ENGINEERING PHYSICS

MODULE – 1

Oscillations and Waves

Free Oscillations: Basics of SHM, derivation of differential equation for SHM, Mechanical simple harmonic oscillators (spring constant by series and parallel combination), Equation of motion for free oscillations, Natural frequency of oscillations.
Damped Oscillations: Theory of damped oscillations (derivation), over damping, critical & under damping (only graphical representation), quality factor.
Forced Oscillations: Theory of forced oscillations (derivation) and resonance, sharpness of resonance.
Shock waves: Mach number, Properties of Shock waves, Construction and working of Reddy shock tube, applications of shock waves, Numerical problems.

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Oscillations and Waves

Oscillatory motion is a type of motion in which the moving particle describes a forward and backward (to and fro) motion again and again.

The oscillation is said to be periodic, if the body reaches the same point in its path at equal intervals of time. The time taken to complete one oscillation is called the period.

Free Oscillations:

Free oscillations are oscillations executed by a body under the action of its own elastic forces, without being subjected to any external force, other than the impulse that initiated the motion and the body oscillates with its natural frequency.

1. There are no resistive forces such as friction or fluid resistance acting on the system
2. Amplitude remains constant and the motion continues indefinitely.
3. Total energy of the system is conserved.

Simple Harmonic Motion (SHM):

Simple Harmonic Motion is a periodic motion in which the acceleration of the moving body is always directed towards a fixed point in its path (equilibrium point) and is proportional to its displacement from that point. (Fig. 1.1)

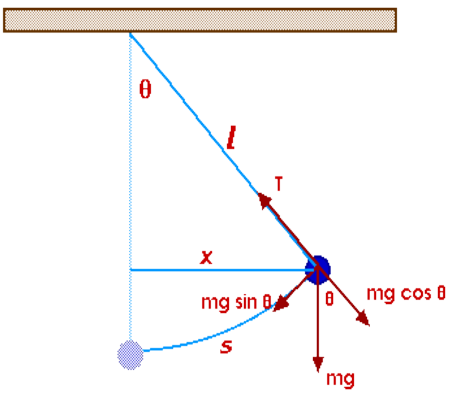

Fig. 1.1 Forces on the oscillating pendulum

Acceleration $a \propto -y$

y is the displacement

$a = -\omega^2 y$; ω is the angular velocity

Differential Equation for SHM

Consider a particle executing uniform circular motion with an angular velocity ω. OP is the radial vector (Fig.1.2)

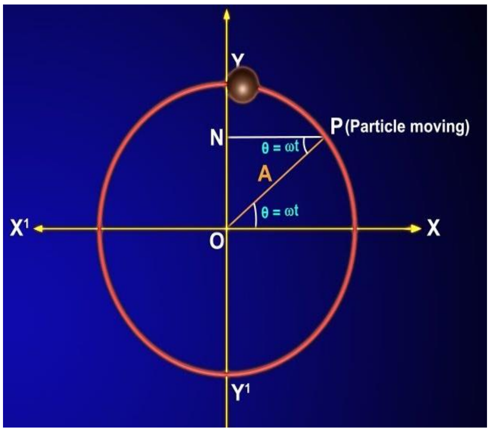

Fig. 1.2 Reference circle for SHM

In a time, interval of ‘t’ seconds the radial vector turns an angle $\theta = \omega t$ from OX

PN is the perpendicular to the diameter YY’ from the position of the particle. As the particle completes one rotation, the foot of the perpendicular N completes one to and fro motion (one oscillation). The displacement of the foot of the perpendicular from the centre O be ‘y’

Then $y = A \sin \omega t$

The velocity $v = \frac{dy}{dt} = A\omega \cos \omega t$

Acceleration $a = \frac{d^2y}{dt^2} = -A\omega^2 \sin \omega t$

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

$$\boldsymbol{\frac{d^2y}{dt^2} + \omega^2 y = 0.}$$

This is the differential equation for a simple harmonic motion

Energy of SHM:

As a body executes SHM, its displacement and the velocity changes continuously.

At the equilibrium point the displacement is zero, hence the potential energy ‘U’ is zero.

At that point, the velocity is maximum, hence the kinetic energy ‘K’ = $\frac{1}{2} mv^2$ is maximum.

At the extreme point, displacement is maximum, hence the potential energy is maximum but velocity is zero and the kinetic energy is zero. So as the body moves the kinetic energy is converted to potential energy and vice versa (Fig.1.3). The total energy ‘E’ remains a constant.

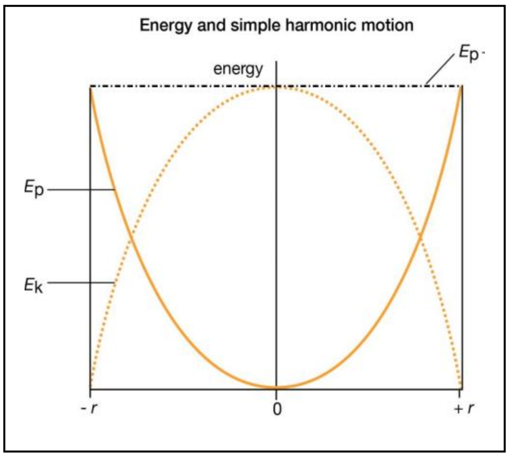

Fig.1.3 Energy curves

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Equations for different characteristic factors of SHM are given below.

Displacement is $y = A \sin \omega t$

Velocity, $v = \pm \omega\sqrt{A^2 - y^2}$

Acceleration, $a = -\omega^2 y$

Kinetic energy; $K = \frac{1}{2} m \omega^2(A^2 - y^2)$

Potential energy $U = \frac{1}{2} m \omega^2 y^2$

Total energy $E = \frac{1}{2} m \omega^2 A^2$

<u>Mechanical Simple Harmonic Oscillator</u> <u>(Mass suspended by a string)</u>

Consider a mechanical spring of negligible mass suspended with a body of mass ‘m’ attached to its free end (Fig. 1.4).

At equilibrium, forces acting on the system are
1. The weight of the body acting downwards ‘mg’ and
2. The restoring force of the spring ‘F_r’
   Both are equal and opposite ie. $mg = -F_r$

If the spring is further stretched through a distance “y” by pulling the mass down, the restoring force developed is proportional to the elongation y and opposite to the displacement.

ie. $F = -ky$

From Newton’s second law; $F = ma$

$ma = -ky$ a is the acceleration of the body

$$a = -\frac{k}{m}y \qquad \text{let } \frac{k}{m} = \omega^2$$

$a = -\omega^2 y$ Hence the motion of the body is SHM.

Period of oscillation $\mathbf{T} = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{k}}$

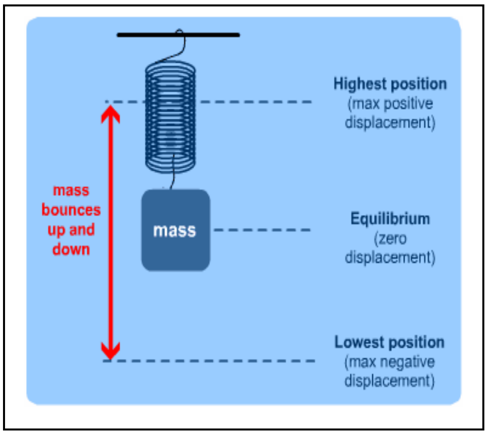

Fig. 1.4 Oscillations of a mass suspended by a spring

<u>Note:</u>

[The elongation ‘l’ produced by the added mass, is proportional to the weight of the mass mg

$mg = k\,l$ where k is the spring constant.

When the body is pulled down by a certain distance y and released, it undergoes SHM.

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Now the net force is $F = mg - k\,(l + y)$

$$= mg - k\,l - ky$$

$$F = -\,ky$$

Combination of Springs: Expression for Spring Constant

1. **Series Combination:**

Consider a mass 'm' suspended at the end of two springs connected in series, with spring constants k_1 and k_2 as shown in (Fig. 1.5(a)).

Both the springs experience the same stretching force 'F'
Let x_1 and x_2 be their elongations produced due to the added mass.

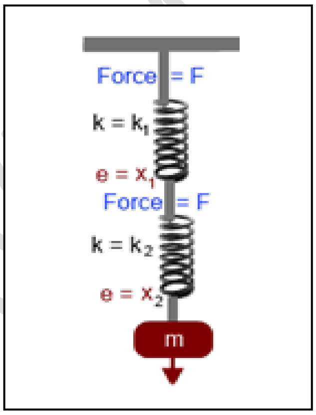

Fig. 1.5(a) Springs in series

Total elongation is given by $x = x_1 + x_2$

From Hooke's law $F = -\,kx$, ie $x = -\,\frac{F}{k}$
where k is the effective spring constant of the combination

For individual springs $x_1 = -\,\frac{F}{k1}$ and $x_2 = -\,\frac{F}{k2}$

Hence $\frac{F}{k} = \frac{F}{k1} + \frac{F}{k2}$

$$\frac{1}{k} = \frac{1}{k1} + \frac{1}{k2}$$

2. **Parallel Combination**

In parallel combination (Fig. 1.5(b)), both the springs elongate through the same distance x but experience the load nonuniformly.
Total load across the two springs is given by

$$F = F_1 + F_2$$

where F_1 and F_2 are the forces acting on the individual springs
From Hooke's law

$F = -\,kx,$

$F_1 = -\,k_1\,x$ and $F_2 = -\,k_2\,x$

$$kx = k_1x + k_2x$$

$$k = k_1 + k_2$$

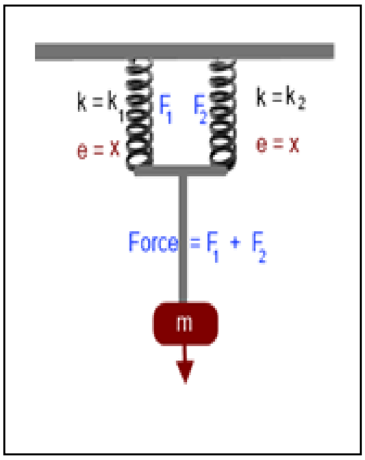

Fig. 1.5(b) Springs in parallel

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Equation of motion for free oscillations:

The motion of a mass suspended by a spring is an example of free oscillations.
The restoring force developed in the spring when it is stretched through a distance 'x' by a force is given by Hooke's law

$$F = -kx$$

By Newton's second law; F = ma

$$ma = -kx$$

$$a = -(k/m)x \qquad k/m = \omega^2$$

$$a = -\omega^2 x$$

$$\frac{d^2y}{dt^2} + \omega^2 x = 0$$

This represents the differential equation for a free oscillation.

And the solution can be written as

$$x = A \sin(\omega t + \varphi)$$

The frequency of oscillation is $f = \frac{\omega}{2\pi}$

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$ is the natural frequency of the oscillation.

Natural frequency

Natural frequency is the frequency of oscillations of a body executing free oscillations.

Damped and Forced oscillations:

Damped Oscillations:

Damped oscillations are oscillations of a gradually diminishing amplitude executed by a body under the combined action of its own elastic forces and the resistive forces of the medium. The amplitude of oscillation decreases due to the involvement of resistive forces and the energy is dissipated.

Examples of damped oscillations:

1. **Simple pendulum oscillating in air:** Consider a simple pendulum oscillating in air. During the motion the pendulum experiences air resistance which leads to the

dissipation of energy. Hence the amplitude of oscillations of the simple pendulum decreases and finally comes to a stop.

2. **Spring mass system with mass immersed in a liquid:** Consider a spring mass system in which the oscillating mass is immersed in a viscous fluid. During the oscillations the viscous force acting on the mass reduces the amplitude progressively.

3. **LC oscillations:** Let a charged capacitor be connected across an inductor. In this system the capacitor discharges through the inductor and gets charged in the opposite direction. This process continues in setting an oscillatory current in the circuit. Such oscillations are called LC oscillations. If the inductor and capacitor are not ideal, the energy is dissipated across the components and the amplitude of the oscillatory current decreases continuously thus leading to damped oscillations.

Theory of Damped oscillations:

In damped oscillations, the free vibrations of the body gradually diminish in amplitude and finally die away because of the forces opposing the motion arising from the viscosity, internal friction or resistance of the outside medium. These forces are usually proportional to the instantaneous velocity and act in a direction opposite to the velocity.

Hence in the case of damped oscillations, the forces acting on the body are,

1. The **restoring force** proportional to the displacement but oppositely directed, given by

$$F_r = -kx$$

$$F_r = -m\omega^2 x \qquad (k = m\omega^2)$$

2. The **damping force** proportional to the velocity and opposing the motion, given by

$$F_d = -r\frac{dx}{dt} \qquad \text{(r is the resistive force per unit velocity)}$$

The total force $F = F_r + F_d$

$$F = -m\omega^2 x - r\frac{dx}{dt} \qquad \text{---------- (1)}$$

By Newton's second law of motion $F = ma$ $\qquad a = \frac{d^2x}{dt^2}$

$$m\frac{d^2x}{dt^2} = -m\omega^2 x - r\frac{dx}{dt}$$

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + m\omega^2 x = 0$$

$$\frac{d^2x}{dt^2} + (r/m)\frac{dx}{dt} + \omega^2 x = 0$$

Putting (r/m) = 2b, (b is the damping factor)

$$\frac{d^2x}{dt^2} + 2b\frac{dx}{dt} + \omega^2 x = 0 \quad \text{---------} \ (2)$$

To solve the equation, put $x = Ae^{\alpha t}$

Then $\frac{dx}{dt} = \alpha Ae^{\alpha t}$

$\frac{d^2x}{dt^2} = \alpha^2 Ae^{\alpha t}$

$= \alpha^2 x$

Substituting in eq 2. $\alpha^2 x + 2b\alpha x + \omega^2 x = 0$

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

the solution of this quadratic equation is $\alpha = \frac{-2b \pm \sqrt{4b^2 - 4\omega^2}}{2}$

$= -b \pm \sqrt{b^2 - \omega^2}$

$= -b \pm n \qquad (n = \sqrt{b^2 - \omega^2})$

ie. $\alpha_1 = -b + n$ and $\alpha_2 = -b - n$

Hence the general solution is

$$x = Ae^{(-b+\sqrt{b^2-\omega^2})t} + Be^{(-b-\sqrt{b^2-\omega^2})t}$$

The form of the solution depends on the relative magnitudes of b and ω.
There are 3 possible cases.

1) **Over damped**

If $b^2 > \omega^2$, $\sqrt{b^2 - \omega^2}$ is real and less than b

Now $(-b + \sqrt{b^2 - \omega^2})$ *and* $(-b - \sqrt{b^2 - \omega^2})$ are both negative

Hence the displacement x dies off exponentially to zero without performing oscillation. This type of motion is called over damped.

2) **Critical damped**

If $b^2 = \omega^2$, the presence of the term e^{-bt} makes the motion non-oscillatory and is called critical damped motion.

3) **Under damping**

If $b < \omega$, $b^2 - \omega^2$ is negative and $\sqrt{b^2 - \omega^2}$ is imaginary.

But $n = \sqrt{b^2 - \omega^2} = \sqrt{-1(\omega^2 - b^2)}$

$= ib$

$$x = Ae^{(-b+ib)t} + Be^{(-b-ib)t}$$

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$$x = e^{-bt}(A\,e^{ibt} + Be^{-ibt})$$

$= e^{-bt}\,[A\,(\cos bt + i\sin bt) + B\,(\cos bt - i\sin bt)\,]$

$= e^{-bt}\,[\,(A + B)\cos bt + i\,(\mathrm{A} - \mathrm{B})\sin bt]$

$= e^{-bt}\,[\,a\sin\varphi\cos bt + a\cos\varphi\sin bt]$

where $(A + B) = a\sin\varphi$ and $i(A - B) = a\cos\varphi$

$$\boldsymbol{x = ae^{-bt}\sin(bt + \varphi)}$$

as time passes the amplitude of vibration decreases and ultimately comes to a halt.

Quality factor:

The quality factor is defined as 2π times the ratio of the energy stored in the system to the energy lost per period

$Q = 2\pi\,\frac{E}{PT}$ where P is the power dissipated and T is the period

P= E/τ τ is the relaxation time

Q = ωτ ω is the 2π/T

It indicates that for higher value of Q, higher would be the value of relaxation time. So lower damping

Forced Vibrations:

Forced vibrations can be defined as the vibrations in which the body vibrates with a frequency other than its natural frequency under the action of an external periodic force.

Ex.: Vibration of a bridge under the influence of marching soldiers

Vibrations of an electrically maintained tuning fork.

In this case the forces acting on the body are

1) The **restoring force** proportional to the displacement but oppositely directed

$F_r = -kx$

2) **Resistive forces** proportional to the velocity but oppositely directed, $F_f = -r\,\frac{dx}{dt}$

3) The **external periodic force** F sin pt

The total force F = - kx - r $\frac{dx}{dt}$ + F sin pt

$$m\frac{d^2x}{dt^2} + r\,\frac{dx}{dt} + kx = F \sin pt$$

$$\frac{d^2x}{dt^2} + (r/m)\,\frac{dx}{dt} + \left(\frac{k}{m}\right)x = (F/m)\sin pt$$

$$\frac{d^2x}{dt^2} + 2b\,\frac{dx}{dt} + \omega^2 x = f \sin pt \quad \text{----- (1)},$$

$$where \quad (r/m) = 2b,\ (k/m) = \omega^2 \text{ and } (F/m) = f$$

In this case, at steady state, the body vibrates with the frequency of the external applied force.

The solution can be written as $x = A \sin(pt-\theta)$

$$\frac{dx}{dt} = A\,p \cos(pt-\theta)$$

$$\frac{d^2x}{dt^2} = -A\,p^2 \sin(pt-\theta)$$

Substituting in eqn(1)

$$-Ap^2 \sin(pt-\theta) + 2b\,Ap \cos(pt-\theta) + \omega^2 A \sin(pt-\theta) = f \sin[(pt-\theta)+\theta]$$

$$A\,(\omega^2-p^2)\sin(pt-\theta) + 2b\,Ap\cos(pt-\theta) = f\sin(pt-\theta)\cos\theta + f\cos(pt-\theta)\sin\theta$$

Equating coefficients of sin (pt-θ) on both sides

$$A\,(\omega^2-p^2) = f\cos\theta \quad \text{----(2)}$$

Equating coefficients of cos (pt-θ) on both sides

$$\text{And } 2bAp = f\sin\theta \quad \text{-----(3)}$$

Squaring and adding eqns. 2 and 3

$$A^2(\omega^2-p^2)^2 + 4b^2A^2p^2 = f^2$$

$$A^2 = \frac{f^2}{(\omega^2-p^2)^2+4b^2p^2}$$

$$\text{Amplitude} \quad A = \frac{f^2}{\sqrt{(\omega^2-p^2)^2+4b^2p^2}} \qquad \text{---------(4)}$$

Dividing (3) by (2)

$$\tan\theta = \frac{2bAp}{A(\omega^2 - p^2)}$$

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$$\text{phase}\,\theta = \tan^{-1}\frac{2bAp}{A(\omega^2 - p^2)}$$

Case 1. When the driving frequency is low ie p << ω

$A = f/\omega^2$ = constant and $\theta = \tan^{-1}(0) = 0$

ie. amplitude of vibration is a constant and force and displacement are always in phase.

Case 2. When p = ω

Frequency of the external force is equal to the frequency of the body

$A = f/2bp = F/r\omega$ $\quad$ (r/m)=2b , p = ω and (F/m) = f

$\theta = \tan^{-1}(bp/0) = \pi/2$

amplitude is governed by damping. For small damping forces, the amplitude will be large. The displacement lags behind the force by a phase of π/2.

Case 3. When p >> ω

The frequency of the external force is greater than the natural frequency of the body

$A = \frac{f}{\sqrt{(p2)2+4b2p2}} = f/p^2$

$\theta = \tan^{-1}(2b/p)$

$\tan^{-1}(-0) = \pi$

In this case the amplitude goes on decreasing and phase difference tends towards π.

Resonance

When the frequency of the periodic force acting on a vibrating body is equal to the natural frequency of vibration of the body, the amplitude of vibration of the body increases. This phenomenon is called resonance.

Examples: Helmholtz resonator, resonance column, radio receiver set tuned to the frequency of the transmitting station. etc.

Condition for the amplitude to become maximum in eqn. (4) is

$(\omega^2 - p^2)^2 + 4b^2p^2$ should become minimum

ie. $\frac{d}{dp}[(\omega^2 - p^2)^2 + 4b^2p^2\,] = 0$

$8b^2p - 2(\omega^2 - p^2) * 2p = 0$

$$2b^2 - (\omega^2 - p^2) = 0 \quad \text{ie.} \quad p^2 = \omega^2 - 2b^2$$

When damping is minimum, $p = \omega$ and amplitude becomes maximum

$$\text{At resonance, } A_{max} = \frac{F/m}{\sqrt{4b^2\omega^2}} = \frac{F/m}{2b\omega}$$

Sharpness of Resonance

When the frequency of the applied force is varied and made equal to the natural frequency of the body, the amplitude of vibration reaches a maximum. This is called as tuning.

Sharpness of resonance is the rate at which the amplitude changes corresponding to a small change in frequency of the applied force, at the point of resonance.

$$\text{ie. sharpness of resonance} = \frac{change\ in\ amplitude}{change\ in\ frequency}$$

the rise of amplitude will be very sharp when the damping is very small.

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Shock Waves

Mach number:

In Aerodynamics, the speeds of bodies moving in a fluid medium are classified into different categories on the basis of Mach number. It is defined as the ratio of the speed of the object to the speed of the sound in the given medium, i.e.,

$$Mach\ number\ = \frac{\text{object speed}}{\text{speed of sound in the medium}}$$

It is denoted as M. Let 'v' be the object speed and 'a', the speed of sound in the medium , then, $M\ = \frac{v}{a}$. Since it is a ratio of speeds, it doesn't have a unit as the name itself indicates, it is a pure number.

Speed of sound:

The speed of sound 'a' in air or any gas medium at a temperature T (in Kelvin) is given by, $a = \sqrt{\gamma RT}$, where γ is the ratio of specific heats and R is the specific gas constant.

Distinction between acoustic, ultrasonic, subsonic and supersonic waves:

Acoustic waves:

An acoustic wave is simply a sound wave. It moves with the speed 333 m/s in air at STP. Sound waves have frequencies between 20 Hz to 20, 000 Hz. Amplitude of acoustic wave is very small.

Ultrasonic waves:

Ultrasonic waves are pressure waves having frequencies beyond 20,000 Hz. but they travel with the same speed as that of sound. Amplitude of the ultrasonic wave is also small.

Subsonic waves:

If the speed of the mechanical wave or body moving in the fluid is lesser than that of sound then such a speed is referred to as subsonic and the wave is a subsonic wave. All subsonic waves have Mach number M<1. The speeds of almost all the vehicles such as motor cars or trains that we see moving on the road fall in the subsonic category. The speeds of flight of birds is also subsonic.

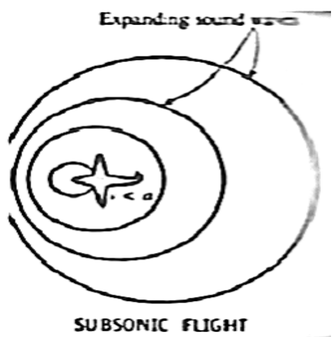

Fig. 1.6 Subsonic flight

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Subsonic flight:

For a body moving with subsonic speed, the sound emitted by it manages to move ahead &away from the body since it is faster than the body (Fig.1.6)

Supersonic waves: Supersonic waves are mechanical waves which travels with speeds greater than that of sound, i.e., with speeds for which, Mach number M >1. A body with supersonic speed. Zooms ahead by piercing its own sound curtain leaving behind a series of expanding sound waves with their centers displaced continuously along its trajectory. Today's fighter planes can fly with supersonic speed (Fig. 1.7). Amplitude of supersonic waves will be high & it affects the medium in which it is travelling.

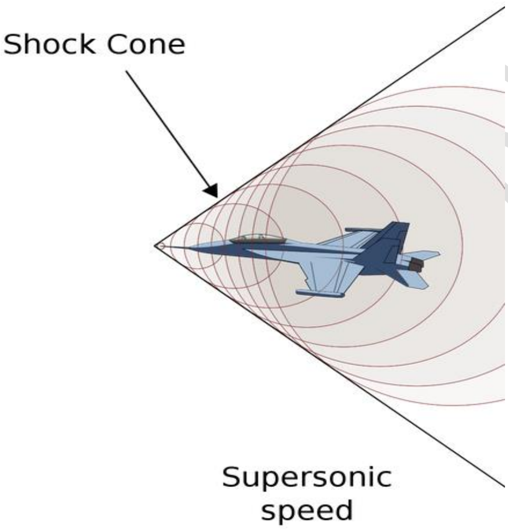

Fig. 1.7 Supersonic flight.

Mach angle:

A number of common tangents drawn to expanding sound waves emitted from a body at supersonic speed, formulates a cone called the Mach cone. The angle made by the tangent with the axis of the cone (half angle of the cone) is called Mach angle μ. μ is related to the Mach number, M through the equation, $\mu = \sin^{-1}\left(\frac{1}{M}\right)$

In supersonic waves, we have a special class of waves called hypersonic waves. They travel with speeds for which Mach number ≥ 5.

Research is being carried out in half a dozen countries including India, to develop engines named "scram jets" which can empower vehicles to fly at speeds of Mach number ≥ 5.

Transonic waves:

There is a speed range which overlaps on the subsonic & supersonic ranges. This is actually in the domain in which, there is a change of phase from subsonic to supersonic. Since it becomes very difficult to precisely categorize certain parameters at speeds near (or at) M=1, this range is brought into picture. We say it is transonic range for speeds $0.8 < M < 1.2$. It is what we call as grey area, where there is overlapping of some of the characteristics of both the subsonic &supersonic speeds.

SHOCK WAVES

Description of a shock wave: Any flood that propagates at supersonic speeds, gives rise to a shock wave. Shockwaves are produced in nature during earthquakes and when lightning strikes. When velocity of a body increases from subsonic to supersonic, we can hear the booming sound of shockwaves. It is called the "Sonic boom". Shockwaves can be produced by the sudden dissipation of mechanical energy in a medium enclosed in a small space. Shockwave is a surface that manifests as a discontinuity in a fluid medium in which it is propagating with supersonic speed. They are characterized by a sudden increase in pressure and density of gas through which it propagates. Shockwaves are identified as strong or weak depending on the magnitude of instantaneous change in pressure and temperature in the medium of space bound within the thickness of the shock front. It is of the order of a few micrometres.

For example, the shockwaves created by a nuclear explosion of crackers are weak and they are characterized by low Mach number.

Properties of shock waves:

1. A Shock wave is not a continuous wave, it is an instantaneous pulse wave.
2. They are characterized by the abrupt change in the pressure, temperature and density of the medium.
3. Shock waves are supersonic waves, which travel in any medium with a speed more than the speed of sound in that medium.
4. Shock waves propagating in any medium obey the laws of conservation of mass, energy and momentum.
5. The effects caused by shock waves in a medium are an irreversible process, which leads to the increase in the entropy of the medium.
6. Shock waves exist in the medium of propagation confined to a very thin space of thickness, less than 1 μm. This small volume around the shock wave front is called the control volume.

Applications of Shock waves:

1. Aerodynamics – hypersonic shock tunnels, scramjet engines.
2. Shock waves are used to cause high temperature chemical kinetics.
3. They are used in rejuvenating depleted bore wells.
4. Material studies – effect of sudden impact pressure, blast protection materials
5. In industry shock waves are generated for preservative impregnation studies into wood slats used for manufacturing pencils.
6. In medicine:

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i. Shock waves are used in the treatment of urolithiasis. It is widely used to treat kidney and urethral stones.
ii. Investigation of traumatic brain injuries.
iii. Needle-less drug delivery.

REDDY SHOCK TUBE:

Reddy shock tube is a hand operated shock tube capable of producing shockwaves by using human energy. It has a long cylindrical tube with two sections separated by a diaphragm. Its one end is fitted with a piston and the other end is closed or open to the surroundings (Fig. 1.8).

Construction: Reddy shock tube consists of a cylindrical stainless-steel tube of about 30mm diameter and length 1m. It is divided into two sections, each of length 50 cm, where the first section (which is attached to the piston) is called the driver tube and other one is driven tube separated by 0.1mm thick of diaphragm.

1. The Reddy tube has a piston fitted at far end of the driver section and the far end of the driven section is closed.

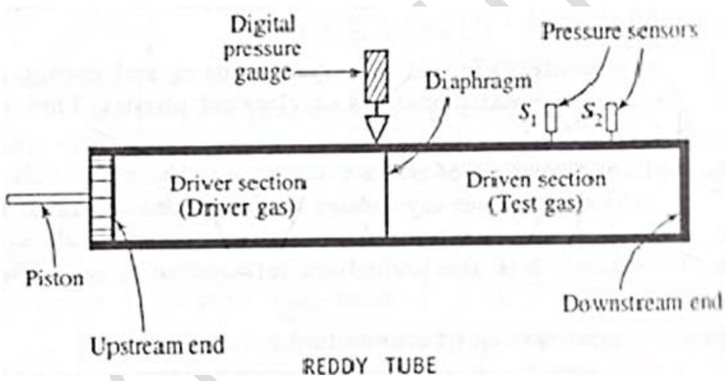

Fig. 1.8 Reddy's shock tube

2. Digital pressure gauge is mounted in the driver section next to the diaphragm. Two piezoelectric sensors S_1 and S_2 are mounted 70mm apart towards the closed end of the shock tube. A port is provided at the closed end of the driven section for the filling the test gas to the required pressure.

3. The driver section is filled with a gas termed as driver gas, which is held at relatively high pressure due to the compressing action of the piston.

Working: The driver gas is compressed by pushing the piston hard into driver tube until the diaphragm ruptures. Then the driver gas rushes into the driven section and pushes the driven gas towards the far downstream end. This generates a moving shock wave which instantaneously raises the temperature and pressure of the driven gas, as the shock wave moves over it. The propagating primary shock waves are reflected from the downstream end. After the reflection, the test gas undergoes further compression which boosts its temperature and pressure to still higher values by the reflected shock waves.

This state of high values of pressure and temperature is sustained or continuous (time of the order of milliseconds) at the downstream end until an expansion wave reflected from the upstream end of the driver tube arrives there and neutralizes the compression partially. These expansion waves are created at the instant the diaphragm is ruptured and they travel in the direction of the shock waves.

Actual creation of shock waves depends on the properties of driver and test gases and dimension of the shock tube. Pressure rise caused by primary shock waves and reflected shock waves are sensed by sensors S_1 and S_2 respectively and they are recorded in digital cathode ray (CRO). The pressure sensors are piezoelectric transducers.

Since the experiment involves 1 millisecond duration measurement, the rise time of the oscilloscope should be a few microseconds with a bandwidth of 1 MHz. From the recording on the CRO, the time taken by the shock wave to travel the distance between the sensors is noted. From this, the speed and the Mach number can be calculated. The pressures and temperatures before and after the generation of the shock waves can also be calculated.

Methods of creating shock waves in the laboratory using a shock tube:

Shock waves can be created in the laboratory by

1. Using a Reddy's tube
2. Detonation (A violent release of energy or explosion)
3. Very high-pressure gas cylinder
4. Combustion
5. Using small charge explosives

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QUESTION BANK:

1. Define SHM. Derive the differential equation of SHM.
2. Derive the equations for the equivalent spring constants for two springs in series and parallel combinations.
3. Explaining the theory of damped oscillations derive the general solution for damped oscillations.
4. Derive the equation for the amplitude of a forced oscillation.
5. Explain Mach number and Mach cone.
6. What are shock waves, mention any 4 applications of it.
7. List the properties of shock waves.
8. Define the following: (i) ultrasonic, (ii) subsonic and (iii) supersonic waves.
9. Explain the principle and working of Reddy's shock tube.
10. Give the characteristics of Reddy tube.