Chapter One

Introduction to Mechanical Vibration

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Outlines

- Introduction
- Brief History of vibration
- Why to study vibration?
- Basic concepts of vibration
- Classification of vibration
- Kinematics of vibration

Introduction

What is vibration?

- is the periodic back and forth or to and fro motion of the body. *(Encyclopedia Britannica)*
- is any motion that repeats itself after an interval of time. *(Scientific definition)*
- is the relationship between forces and oscillatory motion of mechanical systems. *(Engineering Definition)*

Introduction

- Vibration in the human body
  - oscillations of the lungs and the heart
  - oscillations of the ear
  - oscillations of the larynx as one speaks, and
  - oscillations induced by rhythmical body motions such as walking, jumping, and dancing.

So, we limit our discussion to **Mechanical Vibration.**

What is mechanical vibration?

Brief History of Vibration

Phenomenon of Vibration →

Musical instrument (string)

↓

Use monochord

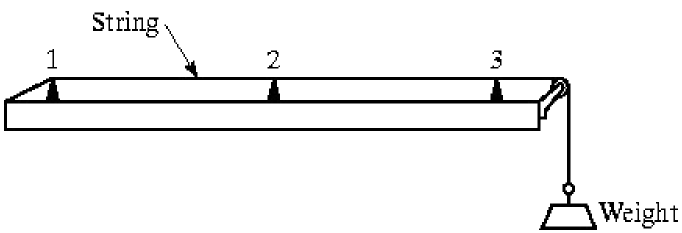
↓

Observed that if 2 string of different length are subject to the same tension, the shorter one emits a higher note.

↓

Frequency of vibration

Pythagoras (582 - 507 BC)



The Greek philosopher and mathematician Pythagoras (582 507 B.C.) is considered to be the first person to investigate musical sounds on a scientific basis.

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.
- The vibrating string was also studied by Galileo Galilei (1564–1642), who was the first to show that pitch is related to the frequency of vibration.

(1642 – 1727) → Sir Isaac Newton

- Derive the equation of motion of a vibrating body.

(1902 – 1909) → 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.

Why to Study Vibration

- Vibrations are mechanical oscillations about an equilibrium position.
- There are cases when vibrations are desirable such as in
  - atomic clocks,
  - ultrasonic instrumentation used in eye and other types of surgeries, sirens and alarms for warnings,
  - vibration testing equipments,
  - vibratory conveyors,
  - hoppers, etc.
- Vibration is found very fruitful in mechanical workshops such as in improving the efficiency of machining, casting, forging and welding techniques, musical instruments and earthquakes for geological research.
- It is also useful for the propagation of sound.

Why to Study Vibration

- But, most of the times vibrations are unintended and undesirable in machines and structures. The effects of vibrations are
  - unwanted noise
  - early failure due to cyclical stress (fatigue failure)
  - increased wear
  - poor quality product
  - difficult to sell a product
  - in machine tools can lead to improper machining of parts.
- Generally, vibrations can lead to excessive deflections and failure on the machines and structures.

What are the causes of vibration?

1. Bad design
2. Unbalanced inertia / centrifugal forces
3. Poor quality of manufacture
4. Improper bearings (Due to wear & tear or bad quality)
5. Worn out gear teeth
6. External excitation applied on the system
7. Elastic nature of the system
8. Winds may also cause vibrations of certain systems

Why to Study Vibration

- Bridge collapse: http://www.youtube.com/watch?v=j-zczJXSxnw
- Hellicopter resonance: http://www.youtube.com/watch?v=0FeXjhUEXlc
- Resonance vibration test: http://www.youtube.com/watch?v=LV_UuzEznHs
- Flutter (Aeordynamically induced vibration): http://www.youtube.com/watch?v=OhwLojNerMU

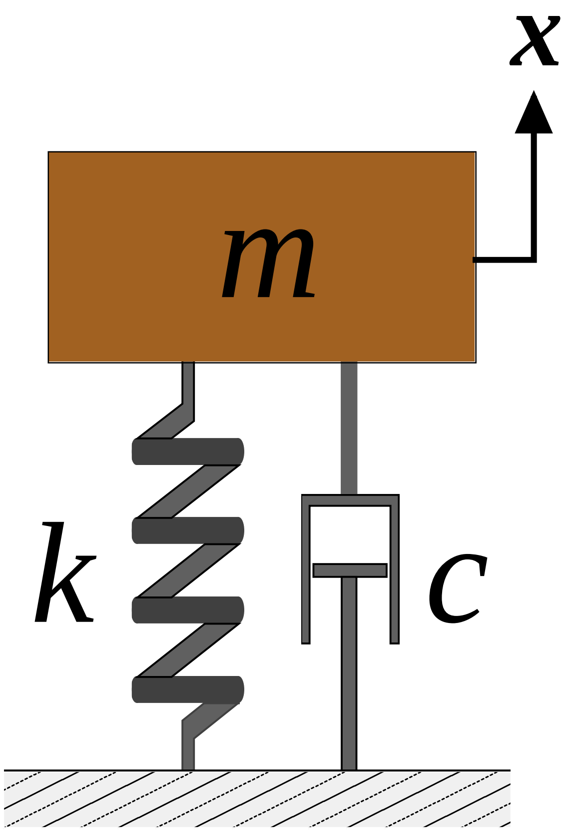
Why to Study Vibration

- Thus undesirable vibrations should be eliminated or reduced up to certain extent by the following methods:
  - Removing external excitation, if possible
  - Using shock absorbers.
  - Dynamic absorbers.
  - Resting the system on proper vibration isolators.

What are your tasks to reduce or eliminate unwanted vibration?
Can you eliminate vibration totally?

BASIC CONCEPTS OF VIBRATION

- All bodies having mass and elasticity are capable of producing vibration.
- The mass is inherent of the body and elasticity causes relative motion among its parts.
- Vibratory system consists of:
    1) Spring or elasticity
        (capable of storing potential energy $= \frac{1}{2}kx^2$*)*
    2) Mass or inertia
        (capable of acquiring kinetic energy $= \frac{1}{2}mv^2$)
    3) Damper
        (involved in the energy dissipation)



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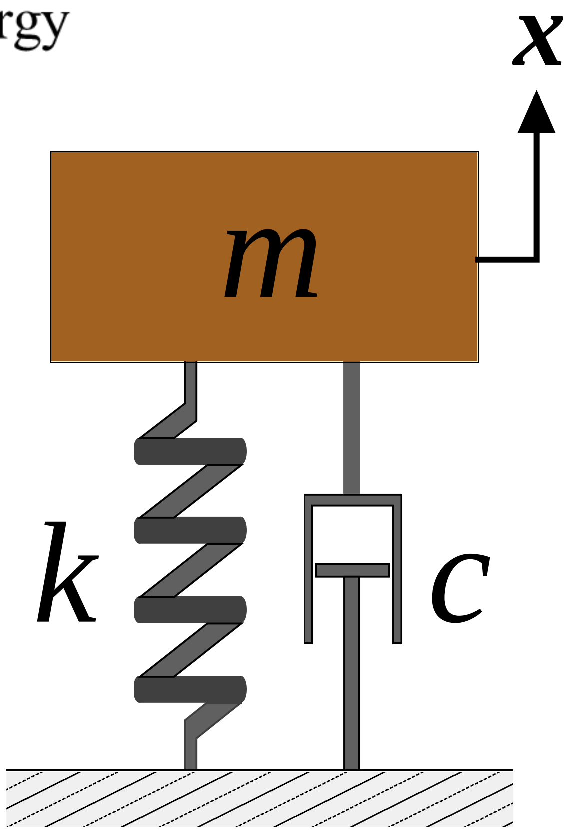
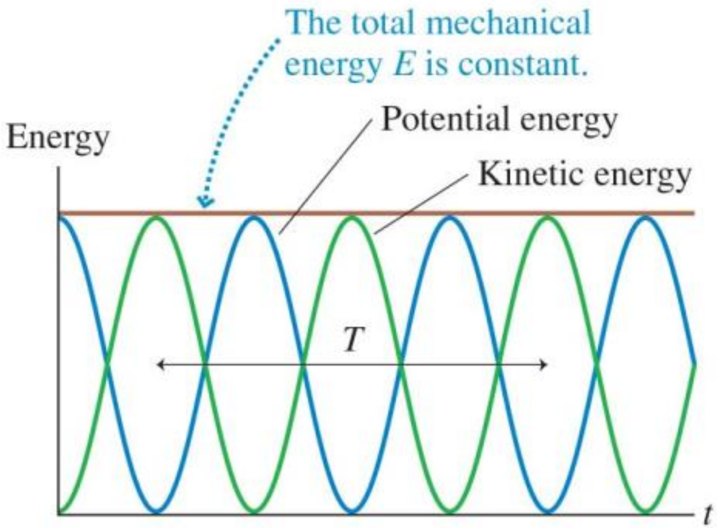


- The vibration of a system involves the alternating transfer of energy between its potential and kinetic forms.

Mechanical Energy = Potential + Kinetic

$$E_{\text{total}} = \frac{1}{2}m\text{v}^2 + \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2 A^2 = \text{constant}$$

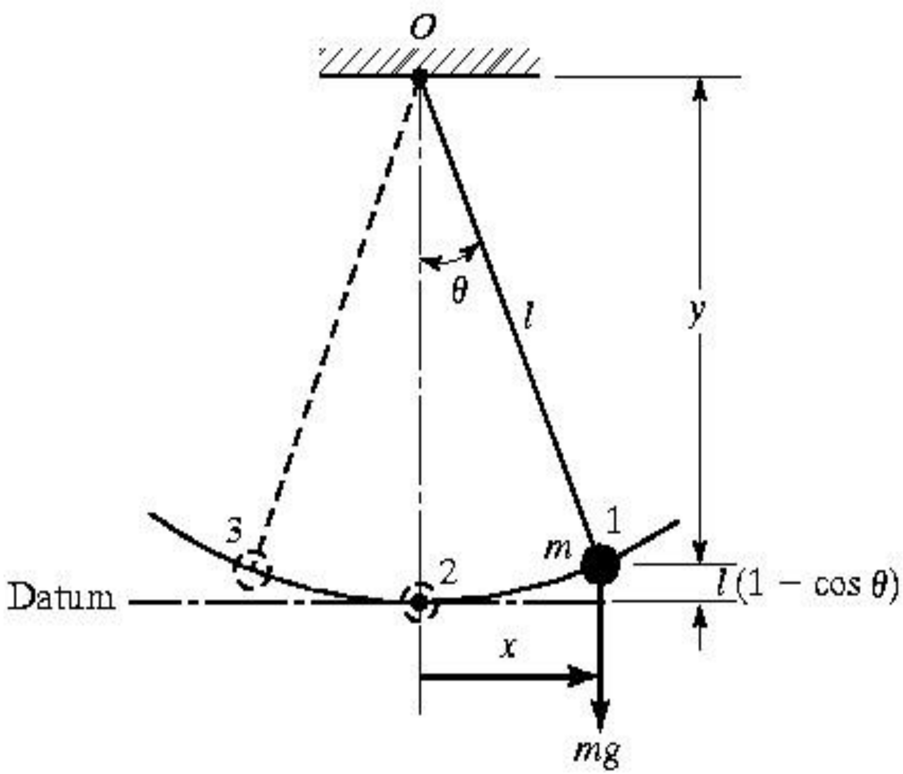


- When all energy goes into PE, the motion stops.
- When all energy goes into KE, max velocity happens.

- From the energy point of view, vibration is the exchange of potential and kinetic energy (unrealistic).
- In a damped system, some energy is dissipated at each cycle of vibration and must be replaced from an external source if a steady vibration is to be maintained (realistic).

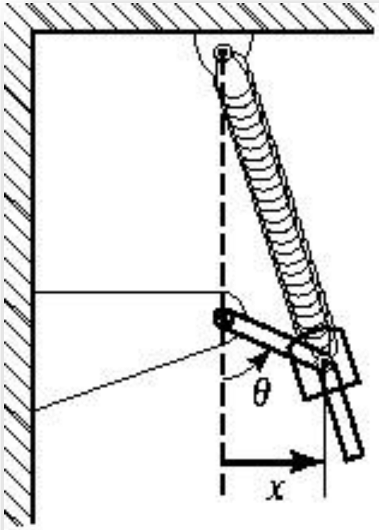
Basic Concepts of Vibration

- Degree of Freedom *(d.o.f.)* is the minimum number of independent coordinates required to determine completely the positions of all parts of a system at any instant of time.
- Single-degree-of-freedom (SDOF) system is a system whose motion is defined just by a single independent co-ordinate (or function) e.g. x which is a function of time.

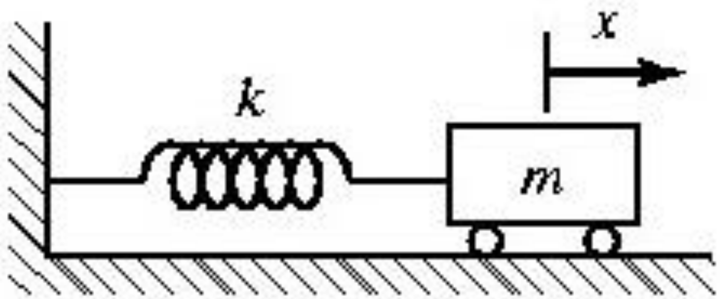


Basic Concepts of Vibration

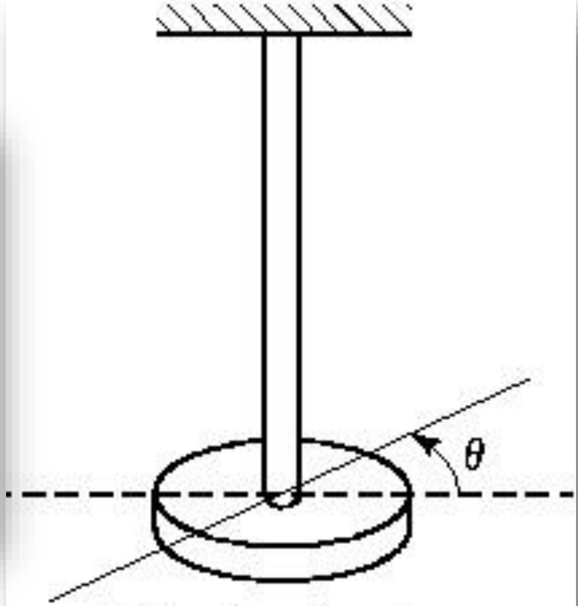
- Examples of single degree-of-freedom systems:



(a) Slider-crank-spring mechanism



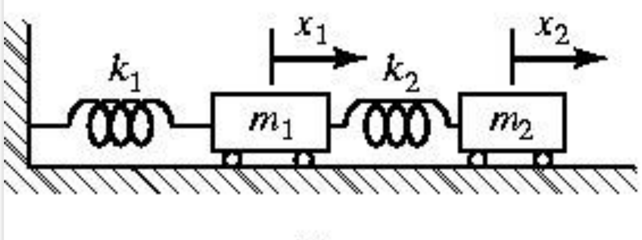
(b) Spring-mass system



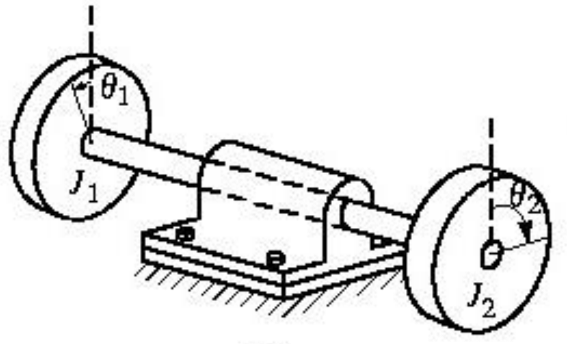
(c) Torsional system

Basic Concepts of Vibration

- Examples of Two degree-of-freedom systems:



(a)



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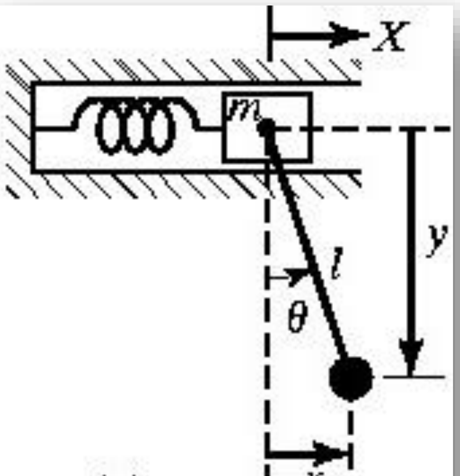
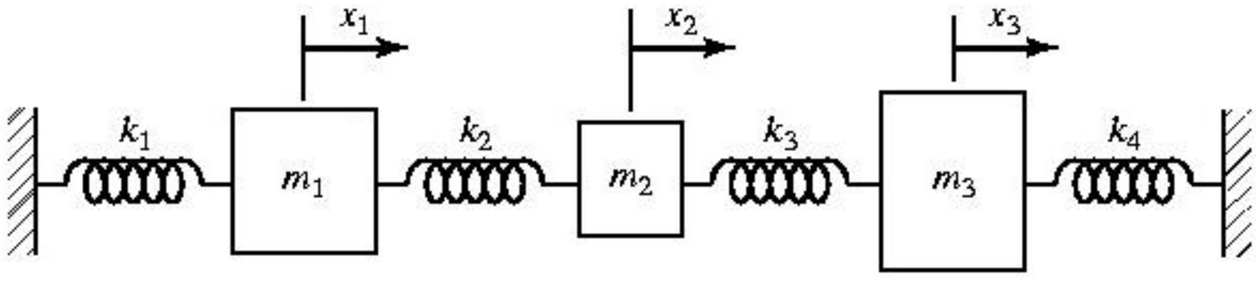


(c)

Basic Concepts of Vibration

- Examples of Three degree of freedom systems:



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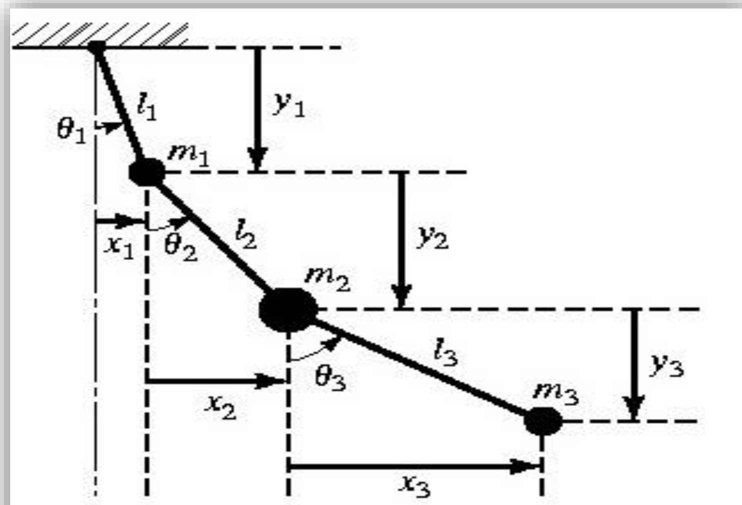

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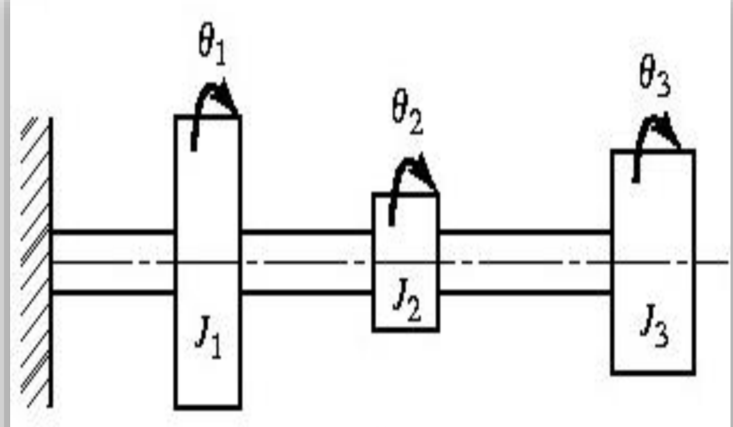
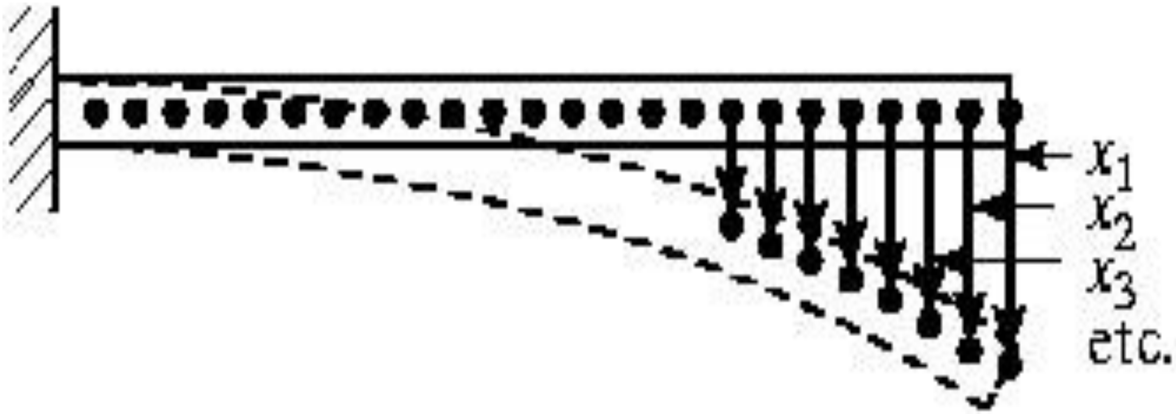


(c)

Basic Concepts of Vibration

- Example of Infinite number of degrees of freedom system



- Most of the mechanical systems include elastic members which have infinite number of degree of freedom.
- Those with an infinite number of degrees of freedom are called continuous or distributed systems.
  - Cantilever beam, simply supported beam, etc. are the examples of continuous systems.

NB: Systems with a finite number of degrees of freedom are called discrete or lumped parameter systems.

Classification of Vibration

Some of the important types of vibration are as follows

1) Free and Forced Vibration

- A free vibration is any system that vibrates under the action of forces that are part of, or are inherent to the system itself.
  - Simple pendulum is one of the examples.
- The vibration which is under the influence of external force is called forced vibration.
  - Machine tools, electric bells, etc. are the suitable examples.

2) Linear and Non-linear Vibration

- In a system., if mass, spring and damper behave in a linear manner, the vibrations caused are known as **linear in nature**.
  - – Linear vibrations are governed by linear differential equations.
  - – They follow the law of superposition.
- On the other hand, if any of the basic components of a vibratory system behaves non-linearly, the vibration is called non-linear.
  - – Linear vibration becomes, non-linear for very large amplitude of vibration.– It does not follow the law of superposition.

3) Damped and Un-damped Vibration

- **Undamped vibration:** (Ideal system)

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

- **Damped Vibration:** (Real system)

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

4) Linear and Nonlinear Vibration

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

- **Nonlinear Vibration:**
  If ***any*** of the components behave nonlinearly.

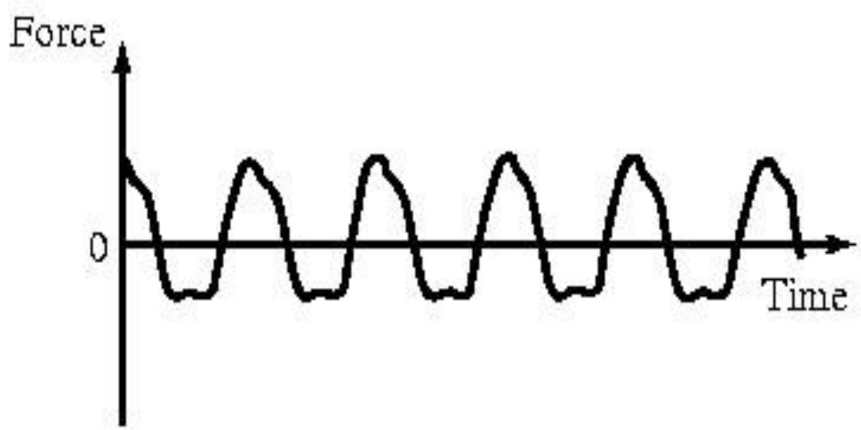
5) Deterministic and Nondeterministic Vibration:

- **Deterministic or Periodic Vibration:**

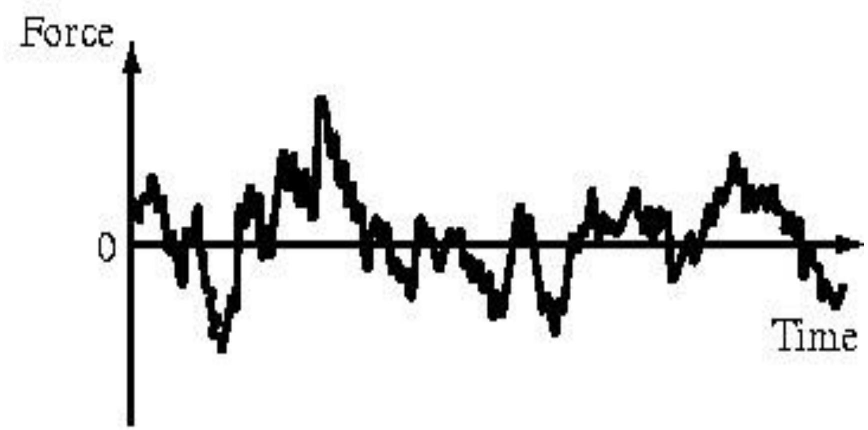
If the value or magnitude of the excitation (force or motion) acting on a vibratory system is known at any given time, the type of vibrations is known as deterministic or periodic vibrations.

- **Nondeterministic or random Vibration**:

When the value of the excitation at a given time cannot be predicted, the type of vibrations is known as non deterministic or random vibrations.

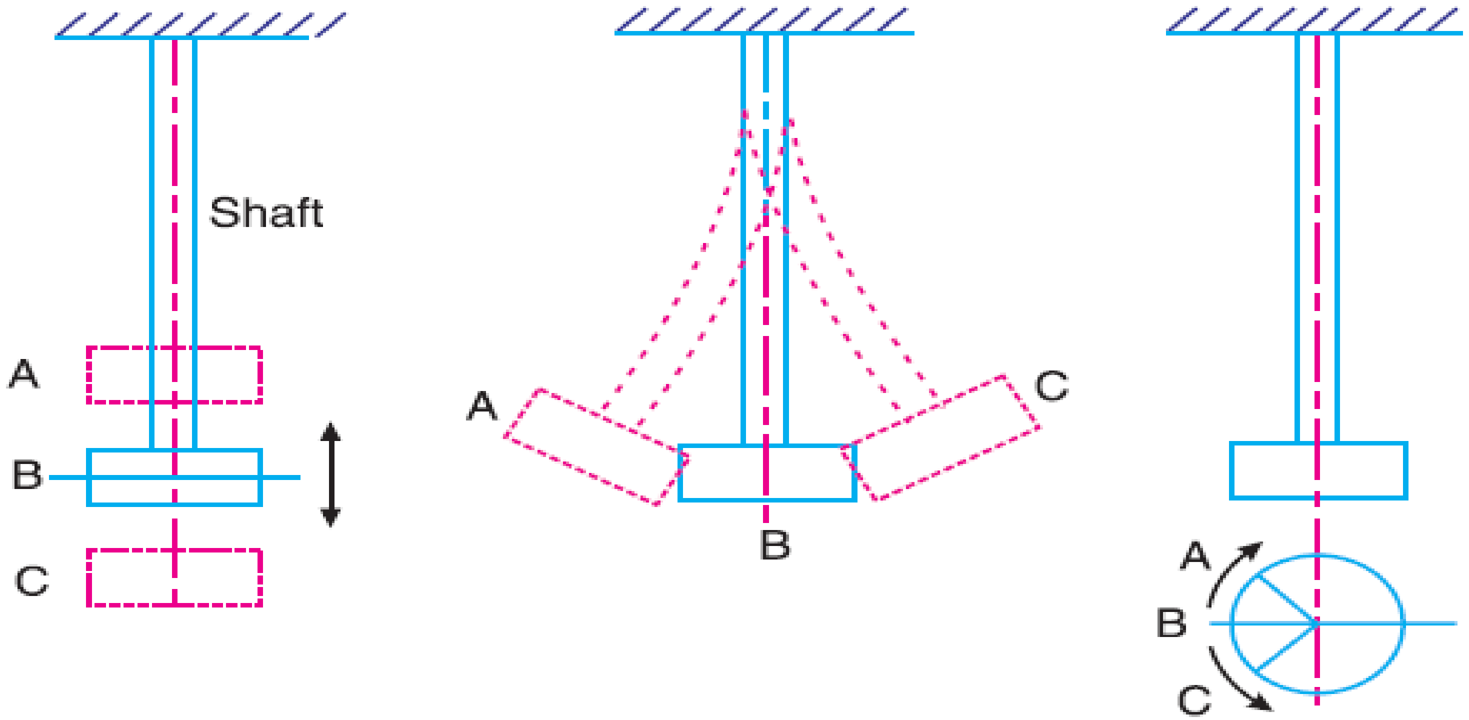


(a) A deterministic (periodic) excitation



(b) A random excitation

6) Longitudinal vibrations, Transverse vibrations and Torsional vibration



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

a) Longitudinal vibration

b) Transverse vibration

c) Torsional vibration

KINEMATICS OF VIBRATION

- All mechanical system undergo oscillatory motion.

  Question:

  What is the difference between periodic and harmonic motion?

Periodic Motion

- Periodic motion is a motion that repeats itself after equal intervals of time.
- A special type of periodic motion is simple harmonic motion and we now proceed to investigate it.

Simple Harmonic Motion:

- The motion of a body to and fro about a fixed point is called simple harmonic motion.
- The motion pattern can be described either a sine or cosine function.
- The motion of a simple pendulum is simple harmonic in nature.

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. The time to complete one full cycle or one oscillation is called the **period** (T).

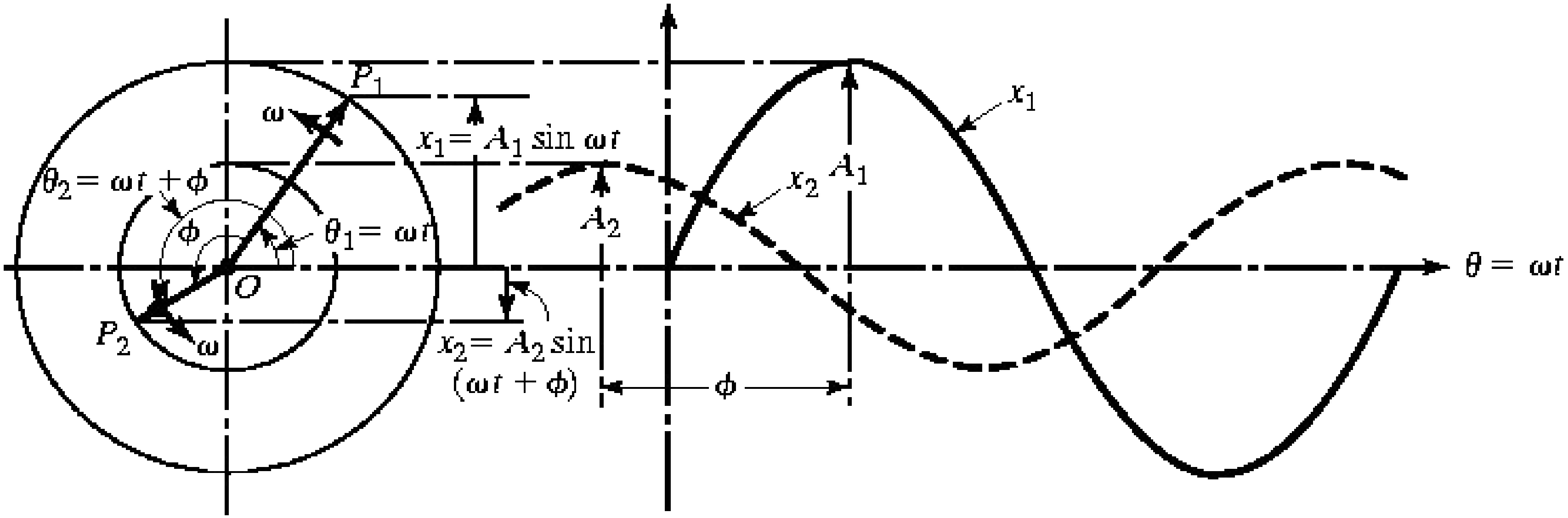
$$T = \frac{2\prod}{\omega}$$

- Frequency of oscillation (f) is the no. of cycles per unit time.

$$f = \frac{1}{T} = \frac{\omega}{2\pi}$$

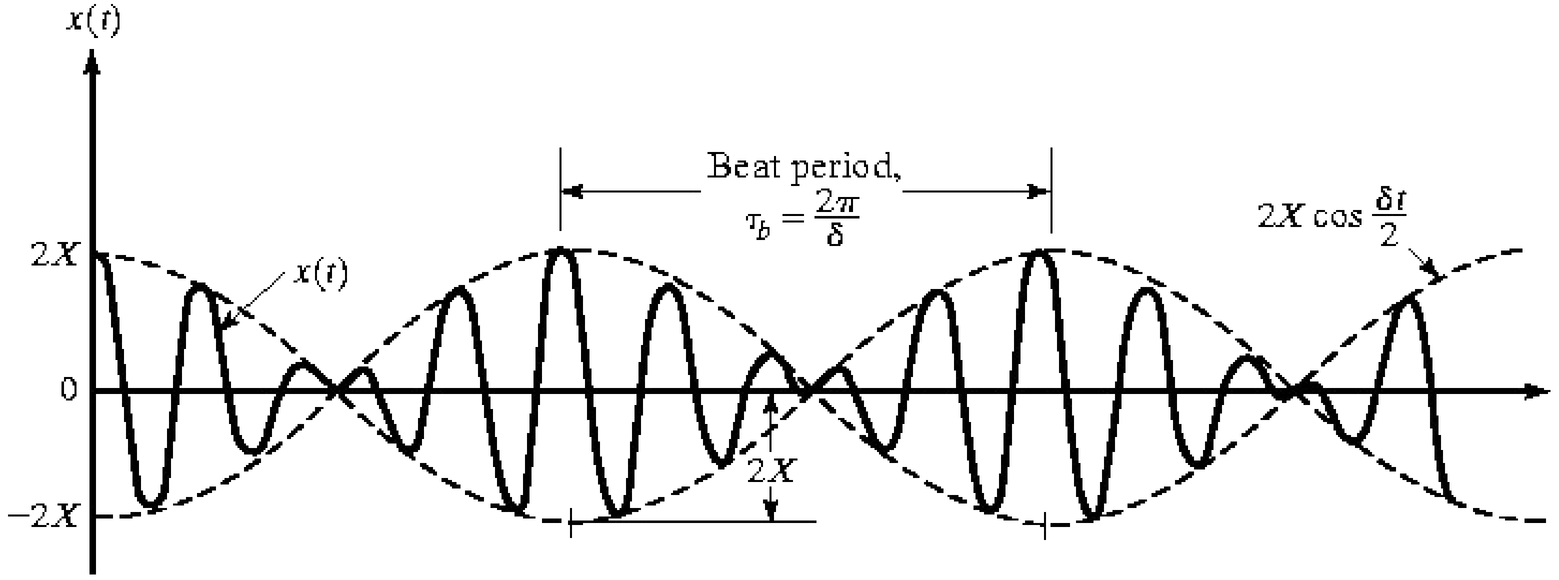
- Natural frequency is the frequency which a system oscillates without external forces.
- Phase angle (ϕ) is the angular difference between two synchronous harmonic motions.

$$x_1 = A_1 \sin \omega t$$
$$x_2 = A_2 \sin(\omega t + \phi)$$



Definitions of Terminology:

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



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.

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

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

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

Simple Harmonic Motion

Kinematic description. We initiate from the position-time relationship and derive other physical quantities.

The position (x coordinate) vs. time:

$$x = A \cdot \sin(\omega t + \phi)$$

The velocity:

$$\mathrm{v} = \frac{dx}{dt} = A\omega \cdot \cos(\omega t + \phi)$$

has maximum while crossing the origin at times t = 0, T/2, T, ... and disappears (v = 0) at the turning points (amplitudes) of the oscillation at times t = T/4, 3T/4, ...

The acceleration:

$$a = \frac{d\mathrm{v}}{dt} = -A\omega^2 \cdot \sin(\omega t + \alpha) = -\omega^2 \cdot x$$

which is proportional to the deviation from the origin and shows in opposite direction therefore it is directed always to the equilibrium position (origin).