VIBRATION IN MECHANICAL SYSTEMS

DEFINITION OF VIBRATION

- Any motion which repeats itself after an interval of time is called vibration or oscillation.
- All bodies possessing mass and elasticity are capable of vibration.
- The theory of vibration deals with the study of oscillatory motions of the bodies /components of body and the forces associated with them.
- The vibrations experienced by the components /structures usually result in stretching/unstretching or twisting/untwisting or both and as a result alternating stresses and thereby stress induced fatigue and eventually failure.

  Eg: **classical spring mass system, simple pendulum, cantilever beam, guitar spring etc**

Speech is caused by vibrations of the vocal chord, tongue and lips. Vision requires the vibration of eyelids, walking requires oscillation of legs, breathing requires vibration of lungs and life requires vibration of the heart.

Is the presence of vibrations desirable or undesirable?

It has many desirable effects in the following applications:

1. Musical instruments like flute, harmonium, tabor (tabla), violin, *veena*, etc.
2. Agitators used in concrete setting.
3. Horns and sirens, etc.

It has many undesirable effects in the following applications: machine tools, automobiles, bridges, dams, buildings as it produces noise or sound, excessive stress, unbalanced forces in rotating and reciprocating parts, etc.

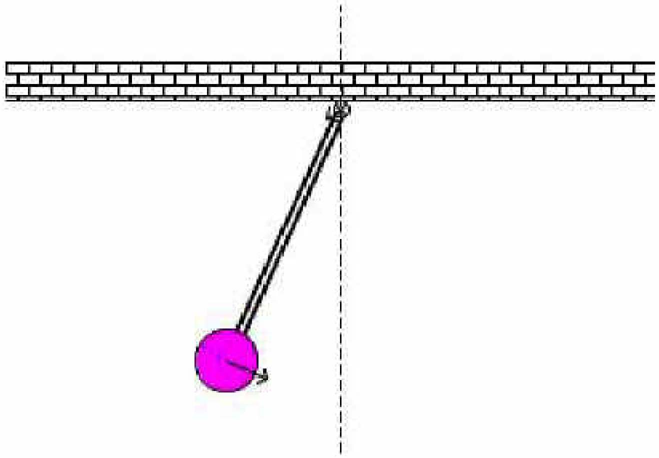
REASON FOR STUDYING THE SUBJECT OF THEORY AND PRACTICE OF VIBRATION ANALSIS

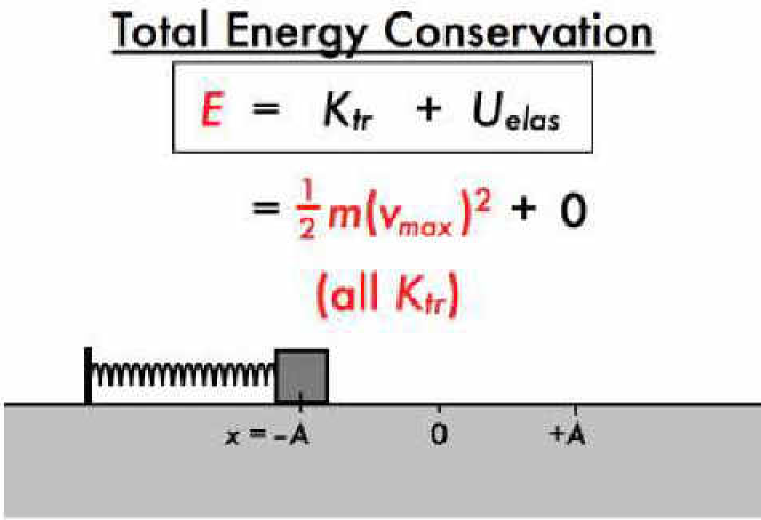
- Vibrations generated by the machinery/structures cause physical discomfort.
- Long term exposure of vibration will result in mechanical failure of machinery/structure.
- **Basically engineers would like to know why a structure/machine vibrates and also the methods to eliminate these vibrations or atleast reduce their intensity so that vibration related failures do not occur during the designated life time of the structure/machine**

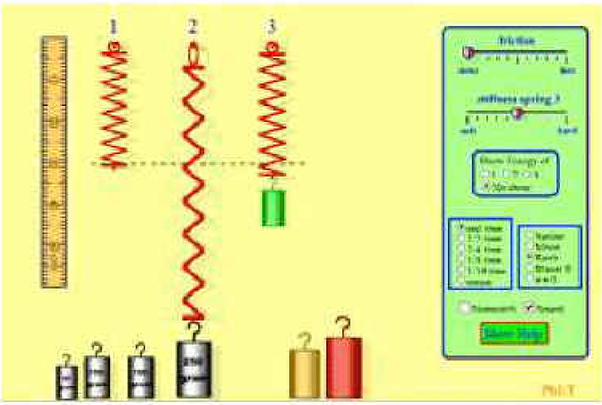
AIM OF VIBRATION ANALYSIS

The main consideration of vibration analysis is to **find the natural frequency of vibration of system**, which is one of the characteristic frequencies of vibration of a body when it is under free vibration.

- ✓ If the excitation frequency is very near the natural frequency, the amplitude of vibration is excessively large which readily leads to failure due to resonance. We need to ensure that the system is excited by frequencies far away from the natural frequency of system.




Total Energy Conservation
$E = K_{tr} + U_{elas}$
$= \frac{1}{2}m(v_{max})^2 + 0$
(all K_{tr})
x = -A
0
+A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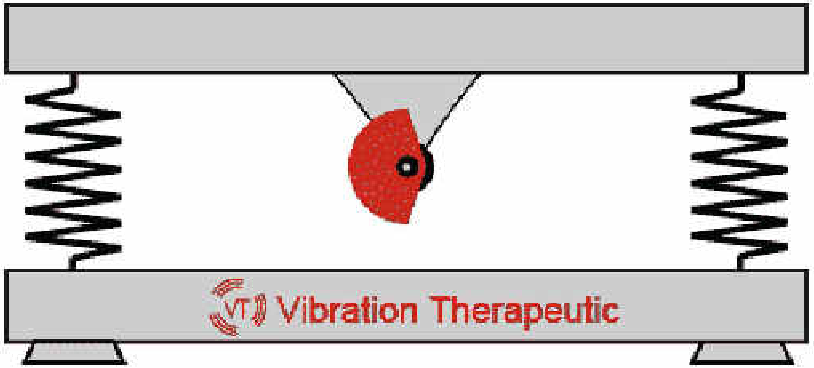

VT
Vibration Therapeutic

IMPORTANT DEFINITIONS IN VIBRATION ANALYSIS

1. **Inertia**: The property of a body (either in rest or in motion) by which it continues to be in present state unless acted upon by an external force.
2. **Displacement**: The change in position of an object in a particular direction by application of an external force.
3. **Disturbance**: Any action which destroys the static equilibrium of a vibrating system is called as disturbance to the system.
4. **Restoring force**: The displaced body doesn’t stay in the new position, because of the restoring force which is provided either by gravity or by elasticity or both.
5. **Damping**: It is the resistance offered to the motion of the vibrating body.
6. **Periodic motion**: The motion which repeat itself after equal interval of time.
7. **Amplitude**: The maximum displacement from the mean position of the vibrating body.

IMPORTANT DEFINITIONS IN VIBRATION ANALYSIS

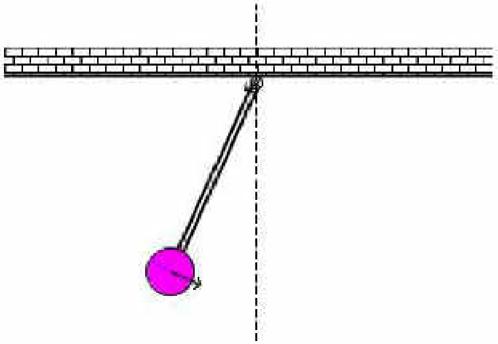
8. **Cycle**: It is the motion completed during one time period.
9. **Time period** (τ): It is the time taken by a motion to repeat itself and is measured in seconds. $\tau = \frac{2\pi}{\omega}$
10. **Frequency** (f): It is the number of cycles of motion completed in one second. It is expressed in hertz and is equal to 1cycle/sec. $f = \frac{1}{\tau} = \frac{\omega}{2\pi}$ or $\omega = 2\pi f$
11. **Natural frequency** (ω_n): It is the frequency of free vibration without damping.
12. **Damped natural frequency** (ω_d): It is the frequency of the system having free vibration with friction.

- VIBRATIONS
  - FREE VIBRATION / NATURAL VIBRATION
  - DAMPED VIBRATION
  - FORCED VIBRATION

Free (natural) vibrations

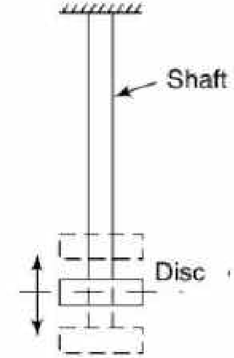
After giving initial disturbance, if a system is left to vibrate on its own without external forces and damping is called free or natural vibration .The frequency of free vibration is known as natural frequency of vibration, which is an important parameter in vibration analysis.

eg: oscillation of a simple pendulum



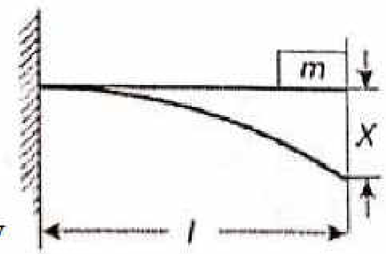
Classification of **Free Vibration** based on movement of particles of body

- Rectilinear/Longitudinal vibration
- Lateral/Transverse vibration
- Torsional Vibration



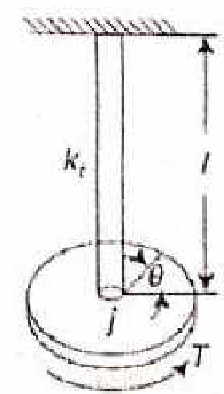
(a)

Longitudinal vibration: When the particles of a body/shaft moves parallel to the axis of body/shaft, then the vibrations are known as longitudinal vibration.ie If the shaft is elongated and shortened results in tensile and compressive stresses on the shaft, the vibrations are said to be longitudinal.



(b) Transverse vibration

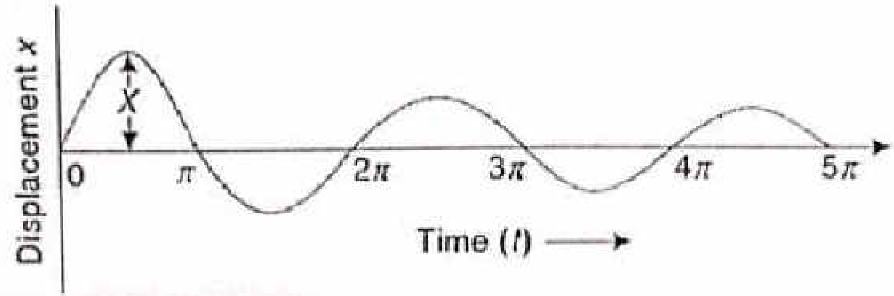
Transverse vibrations: When the particles of a body or system move approximately perpendicular to the axis of the body or system, then the vibrations are known as lateral or transverse vibration.ie when the shaft is bent alternatively and tensile and compressive stresses due to bending results ,the vibrations are said to be transverse.



(c) Torsional vibration

Torsional vibrations: When the particles of the body or system move in a circle about its axis of the body or system, then vibrations are known as torsional vibrations.ie when the shaft is twisted and untwisted alternatively results in inducing torsional shear stresses in the body, the vibrations are called torsional vibrations.

Damped vibration: When the energy of a vibrating system is gradually dissipated by friction and other resistances, the vibrations are said to be damped. The vibrations gradually cease and system rests in its equilibrium position.



Forced vibrations: When a repeated force continuously acts on a system, the vibrations are said to be forced. The frequency of vibrations is that of applied force and is independent of their own natural frequency of vibrations.

4. *Linear vibration* If all the basic components of a vibratory system behave linearly, the resulting vibration is known as linear vibration. The differential equations that govern a linear vibratory system are linear. If the vibration is linear the principles of superposition hold and mathematical techniques of analysis are well developed.

Example Spring-mass and damper system

5. *Nonlinear vibration* If any of the basic components of a vibratory system behave nonlinearly, the resulting vibration is known as nonlinear vibration. The differential equations that govern a nonlinear vibratory system are nonlinear. If the vibration is nonlinear the principles of superposition don't hold good.

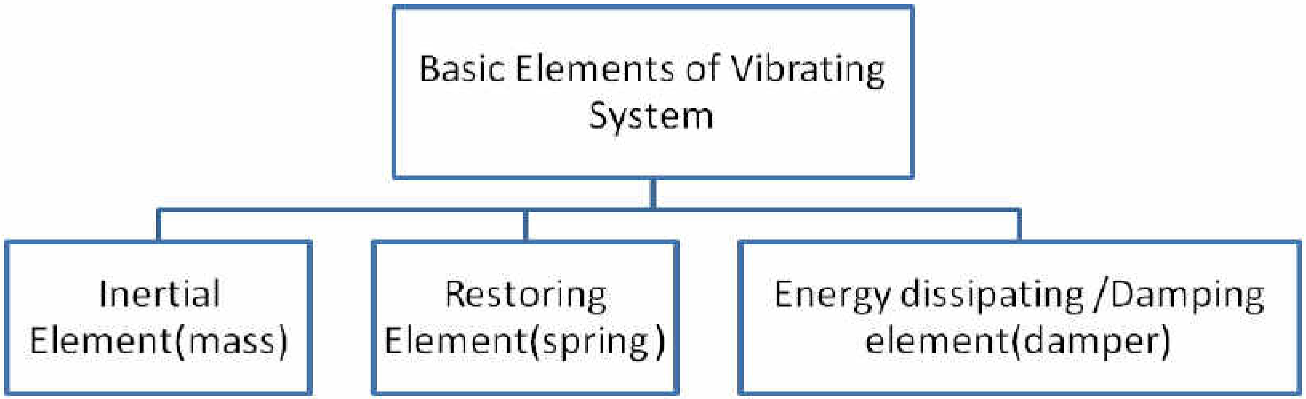
6. *Deterministic vibration* If the magnitude of excitation on a vibratory system is known at any given time, the resulting vibration is known as deterministic vibration.

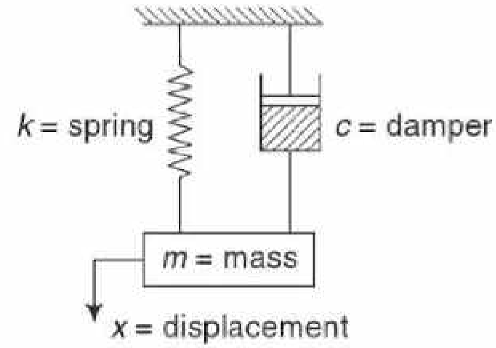
7. *Nondeterministic vibration, or random vibration* If the magnitude of excitation acting on a vibratory system at any given time can't be predicted, the resulting vibration is known as nondeterministic vibration or random vibration.

Example Road roughness, wind velocity and ground motion during earthquakes.

REASON FOR VIBRATION

- ✓ Unbalanced forces present in the system.
- ✓ Elastic nature of the system.
- ✓ External excitation applied on system.
- ✓ Random excitations.





- The mass of the vibrating system provides Inertia force.
- Damper provides the Resisting force.
- The spring provides the Restoring force.
- The constant coefficients m, c and k represent the System Parameters.
- System parameters (m, c and k) are Passive Elements of Mechanical System.
- Active Elements of the Mechanical System are Exciting forces.

SPRING ELEMENT (*K*)

Whenever there is relative motion between the two ends of a spring, a force called *spring force* or *restoring force* is developed. The spring force 'F' is directly proportional to the amount of deformation, i.e. $F \alpha x$ or $F = kx$

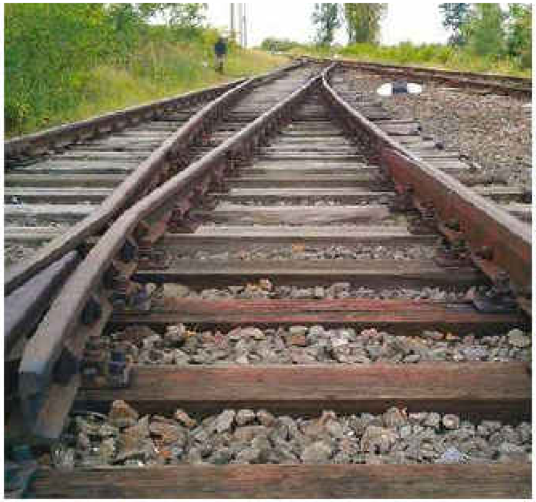
where k = Stiffness of spring or spring constant

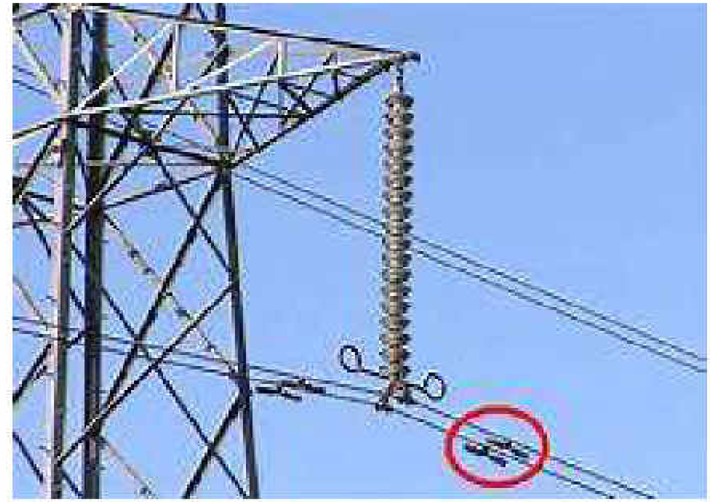
The spring stiffness 'k' in the spring force required to cause a unit deformation of the spring $k = F/x$ N/mm.

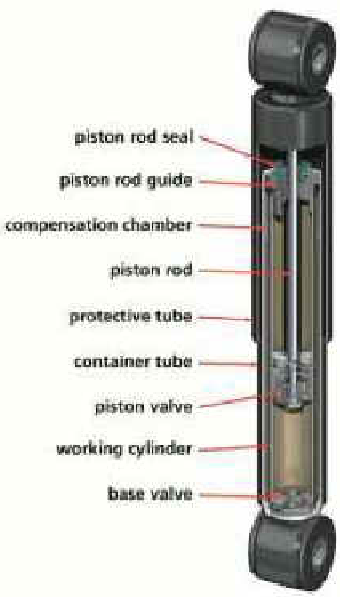
DAMPER

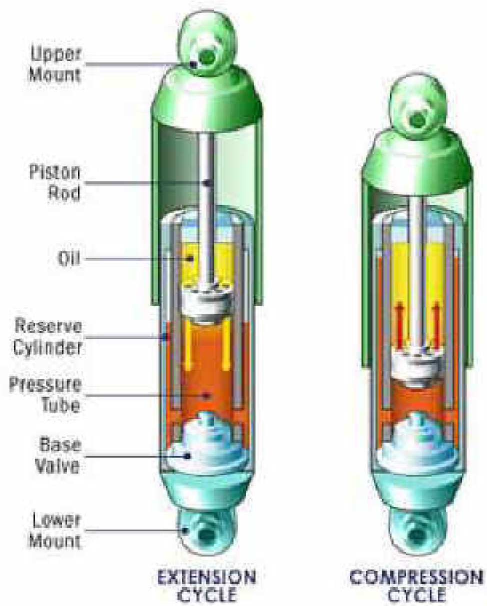
Damping is the resistance offered to the motion of a vibrating body. Damping occurs as a result of system vibrations in a fluid. Hydraulic dashpots and shock absorbers are systems which can be represented by viscous damping. Most mechanical systems themselves have damping which is quiet complex. They can be represented by an equivalent viscous damping. In viscous damping, the damping resistance is proportional to the relative velocity between piston and cylinder ($c\dot{x}$) where 'c' is the damping coefficient. The importance of viscous damping is that it affords an easy analysis of the damping element (c).

Dampers used

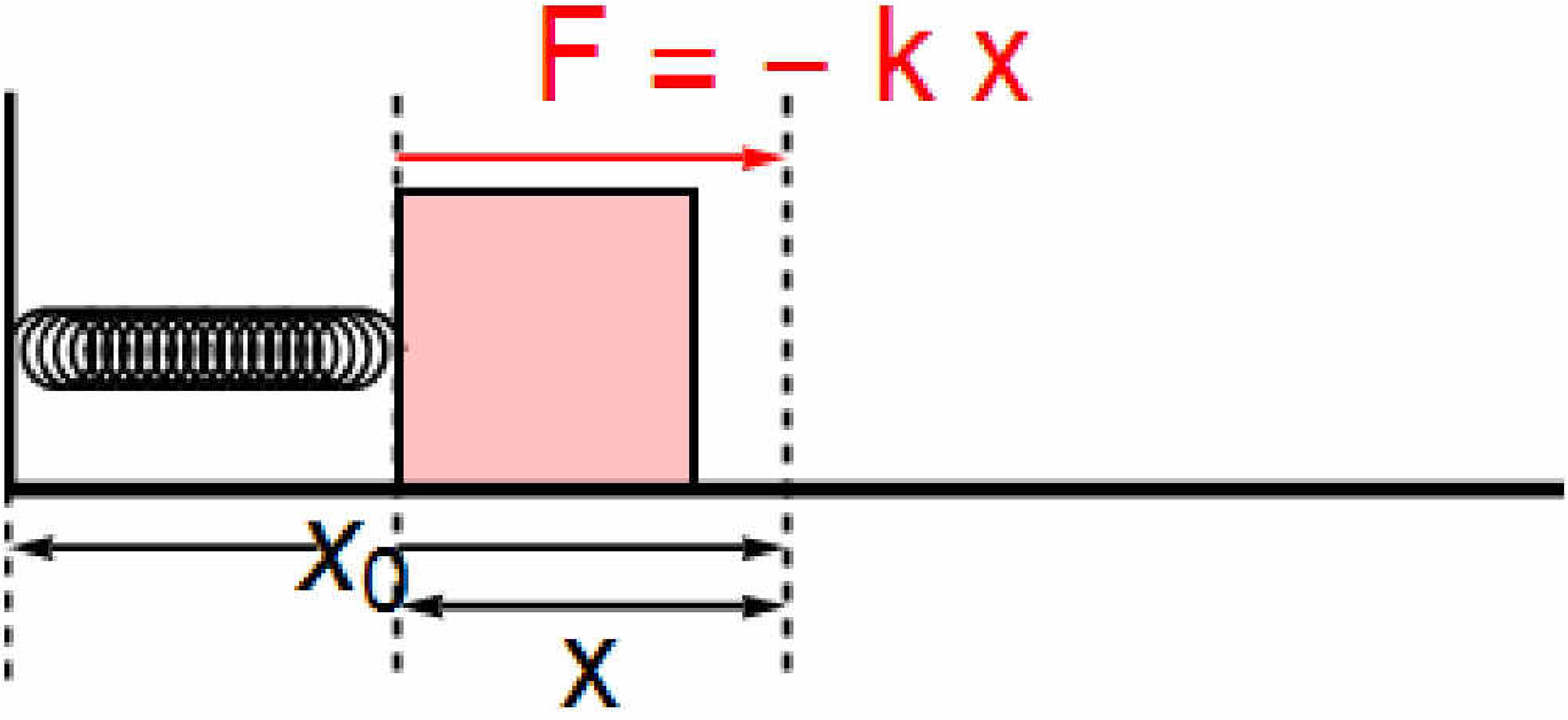








FREE VIBRATION OF SINGLE DEGREE FREEDOM SYSTEM WITHOUT DAMPING



FREE VIBRATIONS OF 1 DOF SYSTEMS WITHOUT DAMPING