3

Chapter

ACOUSTICS

CHAPTER OUTLINE

After completion of this chapter, you will be able to know:

- Classification of sound waves, Acoustics of building, Reverberation of sound, absorption coefficient, Noise pollution and its control, Sound insulation, Sabine equation.
- Introduction, production and applications of ultrasonic wave. Ultrasonic method in non-destructive testing.

INTRODUCTION

Sound is a vibration that travels in the form of longitudinal waves through the medium. This means that sound waves are waves in which the particles of the medium vibrate in the same direction as the wave. Because sound waves require a medium to propagate, they are referred to as mechanical waves. The most fundamental properties of sound waves are wavelength, frequency, amplitude, speed, intensity etc. There are different types of sound including, audible, inaudible, unpleasant, pleasant, soft, loud, noise and music. Sound waves are classified into three groups based on their frequency range.

1. **Infrasonic waves:** These are sound waves with frequencies less than 20 hertz. These frequencies are inaudible to humans. Infrasound is used by scientists to detect earthquakes and volcanic eruptions, to map underground rock and petroleum formations, and to study heart activity. Despite our inability to hear infrared waves, many animals use them to communicate in nature.
2. **Audible waves:** These are sound waves with frequencies ranging from 20 hertz to 20,000 hertz (20 kHz). These frequencies are audible to humans.
3. **Ultrasonic waves:** Ultrasonic waves are sound waves with frequencies greater than 20 kilohertz. These frequencies are inaudible to humans.

ACOUSTICS OF BUILDING

The branch of physics which deals with the planning of a building or a hall with a view to provide best audible sound to the audience is called acoustics of building.

Factors Affecting the Acoustics of Building

1. **Extraneous Noise**
   - There may be penetration of sound between rooms.
   - For this the wall must be covered with sound absorbing material and doors must have heavy curtains. (There should be no penetration of sound between rooms)
2. **Loudness**
   - The loudness of sound may vary with position.
   - To make proper loudness every where, wooden reflecting surface can be kept above the speaker. Low ceiling is also help full in reflecting sound towards audience.
     (The sound must sufficiently be loud every where).
3. **Echelon effect**
   - If there is a series of steps between floors or levels (or a set of railing), the sound produced in front of such a structure may produce a musical note due to regular successive echoes of sound. Such an effect is called Echelon effect. If this note is in audible range, the listener will hear it prominently.
   - To avoid Echelon effect steps are covered with carpet.

     (There should be no Echelon effect)
4. **Focusing**
   - There may be concentration of sound or a zone of silence in any part of the hall.
   - For uniform distribution curved surface and projection should be designed. One method is to make the wall in front of audience parabolic with speaker at its focus.

     (Their must be proper focusing of sound every where in the hall.

5. Echo

- Echo is a reflection of sound that arrives at the listener with a delay after the direct sound. The distortion of sound takes place because of echo.
- The average interval between two syllables spoken by a person is about 0.2 sec. These walls and ceilings should be made in such a way that the reflection of sound takes place in more than 0.2 sec. Otherwise it creates a confusion due to overlapping of direct and reflected sound.

(There should not be echo).

6. Resonance

- The resonance of any audio frequency note causes the sound of different intensity than that of direct one.
- For the hall of large size, the resonance frequency is much below the audible limit and harmful effects due to resonance will not be present.

7. Reverberation

- The persistence of sound for some time even when the source of sound has ceased is called Reverberation. This is due to the multiple reflection of sound from various part of the hall.
- It can be controlled by proper maintenance of absorbing material i.e. providing window, doors, carpets on the floor, heavy curtains, using full capacity of audience etc.

REVERBERATION

The persistence of sound for some time even when the source of sound has ceased is called reverberation.

Causes:

i. The fall in intensity of the sound produced in room is exponential and so it will take longer time to become zero.

ii. Due to multiple reflection from walls, ceilings and floor or other material, the sound reverberates inside the hall for longer time.

Time of Reverberation

The duration for which the sound can be heard after the source has ceased to produce the sound is called reverberation time.

OR: The time taken by sound intensity to fall it's intensity equal to one millionth of its original value (i.e. by a factor of 10^{-6}) is called time of reverberation. (i.e. time to fall loudness by 60dB)

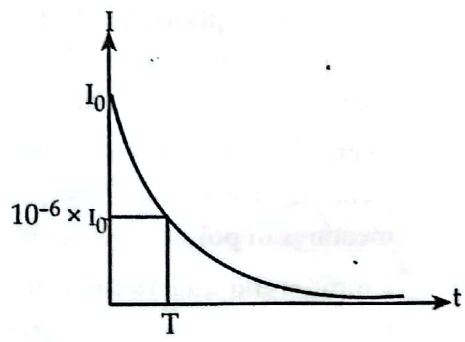

Figure (1): Variation of intensity of sound

Absorption of Sound

Coefficient of absorption of sound for the surface of material is defined as the ratio of sound energy absorbed by the surface to the sound energy absorbed by an equal area of a perfect absorber such as an open window.

The unit of absorption coefficient is Sabine. The sound energy absorbed by 1. sq.ft. of perfect absorber is called one Sabine.

If A is effective surface area for surface having total surface area S. The absorption coefficient 'α' is given by the relation

$$A = \alpha S$$

If $\alpha_1, \alpha_2, \ldots \alpha_n$ are absorption coefficient for each reflecting surface and $S_1, S_2, S_3 \ldots$ are corresponding area, then the average value of absorption coefficient is.

$$\alpha = \frac{\alpha_1 S_1 + \alpha_2 S_2 + \ldots + \alpha_n S_n}{S_1 + S_2 + S_3 + \ldots + S_n} = \Sigma \frac{\alpha_i S_i}{S_i}$$

$$\Rightarrow \quad \alpha = \frac{\Sigma \alpha_i S_i}{S}$$

NOISE POLLUTION

Any undesired or irritating sound that has an impact on the health and well being of people and other living things is referred to as noise pollution. It is not harmful to air, soil and water but affects the animals including humans. Sound is typically described in terms of the loudness (amplitude) and the pitch (frequency) of the wave. Loudness is measured in logarithmic units called decibels (dB).

Humans have a hearing range called as audible range. Audible range depends upon frequency and loudness of sound. For a person with normal hearing, frequency ranges from 20 to 20,000 Hz and loudness ranges from 0 to 120 dB. Sound is measured in decibels (dB). A decibel value above 80 is considered to be noise pollution.

Causes of Noise Pollution

1. **Domestic Sources:** People utilize devices heavily in their daily lives and are constantly surrounded by them. The quantity of noise created by appliances like TVs, mobile phones, mixer grinders, pressure cookers, vacuum cleaners, washing machines, dryers, coolers, and air conditioners is also a factor, but it frequently lowers the quality of life.
2. **Poor urban planning:** In the majority of developing nations, poor urban planning is also quite important. Large families living in tiny spaces, parking lots, street noise, honking, and business areas all contribute to noise pollution, which disturbs the social environment.
3. **Social Events and Celebrations:** Most social events have a high level of noise. Whether it's a wedding, party, pub, disco, fire work, place of worship with loud speakers, election rallies, meetings of political parties etc, typically break the restrictions and contribute to noise pollution.
4. **Commercial and Industrial activities:** The majority of industries employ large, noise-producing machinery. Additional equipment that contributes to noise production includes Tractors, Thrashers, Harvesters, Tube Wells, Powered Tillers, Compressors, Generators, Exhaust Fans, and Grinding Mills.
5. **Construction Activities:** Construction activities like mining, construction of bridges, dams, buildings, stations, roads, flyovers take place in almost every part of the world. To fulfill the demands of a population that is always growing, these construction projects should be continued. Additionally, it generates noise pollution.

6. **Transportation:** Heavy noise is produced by a large number of automobiles on the road, planes, and trains. A regular individual would lose their capacity to hear well due to the extreme noise level.

Effects of Noise Pollution

1. **Auditory effect:** Long-term exposure to noise causes the internal ear to slowly deteriorate, which can result in hearing loss or deafness. Continuous exposure to noise levels greater than 90 dB may cause it. It might be either temporary or permanent. Explosions and other loud noises can also instantly make a person deaf by rupturing the ear drums or harming the cochlea. Hearing loss is frequently connected to one's profession.

2. **Non Auditory effect:** Noise can occasionally cause emotional disruptions and people to lose their cool. It has been found to decrease productivity at work, emotional disruption, may obstruct getting enough rest and sleep. It includes the pale complexion of the skin, tensing of the voluntary muscles, reduction of gastric secretions, an increase in blood pressure, and the abrupt release of hormone, which magnifies neuro muscular tension, nervousness, irritability, and anxiety. Loud noise can lead to problems and make it difficult for people to freely communicate.

3. **Effects on Animals:** Noise pollution makes it difficult for animals to use sound for navigation, finding food, mating, and avoiding predators, affecting many animals ability to survive. It may cause animal migration on an ecosystem level. Their movement may have an impact on crop output. Because many animals such as bats pollinate bananas, peaches and other cash crops.

4. **Effect on non-living things:** The noise booms cause cracks in walls of buildings as well as in hills. Sonic boom can break window panes and buildings.

Preventing Noise Pollution

1. **Noise reduction at source:** It can be done using by designing, fabricating and using quieter machines to replace the noisy ones. Also Covering noise-producing machine with sound-absorbing materials to check noise production.

2. **Control at receiver's end:** To minimize occupational exposure, ear protection equipment such as earplugs, earmuffs, noise helmets, headphones, etc. must be made available to workers in noisy environments.

3. **Acoustic Zoning:** There should be quiet zones near residential areas, educational institutions, and hospitals. Distancing noisy industrial areas, bus terminals and railway stations, aerodromes, and so on from residential areas, i.e. increasing the distance between source and receiver.

4. **Sound Insulation at Construction Stages:** The construction techniques of walls, windows, doors, and floors, as well as the selection of appropriate building materials, all contribute to better acoustic control in buildings.

5. **Planting of Trees:** Green muffler scheme involves planting green trees and shrubs along roads, hospitals, educational institutions etc. to reduce noise to a considerable extent.

6. **Legislative Measures:** To address the threat of noise pollution, strict legislative measures must be implemented. Noise standards must be strictly followed, banning pressure horns in automobiles, minimum use of loudspeakers and amplifiers especially near silence zones.

Advantages of Ultrasonic Waves in NDT

i. High penetrating power enables the identification of defects present deep within the component.

ii. Extremely high sensitivity, allowing for the detection of minute faults.

iii. More precise than other nondestructive methods in determining the thickness of components with parallel surfaces and the depth of internal faults.

iv. The capacity to estimate flaws' size, orientation, shape, and nature.

v. Not harmful to surrounding workers or processes, and has no impact on nearby materials and equipment.

vi. Able to operate in a portable or highly automated manner.

Limitations of Ultrasonic Waves in NDT

i. For ultrasound to be transmitted, the surface must be reachable.

ii. Skill and training is more extensive than with some other methods.

iii. It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.

iv. It is challenging to evaluate materials that are rough, have irregular shapes, are extremely small, extremely thin, or are not uniform.

v. Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.

vi. Linear defects oriented parallel to the sound beam may go undetected.

vii. Reference standards are required for both equipment calibration and the characterization of flaws.

Solved Example

Example 1: The time of reverberation of an empty hall and with 500 audience in the hall is 1.5 sec and 1.4 sec respectively. Find the reverberation time with 800 audience in the hall.

Solution:

Sol/

According to question, $1.5 = \frac{0.158\,V}{\alpha.S}$ ...(i)

[use $T = \frac{0.158V}{\alpha S}$]

and $1.4 = \frac{0.158\,V}{\alpha.S + 500}$ ...(ii)

for empty room

Dividing equation (1) by (2)

$$\frac{1.5}{1.4} = \frac{\alpha S + 500}{\alpha S} \Rightarrow 1.5\,\alpha S = 1.4\alpha S + 700$$

$$\Rightarrow \quad \alpha S = 7000$$

From equation (1), $V = \frac{1.5 \times \alpha S}{0.158} = \frac{1.5 \times 7000}{0.158} = 66455.7$

Therefore, time of reverberation with 800 audience,

$$T_3 = \frac{0.158\ V}{\alpha S + 800} = \frac{0.158 \times 66455.7}{7000 + 800} = 1.346 \text{ sec}$$

Example 2: Same sum (1) The time of reverberation of an empty hall and with 600 audiences is 1.8 sec. and 1.6 sec respectively. Find the reverberation time with 1000 audiences in the hall.

Solution:

According to question,

$$T_1 = 1.8 = \frac{0.158V}{aS} \quad \ldots (i)$$

$$\text{and } T_2 = 1.6 = \frac{0.158V}{aS + 600} \quad \ldots (ii)$$

Dividing equation (i) and (ii)

or, $1.125\ \alpha S = \alpha S + 600 \Rightarrow \alpha S = 4800$

From equation (1)

$$V = \frac{1.8 \times 4800}{0.158} = 54683.54$$

Therefore time of reverberation with 1000 audience

$$T_3 = \frac{0.158V}{\alpha S + 1000} = \frac{0.158 \times 54683.54}{4800 + 1000} = 1.4896 \text{ sec.}$$

Example 3: The time of reverberation of an empty hall is 1.5 sec with 500 audiences present in the hall the reverberation time falls to 1.4 sec. Find the number of persons present in the hall if the reverberation time falls down to 1.312 sec.

Solution: Seeing diff made (7)

For first case, $1.5 = \dfrac{0.158\ V}{\alpha s}$ ... (i)

For second case, $1.4 = \dfrac{0.158\ V}{\alpha s + 500\ \alpha_m}$ ... (ii) α_m = absorption coefficient for a person

For third case, $1.312 = \dfrac{0.158\ V}{\alpha S + n\alpha_m}$ ... (iii) n = number of person

Dividing (1) by (2)

$$\frac{1.5}{1.4} = \frac{\alpha s + 500\ \alpha_m}{\alpha s} = 1 + \frac{500\ \alpha_m}{\alpha s}$$

$\Rightarrow \quad 500\ \alpha_m = 0.07143\ \alpha s$ ... (iv)

Again dividing (1) by (3),

$$\frac{1.5}{1.312} = \frac{\alpha s + n\alpha_m}{\alpha s} = 1 + \frac{n\alpha_m}{\alpha s}$$

$\Rightarrow \quad n\alpha_m = 0.1433\ \alpha s$ ... (v)

Again dividing (5) by (4)

$$\frac{n}{500} = \frac{0.1433}{0.07143}$$

n = 1003

Example 4: What is the reverberation time for a hall with length 12m, breadth 11m, and height 9m. If the coefficients of absorption of walls, ceiling and floor are 0.02, 0.04 and 0.08 respectively.

Solution:

Volume of the hall, $V = 12 \times 11 \times 9 = 1188\ m^3$

Area of floor = Area of ceiling = $l \times b = 132\ m^2$

Area of walls = $l \times h + l \times h + b \times h + b \times h = 2\,(l+b).\,h = 2\,(12 + 11) \times 9 = 414\ m^2$

Total absorption, $\alpha s = 414 \times 0.02 + 132 \times 0.04 + 132 \times 0.08 = 24.12$

Reverberation time, $T = \dfrac{0.158\ V}{\alpha s} = \dfrac{0.158 \times 1188}{24.12} = 7.78$ sec

Example 5: A lecture hall with a volume of 4500 m^3 is found to have a reverberation time of 1.5 sec. What is the total absorbing power of all the surfaces in the hall? If the area of the sound absorbing surface is 1600 m^2, calculate average absorption coefficient.

Solution:

Volume of hall, $V = 4500\ m^3$

Reverberation time, $T = 1.5$ sec

Since $T = \dfrac{0.158\ V}{\alpha S} \Rightarrow \alpha S = \dfrac{0.158V}{T} = \dfrac{0.158 \times 4500}{1.5} = 474$

Absorbing power of all surfaces, $\alpha s = 474$ Sabine.

Area of absorbing surface, $S = 1600\ m^2$

Average absorption coefficient, $\alpha = \dfrac{\alpha S}{S} = \dfrac{474}{1600} = 0.3$

Example 6: A class room has dimensions $20 \times 15 \times 5\ m^3$. The reverberation time is 3.5 sec. Calculate the total absorption of its surfaces and the average absorption coefficient.

Solution:

Volume of the room (V) = $20 \times 15 \times 5 = 1500\ m^3$

Total surface area (ΣS) $= 2\,(lb + lh + bh)$

$= 2\,(20 \times 15 + 20 \times 5 + 15 \times 5) = 950\ m^2$

Then, Reverberation time $T = \dfrac{0.158V}{aS}$ $3.5 = \dfrac{0.158 \times 1500}{\alpha S} \Rightarrow \alpha S = 67.71\ m^2$

Also, Average absorption coefficient $(\alpha_{avg}) = \dfrac{\Sigma \alpha S}{\Sigma S} = \dfrac{67.71}{950} = 0.0713$

Example 7: The volume of a room is 600 m^3, wall area of room is 220m^2, the floor and ceiling area each is 120 m^2. If average absorption coefficient for walls is 0.03, for ceiling is 0.80 and for floor is 0.06 calculate average absorption coefficient and reverberation time.

Solution:

Here, $V = 600\ m^3$

Absorption due to wall = $\alpha_1 S_1 = 220 \times 0.03 = 6.6$

Absorption due to floor = $\alpha_2 S_2 = 0.06 \times 120 = 7.2$

Absorption due to ceiling = $\alpha_3 S_3 = 0.80 \times 120 = 96$

Total absorption $\alpha S = \alpha_1 s_1 + \alpha_2 s_2 + \alpha_3 s_3 = 109.8$ Sabines

Example 10: A hall with floor is $15 \times 30\ m^2$ along with height of 6m in which 500 people occupy upholsters seat and the remainder sit on wooden chair, optimum reverberation time for orchestral music is 1.34 sec and absorption coefficient per person is 0.44

a. Calculate the total absorption to be provided by the walls, floor and ceiling when the hall is fully occupied.

b. Calculate the reverberation time if only half upholstered seats are occupied. (α = 0.02 for each wooden chair)

Solution:

Volume of hall, $V = 15 \times 30 \times 6 = 2700\ m^3$

Area of walls $= 2\,(l + b)\,h = 2\,(15 + 30) \times 6 = 540\ m^2$

Area of floor $= 15 \times 30 = 450\ m^2$

Area of ceiling $= 15 \times 30 = 450\ m^2$

We have, $T = \dfrac{0.158\ V}{\alpha s} \Rightarrow \alpha s = \dfrac{0.158\ V}{T}$

$$\alpha s = \frac{0.158 \times 2700}{1.34} = 318.36$$

Total absorption, $\alpha s = 318.36$

Absorption due to audience $= 500 \times 0.44 = 220$

a. Absorption provided by walls, floor and ceiling $= 318.36 - 220 = 98.36$

b. If only half seats are occupied, then absorption due to 250 people $= 250 \times 0.44 = 110$ and absorption due to 250 wooden seats $= 250 \times 0.02 = 5$

Total absorption for this case $= 318.36 - 220 + 110 + 5 = 213.36$

$$T = \frac{0.158\ V}{\alpha S} = \frac{0.158 \times 2700}{213.36} = 2.0\ \text{sec}$$

Example 11: A quartz crystal of thickness 0.001 m is vibrating at resonance. Calculate the fundamental frequency. Given, young's modulus for quartz (γ) $= 7.9 \times 10^{10}\ N/m^2$ and, density of quartz (ρ) $= 2.650 \times 10^3\ kg/m^3$

Solution:

We have the relation for fundamental frequency.

$$f = \frac{1}{2l}\sqrt{\frac{\gamma}{\rho}}$$

In this case, $\gamma = 7.9 \times 10^{10}\ N/m^2$

$\rho = 2.650 \times 10^3\ kg/m^3$

$l = 0.001$ m

Therefore, $f = \dfrac{1}{2 \times 0.001}\sqrt{\dfrac{7.9 \times 10^{10}}{2.65 \times 10^3}} = 2.73 \times 10^6$ Hz

Example 12: A room has dimension of 6m × 4m × 5m find,

1. mean free path of sound wave in the room.
2. The number of reflections made per second by the sound wave with the walls of the room (Take velocity of sound in air = 350 ms^{-1})

Solution:

i. Mean free path (λ) $= \frac{4 \text{ (volume of room)}}{\text{Total surface area}} = \frac{4V}{S}$

Here volume of the room (V) $= 6 \times 4 \times 5 = 120 \text{ m}^3$

and total surface area (S) $= 2\,(lb + bh + hl)$

$= 2\,(6 \times 4 + 4 \times 5 + 6 \times 5) = 148 \text{ m}^2$

Mean free path (λ) $= \frac{4 \times 120}{148} = 3.243$ m

ii. The no of reflection made per second, $N = \frac{\text{velocity of sound}}{\text{mean free path}} = \frac{350}{3.243} = 107.9 = 108$

Example 13: A lecture hall of volume $12 \times 10^4 \text{ m}^3$ has a total absorption of 13200 m^2 of open window unit. Entry of students into the hall raises the absorption by another 13200 m^2 of open window unit. Find the change in reverberation time.

Solution:

Volume of the hall, $V = 12 \times 10^4 \text{m}^3$

Total absorption, $\alpha s = 13200 \text{ m}^2$ of open window unit.

Reverberation time (T) $= \frac{0.158 V}{\alpha s} = \frac{0.158 \times 12 \times 10^4}{13200} = 1.44$ sec

Due to the entry of students the raise in absorption $= 13200 \text{ m}^2$

New total absorption, $\alpha s = 13200 + 13200 = 26400 \text{ m}^2$

New, reverberation time,

$$T_1 = \frac{0.158 V}{\alpha s} = \frac{0.158 \times 12 \times 10^4}{26400} = 0.72 \text{ sec}$$

Therefore, change in reverberation time = 1.44 - 0.72 = 0.72 sec

Example 14: The size of an empty assembly of bell has dimension $20 \times 15 \times 5 \text{ cm}^3$ and the reverberation time is 3.5 sec. What area of the wall should be covered by curtain cloth to reduce the reverberation time by 2.5 if the absorption coefficient of curtain cloth is 0.5. Also calculate the average absorption coefficient of the bell.

Solution:

Volume of the bell, $V = 20 \times 15 \times 5 \times 10^{-6} \text{ m}^3 = 0.0015 \text{ m}^3$

We have,

$$T = \frac{0.158 V}{\alpha S}$$

or, $$3.5 = \frac{0.158 \times 0.0015}{\alpha S}$$

$$\alpha S = \frac{0.158 \times 0.0015}{3.5} = 6.77 \times 10^{-6}$$