B.Sc. Computer Science

Sem - IV

Wave and Optics

Sound Waves

Sound waves produced by the vibrating body which excites mechanical waves in the surrounding medium.It consist of areas of high and low pressure known as compressions and rarefaction.

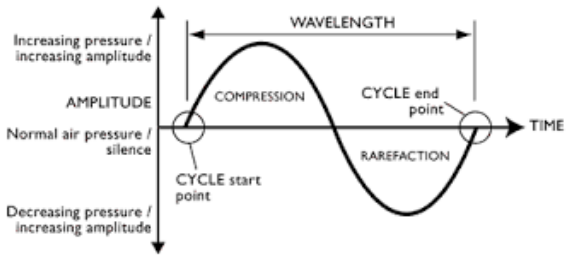

Figure: propagation of sound wave

Compressions are the regions where particles are crowded together i.e. the region of higher density and pressure and Rarefaction are the region of lower density and pressure.The distance between two successive compression and rarefaction is the wavelength represented by the symbol λ.

Classification of sound

- **On the basis of frequency**
  1. **Audible waves**:-16Hz to 200000Hz.
     - ★ Musical Sound:- Periodic vibration.
     - ★ Noise:- Non - periodic vibration.
  2. **Infrasonic waves**:-below16Hz.
  3. **Ultrasonic waves**:-above20KHz.
  4. **hypersonic waves**:-elastic wave of frequency $10^{10}Hz$.

CHARACTERISTICS OF MUSICAL SOUND

- **Loudness or intensity**:- "The amount of sound energy crossing per unit area per unit time is known as intensity of sound". Loudness of sound depends upon its intensity and sensitivity of the ear.

$$S \propto log_e I \tag{1}$$

Where S is the sensation of loudness and I is the intensity of sound.

Factors affecting the Loudness or Intensity of sound

- **Amplitude**:The loudness of sound is directly proportional to the square of the amplitude of the sounding body.i.e. if amplitude is greater then sound will be louder.
- **Surface area**:- The loudness of sound is directly proportional to the surface area of the sounding body.
- **Motion of air**:-Loudness is more in the direction of flow of air
- **Distance between the source and listener**:-The intensity of sound is inversely proportional to the square of distance between source and listener.
- **Density of the medium**:-The intensity of sound is directly proportional to density of medium.

- **Pitch**:- "When a tone of given frequency is sounded then the subjective sensation percieved by the ear is known as Pitch".
  Note
  - Sound having well defined frequency is known as **tone**.
  - The tone having frequency n is known as **fundamental tone**.
  - The additional tones having frequency $2n$,$3n$,$4n$,.... are known as **overtones** or **harmonics**
- **Quality or Timber**:-It helps us to identify the sounds produced by the instrument. It is also a subjective sensation and it is the quality of the sound that corresponds to quality of waveform which is produced by the source.

Intensity of sound

If p is the pressure amplitude and I is the intensity of the sound
Than

$$I \propto p^2 \tag{2}$$

$$I = \frac{p_{max}^2}{2\rho v} \tag{3}$$

Let ρ = the density of the medium
n = frequency of the sound
v = velocity of the sound
a = amplitude of the wave
Therefore the amount of sound energy transferred per unit area per unit time is given by

$$I = 2\pi^2 \rho n^2 a^2 v \tag{4}$$

$$\text{v} = \sqrt{\frac{E}{\rho}}$$

Let dV is the change in volume and V is the original volume

$$\text{E} = -\frac{p}{dV}$$

Therefore

$$v = \sqrt{\frac{-p}{(\frac{dV}{V})\rho}}$$

let $\frac{dV}{V} = \frac{dy}{dx}$

$$v = \sqrt{\frac{-p}{(\frac{dy}{dx})\rho}}$$

Squaring both sides

$$v^2 = \frac{-p}{(\frac{dy}{dx})\rho}$$

$$p = -v^2\rho\frac{dy}{dx} \tag{5}$$

The equation for Simple Harmonic Wave is given by

$$y = aSin\frac{2\pi}{\lambda}(vt - x)$$

$$\frac{dy}{dx} = \frac{-2\pi a}{\lambda}Cos\frac{2\pi}{\lambda}(vt - x)$$

Putting the value of $\frac{dy}{dx}$ in equation (4) we get

$$p = v^2\rho\frac{2\pi a}{\lambda}Cos\frac{2\pi}{\lambda}(vt - x)$$

$$p = \frac{2\pi a v^2\rho}{\lambda}\lambda Cos\frac{2\pi}{\lambda}(vt - x)$$

$$p = p_{max} Cos \frac{2\pi}{\lambda}(vt - x)$$

Where $p_{max} = \frac{2\pi a v^2 \rho}{\lambda} \lambda =$ Maximum excess of prssure

$$p_{max} = 2\pi a \rho v \frac{v}{\lambda}$$

$$p_{max} = 2\pi a \rho v n \tag{6}$$

Therefore

$$I = 2\pi^2 \rho n^2 a^2 v$$
$$I = \frac{(2\pi \rho n a v)^2}{2\rho v}$$
$$I = \frac{p_{max}^2}{2\rho v}$$

SOUND INTENSITY LEVEL-DECIBEL

The lowest intensity of the sound at 1 kHz to which a normal human ear can respond is known as **threshold of hearing** and is chosen as the "zero" or "standard" intensity. The ratio of the intensity of the sound wave to the threshold intensity is known as the intensity level of the sound.
If I and I_0 are the represents the intensity of two sound of a particular frequency and L_1 and L_0 are there corresponding loudness then according to Weber-Fechner law

$$L_1 = klogI \tag{7}$$

$$L_0 = klogI_0 \tag{8}$$

Therefore the difference in the loudness of the two sounds is given by

$$L = log\frac{I}{I_0}bels \tag{9}$$

L is called intensity level and is expressed in bels.

$$1 \text{ decibel} = \frac{1}{10} \text{ bel}$$
$$\text{L} = 10 log \frac{I}{I_0} \text{ decibels}$$

The intensity level corresponding to the intensity I_0 will be 0 dB

$$\text{L} = 10 log \frac{I_0}{I_0} = 10 log 1 = 0$$

0 dB represents the **threshold of audibility**
The smallest change in intensity level that human ear can detect is 1 dB

$$1 decibel = 10 log \frac{I}{I_0} \tag{10}$$

$$log \frac{I}{I_0} = \frac{1}{10} = 0.1 \tag{11}$$

$$\frac{I}{I_0} = 10^{0.1} = 1.26 \tag{12}$$

$$I = 1.26 I_0 \tag{13}$$

It means that a change in intensity by 26 percent increases the intensity level by one decibel.

Sound pressure level(SPL)

Sound level in terms of pressure

i.e. SPL $= 10log\frac{I}{I_0}$=$10log(\frac{P}{p_0})^2$=$20log\frac{P}{P_0}$

The reference pressure P_0 is usually taken as P_0= $2 \times 10^{-5} N/m^2$.

Phon

Phon is the measure of loudness and it is equal to the loudness of an equally loud $1KHz$ frequency note expressed in decibels.

Loudness in phons

(L.P)= $10log\frac{I}{I_0}$

=$10logI$ +$10log\frac{I}{I_0}$

=$10logI$ +$10log10^{12}$

=$10logI$ + 120

Therefore

$$logL = 0.003(10logI + 120 - 40) = 0.033logI + 2.64 \quad (14)$$

A **Sone** is defined to be equal to 40 phons i.e. a **Sone** is the loudness of a 1 KHz tone of 40dB intensity level.

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