Acoustics

It is branch of sound engineering that deals with the production, control, transmission, absorption and effect of sound.

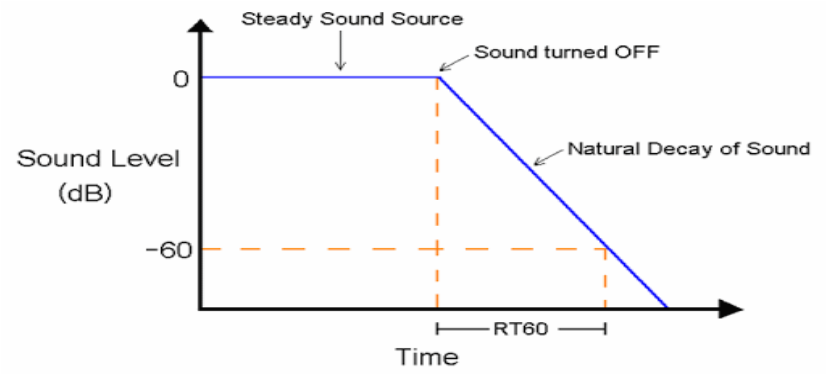
Acoustics of building:-

The acoustics of building is a branch of sound engineering. It has an important role in civil and architectural engineering. Acoustics of building is connected with the hearing to speakers and musicians in halls and auditoriums. It is found that some auditoriums are acoustically good and some bad. In bad, sound lack in distinctness. It is sometimes observed that a speech made in a certain hall or sound produced in theatre is not audible at certain places. In some areas there is so much interference that it is sometimes difficult to understand what is being said. Therefore in good hall the following conditions should be satisfied;

- The sound must be sufficiently loud everywhere.
- The sound must be clear and distinct.
- There should be no echo or disturbance.
- The quality of sound must not be change.
- There should be neither be any focusing of sound nor any zone of silence in any part of the hall.

Reverberation:-

It is the collection of reflected sounds from the surface in an enclosure like an auditorium. The distance between source and observer must be less than 17.5 m.



If the source is stopped, the sound does not stop immediately but the listener continuous to pick up the successive reflection until they fall below the minimum audibility, this gradually decay of sound is known as reverberation.

Reverberation time:-

The duration for which the sound can be heard after the source has stopped to produce the sound is called reverberation time. It is also defined as the time taken by sound to fall to one millionth of its intensity just before the cutoff.

Absorption of sound:-

The amount of absorption of sound depends upon the nature of the material and their surface area. The absorption coefficient of sound is the ratio of sound energy absorbed by the given surface

to the sound energy by an equal area of a perfect absorber. Window is a example of perfect absorber.

Let $\alpha_1, \alpha_2, \alpha_3$..... are the absorption coefficient of absorbing surface of area S_1, S_2, S_3 ... .made of different materials forming the interior surface of the room. The total absorption is $A = \sum \alpha_i S_i$

The average absorption is given by;

$$\alpha = \frac{\sum \alpha_i S_i}{\sum S_i}$$

Sabine's Relation:-

Fall in intensity (δI) at a small time interval (δt) is mainly depends upon mean absorption coefficient (α), average intensity (I) and number of reflection of sound per second (n).

$$i.e. \delta I = -\alpha n I \delta t \ldots\ldots\ldots (1)$$

Jaeger has shown statistically that number of reflection per second is,

$$n = \frac{Sv}{4V} \ldots\ldots\ldots (2)$$

Where, v is velocity of sound, V is volume of hall and S is total surface area of all reflecting surface.

From equation (1) and (2);

$$\delta I = -\alpha \frac{Sv}{4V} I \delta t$$

$$or, \qquad \frac{\delta I}{I} = -\alpha \frac{Sv}{4V} \delta t$$

$$or, \qquad \frac{dI}{I} = -\alpha \frac{Sv}{4V} dt$$

Now, integrating both sides we get;

$$\int_{I_0}^{I_t} \frac{dI}{I} = \int_{0}^{t} -\alpha \frac{Sv}{4V} dt$$

$$log \frac{I_t}{I_0} = -\alpha \frac{Sv}{4V} t$$

$$\frac{I_t}{I_0} = e^{-\alpha \frac{Sv}{4V} t}$$

But we have; $I_t = \frac{I_0}{10^6}$

$$10^{-6} = e^{-\alpha \frac{Sv}{4V} t}$$

$$t = 6 log_e 10 \times \frac{4V}{\alpha Sv}$$

$$t = 6 \times 2.3026 \times \frac{4V}{\alpha Sv}$$

Taking speed of sound in room temperature $(v) = 350\ m/sec.$

$$t = 6 \times 2.3026 \times \frac{4V}{\alpha S \times 350}$$

$$\therefore t = \frac{0.158V}{\alpha S} \text{ in S. I. unit}$$

Which is required Sabine's Relation.

If we put $v = 1120\ ft/sec$, The expression for reverberation time will be,

$$t = \frac{0.05V}{\alpha S} \text{ in F. P. S.}$$

This shows that Reverberation time is directly proportional to the volume of auditorium and inversely proportional to absorption coefficient and total surface area.

For good acoustics of a hall, the reverberation time should have appropriate value. If it is too large, there may be multiple reflections and over lapping of sound causing confusing to listener. If it is too small, the sound drops instantaneously and gives the dead effect. The suitable value of reverberation time is 1.03 sec for a hall of 10,000 cu ft capacity.

Ultrasonic Waves:-

Wave of frequency greater than that of audible sound is called ultrasonic wave. The frequency of such wave is just greater than 20 KHz. The sound waves of frequency lower than the audible

limit are called infrasonic waves. Velocity of wave higher than the velocity of sound is called supersonic waves.

Production of ultrasonic waves:-

There are two different methods for the generation of ultrasonic waves. Which are

(1) Piezo-electric generation:-

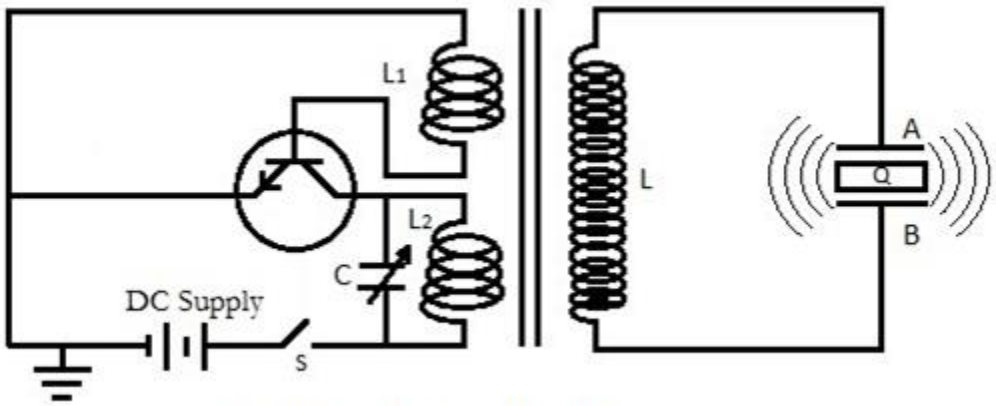


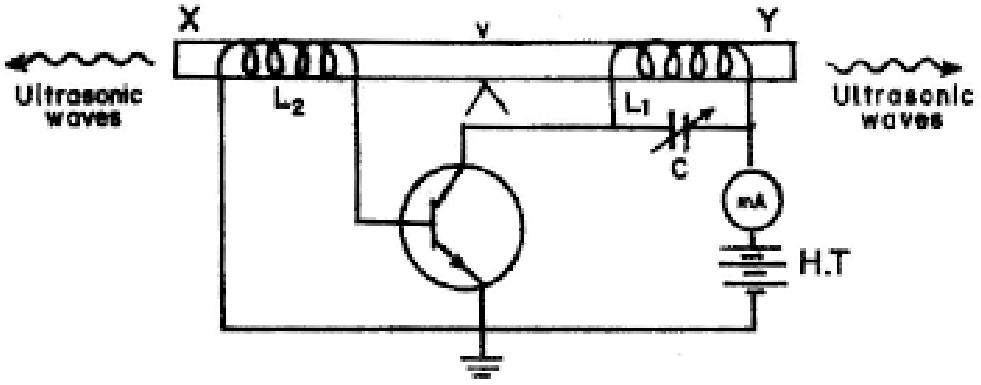
Fig. 7.1: Piezoelectric Oscillator

If a transverse electric field is applied along the certain crystal like quartz or tourmaline then mechanical stress is produced on the crystal. This effect is used to produce the ultrasound.

An ac field produced by the oscillator circuit is applied in two metallic plates A and B with the help of setup transformer there is a crystal like quartz or tourmaline as a dielectric between two plates as shown in figure above. On the application high electric field the crystal starts to vibrate and surrounding the crystal

there produced a wave whose frequency is very high. That wave is ultrasound.

(2) Magneto-striction generation:-



When a ferromagnetic rod like iron and nickel is placed in a magnetic field parallel to its length, the rod experiences a small change in its length. This is called magneto-striction generation. The change in length produced in the rod depends upon the magnetic field, the nature of the materials and is independent of the direction of the magnetic field applied. The experimental arrangement is as shown in figure above.

In figure XY is rod of ferromagnetic materials like iron or nickel. The rod is clamped in the middle. The alternating magnetic field is generated by electronic oscillator. The coil L_1 wound on the right hand portion of the rod along with a variable capacitor C. This forms the resonant circuit of the collector tuned oscillator. The frequency of oscillation is controlled by variable capacitor. The coil wound on the left hand portion of the rod is connected to the base circuit. The coil L_2 acts as a feedback loop.

Application of ultrasonic waves:-

- Directional signaling.
- Detection of sub-marine and aircraft.
- Depth of sea investigation.
- Structure of matter investigation.
- Detection of cracks in metal.
- Mechanical Engineering.
- Chemical uses such that an emulsion of water and oil.
- Biological uses such that it is use to lame smaller animals.
- Medical uses such that ultrasound.

Numerical Examples:-

1. **The volume of a room is $600\ m^3$, wall area of a room is $220\ m^2$. The floor and ceiling area each is $120\ m^2$. If average absorption coefficient for wall is 0.03 for ceiling is 0.80 and for floor is 0.06, calculate average absorption coefficient and reverberation time?**

Solution:-

$$\text{Volume of room (V)} = 600\ m^3$$

$$\text{Area of wall } (S_1) = 220\ m^2,$$

$$\text{Absorption coefficeint of wall } (\alpha_1) = 0.03$$

Area of ceiling $(S_2) = 120\ m^2$,

Absorption coefficent of ceiling $(\alpha_2) = 0.80$

Area of floor $(S_3) = 120\ m^2$,

Absorption coefficent of floor $(\alpha_3) = 0.06$

$$\therefore \sum \alpha_i\ S_i = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3$$

$$= 220 \times 0.03 + 120 \times 0.80 + 120 \times 0.06$$

$$= 109.8$$

$$\text{And } \sum S_i = S_1 + S_2 + S_3$$

$$= 220 + 120 + 120$$

$$= 460$$

Now, average absorption coefficient $(\alpha) = \frac{\sum \alpha_i S_i}{\sum S_i}$

$$= \frac{109.8}{460}$$

$$= 0.2386$$

And reververation time $(t) = \frac{0.158V}{\alpha S} = \frac{0.158 \times 600}{0.2386 \times 460}$

$$\therefore t = 0.864\ sec$$

2. **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 the entire surface in the hall? If the area of sound absorbing is $1600\, m^2$. Calculate average absorption coefficient.**

Solution:-

Volume of hall (V) $= 4500\ \text{m}^3$

Reverberation time $(t) = 1.5\ sec$

Total absorption power $(\alpha S) = ?$

We know that;

Reverberation time $(t) = \frac{0.158V}{\alpha S}$

$$or, \alpha S = \frac{0.158V}{t} = \frac{0.158 \times 4500}{1.5}$$

$\therefore$ Total absorbing power $(\alpha S) = 474$

Since, area of sound absorbing surface $(S) = 1600\, m^2$

$$\therefore\ \alpha = \frac{\alpha S}{S} = \frac{474}{1600} = 0.296$$

3. **What is the reverberation time for hall with length $12\, m$, breadth $11\, m$ and height $9\, m$, If the**

coefficient of absorption of walls, ceiling and floor are 0.02, 0.04, and 0.08 respectively.

Solution:-

Volume of room $(V) = l \times b \times h = 12 \times 11 \times 9 = 1188\ m^3$

Area of floor = Area of ceiling $= (l) \times (b) = 132\ \text{m}^2$

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

$\therefore$ Total absorption (αS)

$$= 414 \times 0.02 + 132 \times 0.04 + 132 \times 0.08$$
$$= 24.12$$

$$\therefore \text{Reverberation time } (t) = \frac{0.158V}{\alpha S}$$

$$= \frac{0.158 \times 1188}{24.12}$$

$$= 7.78\ sec$$

4. **The time of reverberation of an empty hall and with 500 audience is $1.5\ sec$ and $1.4\ sec$ respectevely. Find the reverberation time with 800 audience in the hall.**

Solution:-

According to the question;

$$\text{For empty hall, } 1.5 = \frac{0.158V}{\alpha S} \ldots\ldots\ldots (i)$$

$$\text{And with 500 audience, } 1.4 = \frac{0.158V}{\alpha S + 500} \ldots\ldots\ldots (ii)$$

Dividing (i) by (ii);

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

$$1.5\ \alpha S = \ 1.4\ \alpha S + 700$$

$$or, 0.1\ \alpha S = 700$$

$$\therefore \alpha S = 7000$$

Now from equation (i);

$$V = \frac{1.5 \times \alpha S}{0.158}$$

$$= \frac{1.5 \times 7000}{0.158}$$

$$= 66455.7\ m^3$$

Now time of reverberation with 800 audience is;

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

$$\therefore\ T_3 = 1.346\ sec$$

5. **The time of reverberation of an empty hall and with 500 audience is $1.5\ sec$ and $1.4\ sec$ respectevely. Find the number of person in the hall if the reverberation time falls to $1.312\ sec$.**

Solution:-

According to the question;

$$\text{For empty hall, } 1.5 = \frac{0.158V}{\alpha S} \dots\dots\dots (i)$$

$$\text{And with 500 audience, } 1.4 = \frac{0.158V}{\alpha S + 500} \dots\dots\dots (ii)$$

$$\text{Also } 1.312 = \frac{0.158V}{\alpha S + x} \dots\dots\dots (ii)$$

where x is number of person considered

From solving equation (i) and (ii) we get;

$$\alpha S = 7000$$

$$\text{We have from (i), } V = \frac{1.5 \times \alpha S}{0.158} = \frac{1.5 \times 7000}{0.158}$$

$$\therefore V = 66455.7\ m^3$$

Now, from equation (ii)we get;

$$1.312 = \frac{0.158 \times 66455.7}{7000 + x}$$

$$x = 1003.04$$

∴ Number of person in the hall if the reverberation time falls to 1.312 sec is 1003.

6. A room has dimension of $6m \times 4m \times 5m$. Find (i) mean free path of sound wave in the room. And (ii) The number of reflection made per second by the sound wave. Given that velocity of sound is $350\ m/sec$.

Solution:-

Here, volume of room$(V) = 6 \times 4 \times 5 = 120\ m^3$

Total surface area $(S) = 2(\ lb + bh + lh) = 148\ m^2$

∴ Mean free path $(\lambda) = \frac{4V}{S} = \frac{4 \times 120}{148} = 3.243\ m$

∴ Total number of reflection (N) $= \frac{\text{velocity of sound}}{\text{mean free path}}$

$= \frac{350}{3.243} = 108$

Exercise:-

1. Give an account of bad acoustic properties of a hall and discuss the method to improve these defects.
2. What is piezoelectric effect? Describe the construction of a piezoelectric oscillator for the production of ultrasonic waves.
3. What are the measures of good acoustic building? Show that the reverberation time decreases with increase in absorbing factor in a hall.
4. Write some features of acoustically good auditorium. Derive Sabine's formula.
5. Why is it important to study the reverberation time, before the construction of the Cinema hall? Derive the relation for the reverberation time based on absorption coefficient, volume and surface area of the hall?
6. What is ultrasonic wave? Discuss a method for the production of ultrasonic wave.
7. A lecture hall with a volume of 60,000 cu. Ft. is found to have a reverberation time of 1.6 sec. What is total absorbing power of the entire surface in the hall? If the area of the sound absorbing surface is 9000 sq. ft. Calculate average absorption coefficient.
8. The volume of room is 960 m^3. The wall area of the room is 160 m^2, ceiling area 96 m^2 and floor area 90 m^2. The average sound absorption coefficient (i) for wall is 0.03 (ii) for ceiling is 0.80 and (iii) for the floor is 0.06. Calculate

the average sound absorption coefficient and reverberation time.

9. A lecture hall of volume $12 \times 10^4\, m^3$ has a total absorption of 13200 m^2 of open window unit. Entry of students in to the hall raises the absorption by another 13200 m^2 of open window unit. Find the change in reverberation time.
10. Calculate the reverberation time of small hall of 1500 m^3 having seating capacity of 120 persons when i) The hall is empty and ii) with full capacity of the audience for the following data.

Surface	Areas	Coefficient of absorption
Plastered wall	112 m^2	0.03
Wooden flower	130 m^2	0.06
Plastered ceiling	170 m^2	0.04
Wooden doors	20 m^2	0.06
Cushioned chairs	120	0.5
Audience	120	0.44