INSTITUTE OF DISTANCE LEARNING

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

ME 362 VIBRATIONS I

Lecture 5

DESIGN FOR VIBRATION SUPPRESSION

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VIBRATION ISOLATION AND ABSORPTION

- Vibration can often lead to a number of undesirable circumstances.
- For example, vibration of an automobile or truck can lead to driver discomfort and, eventually, fatigue.
- Structural or mechanical failure (e.g., cracks) can often result from sustained vibration.
- Electronic components used in automobiles, machines, and so on may also fail because of vibration, shock, and/or sustained vibration input.

Acceptable Levels of Vibration

Average displacement

$$\bar{x} = \lim_{t\to\infty} \frac{1}{\pi} \int_0^{\pi} x(t)dt$$

$$if \qquad x(t) = A sin\omega t$$

$$\bar{x} = 2A/\pi$$

Mean square value

$$\langle x^2 \rangle = \lim_{t\to\infty} \frac{1}{\pi} \int_0^{\pi} \left(x(t)\right)^2 dt = \frac{A}{\sqrt{2}}$$

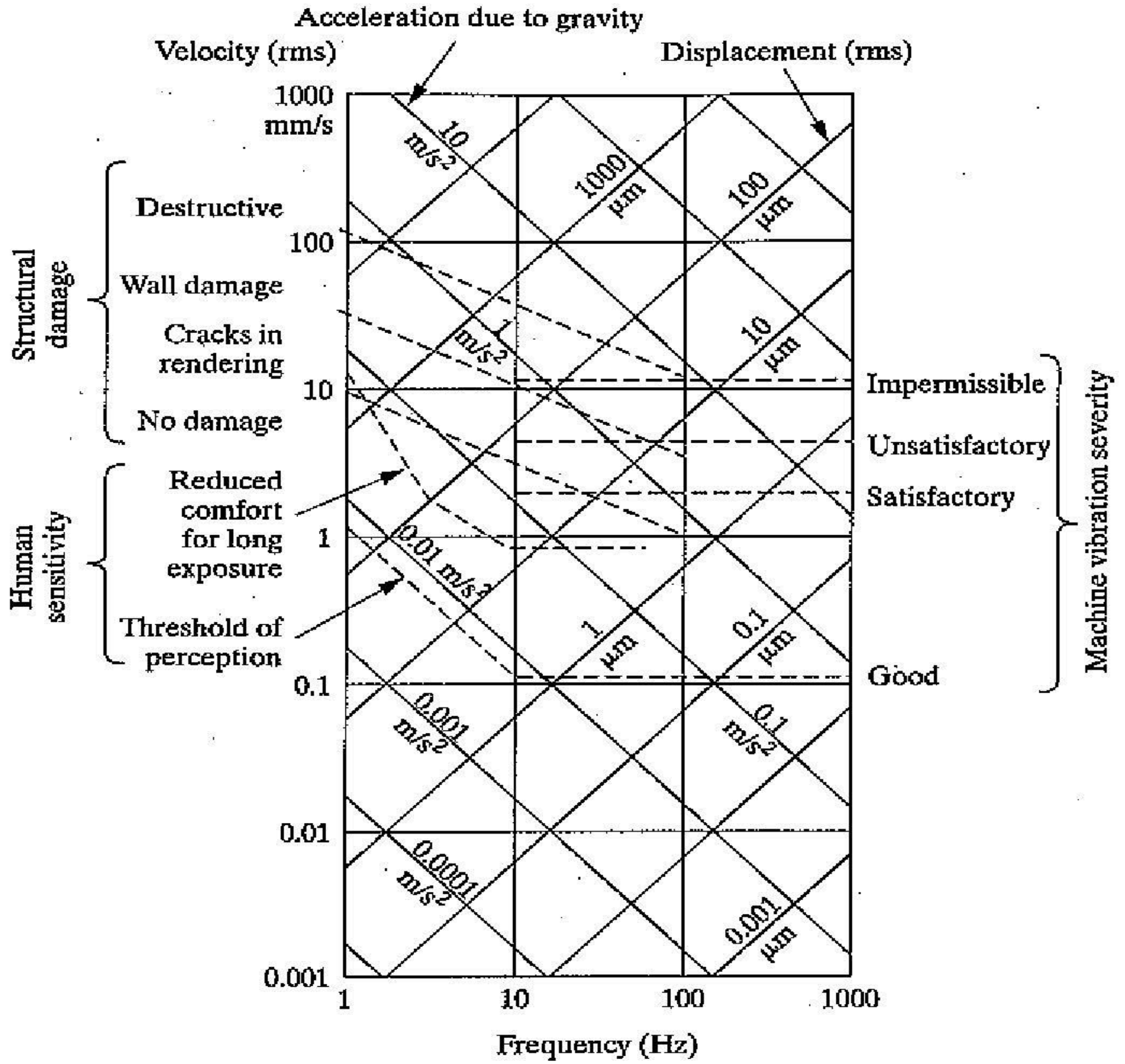
Decibel(dB)

$$dB = 10\log_{10}\left(\frac{P_1}{P_2}\right) = 10\log_{10}\left(\frac{{x_1}^2}{{x_o}^2}\right)$$

Octave

$$\log_2\left(\frac{f_{max}}{f_{min}}\right)$$

Acceptable Levels of Vibrations

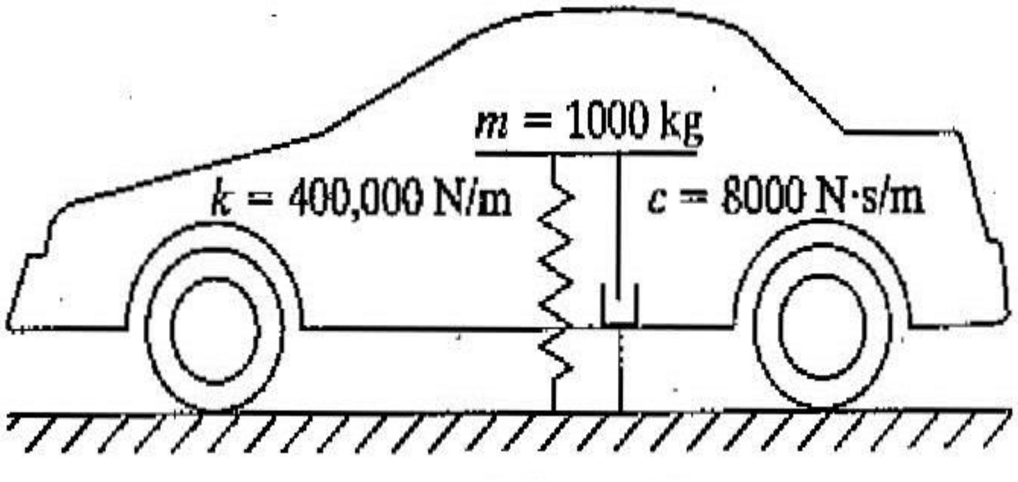


Discuss

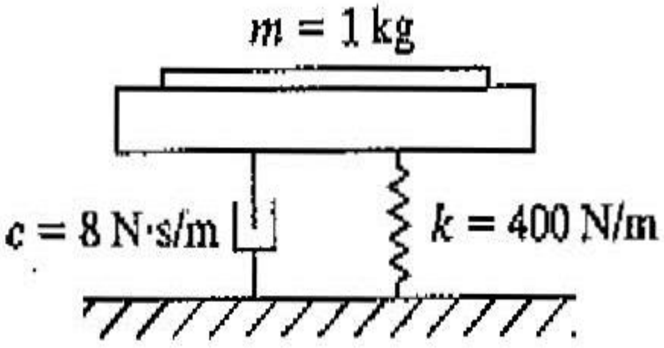
An automobile has a mass of 1000 kg and a stiffness of 400,000 N/m. If it hits a bump that is 0.1 mm high, it will sustain a sinusoidal vibration. Assuming that the height of the bump corresponds to the rms value of displacement, what velocity and acceleration correspond to this vibration? Is this vibration perceived by the passenger? If the vibration is perceptible and hence not desirable, suggest a means of redesigning the system so that the vibration does not disturb the passengers.

Discuss

Calculate and compare the natural frequency, damping ratio, and damped natural frequency of the single-degree-of-freedom model of a stereo turntable and of the automobile given in the Figure. Also plot and compare their frequency response functions and their impulse response functions. Discuss the similarities and differences of these two devices.



Automobile model

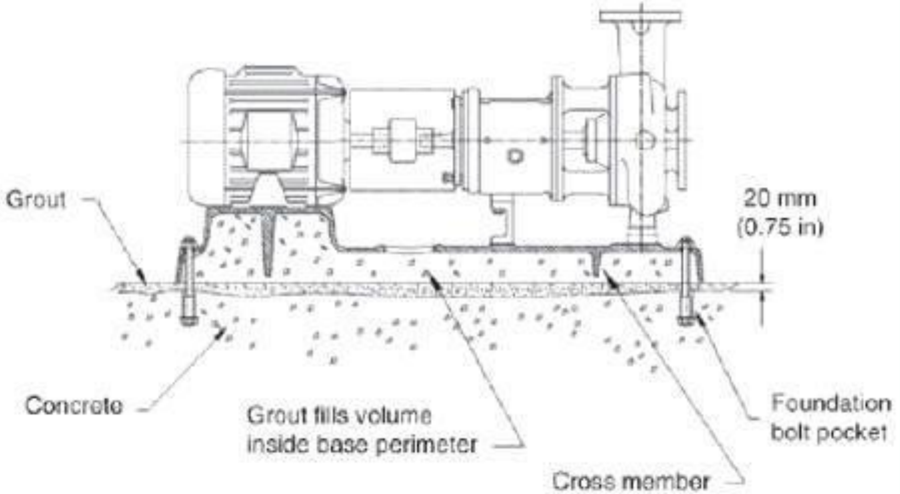


Stereo turntable model

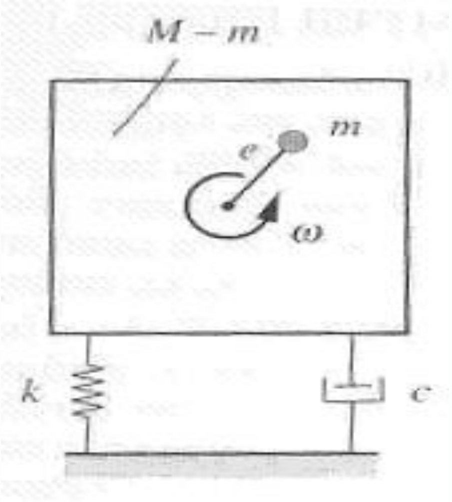
Vibration Isolation

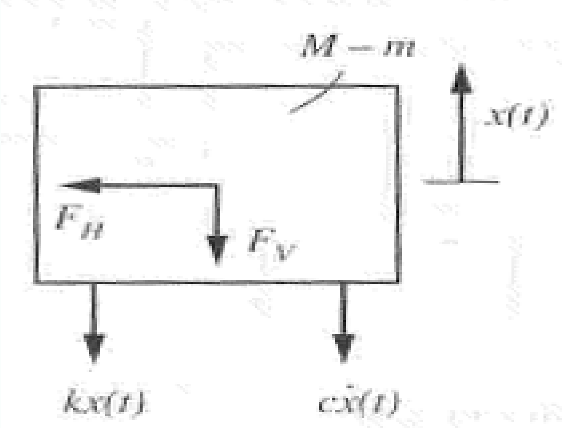
- The most effective way to reduce unwanted vibration is to stop or modify the source of the vibration.
- If this cannot be done, it is sometimes possible to design a vibration isolation system to isolate the source of vibration from the system of interest or to isolate the device from the source of vibration.
- This can be done by using highly damped materials such as rubber to change the stiffness and damping between the source of vibration and the device that is to be protected from the vibrations

Vibration Isolation



Force Transmitted to support





$$F_T = \mathrm{c\dot{x}} + \mathrm{kx}$$

$$x = X_o \sin(\omega\, \mathrm{t} - \emptyset)$$

$$F_T = F_o\sqrt{\frac{1 + (2\xi\tau)^2}{(1-\tau^2)^2 + (2\xi\tau)^2}}$$

$$Transmissibility = T = \frac{F_T}{F_o}$$

Example 1

An exhaust fan, rotating at 1000 rpm, is to be supported by four springs, each having a the same stiffness(k). If only 10% of the unbalanced force of the fan is to be transmitted to the base, what should be the value of k? Assume the mass of the exhaust fan to be 40 kg.

Solution

T=10%=0.1

ξ=0

$$T = \frac{F_T}{F_o} = \sqrt{\frac{1 + (2\xi\tau)^2}{(1 - \tau^2)^2 + (2\xi\tau)^2}}$$

$$T = \frac{1}{1 - \tau^2}$$

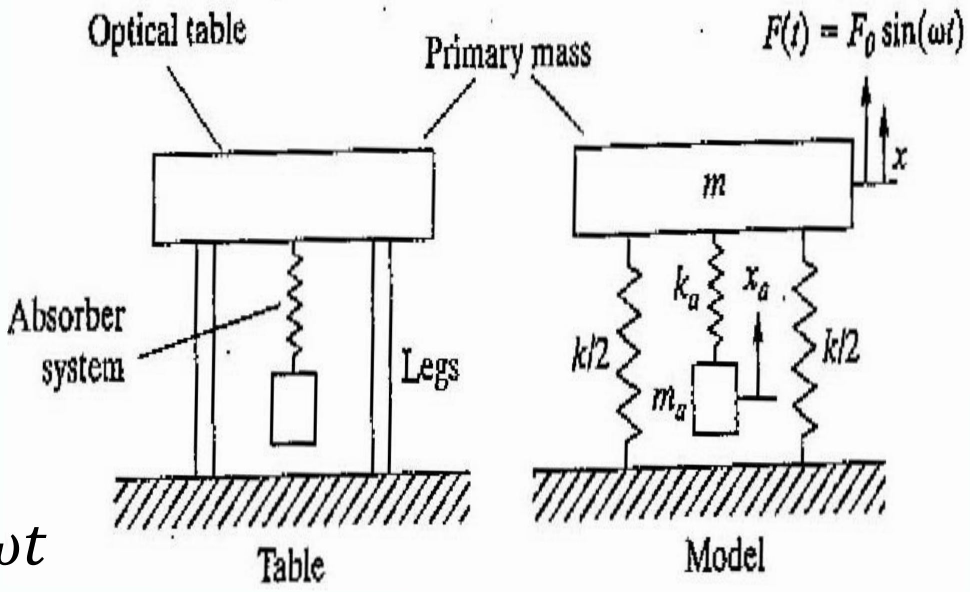
$$\tau = \sqrt{\frac{1 + T}{T}} = \sqrt{\frac{1 + 0.1}{0.1}} = 3.317$$

$$\tau = \frac{\omega}{\omega_n} = 3.317 = \frac{1000 \times 2\pi}{60\sqrt{\frac{4k}{m}}}$$

$$k = 9969.63\ N/m$$

Vibration Absorption

Vibration Absorption



$$x(t) = X \sin\omega t$$

$$x_a(t) = X_a \sin\omega t$$

$$\begin{bmatrix} k + k_a - m\omega^2 & -k_a \\ -k_a & k_a - m_a\omega^2 \end{bmatrix} \begin{bmatrix} X \\ X_a \end{bmatrix} \sin\omega t = \begin{bmatrix} F_0 \\ 0 \end{bmatrix} \sin\omega t$$

$$\begin{bmatrix} X \\ X_a \end{bmatrix} = \frac{1}{(k + k_a - m\omega^2)(k_a - m_a\omega^2) - k_a^2} \begin{bmatrix} k + k_a - m\omega^2 & -k_a \\ -k_a & k_a - m_a\omega^2 \end{bmatrix} \begin{bmatrix} F_0 \\ 0 \end{bmatrix}$$

$$X = \frac{(k_a - m_a\omega^2)F_0}{(k + k_a - m\omega^2)(k_a - m_a\omega^2) - k_a^2}$$

$$X_a = \frac{k_a F_0}{(k + k_a - m\omega^2)(k_a - m_a\omega^2) - k_a^2}$$

Example 2

A radial saw base has a mass of 73.16 kg and is driven harmonically by a motor that turns the saw's blade as illustrated in the Figure. The motor runs at constant speed and produces a 13-N force at 180 cycles/min because of a small unbalance in the motor. The resulting forced vibration was not detected until after the saw had been manufactured. The manufacturer wants a vibration absorber designed to drive the table oscillation to zero simply by retrofitting an absorber onto the base. Design the absorber assuming that the effective stiffness provided by the table legs is 2600 N/m. In addition, the absorber must fit inside the table base and hence has a maximum deflection of 0.2 cm.

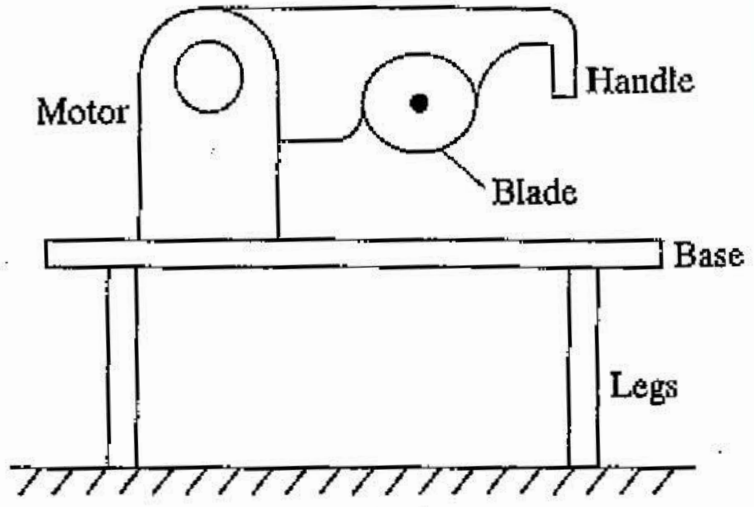
Solution

$$k_a = \frac{F_0}{X_a} = \frac{13\text{ N}}{0.2\text{ cm}} = \frac{13\text{ N}}{0.002\text{m}} = 6500\text{ N/m}$$

Since the absorber is designed such that $\omega = \omega_a$,

$$m_a = \frac{k_a}{\omega^2} = \frac{6500\text{ N/m}}{[(180/60)2\pi]^2} = 18.29\text{ kg}$$

Note in this case that μ = 18.29/73.16 = 0.25.



Assignment 1

A 100-kg machine is supported on an isolator of stiffness 700 x 10^3 N/m. The machine causes a vertical disturbance force of 350 N at a revolution of 3000 rpm. The damping ratio of the isolator is $\xi = 0.2$. Calculate (a) the amplitude of motion caused by the unbalanced force, (b) the transmissibility ratio, and (c) the magnitude of the force transmitted to ground through the isolator.

Assignment 2

An air compressor of mass 200 kg, with an unbalance 0f 0.01 kg-m, is found to have a large amplitude of vibration while running at 1200 rpm. Determine the mass and spring constant of the absorber to be added if the natural frequencies of the system are to be least 20% from the impressed frequency.