated by the motion of some part of the wiring; it is therefore necessary to secure the wire cable at frequent intervals. Mechanical sources causing such motion must be eliminated or controlled.

The purpose in all damping measurements is to determine the energy loss due to internal friction of the specimen alone. Therefore it is important to keep external energy losses, such as that caused by motion of the surrounding air or friction of solid supports, as small as possible. For engineering purposes, the loss due to air motion may be neglected, and the problem is to make the loss caused by supports small. A good way to determine good supports is to try several types, such as wire, cord, knife-edge, or ball supports, and see which type gives the least loss. Once a certain type of support is selected, minor adjustments may be made to give the best possible results.

Measuring Procedure. Once the measuring equipment and the test specimen are properly adjusted and checked, the measuring procedure is rather simple:

1. Turn on equipment power supply switches to warm up components for about 15 to 30 minutes.

2. Check the zero reading of the voltmeter. Obtain a clear, bright trace of the oscilloscope display.

3. Operate the vibration exciter temporarily and make adjustments to obtain adequate meter indication and oscilloscope display.

4. In the damped free vibration method:

a. Adjust the oscilloscope to be triggered by the input signal; the ready light will glow.

b. Adjust the camera focus and place the time setting to the "T" position. Open the shutter.

c. Excite the specimen once to vibrate freely. A trace of the decayed vibration curve will appear on the oscilloscope screen. Then the ready light will go out.

d. Close the camera shutter. This completes the photographing of the decayed free vibration curve.

e. Turn off all power supplies if the test is not continued.

f. Develop the exposed film, (A photograph of two damped-free vibration curves is shown in Plate 2) and measure the amplitudes of successive cycles.

g. Compute the logarithmic decrement, $\delta$, by using Eq. (12) or (13).

5. In the damped forced vibration method:

a. Turn the audio oscillator frequency range switch to the desired range position.

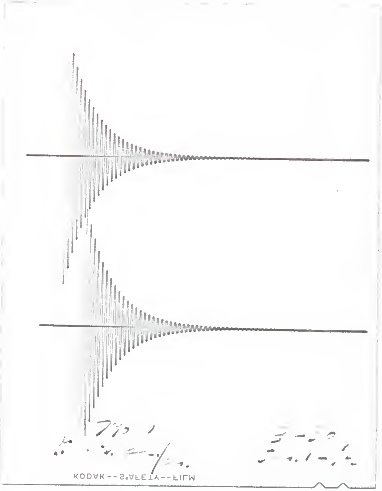
b. Turn the frequency dial of the oscillator slowly to vary the forced frequency continuously. Resonance is detected by noticing a maximum voltmeter reading (make scale adjustment if necessary). Take the resonant frequency reading, $f_n$, on the frequency counter and record the voltmeter reading.

c. Decrease the frequency slowly to get the voltmeter reading equal to 0.707 that taken in Step b. Take the frequency counter reading, $f_1$.

EXPLANATION OF PLATE II

Photograph of two damped-free vibration curves of a typical concrete test specimen.

PLATE II



5. d. Increase the frequency slowly. The voltmeter indication will go up to peak value and then drop. Take the frequency counter reading, $f_2$, when the voltmeter reading drops to 0.707 that taken in b.

e. If a resonance curve is desired, take many frequency and voltage readings in the region of resonance.

f. Turn off all power supplies if the test is not continued.

g. Compute the damping factor, Q, by using Eq. (17).

h. Calculate the logarithmic decrement by using Eq. (16).

The damped-free vibration method is preferred because a number of ratios of successive amplitudes and thus a number of logarithmic decrement values are easily obtained from the photograph of the decay curve, and an average value may be computed from these data. In the damped forced vibration method, only single values of three particular frequencies ($f_n$, $f_1$, $f_2$) and their corresponding amplitudes are taken; it is not convenient to get an average value. The accuracy of the result depends upon the accuracy of these frequency and amplitude readings and thus an error is relatively easily introduced unless extreme care is taken. However, this method is useful in obtaining approximate values of damping capacity quickly.

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THE MEASUREMENT OF DAMPING CAPACITY

by

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AN ABSTRACT OF A MASTER'S REPORT

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Damping capacity is the amount of work dissipated into heat per unit volume of material per cycle of completely reversed stress. It is important both in practical engineering applications and as a research tool. Six general techniques have been developed to measure it:

1. Amplitude decay determination in free vibration;
2. Resonance curve determination during forced vibration;
3. Determination of hysteresis loop in forced vibration;
4. Determination of energy absorption during forced vibration;
5. Mechanical impedance determination during forced vibration; and
6. Measurement of sound wave propagation constants.

Methods 1 and 2 are the most widely used; their precision is relatively high. These two techniques are described in detail in this report.

After a summary of the theory of damping, measuring equipment consisting of vibration exciters and pickups, wave recording devices, amplitude-measuring instruments, frequency meters, and amplifiers is described. The use of this equipment in measuring damping capacity by determining amplitude decay of damped free vibration and by measuring the half-width of the resonance peak in damped forced vibration is discussed in detail.