OSCILLATIONS

Oscillatory/Vibratory periodic motions:

Oscillatory/Vibratory periodic motions are the motions in which the body moves along the same path to and fro about a mean/equilibrium position.

Ex: Swing of the bob of a simple pendulum, Motion of the prongs of tuning fork, up and down motion of a mass suspended from a spring etc
.

Simple Harmonic Motion(SHM) is the periodic motion about an equilibrium position.

or

SHM is the oscillatory motion in which the force acting on the body is directly proportional to the displacement.

or

SHM (Simple Harmonic Motion) is defined as the motion which repeats itself at regular intervals of time.

or

SHM is defines as any periodic motion which repeats about a mean position .

Examples of SHM:

1. Oscillations of a simple pendulum.
2. Swing of the pendulum of a wall clock.
3. Oscillations of the balance wheel of a wrist watch.
4. Projection of uniform circular motion on the diameter.
5. Vibrations of the prongs of an excited tuning fork.
6. Vibrations of the plucked strings of string instruments like veena , Tamburi, Violin, Guitor etc

Conditions for the SHM in case of mechanical oscillations:

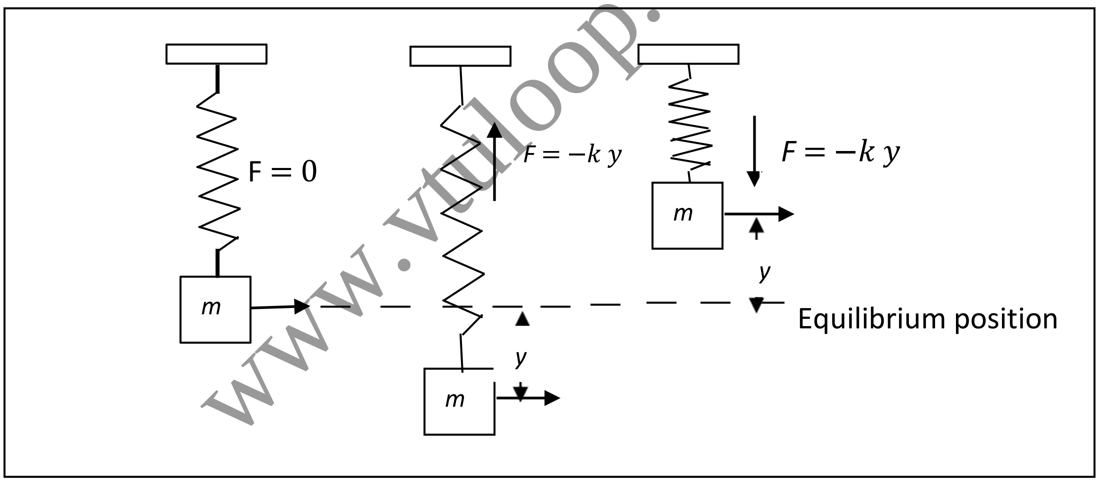
There are three conditions for occurrence of SHM^{S} :
1. Stable equilibrium Position is required.
2. No dissipation of energy.
3. The acceleration must be opposite and proportional to the displacement.

Characteristics of SHM:

1. SHM is a special case of periodic motion.
2. SHM system must have mass and hence Inertia.
3. In SHM a constant restoring force always acts on the body.
4. In SHM the acceleration produced in the body due to restoring force is directly proportional to the displacement of the body from its equilibrium position.
5. In SHM the direction of acceleration/restoring force is opposite to the displacement.
6. SHM is represented as $x = \mathrm{A}\ \mathrm{Sin}\omega t$,
   where $A = \text{amplitude}, \omega = \text{angular frequency}$.

Mechanical simple harmonic oscillator:

Differential equation of motion for SHM $\frac{d^2y}{dt^2} + \frac{k}{m}y = 0$ from Hook's law and mention of its solution OR Differential form of Newton's 2nd Law.



Let a mass 'm' suspended by a spring of spring constant ' k ' rests about its equilibrium position as shown in the diagram.

Pull the mass through a distance ' y ' and release. The mass execute SHM about the equilibrium position. Then the restoring force acting on the body due to elongation /contraction is given by Hook's law as

$\mathbf{F} = -\mathbf{k}\,\mathbf{y}$ ...(1)

where $-$ ve sign indicate that force and displacement are opposite to each other.

According to Newton's 2nd law the restoring force (inertial force) produce an acceleration ' a ' given by $\mathbf{F} = \boldsymbol{ma}$ ....(2)

$\therefore$ from eqns 1 & 2 ,we get $ma = -\mathrm{k}\,\mathrm{y}$, but a = $\frac{d^2y}{}$

$\therefore \quad m\frac{d^2y}{dt^2} = -\text{ k x}$

$\frac{d^2y}{dt^2} = -\frac{k}{m}y$

$\boldsymbol{\frac{d^2y}{dt^2} + \frac{}{m}y = 0}$ **….(3) this eqn is called differential equation of Simple Harmonic Motion.**

But $\frac{k}{m} = \omega^2$

$\therefore \quad \boldsymbol{\frac{d^2y}{dt^2} + \omega^2 y = 0}$ **…..(4)**

The solution of equation 3 or 4 is y = A sin(ωt) , where A is amplitude , ωt is phase at time t.

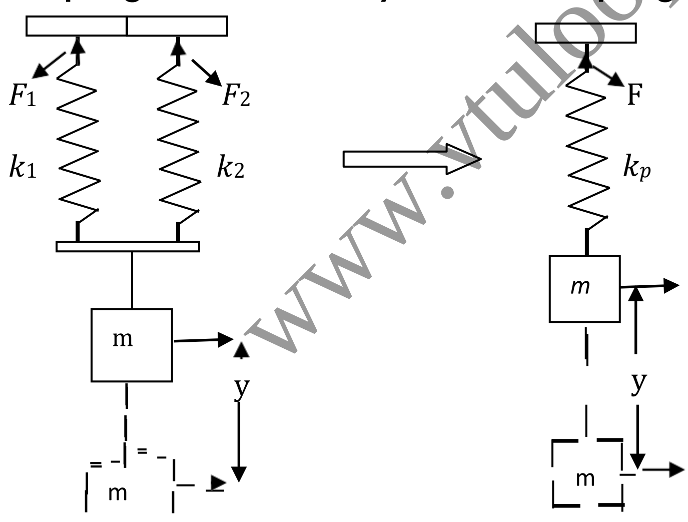
Note: 1. The time period of oscillation is given by T = $\frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{k}}$

2. If ′ ω ‘ is the angular frequency ,then $\frac{k}{m} = \omega^2$,

Eqn 3 becomes $\frac{^2y}{dt^2} + \omega^2$ y = 0….(4)

The solution of eqn (4) is y = A Sin($\omega t + \varphi$) ,this represents equation of motion for free oscillations, where A is amplitude, ωt is phase at time t and φ *initial phase.*

Effective spring constant of a system of two springs in parallel:



Consider two springs of constants $\boldsymbol{k_1}$ ***and*** $\boldsymbol{k_2}$ are suspended in parallel with a load ‘m’

Let the mass is pulled through a distance ‘x’ and released. The mass execute Up And Down motions. Let $\boldsymbol{F_1}$***and*** $\boldsymbol{F_2}$ be the restoring forces that act in the springs of constants $\boldsymbol{k_1}$ ***and*** $\boldsymbol{k_2}$ respectively. Then $\boldsymbol{F_1 = -k_1\, y}$ ***and*** $\boldsymbol{F_2 = -k_2\, y}$

and net restoring force acting on mass, F = $\boldsymbol{F_1 + F_2 = -(k_1 + k_2)y}$ ….(1)

also if k_P be the spring constant of the system of springs in parallel ,then F = = $-k_P y$ …(2)

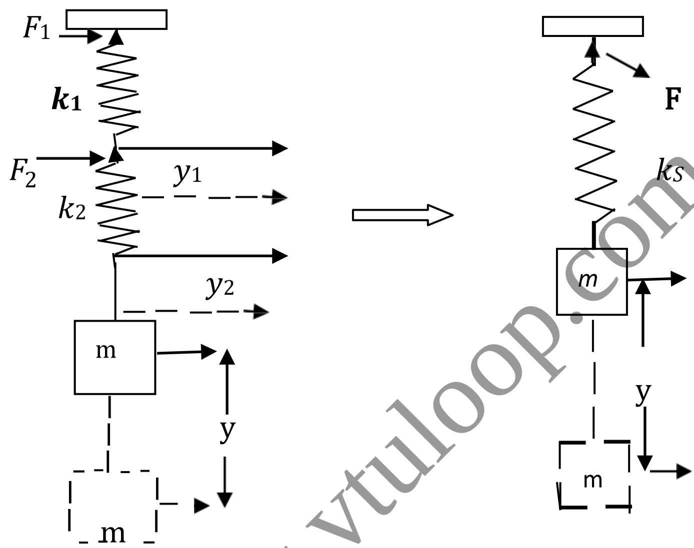
From Eqns 1&2 ,we get , $k_P = k_1 + k_2$

Note:

1. If a system of 'n' springs of spring constants $k_1, k_2, k_3 .... k_n$ are connected in parallel,
   then their effective spring constant $k_P = k_1 + k_2 + k_3 + \cdots + k_n$

2. If $k_1 = k_2 = k_3 = \cdots = k_n$ = k , then $k_P = nk$

Effective spring constant of a system of two springs in series:



Consider two springs of constants k_1 *and* k_2 are suspended in series with a load 'm'

Let the mass is pulled through a distance 'x' and released. The mass execute Up and Down motions. y_1 *and* y_2 be the extensions of the springs of constants k_1 & k ,Then , y = $y_1 + y_2$ ….(1)

Let F_1 *and* F_2 be the restoring forces that act in the springs of constants k_1 *and* k_2 respectively. Then $F_1 = -k_1 \, y_1$ or $y_1 = -\frac{F_1}{k_1}$ ……(2)

$$F_2 = -k_2 \, y_2 \quad \text{or} \quad y_2 = -\frac{F_2}{k_2} \quad …….(3)$$

Also if k_S be the spring constant of series combination and F the net restoring force acting on the mass ,then F= $-k_S \, y$ or $= -\frac{F}{k_S}$ …. (4)

∴ From eqns 1,2,3&4,we get, $\frac{F}{k_S} = \frac{F_1}{k_1} + \frac{F_2}{k_2}$

For light springs , $F_1 = F_2 = F$

Then $\frac{1}{k_S} = \frac{1}{k_1} + \frac{1}{k_2}$ **or** $k_S = \frac{k_1 . k_2}{k_1 + k_2}$

Note: 1. If a system of 'n' springs of spring constants k , k_2, k_3.............. k_n are connected in series, then their effective spring constant k_S is given by
$\frac{1}{k_S} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \cdots + \frac{1}{k_n}$

2 . If $k_1 = k_2 = k_3 = \cdots = k_n$ = k , then $\frac{1}{k_S} = \frac{n}{k}$ or $k_S = \frac{k}{n}$ or k = nk_S

Complex notation of Simple Harmonic motion (A $e^{(\omega t+\varphi)}$)

A number of the form Z = $x + iy$ is called a complex number. Where 'x' is called the real part and 'i ' is called the imaginary part and $i = \sqrt{-1}$

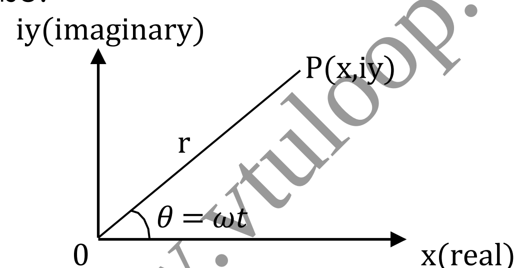
In polar form Z = $r\, cos\theta + i\, r sin$, where θ is called the amplitude/argument. A complex number can be represented by an Argand diagram.

Using Euler's formula is $e^{i\theta} = cos\theta + i\, sin\theta$,

we write Z = r $e^{i\theta}$

As θ changes with time, r is a function of t and θ *is replaced with* ωt .The arrow rotates about the origin with angular velocity ω.

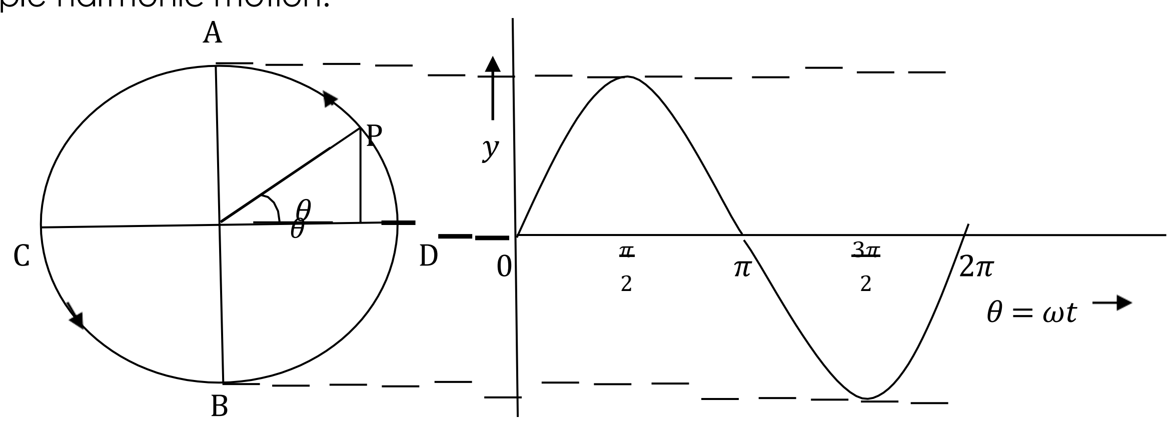
Similarly ,if A is the amplitude ,then the SHM is represented as Z = $A\, e^{i(\omega t+\varphi)}$,where φ is initial phase.



Phasor representation of Simple Harmonic motion

Phasor is a rotating vector whose projection is used to represent a sinusoidally varying quantity.

The following diagram illustrates how the phasors are used to represent the simple harmonic motion.



This kind of phasor diagrams are commonly used in electrical circuits to show the phase difference between electrical components like voltage (V) and current(I)

Types of oscillations(Vibrations):

There are three types of oscillations ,namely

Free oscillations ,Damped oscillations and Forced oscillations.

Free oscillations are the oscillations that appear in a system due to single initial deviation from its stable equilibrium position.

When a pendulum is displaced from its equilibrium position and let go, with no resistance, it execute free oscillations with frequency $\nu = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$,where g is acceleration due to gravity, L is the length.

Free oscillations(Vibrations) are the oscillations of the body which remains unaffected by external forces.

The frequency of free oscillations is called natural frequency.

Ex: Oscillations of simple pendulum in vacuum, Vibrations of excited tuning fork in vacuum, Vibrations of stringed instruments in vacuum, Vibrations of Bridges etc

Equation of motion for free oscillations:

The equation of motion for free oscillations is given by $\frac{d^2y}{dt^2} + \frac{k}{m}y = 0$

Where 'm' is the mass,'k' is force constant and ' y ' is displacement at any instant 't' of oscillating body.

Natural frequency is the frequency with which the pendulum oscillates freely on its own when no external resistive forces acts on it.

Damped oscillations(Vibrations) are the oscillations of the whose amplitude goes on decreasing due to the frictional forces of the medium acting on the body.

Ex: Oscillations of simple pendulum, Vibrations of prongs of tuning fork, vibrations of stringed instruments in air

Forced oscillations(Vibrations) are the oscillations executed by the body with the frequency of the external periodic force with constant amplitude, but not with its natural frequency.

Ex: Two pendulum clocks placed on the same stand show same time after some time. A&B are two pendulums suspended from the same rod with different lengths.If A is set in to oscillations after some time B oscillates with the same frequency due to periodic force through the rod.

Theory of damped vibrations/oscillations:

Consider a body of mass m executing vibrations in a resistive medium.

Then the resistive force acting on the body due to medium = $-r\frac{d}{\ }$

where r is damping constant and $\frac{dx}{dt}$ is the velocity of the body.

Also restoring force acting on the body $= -kx$

where k is force constant and x is displacement.

$\therefore$ The net resultant restoring force acting on the body $= -r\frac{dx}{dt} - kx$ ……(1)

By Newton's 2nd law ,the resultant force acting on the body $= m\frac{d^2x}{dt^2}$ …. (2)

From eqn 1&2 ,we get , $m\frac{d^2x}{dt^2} = -r\frac{dx}{dt} - kx$

$\therefore m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + kx = 0$ This is eqn of damped motion

On re-arranging ,we get , $\frac{d^2x}{dt^2} + \frac{r}{m}\frac{dx}{dt} + \frac{k}{m}x = 0$ …(3)

Let $\frac{r}{m} = 2b$ & WKT $\omega^2 = \frac{k}{m}$ $\because \omega = \sqrt{\frac{k}{m}}$

$\therefore \frac{d^2x}{dt^2} + 2b\frac{dx}{dt} + \omega^2 x = 0$ …..(3)

Let the solution of eqn 3 be $x = Ae^{\alpha t}$ ….(4) ,where A and α are constants.

Differentiating eqn 4 twice w.r.t 't ' we get,

$\frac{dx}{dt} = A\alpha e^{\alpha t}$ …(5)

and $\frac{d^2x}{dt^2} = A\alpha^2 e^{\alpha t}$ …(6)

substituting eqns 4,5&6 in 3 ,we get

$A\alpha^2 e^{\alpha t} + 2b\, A\alpha e^{\alpha t} + \omega^2 A e^{\alpha t} = 0$

$Ae^{\alpha}(\alpha^2 + 2\alpha b + \omega^2) = 0$

$(\alpha^2 + 2\alpha b + \omega^2) = 0$

Thus $(\alpha^2 + 2\alpha b + \omega^2) = 0$ …(7) as $x \neq 0$

The solution of eqn 7 is $= -b \pm \sqrt{b^2 - \omega^2}$ …(8)

From eqns 4 & 8 ,the general solution can be written as

$x = C\, e^{(-b+\sqrt{b^2-\omega^2})t} + D\, e^{(-b-\sqrt{b^2-\omega^2})t}$ …(9) ,where C&D are constants.

Let the time is counted from maximum displacement $x = x_0$,then $t = 0$

From eqn 9,we,get $x_0 = C + D$ …(10)

At maximum displacement the velocity $\frac{dx}{dt} = 0$, Differentiating eqn 9 and equating to zero,

We get , $(-b + \sqrt{b^2 - \omega^2})C\, e^{(-b+\sqrt{b^2-\omega^2})t} + (-b - \sqrt{b^2 - \omega^2})D\, e^{(-b-\sqrt{b^2-\omega^2})t} = 0$

When , t = 0 , $(-b + \sqrt{b^2 - \omega^2})C + (-b - \sqrt{b^2 - \omega^2})D = 0$

On rearranging, $-(C+D)+\sqrt{b^2-\omega^2}\,(C-D)=0$

$$-bx_0+\sqrt{b^2-\omega^2}\,(C-D)=0$$

$\frac{bx_0}{\sqrt{b^2-\omega^2}}=(C-D)$ …….. (11)

Adding eqns 10 and 11 , we get $C=\frac{x_0}{2}\left[1+\frac{b}{\sqrt{b^2-\omega^2}}\right]$

Also subtracting eqn 11 from 10 ,we get D = $\frac{x_0}{2}\left[1 - \frac{b}{\sqrt{b^2-\omega^2}}\right]$

Substituting for C and d in eqn 9 ,we get

$$\mathbf{x} = \frac{x}{2}\left[1 + \frac{b}{\sqrt{b^2-\omega^2}}\right] e^{(-b+\sqrt{b^2-\omega^2})t} + \frac{x_0}{2}\left[1 - \frac{b}{\sqrt{b^2-\omega^2}}\right] e^{(-b-\sqrt{b^2-\omega^2})t} \quad ....(12)$$

This is the general solution for damped vibrations

Discuss over damping ,Critical damping and Under damping:

Case-1. Over damping/dead beat

Oscillations are said to be over damped or heavy damped when the system attains equilibrium state quite slowly without making oscillations.

The condition for over damping is $b^2 > \omega^2$

Case-2. Under damping.

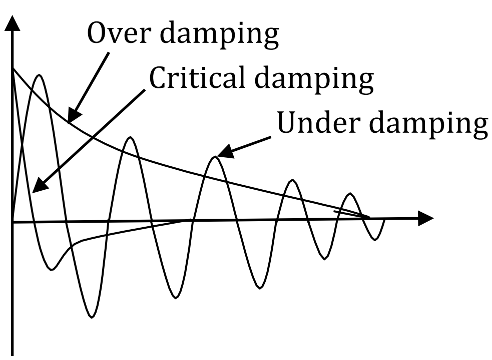
Oscillations are said to be under damped when the amplitude of oscillations decreases with respect to time.

The condition for under damping is $b^2 < \omega^2$

Case-3. Critical damping .

Oscillations are said to be critically damped when the system attains equilibrium state quite quickly without making any oscillations.

The condition for critical damping is $b^2 = \omega^2$



Theory of forced vibrations/oscillations:

Consider a body of mass m displaced through a distance x at any instant of time t ,when an external periodic force F Sin(pt) of angular frequency p acts on it opposite to its direction.

Then the damping force acting on the body opposite to the its direction (p)is $-r\frac{d}{dt}$ where r is damping constant.

Also the restoring force acting on the body is $-k$, where k is force constant.

∴ The net resultant restoring force acting on the body is given by

$$-r\frac{dx}{dt} - kx + F\,\mathrm{Sin}(pt) \ \ldots\ldots(1)$$

According to Newton's 2nd law, the resultant force on the body = $m\frac{d^2x}{dt^2}\ldots(2)$

From eqn 1&2 ,we get, $m\frac{d^2x}{dt^2} = -r\frac{dx}{dt} - kx + F\,\mathrm{Sin}(pt)$

$$\therefore m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + kx = F\,\mathrm{Sin}(pt)$$

This is eqn of forced vibration motion

On re-arranging ,we get , $\frac{d^2x}{dt^2} + \frac{r}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F}{m}\mathrm{Sin}(pt) \ \ldots(3)$

Let $\frac{r}{m} = 2b$ & WKT $\omega^2 = \frac{k}{m}$ $\because \omega = \sqrt{\frac{k}{m}}$

$$\therefore \frac{d^2x}{dt^2} + 2b\frac{dx}{dt} + \omega^2 x = \frac{F}{m}\mathrm{Sin}(pt)$$

The solution of this differential equation is $x = a\,Si(pt-\alpha)$ ……(4) Where a and α represent amplitude and phase of the vibrating body.

Differentiating equn 4, w.r.t ' t ' twice ,we get

$$\frac{dx}{dt} = ap\,Cos(pt-\alpha)$$

$$\frac{d^2x}{dt^2} = -ap^2\,Si(pt-\alpha)$$

∴ from eqn 3 ,we get

$$-ap^2\,Si(pt-\alpha) + 2b\,ap\,Cos(pt-\alpha) + \omega^2\,a\,Sin(pt-\alpha) = \frac{F}{m}\mathrm{Sin}(pt) \ \ldots..(5)$$

But $\frac{F}{m}\mathrm{Sin}(pt) = \frac{F}{m}Sin[(pt-\alpha)+\alpha]$

Substituting in 5 and simplifying, we get

$$[-ap^2\,Si(pt-\alpha) + \omega^2\,a\,Sin(pt-\alpha) + 2b\,ap\,Cos(pt-\alpha)\,] = \frac{F}{m}Sin(pt-\alpha)Cos\alpha + \frac{F}{m}Cos(pt-\alpha)Sin\alpha$$

Equating the coefficients of $Si(pt-\alpha)$ and $Cos(pt-\alpha)$ on both sides separately we get $-ap^2+\omega^2 a=\frac{F}{m}Cos\alpha$ ...(6)

$$2b\,ap=\frac{F}{m}Sin\alpha \quad ....(7)$$

Squaring and adding eqns 6&7,we get

$$[(\omega^2-p^2)]^2+(2bap)^2=\left(\frac{\ }{m}\right)^2[Cos^2{}_\alpha+Sin^2{}_\alpha]$$

$$a^2[(\omega^2-p^2)^2+4b^2p^2]=\left(\frac{F}{m}\right)^2$$

$$\therefore\ \boldsymbol{a}=\frac{(\boldsymbol{F/m})}{\sqrt{\boldsymbol{4b^2p^2}+(\boldsymbol{\omega^2-p^2})^2}} \quad ...(8)$$

This is the equation for amplitude of the forced vibrations.

From eqn 4&8 ,we get $x=\frac{(\boldsymbol{F/m})}{\sqrt{\boldsymbol{4b^2p^2}+(\boldsymbol{\omega^2-p^2})^2}}\boldsymbol{Si(pt-\alpha)}$ **....(9)**

The phase α of the forced vibration is given by dividing eqn 7 by 6,

$$\tan\alpha=\frac{2bap}{(\omega^2-p^2)} \quad .....(10)$$

$$\boldsymbol{tan\alpha}=\frac{\boldsymbol{2bp}}{(\boldsymbol{\omega^2-p^2})}$$

Dependence of amplitude(a) and phase(α) on the frequency (p)of the applied force:

WKT amplitude, $=\frac{(F/m)}{\sqrt{4b^2p^2+(\omega^2-p^2)^2}}$ ...(1)

Phase, $=tan^{-1}\left[\frac{\boldsymbol{2bp}}{(\boldsymbol{\omega^2-p^2})}\right]$ ....(2)

Case(1): For **p**$\ll\boldsymbol{\omega}$,

As p^2 is very small, then $\omega^2-p^2\approx\omega^2$, 2bp= 0 & $\frac{2bp}{\omega^2}\approx 0$

$\therefore from\ eqn\ 1$, amplitude, a $=\frac{F/m}{\omega^2}$

Thus a is independent of p but depends on (F/m) and constant for given F.

Also from eqn 2, $\alpha=tan^{-1}[\mathbf{0}]=0$,thus displacement and force will be in same phase.

Case(2): For **p**= $\boldsymbol{\omega}$, $\omega^2 - p^2 = 0$, 2bp= 0

$\therefore from\ eqn\ 1$, amplitude, a = $\frac{F/m}{2bp} = \frac{F/m}{2(\frac{r}{2m})\omega} = \frac{F}{r\omega}$,thus a will have highest value for a given damping force F.

And phase , $\alpha = tan^{-1}[\frac{2bp}{0}] = = tan^{-1}[\infty] = \frac{\pi}{2}$,thus displacement phase lags $\frac{\pi}{2}$ with respect to phase of applied force.

Case(3): For **p** ≫ $\boldsymbol{\omega}$ is applicable for small b, $(\omega^2 - p^2)^2 \approx (p^2)^2 = p^4$

$\therefore from\ eqn\ 1$, amplitude, a =$\frac{(\frac{F}{m})}{\sqrt{4b^2p^2+p^4}}$ but for small b,

$$4b^2p^2 \ll p^4 \,\&\, \frac{2b}{p} \approx 0$$

a = $\frac{(F/m)}{\sqrt{p^4}} = \frac{F/m}{p^2}$,thus as p increases ,a decreases

Also phase , $\alpha = tan^{-1}[\frac{\mathbf{2bp}}{(\boldsymbol{\omega}^2 - \boldsymbol{p}^2)}] = tan^{-1}[\frac{\boldsymbol{bp}}{-\boldsymbol{p}^2}] = tan^{-1}[\frac{\mathbf{2b}}{-\boldsymbol{p}}]$ but for small b,$\frac{2b}{p} \approx 0$

$\therefore \alpha = tan^{-1}[-\mathbf{0}] = \pi$, thus for large p ,the displacement phase lags by π w.r.t phase of applied force.

Resonance is the frequency with which the body oscillates when the natural frequency of the body is equal to the frequency of the external periodic force acting on the body.At resonance the energy transfer from external periodic force is maximum and the amplitude is also maximum.

Conditions for resonance:

1. The frequency of the applied force (p) must be equal to the natural frequency(ω) of oscillations of the body.
2. b = $\frac{r}{2m}$ must be minimum or Damping caused by the medium must be minimum.

At resonance the amplitude is given by $a_{max} = \frac{F/m}{2b\omega}$ ∵ p= ω

The amplitude of the body near resonance a = $\frac{F/m}{2bp}$ ∵

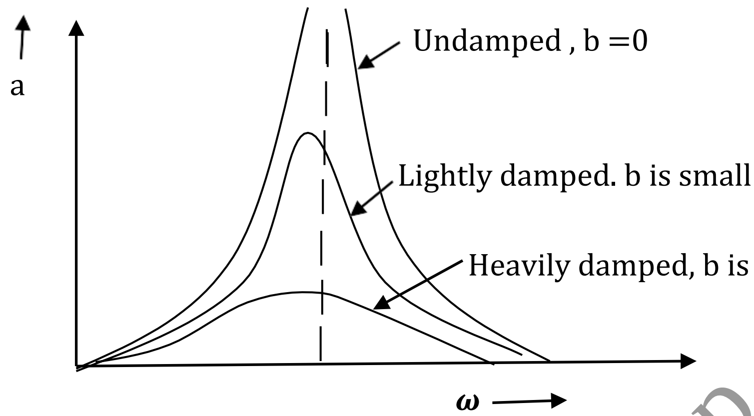
Sharpness of resonance = $\frac{Change\ in\ amplitude}{change\ in\ frequency}$

Sharpness of Resonance:

The sharpness of resonance is the ratio of change of amplitude (Δ) to corresponding small change in frequency($\Delta\omega$) of the applied external periodic force ,at resonance.

ie: Sharpness of resonance $= \frac{\Delta a}{\Delta\omega}$

Effect of damping on sharpness of resonance:



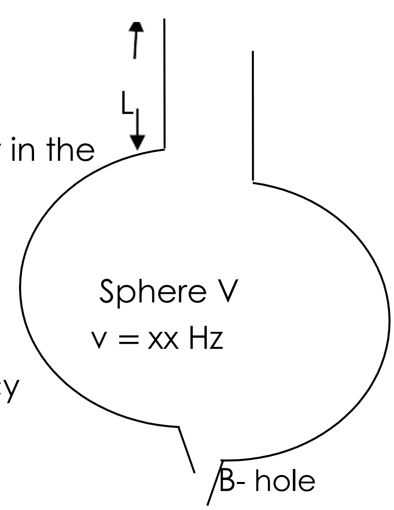
The variation of amplitude of forced oscillations with respect to damping is as shown in the graph diagram.

From the graph it is clear that the maximum amplitude at resonance is a function of damping. Higher the damping lower will be the amplitude at resonance. Thus the sharpness will be higher at lower damping and vice-versa is the significance.

Example of resonance :

1. **Helmholtz resonator (HR)**

Helmoltz resonator is an instrument used to detect A-neckthe presence of sound of a particular frequency in the mixture of sound of different frequencies.



Construction :

It consists of a hollow metallic sphere with a cylindrical long neck(A) and a fine hole(B) opposite to A.

The air inside the sphere has a definite natural frequency which is marked on it.

Working :

When sound of different frequencies enter the sphere through A, the air in resonator resonates for the frequency of the sound which is equal to the natural frequency of air producing resonance ,which can be heard as loud sound at end B. HR cannot resonate for any other frequency.

Resonant frequency , f = $\frac{V_s}{2\pi}\sqrt{\frac{a}{VL}}$

where V_s = velocity of sound , a = area of cross section of neck,

V $= Volume\ of\ the\ sphere$, L $= length\ of\ the\ neck$

2. Tuning of radio receiver set to the broadcasting transmitting frequency.
3. Setting up of standing waves in Melde's experiment string.
4. Exciting second identical tuning fork by excited nearby tuning fork.

SHOCK WAVES

Q:What are shock waves ? Explain.

Shock waves are the waves produced due to the sudden(release)dissipation of energy.

OR

Shock waves are the waves in which the pressure, density and temperature changes are very very large.

Ex: Shock waves are produced during the burst of crackers, Explosion of Dynamites and bombs, Volcanic eruptions, etc.

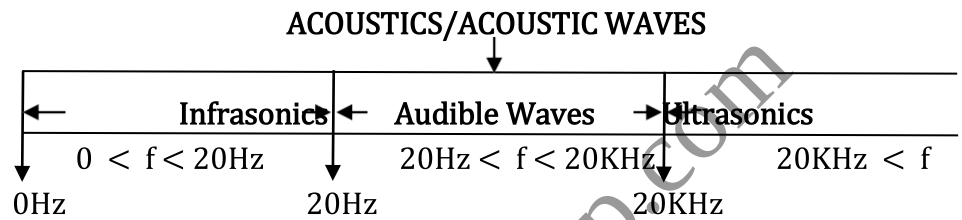
Q:Mention methods of producing shock waves.

Shock waves can be produced by the following methods ,namely By detonation of crackers/explosives, by volcanic eruptions, supersonic objects/waves, by Reddy shock tube in the laboratory.

Q:What are Acoustic waves? Mention the types of acoustic waves.

Acoustic waves are the longitudinal waves which travel with the speed of sound in a medium (Solid/liquid/gas)

Acoustic waves are classified in to THREE types namely:
Infrasonic waves(Infrasonics) are the Acoustic waves of frequency < 20 Hz.
Audible waves are the Acoustic waves of frequency between 20 Hz and 20 kHz.
Ultrasonic waves(Ultrasonics) are the Acoustic waves of frequency greater than 20 kHz. (Elephants detect Infrasonics, Human ear detect Audible waves & Bats/Dogs detec Ultrasonics)



Q: Define Mach number, subsonic waves supersonic waves and Mach angle (Classification of objects based on Mach number)

1. **Mach Number(M)** is the ratio of the speed of an object **(V)** through a fluid to the speed of sound(**a**) in the fluid at that point and is given by **M** = $\frac{V}{a}$

2. **Subsonic waves** are the mechanical waves whose speed is less than that of sound in the same medium. Mach number of **Subsonic waves** is less than 1.

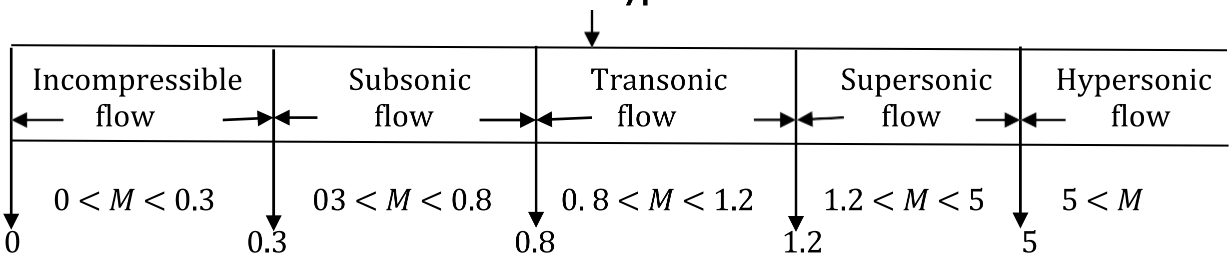
   Ex: Motor cycle, Bus, Train , aeroplanes etc produce subsonic waves.

3. **Supersonic waves** are the mechanical waves whose speed is greater than that of sound in the same medium. for which the Mach number of **Supersonic waves** is greater than 1.

   Ex: Fighter planes, Rockets, Missiles, tornedo etc produce supersonic waves

4. **Mach angle(μ)** is the half the angle of cone of sound waves formed and is given by $\mu = Sin^{-1} \left(\frac{1}{M}\right)$

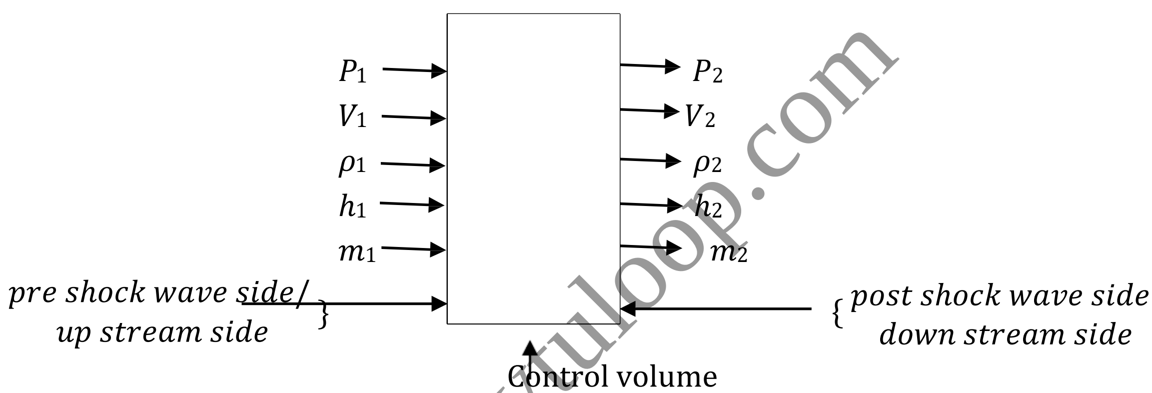
Clasification of types of fluid flow



Q: Control Volume.

Control volume is defined as the imaginary two dimensional volume containing shock wave front to study Shock waves.

Pressure, Volume, density and temperature changes within the control volume are large and they cannot be measured.



Q: Explain the basic conservation laws.

The basics of Conservation of mass, momentum and energy are:-

1. **Conservation of mass** states that the total mass of the system always remains constant as the mass can neither be created nor destroyed.

   Mathematically , $\boldsymbol{\rho v = \text{constant}}$ or

   $\therefore\ \rho_1 v_1 = \rho_2 v_2$, Where ρ_1, ρ_2 densities & v_1, v_2 velocities.

2. **Conservation of momentum** states that the sum total momentum of the system always remain constant.

   Mathematically , $\boldsymbol{P + \rho v^2 = \text{constant}}$ or $P_1 + \rho_1 v_1^2 = P_2 + \rho_2 v_2^2$

   where P_1, P_2 pressures , v_1, v_2 velocities and ρ_1, ρ_2 densities.

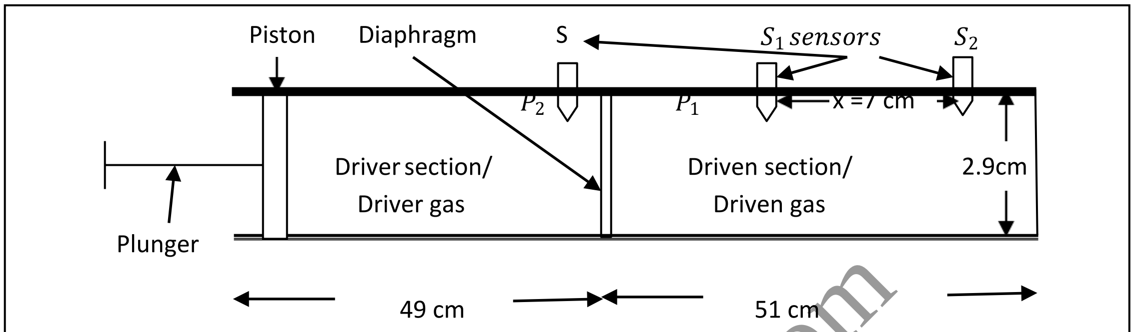
3. **Conservation of energy** states that the sum total energy of a system is always remains constant.

   Mathematically , $\boldsymbol{h + \frac{v^2}{2} = \text{constant}}$ or $h_1 + \frac{v_1^2}{2} = h_2 + \frac{v_2^2}{2}$

   where h_1, h_2 enthalpies and v_1, v_2 velocities.

Q:What is a (Reddy)shock tube ? Describe the construction and working of simple Reddy shock tube .

1. **Reddy Shock tube** is a device used to produce and study shock waves in the laboratory.
2. Schematic labelled diagram of the original Reddy shock tube is as shown in the diagram.



Construction :

1. RST consists of a steel tube of length 100 cm and diameter 2.9 cm.
2. A diaphragm of thickness 0.1cm divides the tube in to two compartments of length 49 cm fitted with piston called Driver section filled with driver gas. The other compartment of length 51 cm is called Driven section filled with driven gas.
3. Sensor S fitted to driver section measures the rupture pressure P_2,temparatureT_2.
4. Two sensors S_1 & S_2 separated by a distance Δ_X fitted to driven section measures the pressures P_4,P_5 and temperatures T_4, T_5 respectively.

Working :

1. Driver section is filled with gas at high pressure ($_2$)and Driven section is filled with gas of low pressure(P_1) .
2. Diaphragm is ruptured to produce shock waves by pushing the piston and the rupture pressure P_2 & temperature is measured using sensor S.
3. The time't' taken by the shock wave to travel the distance ' **x** ' is measured using sensors S_1 , $S_2$and CRO(Cathode Ray Oscilloscope). The speed of the shock waves is calculated using **V =** $\frac{x}{t}$.
4. Then if a is the speed of sound at laboratory temperature, the match number of the shock waves is calculated using **M =** $\frac{V}{a}$
5. The Mach number increases with the increase of the thickness of the diaphragm.

Q: Characteristics/Properties of Shock waves.

1. Shock waves(SWS) carry energy and propagate through a medium(solid/liquid/gas/plasma) and vacuum.
2. Across the shock waves there is always rapid changes in pressure, temperature, density of the flow.
3. SWS travels through most media at higher speed than other waves.
4. SWS dissipate energy relatively quickly with distance.
5. SWS are not conventional sound waves.
6. In SWS properties of the fluid(density, temperature, volume, pressure, mach number) change almost instantaneously.
7. SWS can be normal, oblique and stationary waves.
8. SWS can change from nonlinear to linear over long distance.
9. SWS creates additional drag force on aircrafts with shocks.
10. Energy is preserved when SWS passes through matter but the energy which can be extracted as work decreases and entropy increases.

Weak shock waves are produced by burst of crackers / balloons & Motor vehicles
Strong shock waves are produced by , Supersonic jets ,Rockets, Fighter planes

Q: Uses of Shock waves.

1. Shock waves (SW)are used in the treatment of kidney stones.
2. SW are used in the pencil industry for softening of pencil wood and dry painting.
3. Sw are used in the extraction of sandal wood.
4. Sw are used to rejuvenate/activate dried bore wells.
5. Sw are used for needleless drug delivery.
6. Sw are used to push DNA in to the cell.
7. SW are used for the treatment of orthopedic diseases.
8. SW are used to heal broken bones quickly.

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