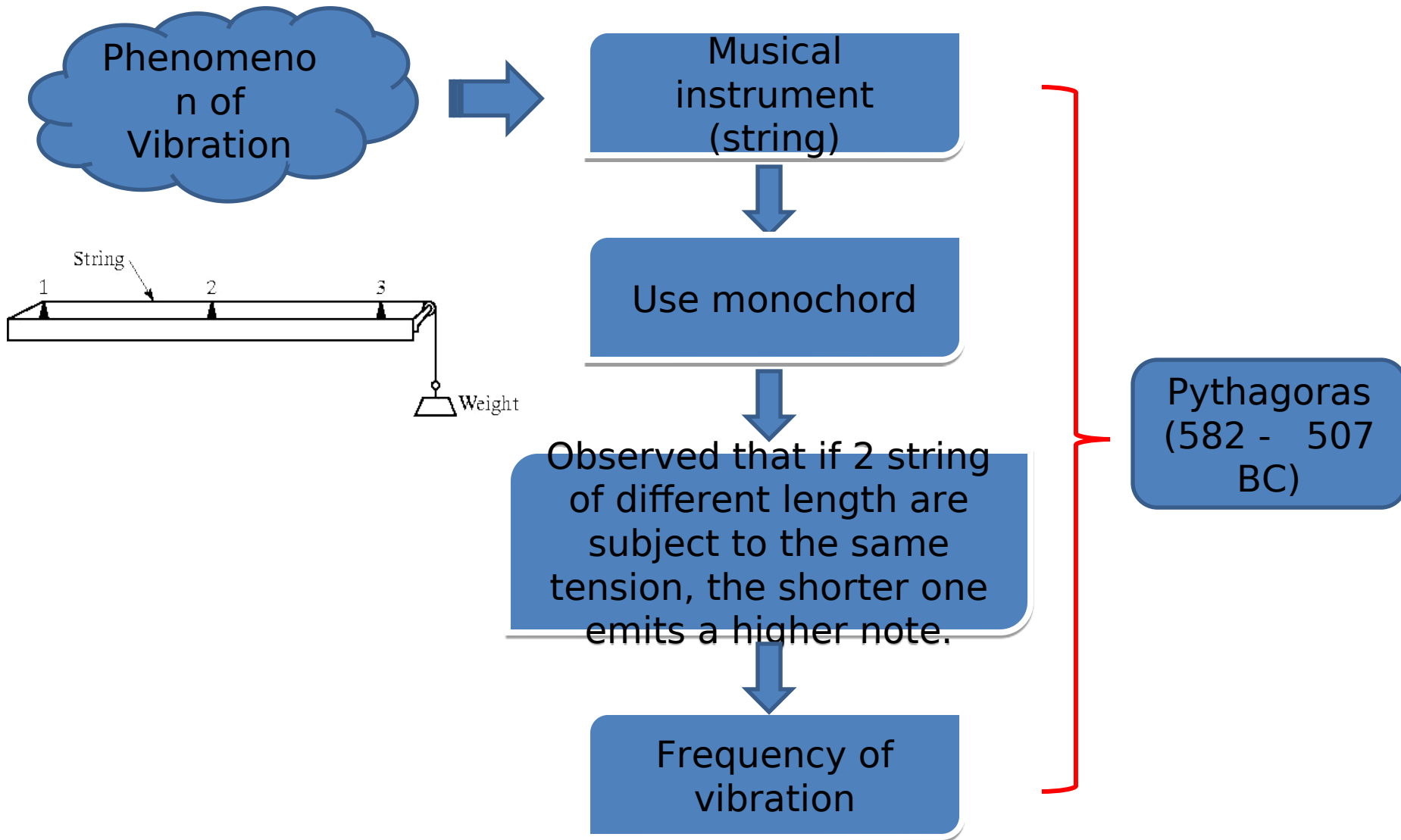


CHAPTER-I FUNDAMENTALS OF VIBRATION

Brief History of Vibration



Brief History of Vibration

(1564 – 1642) → Galileo Galilei

- Founder of modern experimental science.
- Started experimenting on simple pendulum.
- Study the behavior of a simple pendulum (observe pendulum movement of a lamp).
- Describing resonance, frequency, length, tension and density of a vibrating stretched string.

(1642 – 1727) → Sir Isaac Newton

- Derive the equation of motion of a vibrating body.

(1902 – 1908) → Frahm

- Investigate the importance of torsional vibration study in the design of the propeller shafts of steamships.
- Propose the dynamic vibration absorber, which involves the addition of a secondary spring-mass system to eliminate the vibration of main system.

Importance of the Study of Vibration

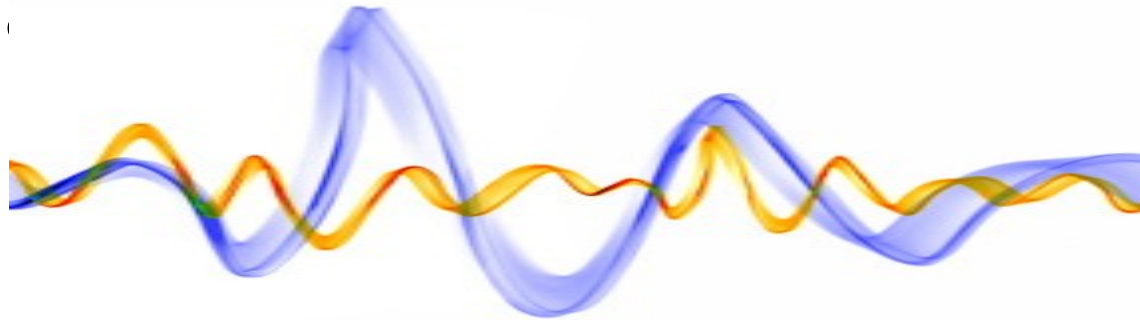
WHY???

- ✓ Vibrations can lead to excessive deflections and failure on the machines and structures.
- ✓ To reduce vibration through proper design of machines and their mountings.
- ✓ To utilize profitably in several consumer and industrial applications.
- ✓ To improve the efficiency of certain machining, casting, forging & welding processes.
- ✓ To stimulate earthquakes for geological research and conduct studies in design of nuclear reactors.

Importance of the Study of Vibration

EXAMPLE OF PROBLEMS

- ✓ Vibrational problems of prime movers due to inherent unbalance in the engine.
- ✓ Wheel of some locomotive rise more than centimeter off the track – high speeds – due to imbalance.
- ✓ Turbines – vibration cause spectacular mech. failure.



Importance of the Study of Vibration

DISADVANTAGES

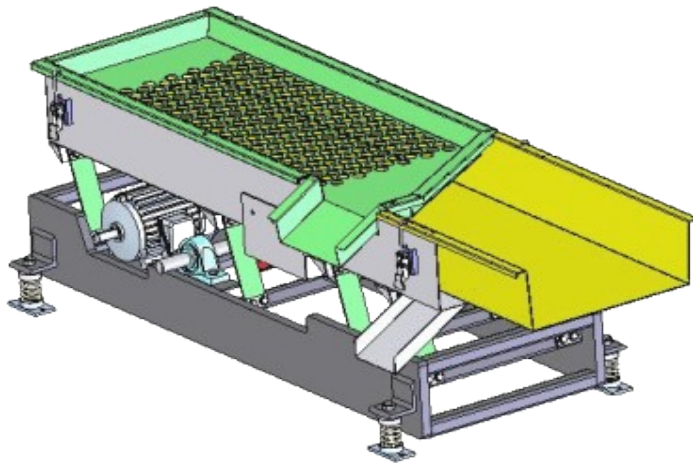
- ✓ Cause rapid wear.
- ✓ Create excessive noise.
- ✓ Leads to poor surface finish (eg: in metal cutting process, vibration cause chatter).
- ✓ Resonance – natural frequency of vibration of a machine/structure coincide with the frequency of the external excitation (eg: Tacoma Narrow Bridge – 1948)

Tacoma Narrow Bridge - 1948



FIGURE 1.7 Tacoma Narrows bridge during wind-induced vibration. The bridge opened on July 1, 1940, and collapsed on November 7, 1940. (Farquharson photo, Historical Photography Collection, University of Washington Libraries.)

Applications

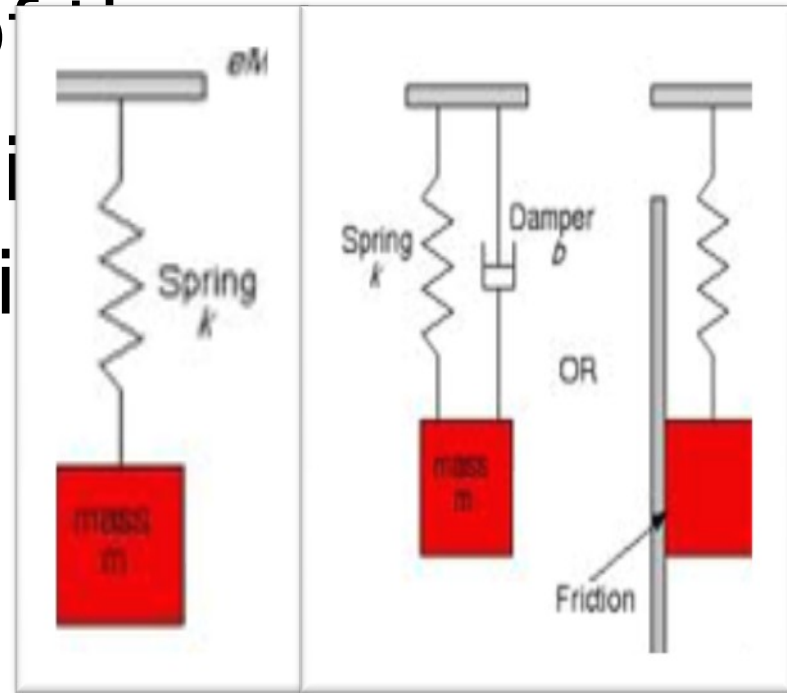


Basic Concepts of Vibration

❑ **Vibration** = any motion that repeats itself after an interval of time

❑ **Vibratory System** consists of

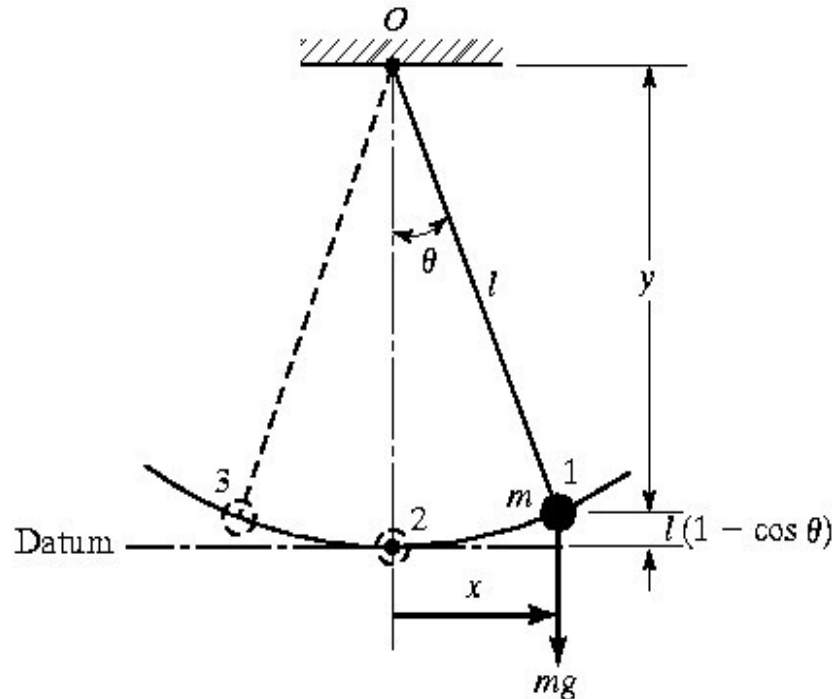
- 1) spring or elasticity
- 2) mass or inertia
- 3) damper



❑ Involves **transfer** of **potential energy** to **kinetic energy** and vice versa.

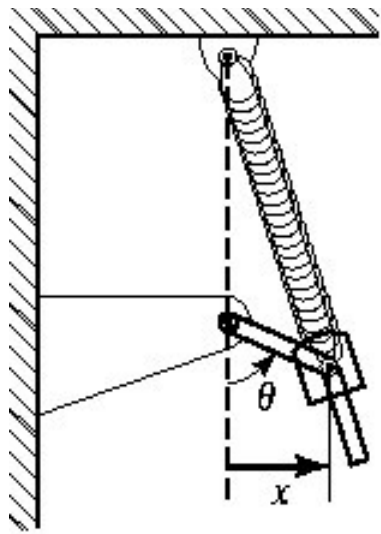
Basic Concepts of Vibration

- **Degree of Freedom (d.o.f.)** = min. no. of independent coordinates required to determine completely the positions of all parts of a system at any instant of time
- Examples of **single** degree-of-freedom systems:

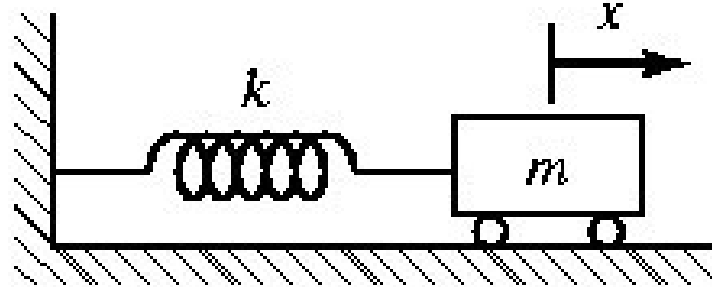


Basic Concepts of Vibration

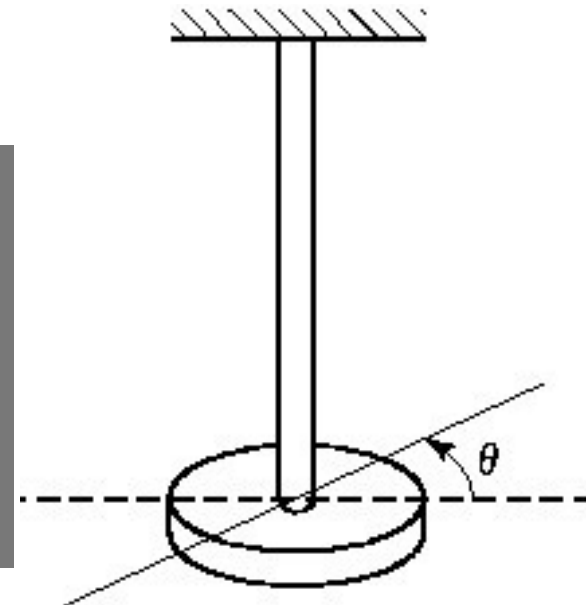
- Examples of **single** degree-of-freedom systems:



(a) Slider-crank-spring mechanism



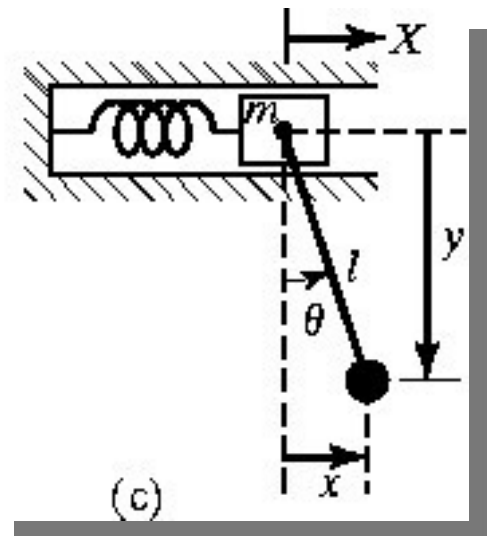
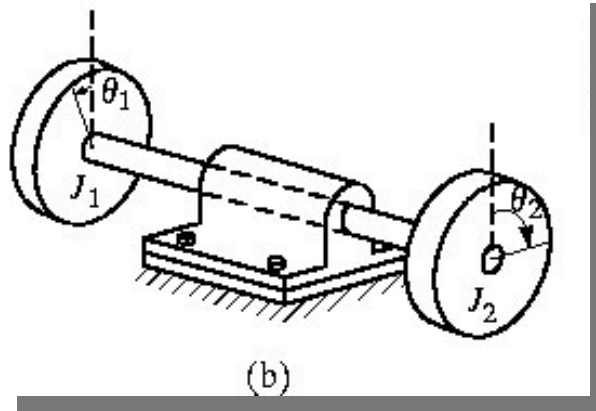
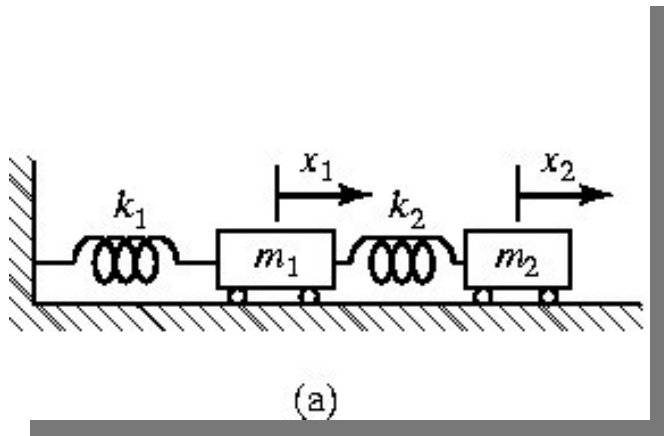
(b) Spring-mass system



(c) Torsional system

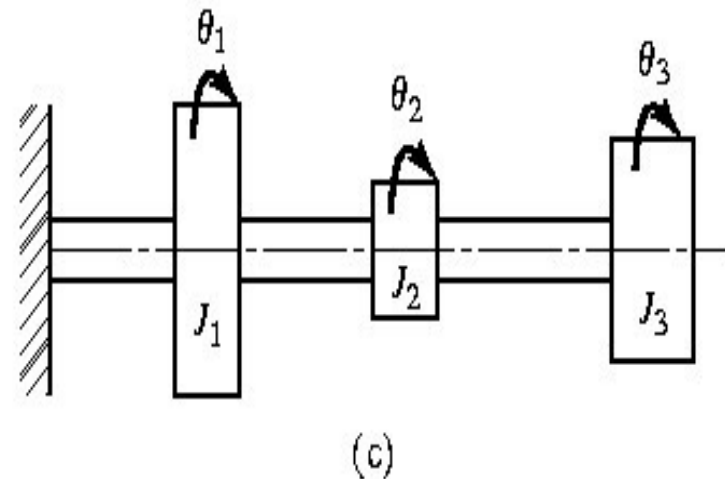
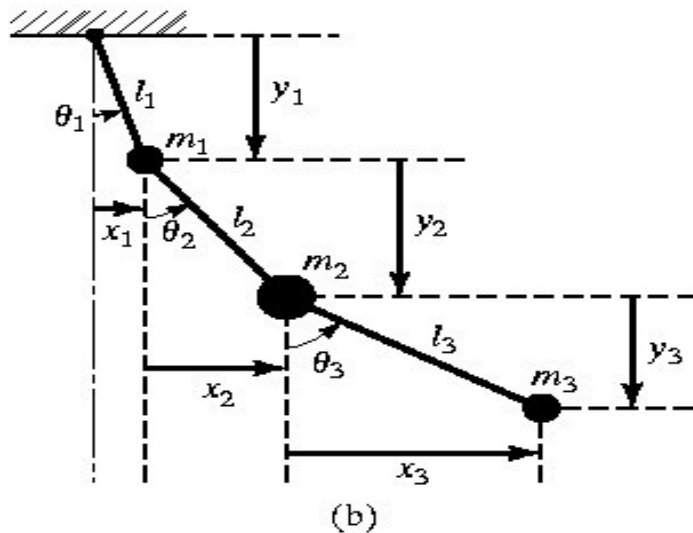
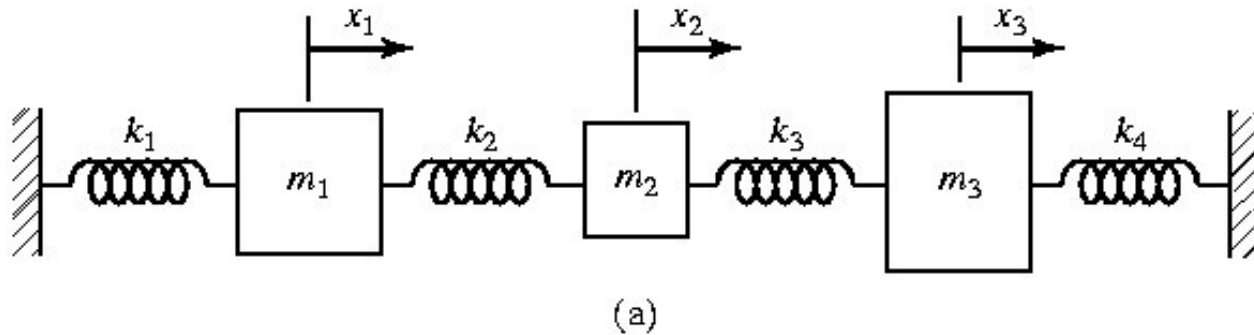
Basic Concepts of Vibration

- Examples of **Two** degree-of-freedom systems:



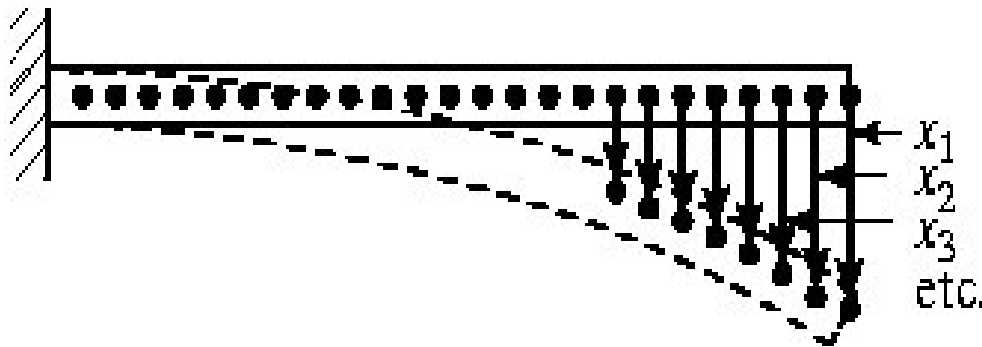
Basic Concepts of Vibration

□ Examples of **Three** degree of freedom systems:



Basic Concepts of Vibration

- Example of **Infinite** number of degrees of freedom system:
- *Infinite* number of degrees of freedom system are termed **continuous** or **distributed** systems.
- *Finite* number of degrees of freedom are termed **discrete** or **lumped** parameter systems.
- More accurate results obtained by **increasing** number of degrees of freedom.



Classification of Vibration

□ Free Vibration:

A system is left to vibrate on its own after an initial disturbance and no external force acts on the system. E.g. simple pendulum

□ Forced Vibration:

A system that is subjected to a repeating external force. E.g. oscillation arises from diesel engines

➤ *Resonance* occurs when the frequency of the external force coincides with one of the natural frequencies of the system

Classification of Vibration

- **Un damped** Vibration:

When **no** energy is lost or dissipated in friction or other resistance during oscillations

- **Damped** Vibration:

When **any** energy is lost or dissipated in friction or other resistance during oscillations

- **Linear** Vibration:

When **all** basic components of a vibratory system, i.e. the spring, the mass and the damper behave linearly

Classification of Vibration

- **Nonlinear** Vibration:

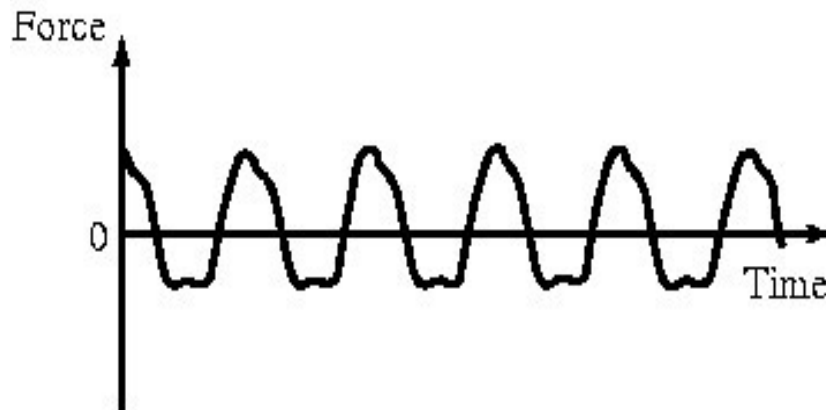
If **any** of the components behave nonlinearly

- **Deterministic** Vibration:

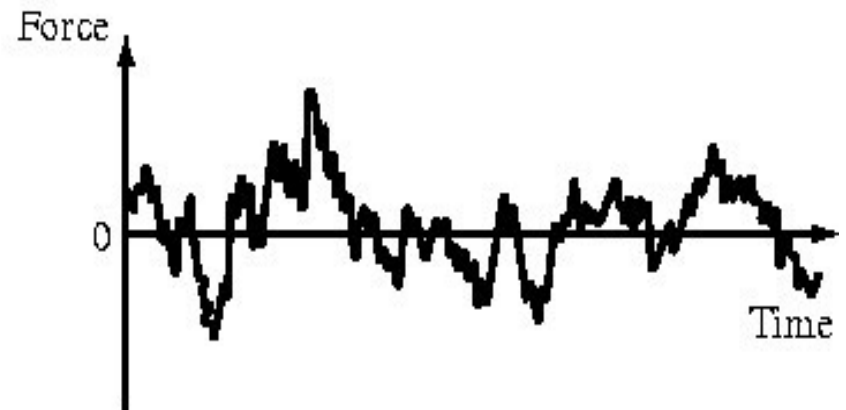
If the value or magnitude of the excitation (force or motion) acting on a vibratory system is known at any given time

- **Nondeterministic or random** Vibration:

When the value of the excitation at a given time cannot be predicted



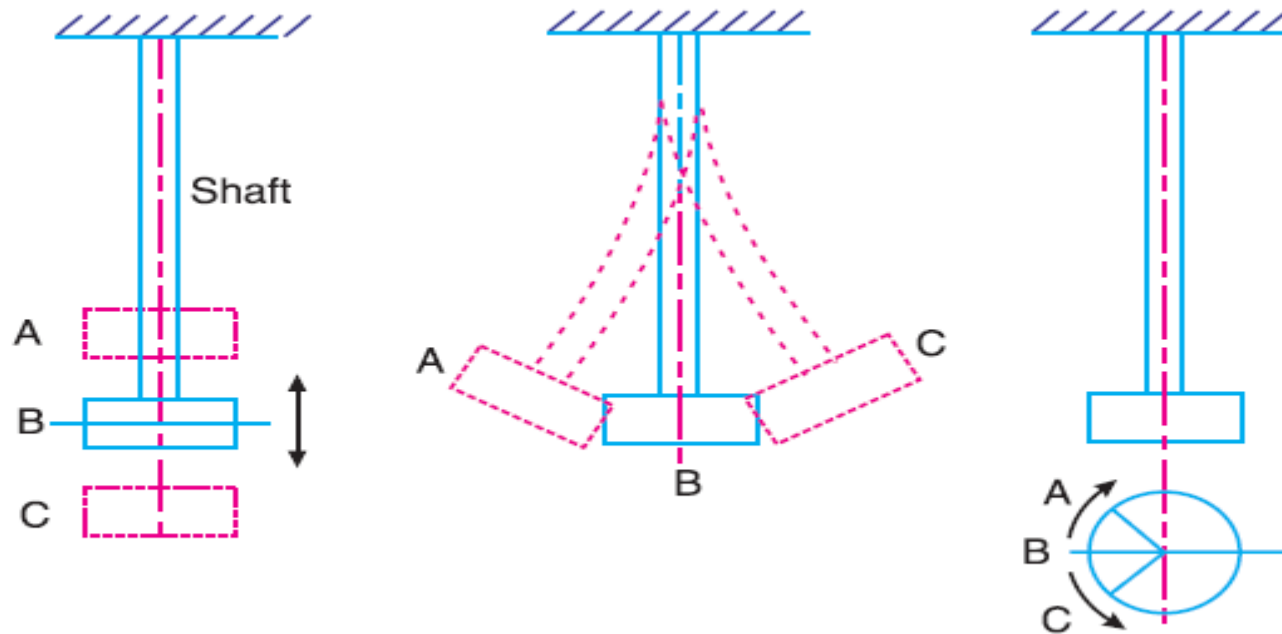
(a) A deterministic (periodic) excitation



(b) A random excitation

Classification of free Vibration

- Longitudinal vibrations, Transverse vibrations, and Torsional vibration



B = Mean position ; A and C = Extreme positions.

Longitudinal	Transverse	Torsional
Along the axis of shaft	Perpendicular to the axis	About the axis

KINEMATICS OF VIBRATION

harmonic Motion

□ **Periodic** Motion: motion repeated after equal intervals of time

□ **Harmonic** Motion: simplest type of periodic motion $x = A \sin \theta = A \sin \omega t$ (1.30)
(On horizontal axis)

□ **Displacement (x):** $\frac{dx}{dt} = \omega A \cos \omega t$ (1.31)

□ **Velocity:** $\frac{d^2x}{dt^2} = -\omega^2 A \sin \omega t = -\omega^2 x$ (1.32)

□ **Acceleration:**

Harmonic Motion

□ Definitions of Terminology:

- **Amplitude (A)** is the maximum displacement of a vibrating body from its equilibrium position
- **Period of oscillation (T)** is time taken to complete one cycle of motion $T = \frac{2\pi}{\omega}$ (1.59)
- **Frequency of oscillation (f)** is the no. of cycles per unit time $f = \frac{1}{T} = \frac{\omega}{2\pi}$ (1.60)

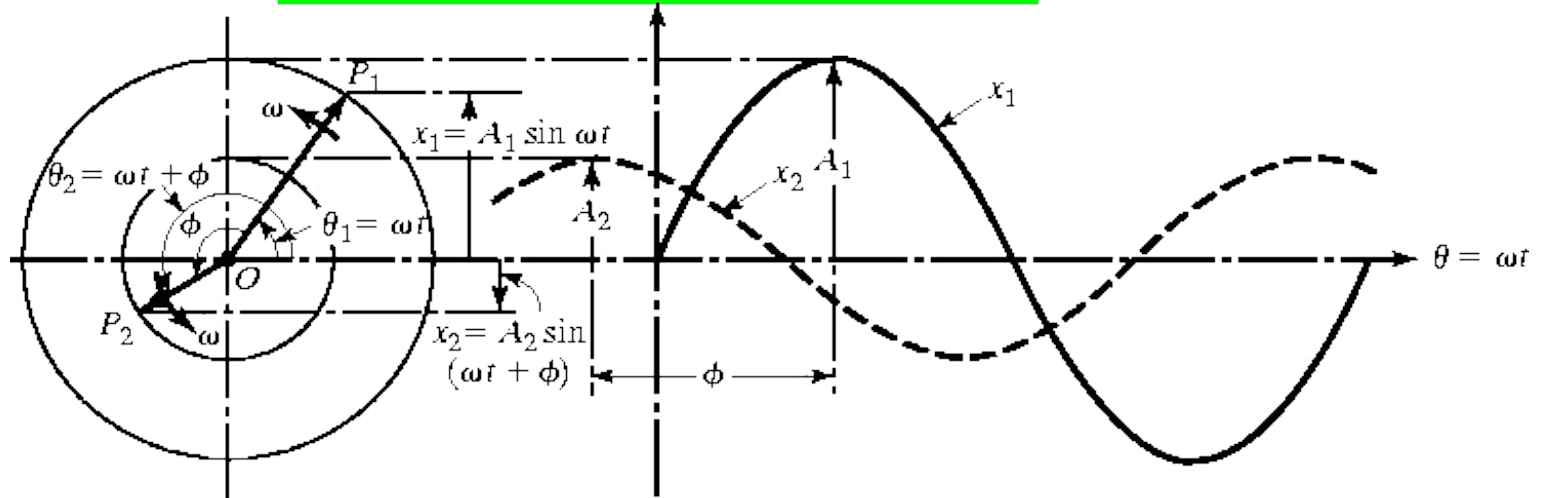
Harmonic Motion

□ Definitions of Terminology:

- **Natural frequency** is the frequency which a system oscillates without external forces
- **Phase angle (ϕ)** is the angular difference between two synchronous harmonic motions

$$x_1 = A_1 \sin \omega t \quad (1.61)$$

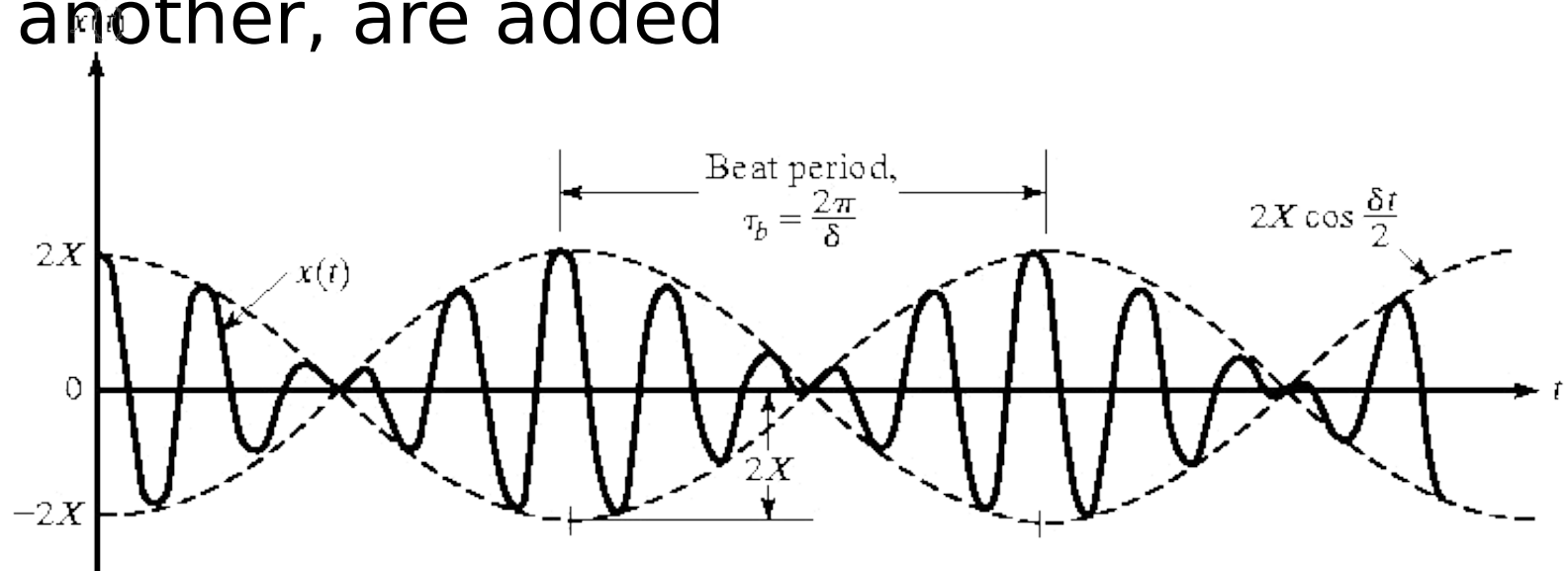
$$x_2 = A_2 \sin(\omega t + \phi) \quad (1.62)$$



Harmonic Motion

Definitions of Terminology:

- **Beats** are formed when two harmonic motions, with frequencies close to one another, are added



Harmonic Motion

□ Definitions of Terminology:

- **Decibel** is originally defined as a ratio of electric powers. It is now often used as a notation of various quantities such as displacement, velocity, acceleration, pressure, and power

$$\text{dB} = 10 \log \left(\frac{P}{P_0} \right) \quad (1.68)$$

$$\text{dB} = 20 \log \left(\frac{X}{X_0} \right) \quad (1.69)$$

where P_0 is some reference value of power and X_0 is specified reference voltage.