F.Y.B.Sc. SEM – II

Subject: Physics

Paper- 101

Unit -1

SOUND

- Introduction
- Sound
- Wave motion
- Types of wave
- Vibrations
- Acoustics of building
- Worked problems

INTRODUCTION:

Sound is produced due to the vibrations of the body. These vibrations are transferred to the air medium and propagated in all directions in the form of waves. When the vibrational sound waves reach our ear, the diaphragm of the ear vibrates with equal vibrations produced by the body. Hence we are able to hear the sound by the sensation perceived by the nerves of the ear.

The number of vibrations made in one second is known as frequency of the sound. It is expressed in hertz (Hz). The range of the frequency between 20 Hz and 20,000 Hz is the audible range, Human ears cannot respond to the sound below and above this range. In this sense, all vibrating bodies cannot produce audible sound. The vibrations of frequency below 20 Hz are called infrasonic and above 20,000 Hz are called ultrasonic.

Sound is a mechanical wave and hence it requires a medium to propagate. So we can't hear the sound in vacuum. It travels with the velocity of 330 ms^{-1} in air. Sound waves are reflected and refracted like light waves.

Wave motion:

When a stone is thrown on a pond of water, ripples spread out in all directions on the surface of water. The stone disturbs the water medium at one place but the disturbance is transferred in all directions continuously. This continuous movement of the disturbance is called a wave.

If a wave passes in a medium, the particles of the medium vibrate about their mean position. The particles do not move along with the wave, only the vibrations are transferred from one particle to adjacent particle of the medium in the form of energy.

There are two types of wave motion. They are

1) Longitudinal wave motion and

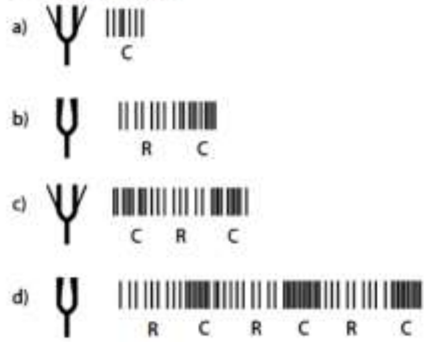
2) Transverse wave motion

1) Longitudinal wave motion:

If the particles of the medium vibrate parallel to the direction of propagation of the wave, the wave is known as longitudinal wave.

Examples:

1. The propagation of sound in air
2. The propagation of sound in gas
3. The propagation of sound inside the liquid



The longitudinal waves travel in a medium in the form of compressions and rarefactions. The place where the particles of the medium crowded together are called compressions and the places where the particles spread out are called rarefactions.

The compressions and rarefactions produced by a vibrating tuning fork are as shown in the figure. When the prong (arm) of the fork moves to the right, it compresses the medium in front of it to form compression. Meanwhile the prong returns to the left, a temporarily vacuum is created there. To fill it, the particles of the medium spread out in that place to form a rarefaction.

Thus as the prong of the fork vibrates to and fro, alternate compressions and rarefactions are transmitted in the medium. As a result, the particles of the medium simply move back and forth about their mean position parallel to the direction of the propagation of the wave.

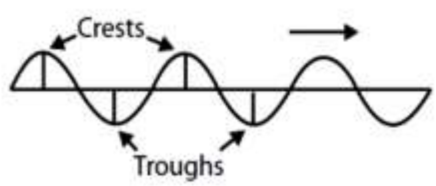
2) Transverse wave motion:

If the particles of the medium vibrate perpendicular to the direction of propagation of the wave, the wave is known as transverse wave.

Examples :

1. Ripples travelling on the water surfaces.
2. Waves travelling along a rope.
3. Other waves like light waves,heat radiations, radio waves etc.

The transverse waves travel in a medium in the form of crests and troughs. The points where the particles of the medium displaced maximum in the upward direction are called crests. The points where the particles displaced maximum in the downward direction are called. troughs



The crests and troughs produced by the transverse wave motion are as shown in the figure. In transverse wave, alternate crests and troughs are transmitted in the medium. As a result, the particles of the medium move up and down about their mean position perpendicular to the direction of propagation of the wave.

Progressive Waves:

If a wave travels continuously in a medium without any disturbance, then the wave is said to be progressive wave. Longitudinal waves and Transverse waves are two types of progressive waves and they can travel continuously in any medium if there is no obstruction.

Amplitude:

When sound wave propagates in a medium, the maximum displacement of the vibrating particles of the medium from their mean position is called amplitude.

Wavelength (λ) :

The wavelength is the distance between two consecutive particles of the medium which are in the same state of vibration.

It is also defined as the distance travelled by the wave during the time the vibrating particle completes one vibration.

In longitudinal waves, the wavelength is the distance between two successive compressions or rarefactions. In transverse waves, the wavelength is the distance between two successive crests or troughs.

Period (T):

The time taken by the vibrating particle to make one vibration is called period.

Frequency (n):

The frequency is the number of vibrations made by the vibrating particle in one second.

Velocity (v):

The distance travelled by the sound wave in one second is known as velocity of sound.

Relation between Wavelength, Frequency and Velocity of a Wave :

Let n be the number of vibrations made by the vibrating particle in one second. It is also known as its frequency.

Time taken for one vibration = period (T) = 1/n.

Let λ be the wavelength of the wave produced

Velocity of the wave is the distance through which the wave advances in the medium in one second

$$\therefore \text{Velocity of wave motion,} V = \frac{\text{distance travelled}}{\text{time taken}}$$

$$V = \lambda/T = \lambda/(1/n) = \lambda n$$

$$\therefore V = n\lambda$$

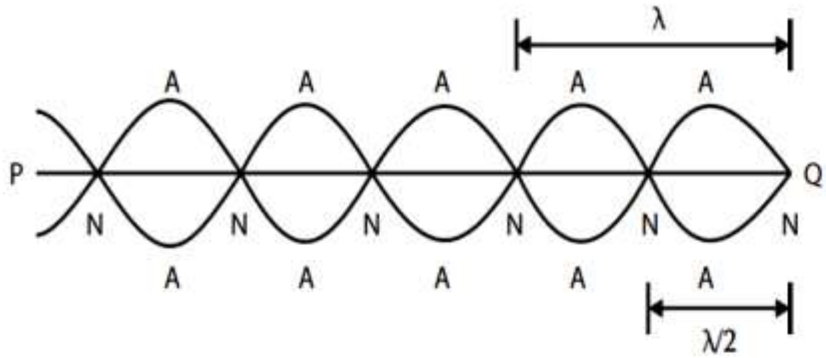
Stationary Waves:

If a progressive wave travelling in a medium meets the surface of an obstacle, it is reflected. The reflected wave is superimposed on the incident wave to form a new type of wave called stationary wave.

Also, when two identical waves having equal wavelength and amplitude travel in opposite directions they superimpose on each other forming stationary wave.

A stationary wave formed by a vibrating string is as shown in the figure. Consider a string P Q fixed at the end Q and it vibrates up and down at the free end P. Then a transverse wave is setup and it proceeds towards the fixed point Q and gets reflected back to the end P. Now the stationary wave is formed in the string.

At certain points of the medium, the displacement due to the two waves cancel each other and those points remain at rest. Such points are called nodes (N). At certain other points there is maximum displacement. Such points are called antinodes (A). The distance between two successive nodes or antinodes is $\lambda / 2$.



The distance between a node and the next antinode is $\lambda / 4$

The longitudinal waves also produce the stationary waves.

VIBRATIONS

Free Vibrations :

The vibrations of any body with its natural frequency are called free vibrations.

When a body is set in vibration and left free, it executes vibrations. The frequency depends upon the dimensions and elastic constants of the body. Such vibrations are called free vibrations and the frequency of vibration is known as the natural frequency.

If a tuning fork is set in vibration, it vibrates with its own frequency. Such vibrations are called free vibrations or natural frequency.

Forced Vibrations :

The vibrations of a body with a frequency induces vibrations on another vibrating agent are called forced vibrations.

Suppose a vibrating tuning fork is placed with its stem on a table, the vibrations of the fork are impressed on the table and the table is forced to vibrate. The vibrations set up on the table are called forced vibrations.

Resonance :

When the forced vibrations given on the body is equal to its natural frequency of vibrations, the body vibrates with maximum amplitude. This phenomenon is called resonance.

When a vibrating tuning fork is kept on a table, the table is forced to vibrate with the frequency of the tuning fork. If the natural frequency of the table is equal to the frequency of the tuning fork, the table vibrates with its natural frequency and hence resonance occurs.

Laws of vibration in stretched strings:

I Law : The frequency of vibrating string is inversely proportional to its length, when the tension and linear density of the string are kept constant.

$$n \propto \frac{1}{l}$$

II Law : The frequency of vibration is directly proportional to the square root of the tension, when the length and linear density of the string are kept constant.

$$n \propto \sqrt{T}$$

III Law : The frequency of vibration is inversely proportional to the square root of the linear density of the string, when the tension and length of the string are kept constant.

$$n \propto \frac{1}{\sqrt{m}}$$

According to above laws,

$$n \propto \frac{1}{l}\sqrt{\frac{T}{m}} \quad \text{(or)} \qquad n = k\frac{1}{l}\sqrt{\frac{T}{m}}$$

Where k – is a constant and its value is equal to ½.

$$\therefore\ n \propto \frac{1}{2l}\sqrt{\frac{T}{m}}$$

ACOUSTICS OF BUILDINGS:

Echo : The first reflected sound is known as echo. The sound produced by a source is propagated continuously in a medium if there is no disturbance. But if it meets the hard surface of an obstacle, it is reflected. The clear echo depends upon the following factors.

1. Good reflector of sound
2. Maximum surface area of the reflector and
3. The distance of the reflector from the source of sound.

Reverberation :

The sound produced in a hall suffers multiple reflections before it becomes inaudible. As a result of these reflections, the listener continues to receive sound, even if the source of sound is cut off. This prolonged reflection of sound in a room even after the sound source has been stopped is called reverberation. It is the persistence of sound due to multiple reflections from the walls, floor and ceiling of a hall. The reverberation is also called multiple echoes. In a room, the walls, floor and other flat surfaces reflect sound with a small loss of energy.

Reverberation time:

If a building is to be acoustically correct, its reverberation time must be in optimum level. It should not be too long or too short. if it is too short, then the room becomes dead in sound aspect. If it is too long, then the reverberation will be there inside the building for long duration. The reverberation produces continuous sound with decreasing intensity upto a particular time after that it disappears. This time is known as reverberation time.

The reverberation time is defined as the time taken by the sound to fall from its original intensity to one millionth of its original intensity.

Sabine formula :

Sabine derived an equation for the reverberation time.

Where V is the volume of the hall, a is the coefficient of absorption of each reflecting surface present in the hall and A is the area of the each

$$T = \frac{0.16\,V}{\alpha\,A} \text{ second}$$

sound absorbing surface present in the hall.

Coefficient of absorption of sound energy:

The co-efficient of absorption of sound energy of any surface is defined as the ratio of the sound energy absorbed by the surface to the total sound energy incident on the surface.

Let α be the coefficient of absorption of sound energy of a surface, then

$$\alpha = \frac{\text{The sound energy absorbed by the surface}}{\text{The total sound energy incident on the surface}}$$

Acoustics of Buildings (Architectural acoustics):

The term 'Acoustics of building' describe the production, transmission and reception of sound inside the building. The following points should be taken into consideration for the acoustic design of the buildings, auditorium, cinema theatres etc.

1. The sound heard by the audience should be sufficiently loud in any part of the hall.
2. The quality of the speech and music should not be changed any where inside the hall.
3. There should not be focusing of sound due to walls and ceiling, in any part of the hall.
4. There should not be any vibrations due to resonance.
5. There should not be any other noise from other sources, both from outside the hall and from with in the hall.

Two more important factors should also be considered for good acoustic design of the buildings.

1. Echo and 2. Reverberation

1. Echo :

The direct sound from the source and the reflected sound (echo) from the walls produce confusion in certain buildings. A hall with large number of open windows is free from the defect. Echoes can be eliminated by making the walls rough. But in the case of musical hall, however echoes are desirable, to a certain extent.

2. Reverberation :

The Reverberation is the prolonged reflections of sound from the walls, floor and ceiling of a hall. The sound produced in the hall undergoes multiple reflections before it becomes inaudible. As a result the clarity of the successive speech is affected. Due to this reason, the reverberation time should be optimum to hear the clear sound in the hall.

To minimize this defect, Sabine derived an equation for the reverberation time,

Where V is the volume of the hall, α is the coefficient of absorption of each reflecting surface present in the hall and A is the area of the each sound absorbing surface present in the hall.

$$T = \frac{0.16V}{\alpha A} \text{ second}$$

In the above Sabine's equation, T will be minimized by increasing the value of α. So the reverberation is minimized by covering the inner surfaces of the hall using absorption materials like carpets, wall screen, porous tiles etc.

The reverberation time value depends on the use for which the building is designed. The acceptable limit for reverberation time is

For speech, 0.5 s

For music, between 1.0 and 2.0 s

For small theatres, between 1.0 and 1.5 s

For larger theatres, up to 2.3 s

WORKED PROBLEMS

1. A wire 50 cm long and of mass 6.5 × 10^{-3} kg is stretched so that it makes 80 vibrations per second. Find the stretching tension.

$$m = \frac{\text{mass}}{\text{length}} = \frac{6.5\times10^{-3}}{0.5} = 13\times10^{-3}\ \text{kgm}^{-1}$$

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} \text{ or } n^2 = \frac{1}{4l^2}\frac{T}{m}$$

$\therefore$ Tension $T = 4l^2m^2\ n = 2 \times 0.5 \times 0.5 \times 13 \times 10^{-3} \times 80 \times 80$

$= 83.2$ N

2. The density of a sonometer wire of radius 0.3mm is 7800 kgm^{-3}. Find its linear density.

Linear density $m = \pi r^2 \rho$

$m = 3.14 \times (0.3 \times 10^{-3})^2 \times 7800$

$= 2204.28 \times 10^{-6}$

$= 2.204 \times 10^{-3}$ kg m^{-1}

QUESTIONS

Part - A and Part – B

1. Define wave motion.
2. Define transverse wave motion.
3. Define longitudinal wave motion.
4. Define progressive wave.
5. Define amplitude of a wave.
6. Define wavelength of a wave.
7. Define period of wave motion.
8. Define frequency of a wave.
9. Define velocity of sound wave.
10. Define stationary wave.
11. Define free vibrations.
12. Define forced vibrations.
13. Define Resonance.
14. State any one of the laws of transverse vibrations in stretched strings.