

UNIT II ACOUSTICS

Sound waves are classified into three categories on the basis of frequency.

1. Infrasonics (below 20 Hz)
2. Audible sound (between 20 Hz to 20,000 Hz)
3. Ultra sound (above 20,000 Hz)

Audible sound is further classified as

- a) **Musical sound** which produces pleasing effect on the ear.
- b) **Noises** which produces unpleasant effect on the ear.

Characteristics of musical sound

- a) Pitch – Pitch is the characteristic of sound that distinguishes between a shrill sound and a grave sound.
- b) Quality – The quality of sound is that characteristic which enables us to distinguish between two notes of the same pitch and loudness produced by two different voices.
- c) Intensity of sound – It is the energy of sound wave crossing per unit time through unit area at right angles to the direction of propagation.
- d) Loudness – It is the degree of sensation produced in the ear.

Weber-Fechner law

Loudness of sound is defined as the degree of sensation produced on the ear. This cannot be measured directly. So that it is measured in terms of intensity. Loudness is proportional to logarithmic value of intensity.

$$L \propto \log I; \quad L = k \log I$$

Sound Intensity Level

It is the ratio of intensity of a sound (I) to the standard intensity of sound (I_0).

$$\beta = \log_{10} (I/I_0)$$

Bel – 1 bel is defined as the relative intensity between two sound notes if one is 10 times more intense than the other.

Decibel – It is the smallest unit compared to Bel. It is the standard unit used to measure the loudness. One decibel is equal to one tenth of bel. An increase of sound intensity level by 1 dB would increase the intensity by 26 %.

Absorption coefficient

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

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

The absorption coefficient can also be defined as the rate of sound energy absorbed by a certain area of surface to that of an open window of same area.

$$a = \frac{\text{Sound energy absorbed by } 1\text{m}^2 \text{ of surface}}{\text{Total sound energy incident on } 1\text{m}^2}$$

Reverberation time

The persistence of audible sound, even after the source has stopped to emit the sound is called reverberation. The time during which the sound persists in the hall is called as reverberation time.

Reverberation time is also defined as the time taken by the sound to fall to one millionth of its original intensity, after the source of sound is stopped.

$$I = I_m / [10]^{-6}$$

When the reverberation time is lower than the critical value, sound becomes inaudible by the observer and the sound is said to be dead and if the reverberation time is too large, echoes are produced. Therefore, the reverberation time should have some optimum value.

Sabine's law

If V is the volume of the hall, a is the average absorption coefficient and S is the total surface area, the reverberation time can be related as

$$T = (0.167 V) / (\sum a_s)$$

Derivation of Sabine's law

Let us consider small element ds on a plane wall AB as shown in fig.



Assume that this element ds receives sound energy. Taking O as a mid-point on ds , two semicircles are drawn with radii r and $r+dr$. Consider a small shaded portion between the circles lying between two radii drawn at angles θ and $\theta+d\theta$.

Radial length of the shaded portion = dr

Arc length of the shaded portion = $r d\theta$

Area of the shaded portion = $r d\theta dr$

Imagine the whole figure is rotated about the normal through an angle $d\phi$ and shaded portion travels through a small distance dx and thus traces a elemental volume dV .

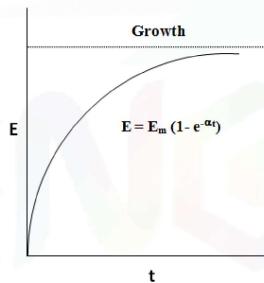
Distance travelled by this shaded portion, $dx = r \sin \theta d\phi$

Volume traced by the shaded portion, $dV = r d\theta dr . r \sin \theta d\phi$

If E is the sound energy density, then sound energy present within the volume element dV ,

$$= E . dV$$

$$= E . r^2 \sin \theta d\theta dr d\phi$$



This equation expresses the growth of sound energy density 'E' with time 't'. This indicated that E increases with t , and when $t \rightarrow \infty$, $E = E_m$.

Decay of sound energy

Assume that, when sound energy has reached its steady (maximum value) state E_m , sound energy is cut off. Then the rate of emission of sound energy, $P = 0$.

Therefore, equation (2) can be written as $Ee^{\alpha t} = K$

Substituting the boundary conditions $E = E_m$ at $t = 0$ and $P = 0$, we get $E_m e^0 = 0 + K$

$$K = E_m$$

Therefore, we get

$$Ee^{\alpha t} = E_m$$

$$E = E_m / e^{\alpha t}$$

Therefore, $E = E_m \cdot e^{-\alpha t}$

This equation represents the decay of sound energy density with time after the source is cut off.

Expression for reverberation time

The standard reverberation time is the time taken by the sound to fall of its intensity to one-millionth of its initial value after the source is cut off. Now, the value of sound energy density before cut off is E_m , at standard reverberation time, it reduces to

$$E = E_m / 10^6$$

To calculate T , we put $E = E_m \cdot 10^{-6}$ and $t = T$,

$$E_m \cdot 10^{-6} = E_m \cdot e^{-\alpha T}$$

$$e^{-\alpha T} = 10^{-6}$$

$$e^{\alpha T} = 10^6$$

Taking log on both sides, we have

$$\alpha T = 6 \log_e 10$$

$$T = (6 \times 2.3026 \times 1) / \alpha$$

$$T = (6 \times 2.3026 \times 1) / (\nu A / 4V)$$

By using velocity of sound, $\nu = 340$ m/s

$$T = 0.165 V / A$$

or

$$T = 0.165 V / \Sigma a_s$$

This equation is in agreement with the experimental values obtained by Sabine.

Factors affecting acoustics of buildings and their remedies

- i) Heavy curtains with folds are used to reduce reverberation time 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.
3. **Echo:** The reflection of sound from a distant reflecting surface is known as echo. If the echo reaches the listener about $1/17^{\text{th}}$ of a second after the direct sound, the listener hears two sounds instead of one which causes confusion. Such echoes must be eliminated in halls.
Remedy: High ceilings and distant walls are covered with sound 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.
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.

Methods of sound absorption

When a sound wave strikes one of the surfaces of a room, a part of the sound energy is reflected back into the room and others are penetrating through the surface. The parts of the sound energy are absorbed by the conversion to heat energy in the material, while the rest is transmitted through it. The level of energy conversion to heat energy depends upon sound absorbing properties of the material.

The listener and the sound source are in the same room, if the room has no sound absorbing surfaces, the sound energy is bounced back between the surfaces and it takes long time before dies out.

The listener will have a problem registering the speaker because listener hears both direct and repeated reflected sound waves. If the surfaces are covered with absorbing material, the reflected sound will decrease, also sound level of the room is decreased.

Noise measurement

The logarithms scale provides comparing the sound pressure of one sound with another. To avoid a scale which is too compressed a factor 10 is introduced, giving rise to the decibel unit.

$$1 \text{ decibel} = 10 \log_{10}(\text{intensity measured}/\text{reference intensity})$$

Where reference intensity 2×10^{-5} Newtons per sq.meter or 10^{-12} watts per sq. meter.

$$\begin{aligned} \text{Sound pressure level}(L_p \text{ or SPL}) &= 10 \log_{10}(P^2 - P_{ref}^2) \quad (\text{unit-db}) \\ &= 20 \log_{10} P - 20 \log_{10} P_{ref} \quad (\text{unit-db}) \end{aligned}$$

Sound insulation and its measurements

It is a measure used to reduce the level of sound when it passes through the insulating building component. It is also called sound proofing.

Methods of sound insulation

By avoiding opening of pipes and ventilators.

By allotting proper places for doors and windows.

iii) When noise is structured-borne
Using double walls with air space between them. Insulating of machinery.

Impact of noise in multi-storeyed buildings

It is defined as the structure whose usage levels are regular in distribution and which correspond roughly to the required for human habitation. There are four main actions which causes impact of noise in multistoried buildings.

i) Speech privacy

It is an issue within office buildings, including individual work space, inside conference halls and between offices. It mainly affects the quality of work in the adjacent buildings.

ii) Back ground noise

It can adversely impact the work space too little background noise and speech privacy is reduced.

iii) Sound masking

It can blend the building systems noise levels within electronic noise systems in the middle. Traditional sound masking systems are located in loud speakers above the ceiling.

iv) Orientation of buildings

The noise impact may also be great for rooms perpendicular to road ways because, a noise pattern can be more annoying in perpendicular rooms. Windows on perpendicular walls do not reduce noise as effectively as those on parallel walls became at the angle of sound.

Sound absorbing materials

Materials used to increase the absorption of sound waves or to reduce the reflection of sound waves in a room or hall are known as sound absorbing materials.

An ideal absorbing materials should be economical in construction and maintenance, water-proof, fire-proof, sufficiently strong and good in appearance.

In the hall treated with absorbing materials, the speech can be heard clearly and music can be fully enjoyed.

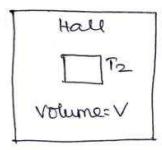
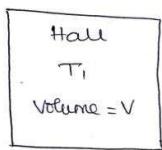
They work on the principle that the sound waves penetrate into the pores and in this process, the sound waves are converted into other form by friction.

Absorbing materials depends on the thickness of the material, its density and frequency of sound.

Improper covering destroys the absorbing properties of the material.

Absorption Coefficient





$$T_1 = \frac{0.167V}{\sum a_s}$$

$$T_2 = \frac{0.167V}{\sum a_s + a_{s1}}$$

$$\frac{1}{T_1} = \frac{\sum a_s}{0.167V}$$

①

$$\frac{1}{T_2} = \frac{\sum a_s + a_{s1}}{0.167V}$$

②

$$\textcircled{2} - \textcircled{1} \Rightarrow \frac{1}{T_2} - \frac{1}{T_1} = \frac{\sum a_s + a_{s1}}{0.167V} - \frac{\sum a_s}{0.167V}$$

$$= \frac{\sum a_s + a_{s1} - \sum a_s}{0.167V}$$

$$\frac{1}{T_2} - \frac{1}{T_1} = \frac{a_{s1}}{0.167V}$$

$$a_{s1} = \frac{0.167V}{S_1} \left\{ \frac{1}{T_2} - \frac{1}{T_1} \right\}$$

$$a_{s1} = \frac{0.167V}{S_1} \left\{ \frac{T_1 - T_2}{T_1 T_2} \right\}$$

UNIT II ACOUSTICS

Characteristics of sound and Classification of Sound

Characteristics of sound and Classification of Sound. Sound is a form of energy. Sound is produced by the vibration of the body.

The sound requires a material medium for its propagation and can be transmitted through solids, liquids and gases.

CHARACTERISTICS OF SOUND

- Sound is a form of energy.
- The Sound is produced by the vibration of the body.
- Sound requires a material medium for its propagation and can be transmitted through solids, liquids and gases.
- When sound is conveyed from one medium to another medium there is no bodily motion of the medium.
- Sound requires a definite interval of time to travel from one point to another point in a medium and its velocity is smaller than the velocity of the light.
- Velocity of sound is maximum in solids, which have higher bulk modulus and least in gases.
- Sound may be reflected, refracted, or scattered. It exhibits diffraction and interference. In transverse mode it exhibits polarization also.

CLASSIFICATION OF SOUND BASED ON CHARACTERISTICS OF SOUND

- Sound waves of frequencies below 20 Hz are termed as Infrasonic (inaudible)
- The Sound waves of frequencies above 20000 Hz are termed as Ultrasonic (inaudible)
- Sound waves of frequencies 20 Hz to 20,000 Hz are termed as audible sound

Further the audible sound is classified as Musical Sounds and Noise.

The sounds which produce effect on the ear are called musical sound and that which produces jarring and unpleasing effect are called noises.
sound is classified into

1. Infrasonics
2. Audible
 1. Music
 2. Noise
3. Ultrasonics

CHARACTERISTICS OF SOUND – CHARACTERISTICS OF MUSICAL SOUND

There are three characteristics of Musical Sound in Characteristics of Sound

- Pitch or Frequency
- Quality or Timbre
- Intensity or Loudness

O PITCH OR FREQUENCY:

Pitch is the characteristic of sound which is the sensation conveyed to our brain by the sound waves falling in our ears.

It depends directly on the frequency of the incident soundwaves.

Though the pitch is directly related to frequency, they are not the same; in general the frequency is a physical quantity whereas the pitch is a physiological quantity.

Example: sound of mosquito produces high pitch than the sound of lion which is a low pitch.

- QUALITY OR TIMBRE

The quality of the sound is the one which helps us to distinguish between the musical notes emitted by the different instruments or voices, even though they have the same pitch and loudness.

- INTENSITY OR LOUDNESS

The intensity of sound at a point is defined as the average rate of flow of acoustic energy(Q) per unit area situated normally to the direction of wave. The intensity depends upon the following factors

Where n =Frequency of the sound wave

a =amplitude of the wave

p =density of the medium v =velocity of sound in that medium

x =distance from the source of sound to the receiving end or Intensity per unit area per unit time

CHARACTERISTICS OF SOUND – LOUDNESS – WEBER FECHNER LAW

Loudness of the sound is defined as the degree of sensation produced on the ear. The loudness varies from one observer to another.

It is a physiological quantity and therefore it is difficult to measure loudness. But, it can be measured a logarithmic value of intensity

Equation 1 is known as WEBER – FECHNER law. Differentiating equation 1, we have is called Sensitiveness of ear.

Therefore the sensitiveness decreases with the increase in Intensity. For example more sound in an auditorium will not be heard properly.

INTENSITY

1. It refers to the external measurement
2. And it is common to hear
3. it can be measured directly

LOUDNESS

1. It is just a sensation produced on the ear.
2. And It depends upon individual listener
3. It is measured only with respect to intensity.

CHARACTERISTICS OF SOUND – UNIT OF LOUDNESS

If L , is the Loudness of sound of intensity I and L_0 is the loudness corresponding to the standard reference intensity $1 = 10 \text{ watts/m}^2$, then according to Weber- Fechner law, we have

Now, the intensity level (I) which is equal to the difference in Loudness, If k is taken as 1, the intensity level or difference in loudness is expressed in bels, a unit named after Alexander Graham Bell, the inventor of Telephone

DECIBEL

The unit of Bel is however quite large and hence I is expressed by another standard unit called decibel 1 bel = 10 decibels.

CASE 1:

If $I=0\text{dB}$, then equation 1 becomes

CASE 2:

If $I = 1\text{dB}$, then equation 1 becomes
Subtracting equation 2 from 3, we get $1.26 - 1 = 0.26$

For a change in intensity level of 1 dB, the intensity changes to about 26%. When $I_1 = 100 I_o$; $I_L = 20\text{dB}$

When $I_1 = 1000 I_o$; $I_L = 30\text{dB}$

To build up a scale of business, zero on the scale is taken as the threshold of hearing, which corresponds to $I_o = 10^{12} \text{ W/m}^2$. The maximum intensity with which an ear can tolerate is $I = 1\text{W/m}^2$

| S.NO | SOURCE | INTENSITY LEVEL IN dB |
|------|--------------------------------|-----------------------|
| 1. | Threshold of hearing | 0 |
| 2. | Rustle of leaves | 10 |
| 3. | Whisper | 15-20 |
| 4. | Average house | 40 |
| 5. | Ordinary conversation | 60-65 |
| 6. | Motors or heavy traffic trucks | 70-80 |
| 7. | Roaring of lion at 20 feet | 90 |
| 8. | Thunder | 100-110 |
| 9. | Painful sound | 120 and above |

Characteristics of Sound and Classification of Sound

PHON

we have expressed the loudness in dB, on the assumption that the threshold of audibility is constant for all frequencies.

But it is found that threshold of audibility varies with frequency. Sounds of same intensity but of different frequency differ in loudness.

Hence a different unit called PHON is used to measure loudness level or equivalent loudness.

DEFINITION:

The measure of loudness in Phons of any sound is equal to loudness in decibels of an equally loud pure tone of frequency 1000Hz.

EXPLANATION:

Let us consider two sources 'S' the standard source and S, the source of sound for which loudness is to be measured.

The two sounds are heard alternatively and the intensity of S is adjusted to be equal to the loudness of the S as shown in the figure.

Now the intensity level of S is measured, If it say 'n' decibels above the standard intensity, then the equivalent loudness is 'n' Phon

The expression for loudness in Phon (L) is given by Where I is the intensity of sound in dB

SONE

Sone is another unit to measure the loudness in terms of Phon or dB.

It is used to measure every high loudness, especially between the ranges of 40 Phons to 100 Phons. i.SONE in terms of PHON

DEFINITION:

The measure of loudness in some of any sound is equal to the loudness of that particular sound having a loudness level of 40 Phons.

EXPLANATION:

Suppose a source of sound is having the loudness or 40 Phons then it can be assumed to have a loudness of 1 Sone.

Expression for Loudness in Sone is empirically given by

EXAMPLE:

Suppose if the loudness in Phon is 40 Phons, then the loudness in Sone is given by

ii. Sone in terms of Decibel

DEFINITION:

In terms of decibels the Sone is defined as the loudness of an equally loud pure tone of frequency 1000Hz with 40dB if intensity level.

EXPLANATION:

It is similar to that of the measurement of loudness in Phon in terms of dB, but the increase in intensity level should be 40dB above the standard intensity, then the equivalent loudness is 1 Sone.

ACOUSTICS OF BUILDINGS

So a new field of science is developed which deals with the planning of a building or a hall with a view to provide best audible sound to the audience and is called Acoustics of building.

Therefore to provide a best audible sound in a building or hall a prime factor called Reverberation.

REVERBERATION

When a sound pulse is generated in a hall, the sound wave travels towards all direction and are reflected back by the walls, floors, doors, windows ceiling etc as shown.

So a sound wave has two to three hundred repeated reflections, before it becomes inaudible.

Therefore, the observer in the hall does not be able to hear a single sharp sound instead a “role of sound” of diminishing intensity (since part of energy is lost at each reflection)

REVERBERATION TIME

The duration for which the sound persists is termed as reverberation time and is measured as the time interval between the sound produced by the source produced by the source and to the sound wave until it dies.

DEFINITION:

It is defined as the time taken for the sound to fall below the minimum audibility measured from the instant when the source sound gets stopped.

In designing the auditorium, theatre, conference halls etc, the reverberation time is the key factor.

If the reverberation time is too large, echoes are produced and if the reverberation time is too short it becomes inaudible by the observer and the sound is said to be dead.

Therefore the reverberation time should not be too large or too short rather it should have an optimum value.

In order to fix this optimum value standard formula is derived by W.C.Sabine, who defined the standard reverberation time as the time taken for the sound to fall to one millionth of its original intensity just before the source is cut off.

SABINES FORMULA FOR REVERBERATION

The relation connecting the reverberation time with the volume of the hall, the area and the absorption coefficient is known as Sabine's Formula.

Sabine's developed the formula to express the rise and fall of sound intensity by the following assumptions.

1. Distribution of sound energy is uniform throughout the hall
2. There is Interference between the sound waves.
3. The Absorption coefficient is independent of sound intensity.
4. The Rate of emission of sound energy from the source is constant.

Let us consider a small element 'ds' on a plane wall AB. Assume that the element ds receive the sound energy 'E'.

Let us draw two concentric circles of radii 'r' and $r + dr$ from the center point 'O' of

Consider a small shaded portion lying in between the two semi circles drawn at an angle θ and $\theta + d\theta$, with the normal to ds as shown.

Let 'dr' be the radial length and $rd\theta$ be the arc length Area of

shaded portion $rd\theta dr$ — (1)

If the whole figure is rotated about the normal through an angle 'dφ' as shown in the figure, then it is evident that the area of the shaped portion travels through a small distance dx.

To find total energy received by the element 'ds' per second, we have to integrate the equation 3 for the whole volume lying within a distance 'v' is the Velocity of sound.

It is obvious from the geometry of the figure that,

GROWTH AND DECAY OF SOUND ENERGY

If 'P' is the Power Output (i.e., the rate of emission of sound energy from the source) then we can write.

Here E_m is the maximum energy from the source (which has been emitted) that is maximum energy which is incident on the wall.

Where k is the constant of integration

GROWTH OF SOUND ENERGY

Let us evaluate for growth

Initially during the growth the boundary conditions Are at

$$t=0 \quad E=0$$

Therefore equation 8 becomes

Where E_m is the maximum sound energy.

This expression gives the growth of sound energy density 'E' with time 't'. The growth is along an exponential curve as shown.

DECAY OF SOUND ENERGY

Let us first evaluate k or decay.

Here the boundary conditions are at $t=0$; $E=E_m$

Initially the sound increases from E to E_m and now it is going to decay from E_m . Therefore time is considered as '0' for $E=E_m$. At $E=E_{mv}$ the sound energy from the source is cut off. Therefore rate of emission of sound energy from the source=0 i.e., $P=0$ Therefore

from equation 8 we can write

Equation 10 gives the decay of sound energy density with time 't' even after the source is cut off. It is exponentially depressing function from maximum energy(E_m) as shown.

The growth and decay of sound energy together is represented in the figure.

PROOF OF REVERBERATION TIME(T)

According to Sabine, the reverberation time is defined as the time taken by a sound to fall to one millionth of its initial value, when the source of sound is cut off.

Equation 13 represents the Reverberation time, which depends on the three factors viz,

1. Volume of the hall(V)
2. Surface area(S)
3. Absorption coefficient(a) of the materials kept inside the hall. Among these three actors volume is fixed.

Therefore, the reverberation time can be optimized by either varying the surface area of the reflecting surfaces or the absorption coefficient of the materials used inside the hall.

ABSORPTION COEFFICIENT

Thus, we can say that the open window behaves as a perfect absorber of sound and hence the absorption coefficient can be defined as the rate of sound energy absorbed by a certain area of the surface to that of an open window of same area.

DEFINITION:

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

For example if $2m^2$ of a carpet absorbs the same amount of sound energy as absorbed by $1 m^2$ of an open window, then the absorption coefficient of the carpet is $1.2=0.5$. The absorption coefficient is measured in open window unit (O.W.U) or Sabines.

AVERAGE ABSORPTION COEFFICIENT

The average absorption coefficient is defined as the ratio between the total absorption in the hall to the total surface area of the hall.

MEASUREMENT OF SOUND ABSORPTION COEFFICIENT

Let us consider a sample for which the absorption coefficient (a_m) is to be measured.

Initially without this material the reverberation time in a room and again the reverberation time is measured and let it be T_2 .

Then from Sabine's formula

For Case (1) i.e. without the sample

Here, by knowing the terms on the right hand side the absorption coefficient of the given sample can be determined.

FACTORS AFFECTING THE ACOUSTICS OF BUILDING

We know, when sound waves are produced in a hall, it reaches the observer directly as well as after reflections from walls, floors, ceilings, etc.

Thus there is a possibility for causing interference between these waves, which in turn affects the originality of the sound produced.

The factors affecting the acoustics (sound) of building are as follows.

1. Unoptimised reverberation time
2. Very low or very high loudness
3. Improper focusing of sound to a particular area, which may cause interference
4. Echoes or echelon effects produced inside the buildings
5. Resonance caused due to matching of sound waves.
6. Unwanted sound from outside or inside the building, so called noise may also affect the acoustics of buildings.

OPTIMUM REVERBERATION TIME AND ITS REMEDY

We know Reverberation time is the time taken for the sound to fall to one millionth of its original sound intensity, when the source of sound is switched off.

If this reverberation time is high then it produces echoes in the hall and if the reverberation time is very low, the sound will not be clearly heard by the audience.

Therefore, for clear audibility, we should maintain optimum reverberation. The optimum reverberation time can be achieved by the following steps

1. By having the full capacity of audience in the auditorium.
2. By choosing absorbents like felt, fiber, board, glass etc inside the auditorium and even at the back of chairs.
3. Reverberation time can be optimized by providing windows and ventilators at the places wherever necessary and using curtains with folds or the windows.
4. The reverberation time can also be optimized by decorating the walls with beautiful pictures.

The optimum reverberation time will not be constant for all types of building; it varies from one building to another as follows.

- For concert halls, the speech should have the optimum reverberation time of 0.5 seconds and music should have the optimum values of 1 or 2 seconds
- For auditoriums or theatres, the optimum reverberation time should be between 1.1 to 1.5 seconds for smaller area and between 1.5 to 3 seconds for larger area.

LOUDNESS AND ITS REMEDY:

We know loudness is the degree of sensation produced on the ear; it varies from observer to observer.

But, it is found that for a single observer the loudness varies from one place to another in the same auditorium.

This defect is caused due to the bad acoustical construction of buildings.

The loudness will be very low in some area and will be very high in some areas. It can be optimized by the following remedies.

REMEDIES

1. Loudspeakers should be placed at the places where we have low loudness.
2. The loudness can also be increased by making reflecting surfaces, wherever necessary
3. Loudness can be increased by constructing low ceilings
4. Absorbents are placed at the places where we have high loudness.

Thus, the loudness should be made even, all over the auditorium, so that the observer can hear the sound at a constant loudness at all the places.

FOCUSING AND INTERFERENCE EFFECTS

In some places of a hall, the sound will not be heard properly and that place is said to be a dead space, which is due to presence of convex or concave surfaces in the hall as shown in the figure.

Sometimes the sound waves will have interference pattern because of ceiling surfaces which will create maximum intensity of sound(due to constructive interference) in some places and minimum intensity of sound(due to destructive interference) at some places and hence causing uneven distribution of sound intensity in the hall and hence causing uneven distribution of sound intensity in the hall.

REMEDIES

1. By avoiding curved surfaces (or) covering the curved surfaces by suitable absorbents the focusing can be avoided.
2. By evenly polishing and decorating with absorbents the interference effects can be avoided.

ECHOES AND ECHELON EFFECT

In some halls, the walls of the halls will scatter the sound waves rather than reflecting it, thus way create nuisance effect due to echoes.

The echoes are formed when the time interval between the direct and reflected sound waves are about $1/15^{\text{th}}$ of a second.

This effect occurs due to the reason that the reflected sound waves reaches the observer later than the direct sound.

If there is a greater repetition of echoes of the original sound to the observer then the effect is called as Echelon effect.

REMEDIES

The echo can be avoided by lining the surfaces with suitable sound absorbing materials and by providing enough number of doors and windows.

RESONANCE

Resonance occurs when a new sound note of frequency matches with standard audio frequency.

Sometimes, the window panel, sections of the wooden portion is thrown into vibrations to produce new sounds, which results in interference between original sound and created sound.

This will create disturbance to the audience.

REMEDIES

1. The resonance effect can be avoided by providing proper ventilation and by adjusting the reverberation time to the optimum level.
2. Nowadays the resonance is completely eliminated by air conditioning the halls.

NOISE

Noise is an unwanted sound produced due to heavy traffic outside the hall which leads to displeasing effect on the ear. There are three types of noises.

1. Air Borne noise
2. Structure Born Noise
3. Inside Noise

All these three noises pollute the area at which it has been produced and create harmful effects to the human beings.

Fortunately human beings have the capability to reject the sound within certain limits with conscious efforts and to carry on his normal work.

But sometimes the noises are strong which results in the following effects.

EFFECTS PRODUCED DUE TO NOISE POLLUTION

- It produces mental fatigue and irritation.
- Diverts the concentration on work and hence reduces the efficiency of the work.
- It sometimes affects the nervous system and lowers the restorative quality of sleep.
- Some strong noises leads to damage the eardrum and make the worker hearing impaired.
- The noises which are produced regularly will even retard the normal growth of infants and young children.
 - AIR BORNE NOISE

The noise which reaches the hall through open windows, doors, and ventilations are called as air borne noise.

This type of noise is produced both in rural areas natural sound of wind and animals and in urban areas noise that arises from factories, aircrafts, automobile, trains, Flights etc.

REMEDIES

1. By making the hall air conditioned, this noise may be eliminated

2. By allotting proper places or doors and windows, this noise can be reduced.
3. It can be further by using double doors and windows with separate frames and by placing the absorbents in-between them
 - o STRUCTURE BORNE NOISE

The noise that reaches the hall through the structure of the building is termed as Structure Borne noise.

Those types of noise produced inside the building, which may be due to the machinery operation, movement of furniture's footsteps etc and these sounds will produce structural vibration giving rise to the Structure Borne Noise.

REMEDIES

1. By properly breaking the continuity of the interposing layers by some acoustical insulators this type of noise can be avoided.
 2. By providing carpets, resilient, antivibration mounts etc., this type of noise can be reduced.
- o INSIDE NOISE

The noises that are produced inside the halls is known as inside noise.

For example in some offices the sound produced by machinery, type writers etc produces this type of noise.

REMEDIES

1. By placing the machineries and type writers over the absorbing materials or pads this type of noise can be reduced.
2. It can be reduced by covering the floors with carpet.
3. By fitting the engine on the floor with a layer of wood or felt between them this type of noise can be avoided.

FACTORS TO BE FOLLOWED FOR GOOD ACOUSTICS OF BUILDING

To have a clear audibility of sound have an optimum level

1. The reverberation time should have an optimum level
2. The sound must be evenly distributed to each and every part of the building.
3. There should not be any focusing of sound to any particular area.
4. Each and every syllable of sound must be heard clearly and distinctly, without any interference.
5. There should not be any echoes, echelon effects and resonance inside the buildings.
6. The building should be made as sound proof building, so that external noises may be avoided.
7. Generally to say the total quality of sound should be maintained all over the building to all the audience.

PROPERTIES OF ULTRASONIC WAVES

The human ear is sensitive to sound waves in the frequency range from 20-20, 000 Hz.

This range is called Audible range. Sound waves of frequency more than 20,000Hz are called Ultrasonics. These frequencies are beyond the audible limit.

These waves also travel with the speed of sound(330m/s) Their wavelength are small.

PRODUCTION OF ULTRASONIC WAVES

Production of Ultrasonic waves

PRINCIPLE:

When a rod of ferromagnetic material like nickel is magnetized. Longitudinally, it undergoes a very small change in length.

This is called Magnetostriction effect.

CONSTRUCTION:

The circuit diagram of magnetostriction ultrasonic generator is as shown in the figure1.3.2.

A short permanently magnetized nickel rod is clamped in the middle between two knife edges.

A coil L_1 is wound on the right hand portion of the rod.

C is a variable capacitor. L_1 and C_1 form the resonant circuit of the collector- tuned oscillator.

Coil L_2 wound on the LHS of the rod is connected in the base circuit. The coil L_2 is used as a feed back loop.

WORKING:

When the battery is switched on, the resonant circuit L_1C_1 sets up an alternating current of frequency.

This current flowing round the coil L_1 produces an alternating magnetic field of frequency f along the length of the nickel rod.

The rod starts vibrating due to magnetostrictive effect. The vibrations of the rod create ultrasonic waves.

The longitudinal expansion and contraction of the rod produces an E.M. in the coil L_2 .

This e.m.f is applied to the base of the transistor.

Hence the amplitude of high frequency of high oscillations in coil L1 is increased due to positive feedback.

The developed alternating current frequency can be turned with the natural frequency of the rod by adjusting the capacitor.

CONDITION FOR RESONANCE:

Frequency of the oscillator circuit = Frequency of the vibrating rod

Where 'l' is the length o the rod

'E' is the Young's modulus o the rod

' ρ ' is the density of the material of the rod.

The resonance condition is indicated by the rise in the collector current shown in the milliammeter.

ADVANTAGES:

Magnetostriction Oscillators are mechanically rugged. The construction cost is low.

They are capable of producing large acoustical power with fairly good efficiency.

LIMITATIONS

It can produce frequencies up to 3MHz only.

They frequency o oscillation depends upon the temperature.

Breadth o the resonance curve is large. It is due to vibrations of elastic constants of ferromagnetic material with the degree of magnetization.

So we cannot get a constant single frequency.

PIEZO ELECTRIC CRYSTALS

The crystals which produce piezo-electric effect and converse Piezo electric effect are termed as Piezo electric crystal.

Example: Quartz, Tourmaline, Rochelle Salts etc.

At typical example or a piezo electric crystal (Quartz) is as shown

It has an hexagonal shape with pyramids attached at both ends. It consists of 3 axes. Viz.,

- (i) Optic Z axis, which joins the edges of the pyramid
- (ii) Electrical axis(X axis), which joins the corners of the hexagon and
- (iii) Mechanical axis, which joins the center or sides of the hexagon as shown

X-CUT AND Y CUT CRYSTALS

X-CUT CRYSTAL:

When the crystal is cut perpendicular to the X-axis, as shown in the figure 1.4.2, then it is called X-crystals.

Generally X-cut crystals are used to produce longitudinal ultrasonic waves.

Y-CUT CRYSTAL:

When the crystal is cut perpendicular to the Y-axis, as shown in the figure 1.4.3, then it is called Y-cut crystal.

Generally, Y-Cut crystal produces transverse ultrasonic waves.

PIEZOELECTRIC EFFECT

Definition: When a mechanical stress is applied to the mechanical axis with respect to optical axis, a potential difference is developed across the electrical axis with respect to optic axis

INVERSE PIEZOELECTRIC EFFECT:

Definition: When an alternating electric field is applied to electrical axis with respect to optical axis, expansion or contraction takes place in the mechanical axis with respect to optical axis.

PRODUCTION OF ULTRA SONIC WAVES – PIEZO ELECTRIC EFFECT

PRINCIPLE:

This is based on the **Inverse piezoelectric effect**.

When a quartz crystal is subjected to an alternating potential difference along the electric axis, the crystal is set into elastic vibrations along its mechanical axis.

If the frequency of electric oscillations coincides with the natural frequency of the crystal, the vibrations will be of large amplitude.

If the frequency of the electric field is in the ultrasonic frequency range, the crystal produces ultrasonic waves.

CONSTRUCTION:

The circuit diagram is shown in the figure 1.5 It is base turned oscillator circuit.

A slice of Quartz crystal is placed between the metal plates A and B so as to form a parallel plate capacitor with the crystal as the dielectric.

This is coupled to the electronic oscillator through the primary coil L_3 of the transformer. Coils L_2 and L_1 of oscillator circuit are taken for the primary of the transformer. The collector coil L_2 is inductively coupled to base coil L_1 .

The coil L_1 and variable capacitor C form the tank circuit of the oscillator.

WORKING:

When the battery is switched on, the oscillator produces high frequency oscillations.

An oscillatory e.m.f is induced in the coil L_3 due to transformer action. So the crystal is now under high frequency alternating voltage.

The capacitance of C_1 is varied so that the frequency of oscillations produced is in resonance with the natural frequency of the crystal.

Now the crystal vibrates with larger amplitude due to resonance. Thus high

power ultrasonic waves are produced.

CONDITION FOR RESONANCE:

Frequency of the oscillator circuit = Frequency of the vibrating crystal Where 'l' is the length o the rod

'E' is the Young's modulus o the rod

' ρ ' is the density of the material of the rod.

'P' = 1,2,3 Etc for fundamental, first overtone, second overtone etc respectively

ADVANTAGES:

1. Ultrasonic frequencies as high as 500MHz can be generated.
2. The output power is very high. It is not affected by temperature humidity.
3. It is more efficient than the Magnetostriction oscillator.
4. The breadth of the resonance curve is very small. So we can get a stable and constant frequency of ultrasonic waves.

DISADVANTAGES:

1. The cost of the quartz crystal is very high.
2. Cutting and shaping the crystal is quite complex.

SONAR – Sound Navigation and Ranging Principle:

It is based on the principle of Echo – Sounding.

When the Ultrasonic waves are transmitted through water, it is reflected by the objects in the water and will produce an echo signal.

The change in frequency of the echo signal, due to Doppler Effect helps us in determining the velocity and direction of the object.

DESCRIPTION:

It consists of timing section which triggers the electric pulse from the pulse generator.

This pulse generator is connected to the transducer so that ultra sonic can be produced.

The transducer is further connected with the CRO for display.

The timing section is also connected to the CRO display or reference of the timing at which the pulse is transmitted as shown in the block diagram.

WORKING:

The transducer is mounted on the ship's hull without any air gap between them as shown.

The timing at which the pulse generated is recorded at the CRO or reference and this electrical pulse triggers the transducer which is kept in hull of the ship to produce ultrasonic waves due to the principle of inverse piezo electric effect.

These ultrasonic waves are transmitted through the water in sea.

On striking the object the ultrasonic waves (echo pulses) are reflected in all directions as shown

CAVITATION:

Definition:

The Ultrasonic sound waves that propagate into the liquid media result in alternating high pressure (compression) and low-pressure (rarefaction) cycles, with rates depending on the frequency.

During the low pressure cycle, high intensity ultrasonic waves create small vacuum bubbles or voids in the liquid.

When the bubbles attain a volume at which they can no longer absorb energy, they collapse violently during a high pressure cycle.

This phenomenon is termed cavitation.

During the low pressure cycle, high intensity ultrasonic waves create small vacuum bubbles or voids in the liquid.

When the bubbles attain a volume at which they can no longer absorb energy, they collapse violently during a high pressure cycle.

This phenomenon is termed cavitation.

During the implosion very high temperature(approx 5,000K) and pressures (approx 2,000atm) are reached locally,

The implosion of the cavitation bubble also results in liquid jets of up to 280m/s velocity.

ACOUSTIC GRATING

The ultrasonic waves generated with the help o a quartz crystal inside the liquid in a container sets up standing wave pattern consisting of nodes and anti-nodes.

The nodes are transparent and anti-nodes are opaque to the incident light.

In effect the nodes and anti-nodes acts like grating(a setup of large number of slits of equal distance) similar to that of ruling in diffraction grating. It is called as acoustic grating or aqua grating.

At nodes the density of the liquid is maximum and at antinodes density is minimum.

This arrangement is very much similar to the diffraction grating and is called acoustic grating.

Hence, by using the condition for direction, we can ind the wavelength of ultrasound and thereby the velocity of sound in the liquid medium.

When ultrasonic waves are generated in a liquid kept in rectangular vessel, the wave can be reflected from the walls of the vessel.

The direct and reflected waves get superimposed, which causes a standing wave to be formed.

The density o the liquid at the node will be more than the density at an antinode.

Under these conditions, if a beam of light is passed through the liquid at right angles to the wave the liquid acts as a diffraction grating. Such a grating is known as an acoustical grating.

Here, the antinode acts as the transmitting slit and the node acts as the opaque part. Thus resembling a normal ruled diffraction grating.

This is obvious because the nodes have points o minimum density and hence allow more amount o light to pass through them than those at antinodes.

Thus, the nodes act like slits.

DIFFRACTION GRATING

A Diffraction grating is an extremely useful device.

It consists of large number of narrow slits side by side. The slits are separated by opaque surfaces.

When a wavefront is incident on the grating surface, light is transmitted through the slits and obstructed by the opaque spaces.

Such a grating is called transmission grating.

ACOUSTICAL GRATING METHOD PRINCIPLE:

When ultrasonic waves travel through a transparent liquid, due to alternate compression and rare action, longitudinal stationary waves are produced.

If monochromatic light is passed through the liquid perpendicular to these waves, the liquid behaves as diffraction grating.

Such a grating is known as Acoustic Grating.

Here the lines of compression and rareaction act as transparent light waves.

It is used to find wavelength and velocity(v) of ultrasonic waves in the liquid.

ACOUSTICAL GRATING METHOD – CONSTRUCTION;

It is consists of a glass tank, filled with the liquid.

A piezo-electric (Quartz) is fixed at the bottom of the glass tank and is connected with piezo-electric oscillatory circuit as shown in the figure 1.7.

An incandescent lamp is used as a monochromatic source (S) and a telescope arrangement is used to view the diffraction pattern.

A collimator consisting of two lenses L1 and L2 is used to ocus the light effectively in the glass tank.

ACOUSTICAL GRATING METHOD – WORKING:

(i) When the piezo-electric crystal is kept at rest:

Initially the piezo-electric crystal is kept at rest and the monochromatic at light is switched ON.

When the light is focused in the glass tank filled with the liquid, a single image, a vertical peak is observed in telescope.

i.e., there is no diffraction.

(ii) WHEN THE PIEZO-ELECTRIC CRYSTAL IS SET INTO VIBRATIONS:

Now the crystal is put into vibrations using piezo-electric oscillatory circuit.

At Resonance, Ultrasonic waves are produced and are passed through the liquid.

These Ultrasonic waves are reflected by the walls of the glass tank and form a stationery wave pattern with nodes and antinodes in the liquid.

At nodes the density of the liquid becomes more and at antinodes the density of the liquid becomes less.

Thus, the liquid behaves as a directing element called acoustical grating element.

Now when the monochromatic light is passed the light gets directed and a diffraction pattern consisting of central maxima and principle maxima on either side is viewed through the telescope as shown in figure 1.7.2 as well as in 1.7.3.

CALCULATION OF ULTRASONIC VELOCITY

The velocity of Ultrasonic waves can be determined using the condition.

Thus, this method is useful in measuring the wavelength and velocity of ultrasonic waves in liquids and gases at various temperatures.

INDUSTRIAL APPLICATIONS

Ultrasonic waves find application in two major fields:

1. Engineering field
2. Medical field

Application of ultrasonic waves in engineering and industry Ultrasonic waves in the wide applications in engineering and industry as follows.

1. Non destructive testing (detection of flaws in metals)
2. Ultrasonic drilling
3. The ultrasonic welding
4. Ultrasonic drilling
5. A ultrasonic soldering
6. ultrasonic cutting and machinery
7. A ultrasonic cleaning
8. Sonar

ULTRASONIC NON DESTRUCTIVE TESTING – INDUSTRIAL APPLICATIONS OF ULTRASONIC WAVES

Principle:

The basic principle behind the ultrasonic inspection is the transmission of the Ultrasound with the medium and the reflection or scattering at any surface or internal discontinuity in the medium due to the change in the acoustic impedance.

The Discontinuity means the existence of the flaw or defect or cracks or hole in the material.

The reflected or scattered sound waves are received and amplified and hence, the defects in the specimen are suitably characterized.

BLOCK DIAGRAM OF THE ULTRASONIC FLAW DETECTOR

PRINCIPLE:

Whenever there is a change in the medium, then the Ultrasonic waves will be reflected.

This is the principle used in Ultrasonic flaw detector.

Thus, from the intensity of the reflected echoes, the flaws are detected without destroying the material and hence this method is known as a Non Destructive method.

WORKING:

1. The pulse generator generates high frequency waves and is applied to the Piezo-electric transducer and the same is recorded in the CRO.
2. The piezo electric crystals are resonated to produce Ultrasonic waves.
3. These Ultrasonic waves are transmitted through the given specimen.
4. These waves travel through the specimen and is reflected back by the other end.
5. The reflected Ultrasonic are received by the transducer and is converted into electric signals. These reflected signals are amplified and is recorded in the CRO.
6. If the reflected pulse is same as that o the transmitted pulse, then it indicates that there is no defect in the specimen.
7. On the other hand, if there is any defect on the specimen like a small hole or pores, then the Ultrasonic will be reflected by the holes(i.e.) defects due to change in the medium.
8. From the time delay between the transmitted and received pulses, the position of the hole can be found.
9. From the height o the pulse received the depth of the hole can also be determined.

ULTRASONIC SCANNING METHODS – A,B AND C SCAN DISPLAYS

– Industrial Applications of Ultrasonic waves

In the Ultrasonic scanning methods, the principle, construction and working is the same as that of the Ultrasonic law detector.

Here, it is based on the position o the transducer and the output displayed in the CRO screen, we can classify the scanning methods into three types

1. A-scan
2. B-scan
3. T-M scan or C-scan

All these three modes of scanning are obtained with respect to the pulses of Ultrasound transmitted into and received from the specimen.

The three modes are explained below.

A-SCAN OR AMPLITUDE MODE DISPLAY

Amplitude mode display gives only one-dimensional information about the given specimen.

In this, a single transducer is used to transmit and receive the pulses from the specimen.

The received or the reflected echo signals from the specimen is given to the Y- Plate and time base is connected to the X-Plate of the CRO, so that they are displayed as vertical spikes along horizontal base line as shown in the figure 1.10.1.

The height of the vertical spikes corresponds to the strength of the echo from the specimen.

The position of the vertical spike from left to right along the X-axis corresponds to the depth of penetration.

i.e, it gives the total time taken by the Ultrasonic sound to travel from transmitter to the specimen and from the specimen to the receiver.

Thus by passing Ultrasonic waves of known velocity and by noting the time delay, we can find the distance at which the defect or flaws are present, by using the formula.

Distance = Velocity x time

In ultrasonic flaw detector, A-scan method is used to detect the position and size of the flaws.

B-SCAN OR BRIGHTNESS MODE SCAN

B-scan or Brightness mode display gives a two dimensional image.

The principle of the B-Scan is same as that of A-Scan except with a small difference.

Here in the B-Scan the transducer can be moved rather than keeping in a fixed position.

As a result each echo's are displayed as dots on the screen as shown in the figure 1.10.2.

T.M SCAN OR TIME-MOTION MODE OR C-SCAN DISPLAY

This method is used to obtain the information about the moving object.

This combines the features of both A-Scan as well as B-Scan. In this the transducer is held stationary as in A-scan and echoes appear as dots in the B- scan.

Here, the X-axis indicates the dots at the relevant location and Y-axis indicates the movement of the object.

Therefore when the object moves, the dot also moves at a low speed.

Thus an object with the oscillatory movement will appear as a trace as shown in the figure 1.10.3.

SONOGRAM RECORDING OF MOVEMENT OF HEART FETAL HEART MOVEMENT

Principle:

It works under the principle of Doppler Effect

i.e., there is an apparent change in the frequency between the incident sound waves on the fetus and the reflected sound waves from the fetus.

DESCRIPTION:

It consists of a Radio Frequency Oscillator(RFO), for producing 2 MHz of frequency and RFA (Radio Frequency Amplifier) to amplify the receiver signal as shown in the figure.

WORKING:

The transducer is fixed over the mother's abdominal wall, with the help of a gel or oil.

RFO is switched on to drive the pulses and hence the transducer produces Ultrasonic waves of 2 MHz.

These Ultrasonic waves are made to be incident on the fetus.

The reflected Ultrasonic waves from the fetus are received by the transducer and are amplified by RFA.

Both the incident and the received signals are mixed by the mixer and is filtered to distinguish the various types of sound and finally the Doppler shift or change in frequency is measured.

The movement of the heart can be viewed visually by CRO or can be heard by the Loud Speaker, after necessary amplification by AF.

ULTRASONIC IMAGING SYSTEM – INDUSTRIAL APPLICATIONS OF ULTRASONIC WAVES PRINCIPLE OF WORKING

During the scanning of the body surface by Ultrasonic transducer, the Ultrasonic waves are transmitted into the patient's body.