Sound Waves

1. Introduction

Sound is a form of mechanical wave that produces the sensation of hearing. It is generated due to vibrations of objects and propagates through a material medium such as solids, liquids, or gases. Sound waves cannot travel through vacuum, which distinguishes them from electromagnetic waves like light.

Sound waves are longitudinal in nature, meaning the particles of the medium vibrate parallel to the direction of wave propagation. During propagation, regions of high pressure (compressions) and low pressure (rarefactions) are formed.

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2. Nature of Sound Waves

Sound waves are mechanical and longitudinal waves. When a source vibrates, it causes the surrounding particles of the medium to oscillate about their mean positions. These oscillations are transferred from one particle to another in the form of pressure variations.

Key Characteristics:

- Require a material medium
- Cannot travel in vacuum
- Energy is transferred without net transport of matter

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3. Types of Sound Waves

Based on frequency, sound waves are classified into:

(a) Audible Sound

- Frequency range: 20 Hz to 20 kHz
- Can be heard by the human ear

(b) Infrasonic Waves

- Frequency less than 20 Hz
- Produced by earthquakes, volcanic eruptions, and large animals like elephants

(c) Ultrasonic Waves

- Frequency greater than 20 kHz
- Used in medical imaging (ultrasonography), SONAR, and non-destructive testing

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4. Wave Parameters

(a) Wavelength (λ)

The distance between two consecutive compressions or rarefactions. Unit: meter (m).

(b) Frequency (f)

The number of oscillations per second. Unit: hertz (Hz).

(c) Time Period (T)

Time taken for one complete oscillation. $T = 1/f$.

(d) Amplitude (A)

Maximum displacement of particles from their mean position. It determines the loudness of sound.

(e) Wave Velocity (v)

Speed at which the sound wave propagates through a medium.

$v = f\lambda$

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5. Speed of Sound

The speed of sound depends on the nature of the medium and temperature.

- In solids: highest
- In liquids: moderate
- In gases: lowest

For gases:

$v = \sqrt{(\gamma P/\rho)}$

Where γ is the ratio of specific heats, P is pressure, and ρ is density.

At 0°C, speed of sound in air ≈ 331 m/s

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6. Reflection of Sound

When sound waves strike a rigid surface, they bounce back. This phenomenon is called reflection of sound.

Echo:

An echo is the repetition of sound heard after reflection from a distant obstacle. For an echo to be heard distinctly:

- Minimum distance of reflector ≈ 17 m
- Time gap ≥ 0.1 s

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7. Reverberation

Reverberation is the persistence of sound in an enclosed space due to multiple reflections. Excessive reverberation causes distortion of sound.

Control of Reverberation:

- Use of sound-absorbing materials like curtains, carpets, and acoustic panels

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8. Intensity and Loudness

Intensity:

Sound intensity is the sound power transmitted per unit area. Unit: W/m^2.

Loudness:

Loudness is the physiological response of the human ear to sound. It depends on intensity and is measured in decibel (dB).

9. Pitch and Quality

Pitch:

Determined by frequency. Higher frequency → higher pitch.

Quality (Timbre):

Helps distinguish between sounds having same pitch and loudness but produced by different sources.

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10. Doppler Effect

The apparent change in frequency of sound due to relative motion between the source and the observer.

Applications:

- Radar and SONAR systems
- Measurement of speed of vehicles

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11. Applications of Sound Waves

- Communication (speech, music)
- Medical diagnosis (ultrasound)
- Industrial testing
- Navigation (SONAR)

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12. Conclusion

Sound waves play an essential role in daily life and scientific applications. Understanding their properties and behavior helps in fields ranging from medicine to engineering and communication technology.