CHAPTER 9

Acoustics

Acoustics, an interesting branch of physics, deals with generation, detection and propagation of sound waves. The study of acoustics is very important to understand the nature of sound waves, its production and propagation.

Sound wave is a form of energy whose transmission is different through different medium. It is characterized with a specific frequency.

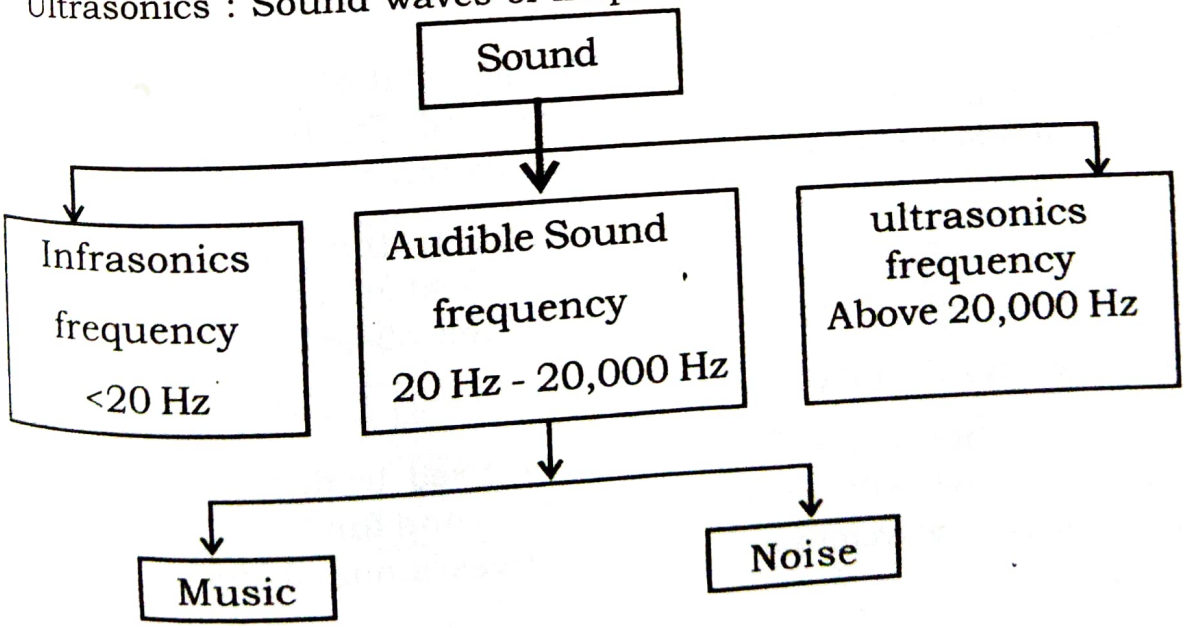
Classification of Sounds

With reference to the frequency of vibration the sound waves are classified into three categories. They are,

Infrasonics : Sound waves of frequencies below 20 Hz.

Audible Sound : Sound waves of frequencies between 20 Hz to 20,000 Hz.

Ultrasonics : Sound waves of frequencies above 20,000 Hz.



The audible sound waves are classified into following:

1. Musical sound

2. Noise

1. Musical sound

Sound waves which produce a pleasing effect to our ears are called musical sound.

Example : The sound produced by violin, tuning fork and piano

Proprties

(i) The waveform has a regular shape.
(ii) They have definite periodicity
(iii) There are no sudden change in amplitude

2. Noise

Sound waves which produce an unpleasant effect or jarring (displeasing) effect on the ear are clled noise.

Properties

(i) Their waveforms are irregular in shape.
(ii) They have lack of periodicity
(iii) They undergo sudden changes in amplitude and frequency.
(iv) Noise of high intensity may produce permanent or temporary deafness.

Characteristics of Musical Sound

The important characteristics of a musical sound are pitch, timbre, intensity and loudness.

Pitch

Pitch is the characteristic of a sound that distinguishes between a sharp classical sound and a grave sound. The pitch increases with the frequency of sound, i.e., It depends directly on the frequency.

The frequency is a physical quantity that can be measured accurately, while the pitch is a physiological quantity which is merely the mental sensation experienced by the observer.

Timbre (or) Quality

The timbre of a musical sound is used to distinguish between two tones having the same intensity level and fundamental frequency but different waveforms. Thus it expresses our ability to recognize

the sound of a violin as different from that of a trumpet.

Normally the timbre or quality of sound depends on the number of overtones present with the fundamental frequency.

Intensity:

Intensity (I) of a sound wave at a point is defined as the amount of sound energy flowing per secondper unit area held normally to the direction of propagation of the sound waves.

$$\text{Intensity } I = \frac{Q}{TA} \quad \text{unit : Joule sec}^{-1}\ \text{m}^{-2}$$

Where $Q \rightarrow$ amount of sound energy

$T \rightarrow$ time

$A \rightarrow$ area of sound source normal to the propagation

It also can be written as.

$$I = \frac{P}{A} \quad \text{Unit : Wm}^{-2} \left[\because P = \frac{Q}{T}\right] \qquad P \rightarrow \text{Power}$$

Loudness of Sound - Weber - Fechner Law

Loudness measures the amount of sensation produced in the ear and hence depends upon the listener. It is not a purely physical quantity but is subjective in nature.

Loudness signifies how far and to what extent, sound is audible. Loudness is directly proportional to the logarithm of intensity.

$$\text{Loudness } L \propto \log_{10} I$$

$$L = k \log_{10} I \qquad \ldots\ldots\ldots\ldots (1)$$

This equation is known as Weber - Fechner law. Here k is a constant depending on the sensitivity of the ear, quality of the sound and other factors.

Differentiating eqn.(1), we have

$$\frac{dL}{dI} = \frac{k}{I}$$

Where, $\frac{dL}{dI}$ is called as sensitiveness of ear. Therefore the

Reverberation

When a source of sound emits sound waves inside a hall, the sound waves travel in all the directions and undergoes multiple reflections from the walls, floors, windows and ceiling before it becomes inaudible. So, a sound wave experiences two to three hundred repeated reflections, before it beocmes inaudible.

The existence of prolongation or persistence of sound in the room due to multiple reflections from the surfaces even after the source of sound is stopped to emit sound is called reverberation.

Reverberation Time and Sabine's formula

The time duration for which the sound persists even after the source is cut off is called reverberation time. Reverberation time is also defined as time taken for the sound to fall down the minimum auidibility measured from the instant when the source is stopped to emit sound.

It is measured as the time interval between the sound produced by the source and the sound until it dies, after the source is cut-off. After measuring reverberation time in various rooms and halls, W.C. Sabine, who defined the standard reverberation time, gave an empirical relation as

$$\text{Reverberation time (T)} = \frac{0.165V}{\Sigma as} \text{ seconds}$$

where, V is the volume of room or hall in m^3.

a is the absorption coefficients of surface areas of different materials present in the hall.

s is surface area of the different materials present in the hall in m^3

Σas is the total absorption of sound i.e., sum of the product of absorption coefficient and surface area of the corresponding surfaces in Sabine.

Absorption Coefficient

The coefficient of absorption of a material is defined as the ratio of the sound energy absorbed by the surface to that of the total incident sound energy on the surface.

Sound energy absorbed by the surface

Absorption coefficient (a)

$$= \frac{\text{Sound energy absorbed by the surface}}{\text{Total sound energy incident on the surface}}$$

As all sound waves falling on an open window pass through, it can be assumed that an open window behaves as a perfect absorber of sound. Hence the standard of absorption is taken as the **unit area of an open window (O.W.U.)** .

The absorption coefficient of a material is defined as the ratio of

the sound energy absorbed by a certain area of the surface to that of open window of same area.

(or)

The absorption coefficient of a surface is defined as the reciprocal of its area which absorbed the same sound energy as absorbed at an unit area of an open window.

Average Absorption Coefficient

The average absorption coefficient $(\bar{a})$ is defined as the ratio between the total absorption in the hall to the total surface area of the hall

$$\bar{a} = \frac{A}{s} = \frac{\Sigma as}{\Sigma s} = \frac{a_1 s_1 + a_2 s_2 + ...}{s_1 + s_2 + ...}$$

$$\therefore T = \frac{0.165 V}{\bar{a} s}$$

Measurement of Absorption Coefficient

The absorption coefficient of the absorbing material can be measured in terms of the reverberation time. Basically it is a relative absorption measurement.

Consider a hall of volume V that is free from any absorbing material. Let s be the surface area of the hall.

The reverberation time T_1 is given by

$$T_1 = \frac{0.165 V}{\Sigma as}$$

$$\frac{1}{T_1} = \frac{\Sigma as}{0.165 V} \qquad .....(1)$$

After calculating the reverberation time without sound absorbing material, the absorbing material is kept inside the hall and the corresponding reverberation time is noted and is given by

$$T_2 = \frac{0.165 V}{\Sigma as + a_1 s_1}$$

$$\frac{1}{T_2} = \frac{\Sigma as + a_1 s_1}{0.165 V} \quad \ldots\ldots\ldots(2)$$

Where a_1 is the absorption coefficient of the absorption material and s_1 is its surface area.

Subtracting equation (2) from equation (1) we get

$$\frac{1}{T_2} - \frac{1}{T_1} = \frac{a_1 s_1}{0.165 V} \quad \ldots\ldots\ldots(3)$$

The absorption coefficient of absorbing material is given by

$$a = \left(\frac{1}{T_2} - \frac{1}{T_1}\right)\frac{0.165V}{s_1} \quad \ldots\ldots\ldots(4)$$

Hence, from equation (4) we can calculate the absorption coefficient of the given material.

Acoustics of Building

Acoustics of buildings deals with the design of auditorium or theatre with good acoustics such that optimum reverberation and uniform distribution of sound intensity. Further there would not be any echo or interference or Echelon effect.

Today sound engineering become very important in film industry, broadcasting and television and even in the traditional music, dance and drama. Any hall meant for music or speech should satisfy some minimum acoustical standards apart from the standards prescribed for accommodation, ventilation and other physical comforts like air conditioning.

An auditorium or a hall is said to be acoustically good if the following conditions are satisfied:

(i) The music (or) speech performed on the dias should be audible in the entire hall either direct or with the amplifier system as the case may be.

(ii) The frequency combination, that is the quality of sound should be uniform throughout the theatre.

(iii) Whether the hall is full with audience or not, the quality of music heard should be the same.

(iv) There must not be any pockets of maxima or minima due to interference or reflections.

(v) The sounds from the exterior must not disturb the proceedings inside.

(vi) No echo should be present.

(vii) The hall should have proper reverberation time about 1.1 to 1.5 second.

(viii) Resonance effect (jarring effect of sound) should be avoided

To accomplish these, a special study of reverberation, echo, interference, etc., in the hall becomes essential. This study is called the study of acoustics of buildings. Thus the chief aim of the study of the acoustics of buildings is to ensure the production and transmission of sound in halls so that unwanted noise is reduced to a minimum and the wanted sounds are conveyed undistorted and with sufficient intensity.

Factors affecting the Acoustics of Building and their Remedy

If every syllable produced in a hall does not reach an audible level of loudness at every point of the hall, then the hall is said to be acoustically defective.

They are

1. Reverberation
2. Reflections and echoes
3. Echelon effect
4. Focusing and interference effects
5. Resonance
6. Extraneous noise.

Now we shall discuss the above factors that affect the acoustics of buildings and their remedy.

1. Reverberation

The persistence of sound in the hall eventhough the source of sound is cut off is called reverberation. This is due to successive reflections taking place on the walls of the hall so that a pulse of previous note of sound is heard for a short definite interval of time eventhough the second note of sound is originated.

When there is no reverberation there is no support for the singer in the stage. Thus it aids the music so that one can hear the music in an enjoyment manner if it is an optimum value.

Too much of reverberation and too low reverberation may create

booming sound and flat sound respectively. Thus it is a necessary evil in the acoustics of buildings.

Remedy

Reverberation can be controlled by the following factors:

i. Providing windows and ventilators
ii. Decorating the walls with pictures and maps
iii. Using heavy curtains with folds
iv. Lining the walls with absorbent materials such as felt, celotex fibre board, glass wool, etc.,
v. Filling the hall to capacity audience
vi. Covering the floor with carpets.

2. Reflections and Echoes

An echo is heard when the direct and reflected sound waves coming from the same source reach the listener with a time interval of about 1/7 second. The reflected sound arriving earlier than this time helps in rising the loudness while those arriving later produce echoes and cause confusion.

Moreover the reflection from loudspeaker will produce a "howl" through the mike.

Remedy

i. The wall of the hall should scatter the sound rather than reflect it.
ii. The surfaces of the wall should be rough and are not polished or smooth to avoid reflections.
iii. The echo effect is avoided by lining the surfaces with sound absorbing materials and by providing a good number of doors and windows.
iv. The balconies provided in some concert halls help in avoiding echoes.

Echelon effect

Echelon effect refers to the development of a separate musical note due to combination of echoes having regular phase difference. If there is staircase within the hall the reflections from equally spaced steps at regular intervals of time, produce a separate sound. Thus a set of railings or any regular spacing of reflected surface may produce a separate musical note due to the regular succession of echoes of

the original sound to the listener. This effect is called Echelon effect. This makes the original sound confused or unintelligible. Hence this must be avoided.

Remedy

The Echelon effect can be removed or reduced by the following methods:

i. The staircases can be covered with carpets

ii. Structures like staircases can be avoided in the hall

iii. The steps of the staircase may be made unequally spaced

4. Focusing and interference effects

If there are focusing surfaces (concave, spherical, cylindrical or parabolic) on the walls ceiling or floor of the hall, they produce concentration of sound in a particular region while no sound reaches some other parts. In this way there will be regions of silence of poor audibility.

If there are extensive reflecting surfaces in the hall, the reflected and direct sound wave may form a stationary wave system thus making the sound intensity distribution bad uneven.

Remedy

For uniform distribution of sound energy in the hall :

i. There should be no curved surfaces. If such surfaces are present, they should be covered with absorbent material.

ii. Ceiling height should be low.

5. Resonance

Sometimes the window panes, sections of the wooden portions and walls lacking in rigid support are set into vibrations and they create disturbing sound. For some note of audio frequency the frequencies of new sounds may be the same, thus resulting in the resonance.

Moreover, if the frequency of the created sound is not equal to the original sound atleast certain tones of the original music will be reinforced. Due to interference between the original sound and the created sound, the original sound is distorted. Thus the intensity of the note is entirely different from the original one. Enclosed air in the hall also cause resonance.

Remedy

The resonance effect can be minimised by :

i. Fixing the window panes properly.

ii. Damping the resonant vibrations by some suitable methods.

iii. Resonances are reduced by convex cylindrical segments on walls and ceilings. They diverge the reflected sound and thus produce a more uniform distribution.

6. Extraneous Noise

In a good hall no noise should reach from outside. Noise may be defined as unwanted sound. Noise produces a jarring or displeasing effect on the ear. Generally, there are three types of noises:

i. Airborne noise

ii. Structure borne noise

iii. Inside noise

The prevention of the transmission of noise inside or outside the hall is known as sound insulation. This is also known as sound proofing. The method of sound insulation will depend on the type of noise to be treated.

Airborne noise

The noise which commonly reaches the hall from outside through open windows, doors and ventilators is known as airborne noise. The noise is transmitted through air.

Remedy

The airborne noise is reduced by :

i. Avoiding openings for pipes and ventilators

ii. Allotting proper places for doors and windows

iii. Using heavy glass in doors, windows and ventilators

iv. Making arrangements for perfectly shutting doors and windows

Structure borne noise

The noises which are conveyed through the structure of the building are known as structure borne noise. These noises may be caused due to structural vibration because of activity around above or below the structure.

The most common sources of this type of sound are foot steps, street traffic, hammering, drilling, moving of furniture, etc.,

Remedy

The structure borne noise is reduced by :

(i) Using double walls with air space between them

(ii) Using anti-vibration mounts

(iii) Soft floor finish

Inside noise

The noise which are produced inside the hall or rooms are called as inside noises. They are produced due to machinery like typewriters in the hall.

Remedy

The inside noises can be reduced by the following methods :

(i) Machinery like typewriters should be kept on absorbent pads.

(ii) The floor should be covered with carpet.

(iii) Any engine inside the hall should be fitted on the floor with a layer of wood.

(iv) The sound absorbing materials should be mounted on the surfaces near the sources of noise.

7. Effect of Impurities

The elastic property of a material may increase or decrease due to the addition of impurities.

If we add carbon in minute quantities to molten iron., the elastic properties of iron are increased enormously. But the carbon content is more than 1 % in iron, then the strength of iron decreases.

If any addition of impurity atoms distorts the lattice structure of the base metal, then the elastic property of the base metal decreases.

2.5 Factors affecting acoustics of buildings and their remedies

The factors affecting acoustics of buildings and their remedies are as follows:

1. **Reverberation time:**

If the reverberation time is very small, the sound intensity decreases very fast and makes the sound appear dead. On the other hand, a large reverberation time causes mixing of different syllables and hence causes confusion.

For good quality sound, optimum reverberation time is required

Remedies:

i) Heavy curtains with folds are used to reduce reverberation time by increasing absorption of sound

ii) Floor is covered with carpets to absorb sound.

iii) Windows and openings are provided in the hall which can be opened or closed to control the reverberation time.

iv) Walls and ceilings are covered with sound absorbing materials.

v) If the hall is filled to its maximum capacity of audience, reverberation time is less.

2. **Loudness:**

There should be adequate loudness in all parts of the hall.

Remedies:

i) Large sounding boards are used behind the speaker facing the audience.

ii) Loudspeakers are used to increase the loudness.

iii) Low ceilings help to reflect the sound towards the audience.

iv) Sound absorbing materials are used in those parts of the hall where sound intensity is large.

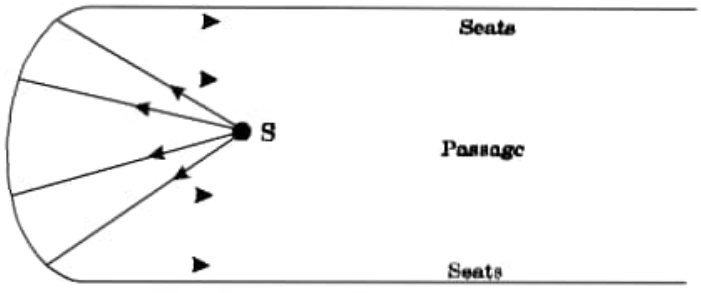


Fig:2.5.1- Reflection of sound

(3)Echo:

The reflection of sound from a distant reflecting surface is known as echo. If the echo reaches the listener about $1/15^{th}$ of a second after the direct sound, the listener hears two sounds instead of one which causes confusion. Such echoes mush be eliminated in halls.

Remedy:

High ceilings and distant walls are covered with second absorbing materials.

(4)Echelon effect:

Succession of echoes produced by a set of regularly spaced reflecting surfaces like staircase causes confusion in original sound. This effect is known as echelon effect.

Remedy:

The regularly spaced reflecting surfaces like stairs are covered with sound absorbing materials like carpets.

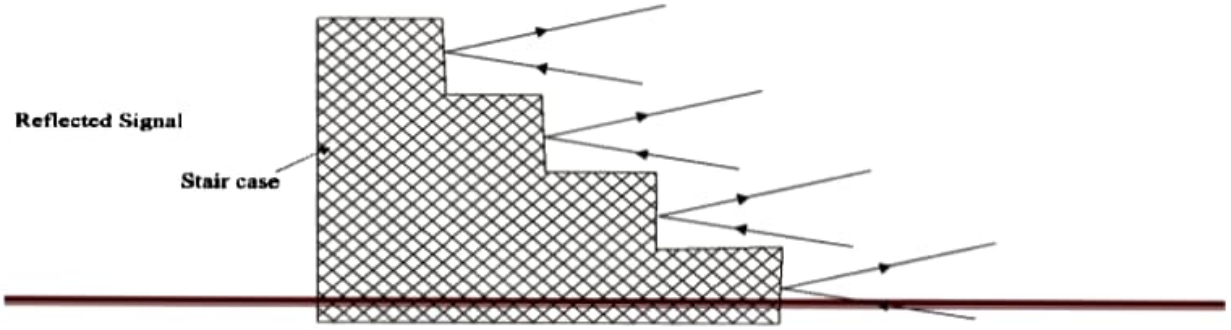


Fig:2.5.2- Stairs like reflecting surfaces

(5)Focusing:

Concave and parabolic surfaces in the hall focus sound. This causes concentration of sound in certain regions of the hall which is not desirable.

Remedies:

Curved surfaces are avoided, If there are curved surfaces, they are covered with sound absorbing materials.

(6)Resonance:

Loose fitting window panels and some other objects resonate at some audible frequencies creating more sound of these frequencies. This distorts the original sound.

Remedies:

Window panels are fixed properly, Vibrating objects are placed on sound absorbing materials.

(7)Noise:

Noise from different sources adversely affects the quality of sound in a hall. The noise can be **air borne, structure borne or inside noise.**

a)Air borne noise: the external noise, for example of traffic, which enters the halls through doors, windows and ventilators is known as external noise.

Remedies:

i) Openings for ventilators inside the hall are avoided.

ii) Doors and windows are provided with rubber covering on frames so that they shut without any gaps.

iii) Double doors and windows having separate frames enclosing sound absorbing materials are used.

b)Structure borne noise:

Noise produced by activities like drilling and hammering or the vibrations of heavy machinery is transmitted through the structure of the building. This is known as structure borne noise.

Remedies:

i) Heavy machinery is mounted on sound absorbing materials like wood or rubber.

ii)Double walls are used with space between them.

c)Inside noise:

It is the noise produced inside the hall by machinery, fans, air conditioners etc.

Remedies:

i)Sound absorbing materials and curtains are provided near the sources of noise.

ii)The sources of noise are mounted on sound absorbing materials.