Wave motion and Sound

Learning Objectives

After studying this chapter, the student will be able to:

- ➡ Understand the fundamental principles of audio frequency acoustic and perform basic calculations
- ➡ Know some basic terms associated with acoustics such as absorption coefficient, reverberation and reverberation time
- ➡ Derive an expression for reverberation time based on Sabine's method
- ➡ Develop an understanding about factors affecting accustics of buildings and their remedies

2.1 INTRODUCTION

Acoustics is the science of sound which deals with the properties of sound waves, their origin, propagation and their action on obstacles.

Acoustics finds wide application in many fields. Some of the important applications in the field of engineering are electro-acoustics, design of acoustical instruments and architectural acoustics.

In this chapter, few topics in architectural acoustics are explained.

Architectural acoustics deals with the design and construction of music halls and sound recording rooms to provide best audible sound to the audience.

2.2 CLASSIFICATION OF SOUND

Sound is a vibration in an elastic medium with definite frequency and intensity which can be heard by the human ear.

On the basis of frequency f sound waves are classified into three types:

1. Infrasound ($f < 20$ Hz)
2. Audible sound (20 Hz $< f <$ 20 kHz)
3. Ultrasound ($f >$ 20 kHz)

The sound waves having frequencies less than 20 Hz are called infrasound. This is sound not audible.

The sound waves having frequency between 20 Hz and 20 kHz are called audible sound.

The sound waves having frequency greater than 20 kHz are called ultrasound. The ultrasound is also not an audible sound.

2.2.1 Classification of Audible Sound

The audible sound is generally classified into two categories:

(i) Musical sound

(ii) Noise

(i) Musical sound

The sound which produces pleasing effect on the ear is called musical sound.

Example: Sounds produced by musical instruments like sitar, violin, flute, piano, etc.

Properties of musical sound

Musical sound is characterised by the following properties:

The musical sound waveforms are regular in shape, have definite periodicity and they do not undergo a sudden change in amplitude, as shown in Figure 1.

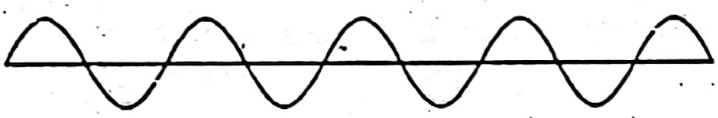

Figure 1: Music waveform

(ii) Noise

The sound that produces a jarring effect on the ear and is unpleasant to hear is called noise.

Example: Sound produced by flying aeroplane, road traffic, crackers, etc.

Properties of noise

Noise is characterisied by the following properties:

The noise waveforms are irregular in shape, they do not have definite periodicity and they undergo a sudden change in amplitudes, as shown in Figure 2.

Figure 2: Noise waveform

2.3 CHARACTERISTICS OF MUSICAL SOUND

The characteristics of musical sound are:

1. **Pitch** - Related to frequency of sound.
2. **Loudness** - Related to intensity of sound.
3. **Timbre** - Related to quality of sound.

2.3.1 Pitch

It is a sensation that depends upon the frequency. Pitch helps in distinguishing between a note of high frequency and low frequency sound (i.e., it helps to distinguish a shrill sound from a flat sound) of the same intensity produced by the same musical instrument. A shrill sound is produced by a sound of high frequency.

The sound produced by ladies and children is of high pitch type because the frequency is high. Similarly, the sound produced by a bee or mosquito is of high pitch due to high frequency.

Thus, greater the frequency of a sound the higher is the pitch and vice versa. The pitch of sound changes due to Doppler's principle when either the source or the observer or both are in motion.

2.3.2 Loudness

Loudness is a characteristic which is common to all sounds, whether classified as musical sound or noise.

Loudness is a degree of sensation produced on ear. Thus, loudness varies from one listener to another. Loudness depends upon intensity and also upon the sensitiveness of the ear.

Loudness and intensity are related to each other by the relation

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

or

$$L = K \log_{10} I$$

where K is a constant.

From this relation it is seen that loudness is directly proportional to the logarithm of intensity, and is known as Weber-Fechner law.

From the above equation,

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

where $\frac{dL}{dI}$ is called sensitiveness of ear. Therefore, sensitiveness decreases with increase in intensity. Loudness is a physiological quantity.

2.3.3 Timbre

It is the quality of sound which enables us to distinguish between two sounds having the same loudness and pitch. It depends on the presence of overtones.

It helps us to distinguish between musical notes emitted by different musical instruments and voices of different persons even though the sounds have the same pitch and loudness.

2.4 INTENSITY

Intensity I of sound wave at a point is defined as the amount of sound energy Q flowing per unit area in unit time when the surface is held normal to the direction of the propagation of sound wave.

i.e.,
$$I = \frac{Q}{At}$$

Therefore, if $A = 1\ m^2$ and $t = 1$ sec, then $I = Q$, where Q is sound energy.

The intensity is a physical quantity which depends upon factors like amplitude a, frequency f and velocity v of sound together with the density of the medium ρ.

Therefore, the intensity I in a medium is given by

$$I = 2\pi^2 f^2 a^2 \rho v$$

The unit of intensity is Wm^{-2}.

The minimum sound intensity which a human ear can sense is called the threshold intensity. Its value is 10^{-12} watt/m². If the intensity is less than this value then our ear cannot hear the sound.

This minimum intensity is also known as zero or standard intensity. The intensity of a sound is measured with reference to the standard intensity.

2.4.1 Intensity Level (Relative Intensity) I_L

The intensity level or relative intensity of a sound is defined as the logarithmic ratio of intensity I of a sound to the standard intensity I_o.

i.e.,
$$I_L = K \log_{10}\left(\frac{I}{I_o}\right)$$

Let I and I_o represent intensities of two sounds of a particular frequency; and L_1 and L_o be their corresponding measures of loudness. Then, according to Weber-Fechner law,

$$L_1 = K \log_{10} I \quad \text{...(1)}$$
$$L_0 = K \log_{10} I_o \quad \text{...(2)}$$

Therefore, the intensity level or relative intensity is

$$I_L = L_1 - L_o$$
$$= K \log_{10} I - K \log_{10} I_o$$
$$= K (\log_{10} I - \log_{10} I_o)$$

$$I_L = K \log_{10}\left(\frac{I}{I_o}\right) \quad \text{...(3)}$$

If K = 1, then I_L is expressed in a unit called *bel*.

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

A second form of definition for absorption coefficient is given by Sabine.

In order to compare the relative efficiency of different sound absorbing material Sabine assumed a standard sound-absorbing material.

Sabine chose an area of 1 m^2 open window to be the standard unit of absorption. Since all the sound energy falling on it passes through it, they can be said to be completely absorbed.

Thus, with this concept the absorption coefficient of a material is defined as the ratio of sound energy absorbed by a material to that absorbed by an equal area of an open window.

Definition 2: It is defined as the reciprocal of the area of the sound-absorbing material which absorbs the same amount of sound energy as that of 1 m^2 of an open window.

For example, if a sound-absorbing material of 5 m^2 absorbs the same amount of sound energy as absorbed by 1 m^2 of open window, then the absorption coefficient of the material is given by $\frac{1}{5} = 0.20$.

The unit of absorption coefficient is sabine and is also called O.W.U. (Open Window Unit).

2.6 REVERBERATION AND REVERBERATION TIME

The persistence or prolongation of sound in a hall even though the source of sound is cut off is called reverberation.

This is because the sound produced in a room undergoes multiple reflection from the walls, floor, ceiling and any other reflecting materials before it becomes inaudible. Thus, a person in the room continues to receive the successive reflections of progressively diminishing intensity. Therefore, the sound lasts for sometime even after the source has stopped emitting the sound. This effect is called reverberation.

The time taken by the sound to fall below the minimum audibility level after the source stopped sounding is called reverberation time.

In the following section an expression for reverberation time is derived based on Sabine's method.

2.6.1 Sabine's Formula

Sabine defined the reverberation time as the time taken by the sound intensity to fall to one millionth of its original intensity after the source stopped emitting sound.

The reverberation time is given by

$$T = \frac{0.167\ V}{\Sigma a S}$$

where V is the volume of the hall

a is the absorption coefficient

S is the surface area.

1.8 FACTORS AFFECTING ACOUSTICS OF BUILDINGS AND THEIR REMEDIES

The various factors affecting the acoustics of buildings such as reverberation time, loudness, focussing, echo, echelon effect, resonance and noise with their remedies are explained in brief in this pection.

(i) Reverberation Time

Reverberation is the persistence or prolongation of sound in a hall even after the source stopped emitting sound.

The reverberation time is the time taken by the sound to fall below the minimum audibility level.

In order to have a good acoustic effect, the reverberation time has to be maintained at optimum value. The reason is, if the reverberation time is too small, the loudness becomes inadequate. As a result the sound may not reach the listener. Thus, this gives the hall a dead effect. On the other hand, if the reverberation time is too long, it will lead to more confusion due to mixing of different syllables. This makes the sound unintelligible. Thus, reverberation time should neither be too large nor small. Hence, to maintain a good acoustic effect the reverberation time should be maintained at optimum value.

Remedies

The reverberation time can be maintained at an optimum value by adopting the following ways:

1. By providing windows and openings.
2. By having full capacity of audience in the hall or room.
3. By using heavy curtains with folds.
4. By covering the floor with carpets.
5. By decorating the walls with beautiful pictures, maps, etc.
6. By covering the ceiling and walls with good sound-absorbing materials like felt, fibre board false roofing, etc.

The reverberation time depends on the size of the hall and the quality of sound. Thus, the reverberation time can be controlled either by inserting or removing sound-absorbing material in a hall or room.

(ii) Loudness

The uniform distribution of loudness in a hall or a room is an important factor for satisfactory hearing. Sometimes, the loudness may get reduced due to excess of sound-absorbing materials used inside a hall or room.

Remedies

If the loudness of sound is not adequate, the loudness can be increased by adopting the following methods.

1. By using suitable absorbents at places where noise is high. As a result, the distribution of loudness may become uniform.
2. By constructing low ceilings for the reflection of sound towards the listener.
3. By using large sounding boards behind the speaker and facing the audience.
4. By using public address system like loudspeakers.

(iii) Focussing and Interference Effects

The presence of any concave surface or any other curved surface in the hall or room may make the sound to be concentrated at this focus region. As a result, the sound may not be heard at all at other regions. These regions are referred as dead space. Hence, such surfaces must be avoided.

In addition to focussing there should not be interference of direct and reflected waves. This is because, a constructive interference may produce a sound of maximum intensity in some places and a destructive interference may produce a sound of minimum intensity in other places. Thus, there will be an uneven distribution of sound intensity.

Remedy

Curved surfaces can be avoided. If curved surfaces are present, they should be covered with suitable sound-absorbing materials.

(iv) Echo

An echo is heard due to reflection of sound from a distant sound-reflecting object.

If the time interval between the direct sound and reflected sound is less than $\frac{1}{15}$th of a second, the reflected sound is helpful in increasing the loudness. But, those sounds arriving later than this cause confusion.

Remedy

An echo can be avoided by covering long-distance walls and high ceiling with suitable sound-absorbing material. This prevents reflection of sound.

(v) Echelon Effect

It refers to the generation of a new separate sound due to multiple echos. A set of railings or any regular reflecting surface is said to produce the echelon effect. This echelon effect affects the quality of the original sound.

Remedy

The remedy to avoid echelon effect is to cover such surfaces with sound-absorbing materials.

(vi) Resonance

Resonance occurs due to the matching of frequency. If the window panels and sections of wooden portions have not been tightly fitted, they may start vibrating, thereby creating an extra sound in addition to the sound produced in the hall or room.

Remedy

The resonance may be avoided by fixing the window panels properly. Any other vibrating object which may produce resonance can be placed over a suitable sound-absorbing material.

(vii) Noise

The hall or room should be properly insulated from external and internal noises. In general, there are three types of noises:

1. Air-borne noise
2. Structure-borne noise
3. Inside noise.

Air-borne Noise

Extraneous noises which are coming from outside through open windows, doors and ventilators are known as air-borne noise. The air-borne noise can be avoided by following the remedies mentioned below.

Remedies

1. The hall or room can be made air conditioned.
2. By using doors and windows with separate frames with proper sound-insulating material between them.

Structure-borne Noise

The noise which is conveyed through the structure of the building is called structure-borne noise. The structural vibration may occur due to street traffic, operation of heavy machines, etc.

Remedies

1. This noise can be eliminated by using double walls with air space between them.
2. By using anti-vibration mounts this type of noise can be reduced.
3. By covering the floor and walls with proper sound-absorbing material this noise can be eliminated.

Inside Noise

The noises which are produced inside the hall or room is called inside noise. The inside noise may be produced due to machineries like air conditioners, refrigerators, generators, fans, typewriters, etc.

To avoid these inside noises the following remedies can be adopted.

Remedies

1. The sound-producing machineries can be placed over sound-absorbing materials like carpet, pads, wood, felt, etc.
2. By using curtains of sound-absorbing materials.
3. By covering the floor, wall and ceiling with sound-absorbing materials.

.8.1 Conditions for Good Acoustics

A hall or an auditorium is said to be acoustically good if they satisfy the following conditions:

1. The quality of the sound should be uniform throughout the entire hall or auditorium.
2. There should not be any overlapping of sounds.
3. The loudness of the sound should be uniform throughout the hall or auditorium. To achieve this a public address system can be used in big halls.
4. The presence or absence of audience should not affect the quality of sound.
5. Resonance effect should be avoided.
6. The hall should have a proper reverberation time.
7. The external noises should not disturb the proceedings inside the hall or auditorium.
8. There should not be any echelon effect.

SUMMARY

- Sound is classified into infrasound, audible sound and ultra sound based on frequency.
- Audible sound is classified into music and noise.
- The characteristics of a musical sound are pitch, loudness and timbre (quality).
- The reciprocal of the area of the sound absorbing material which absorbs the same amount of sound energy as that of $1m^2$ of an open window is called the absorbtion coefficient. Its unit is O.W.U.
- Reverberation time is the time taken by a sound intensity to fall to one millionth of its original intensity when the source is cut off. It is given by $T=\frac{0.167V}{A}$.
- Reverberation time, loudness, focussing and interference effects, echo, echelon effect, resonance and noise are the important factors which affect the acoustics of a building.

Assignment Problems

1. The intensity of sound produced by thunder is $0.1\ Wm^{-2}$. Calculate the relative intensity in dB.
   (Ans.: $I_L = 110$ dB)
2. The intensity of sound in a street during heavy traffic is $10^{-4}\ Wm^{-2}$. Calculate the intensity level in dB.
   (Ans.: $I_L = 80$ dB)
3. What is the resultant sound level when a 70 dB sound is added to a 85 dB sound ?
   (Ans.: $I_L = 85.13$ dB)

1 INTRODUCTION

The sound waves of frequency greater than 20 kHz are called ultrasonic waves. These sound waves are inaudible to human ear. The ultrasonic waves due to their shorter wavelength have a greater penetrating power.

Ultrasonic waves are widely used in medical diagnostics, marine applications, NDT, etc.

In this chapter, two different methods of producing ultrasonic sound waves, their velocity determination and their application in SONAR are explained.

1.1 Properties of Ultrasonic Waves

(i) The frequency of ultrasonic wave is greater than 20 kHz.

(ii) Their wavelengths are small. As a result, their penetrating power is high.

(iii) They can travel over long distances as a highly directional beam.

(iv) They have high energy content.

(v) Their speed of propagation increases with increase in frequency.

2 PRODUCTION OF ULTRASONIC WAVES

Based on frequency range and power output, the ultrasonic wave generators are divided into two groups.

(i) Mechanical generator

(ii) Electrical generator

In the following section, the electrical generator methods of producing ultrasonic waves are explained.

The electrical generators are subdivided into two categories.

(i) Magnetostriction generator or oscillator

(ii) Piezoelectric generator or oscillator

The above two methods are widely used nowadays for producing ultrasonic waves.

2.1 Magnetostriction Method

Principle: Magnetostriction Effect

When a ferromagnetic material in the form of a rod is subjected to an alternating magnetic field parallel to its length as shown in Figure 1, the rod undergoes alternate contractions and expansions at a frequency equal to the frequency of the applied magnetic field. This phenomenon is known as magnetostriction effect.

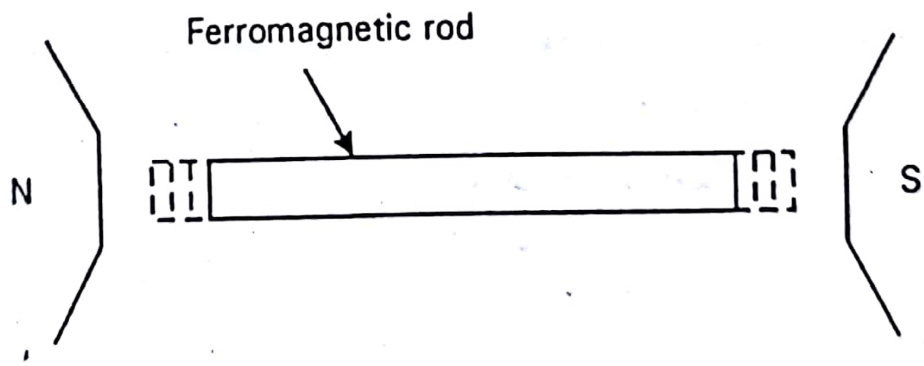

Figure . 1: Magnetostriction effect

Due to resonance the rod is thrown into longitudinal vibrations, thereby producing ultrasonic waves in the surrounding medium. Such *ferromagnetic materials which are used for the production of ultrasonic waves are called* ***'magnetostriction materials'***.

Construction

The circuit diagram is shown in Figure 2.

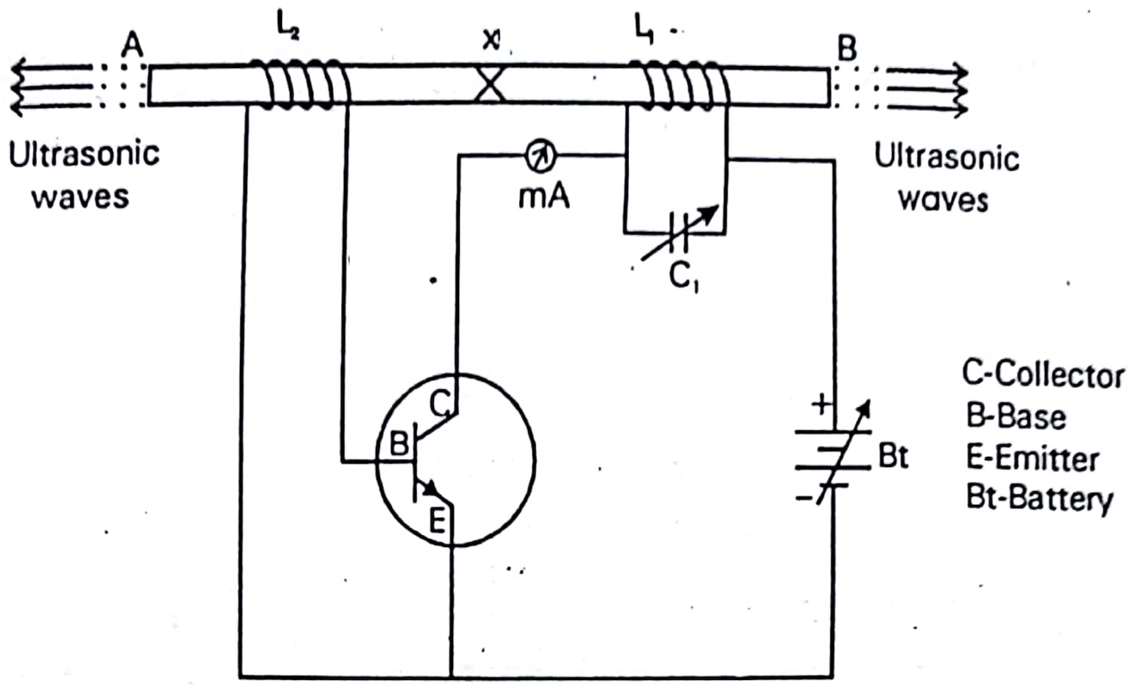

Figure 2: Circuit diagram for magnetostriction oscillator method

The ferromagnetic rod AB is clamped at the middle X. The coils L_1 and L_2 are wound at the ends of the rod. To the coil L_1 a variable capacitor C_1 is connected in parallel and this combination forms the tank or resonant circuit. One side of the resonant circuit is connected to the collector of the transistor through a milliammeter. The other side of the resonant circuit is connected to the emitter through a battery. The coil L_2 is connected between the base and the emitter and is used as a feed back loop.

Working

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

$$f = \frac{1}{2\pi\sqrt{L_1C_1}}.$$

As a result, the rod gets magnetised by the collector current. Any change in the collector current brings about a change in the magnetisation, and consequently a change in the length of the rod. This gives rise to a change in flux in coil L_2 in the base circuit, thereby inducing an emf in the coil L_2. This varying emf is applied to the base of the transistor and is fed back to the coil L_1, thereby maintaining the oscillations.

By varying the capacitor C_1, the frequency of oscillation of the tank circuit gets varied. If the frequency of the tank circuit matches with the natural frequency of the material, then due to resonance the rod vibrates vigorously producing ultrasonic waves at the ends of the rod. The milliammeter reading gives maximum value at the resonance condition. The frequency of ultrasonic waves produced by this method depend upon the length l, density ρ and elastic constant E of the rod.

i.e., $$f = \frac{1}{2l}\sqrt{\frac{E}{\rho}}.$$

Thus, by varying l and E of the rod, ultrasonic waves can be generated at any desired frequency. Hence, at resonance condition,

Frequency of the oscillatory circuit = frequency of the vibrating rod

i.e., $$\frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2l}\sqrt{\frac{E}{\rho}}.$$

Merits

1. The design of this oscillator is very simple and production cost is low.
2. At low ultrasonic frequencies, large power output is possible without the risk of damage to the oscillatory circuit.
3. Frequencies ranging from 100 Hz to 3,000 kHz can be produced.

Demerits

1. It cannot generate ultrasonics of frequency above 3,000 kHz.
2. The frequency of oscillations depends greatly on temperature.
3. There will be losses of energy due to hysteresis and eddy current.

2.2 Piezoelectric Effect

When pressure is applied to one pair of opposite faces of crystals like quartz, tourmaline, rochelle salt, etc., cut with their faces perpendicular to its optic axis, equal and opposite charges appear across its other faces as shown in Figure . 3. This phenomenon is known as piezoelectric effect. The frequency of the developed emf is equal to the frequency of dynamical pressure.

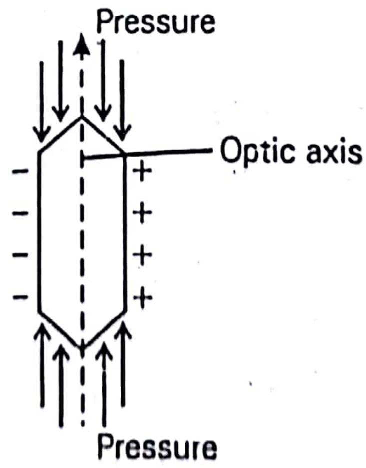

Figure . 3:

The sign of the charges gets reversed if the crystal is subjected to tension instead of pressure.

The electricity produced by means of piezoelectric effect is called piezoelectricity. The materials which can undergo piezoelectric effect are called piezoelectric materials or crystals.

Note:

- The type of crystal used for ultrasonic production is generally the X-cut crystal.
- An X-cut crystal is a piezoelectric crystal cut in a direction perpendicular to its X-axes.
- **Electric (X-axes) axes.**

The cross-section of a natural quartz crystal is hexagonal. The lines joining the opposite corners of the hexagon are called the electric axes or X-axes and the lines joining the midpoint of the opposite faces of the hexagon are called the mechanical axes or Y-axes (Figure ' 4).

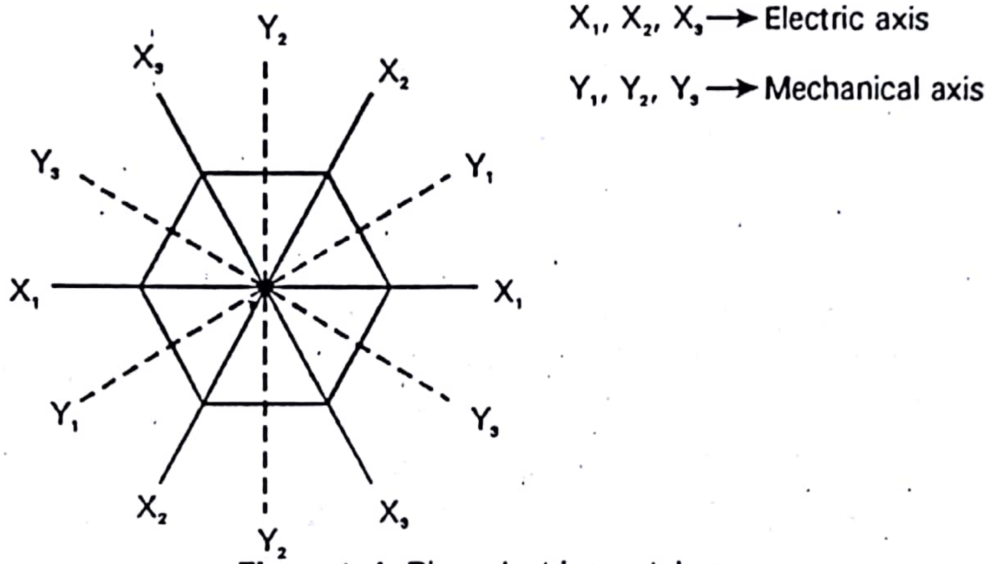

Figure . .4: Piezoelectric crystal axes

2.3 Piezo-electric Method

The piezoelectric method of producing ultrasonic waves is based on the principle of inverse piezoelectric effect.

Principle: Inverse Piezo-electric Effect

If an alternating voltage is applied to one pair of opposite faces of the crystal, alternatively mechanical contractions and expansions are produced in the crystal and the crystal starts vibrating. This phenomenon is known as inverse piezoelectric effect or electrostriction effect (Figure 5).

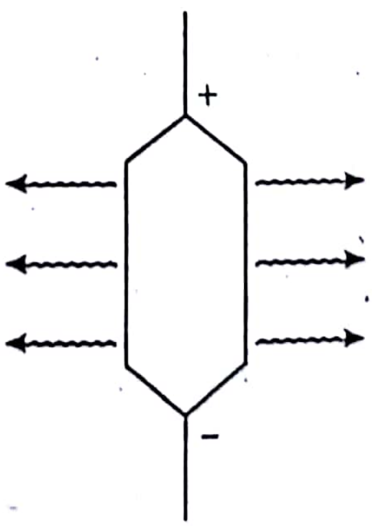

Figure ..5: Inverse piezoelectric effect

If the frequency of the applied alternating voltage is equal to the vibrating frequency of the crystal, then the crystal will be thrown into resonant vibration producing ultrasonic waves.

Construction

The circuit diagram is shown in Figure :.6.

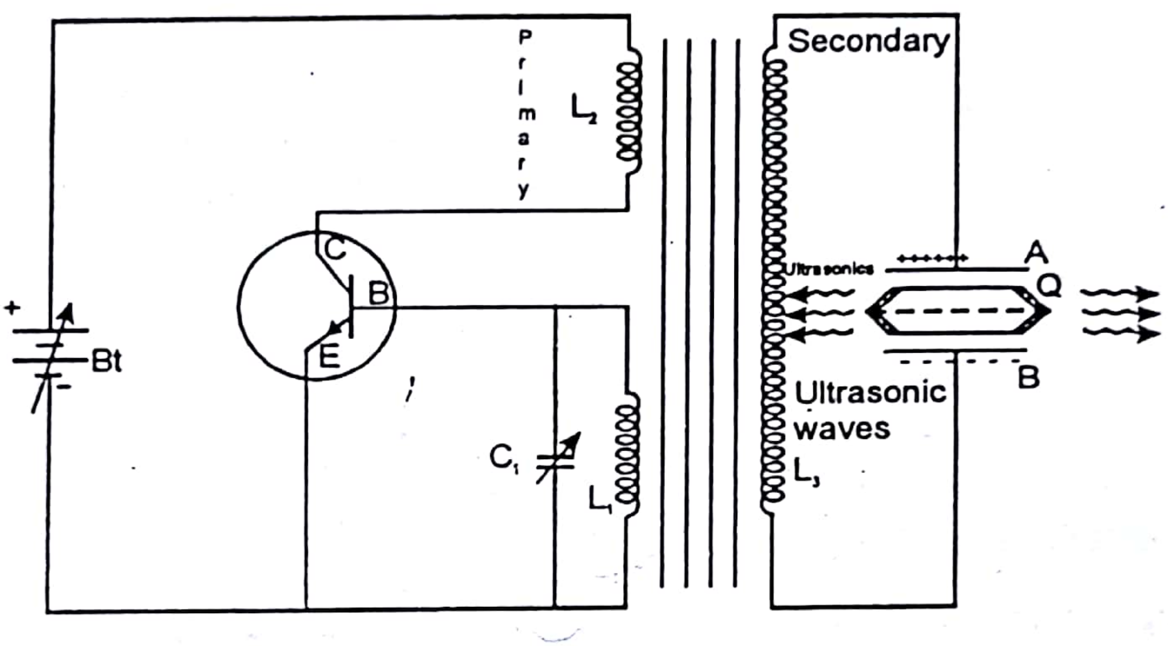

Figure : 6: Piezoelectric oscillator method

The quartz crystal Q is placed between two metal plates A and B. The plates A and B are connected to the coil L_3. The coils L_1, L_2 and L_3 are inductively coupled to the oscillatory circuit of a transistor. The coil L_2 is connected to the collector circuit, while the coil L_1 with a variable capacitor C_1 forming the tank circuit is connected between the base and the emitter. The battery is connected between free end of L_2 and the emitter of transistor.

Working

When the battery is switched on, the oscillator produces highfrequency alternating voltage given by

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}.$$

The frequency of oscillation can be controlled by the variable capacitor C_1. Due to the transformer action an emf is induced in the secondary coil L_3. This emf is impressed on plates A and B and thus excite the quartz crystal into vibrations. By adjusting the variable capacitor C_1, the crystal is set into one of the modes of resonant conditions. Thus, the vibrating crystal produces longitudinal ultrasonic waves in the surrounding air. The frequency of vibration of the crystal is

$$f = \frac{p}{2l}\sqrt{\frac{E}{\rho}}.$$

where E is the Young's modulus, ρ is the density of the material and p = 1, 2, 3... for fundamental, first overtone, second overtone ..... respectively.

At resonance condition,

Frequency of the oscillatory circuit = Frequency of the vibrating crystal

i.e.,
$$\frac{1}{2\pi\sqrt{L_1C_1}} = \frac{p}{2l}\sqrt{\frac{E}{\rho}}$$

3 DETECTION OF ULTRASONIC WAVES

Presence of ultrasonic waves can be detected by using any one of the following methods. The methods are,

1. Quartz crystal method
2. Thermal detection method
3. Sensitive flame method
4. Kundt's tube method.

3.1 Quartz Crystal Method

This method of detecting ultrasonic waves is based on the principle of piezoelectric effect. When one pair of opposite faces of the quartz crystal is exposed to ultrasonic waves, in the other pair of opposite faces, charges get developed as shown in Figure 7. These charges are amplified and detected using suitable electronic circuits.

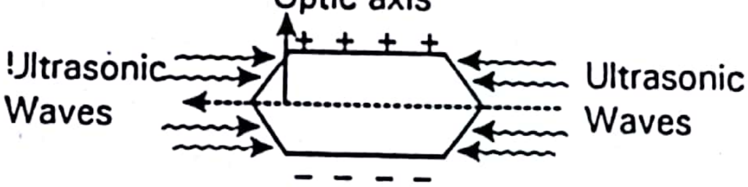

Figure 7: Quartz crystal method

3.2 Thermal Detection Method

Principle

When the ultrasonic waves are propagated through a medium, the temperature of the medium changes due to alternate compressions and rarefactions. In the case of stationary waves, there is a change in temperature at nodes and no change in temperature at antinodes. Based on this principle, by sensing the change in temperature using suitable components, the ultrasonic waves can be detected.

It is the most commonly used method to detect ultrasonic waves. In this method, a fine platinum wire included in Callender and Griffith bridge circuit arrangement, as shown in Figure 8, is used to detect the ultrasonic waves.

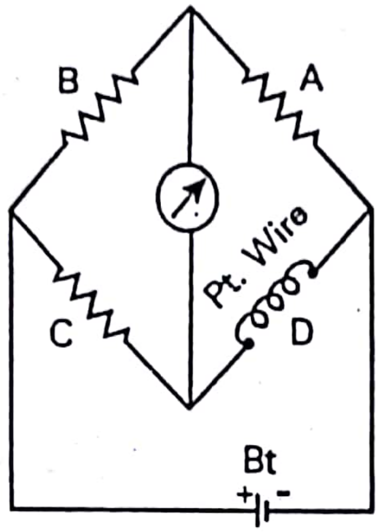

Figure ...8: Thermal detection method

This circuit is placed in the region where the presence of ultrasonic waves is to be detected. If in the medium there is a presence of ultrasonic waves, then at nodes due to alternate compressions and rarefactions alternate heating and cooling effect gets produced in the platinum wire. Thus, a change in temperature brings about a change in electrical resistance of the platinum wire which can be detected (the balanced position of the circuit gets disturbed) with the help of electrical circuit shown in Figure ...8. At antinodes, the temperature remains constant which is indicated by undisturbed balance position of the bridge.

3.3 Sensitive Flame Method

This is a qualitative method to detect ultrasonic waves. When a narrow sensitive flame is moved in a medium of ultrasonic waves, the flame remains steady at the antinodes but flickers at nodes due to the maximum change in pressure. Thus, by observing the behaviour of the flame, the ultrasonic waves presence can be detected.

3.4 Kundt's Tube Method

This method is used to detect ultrasonic waves of low frequency.

A Kundt's tube apparatus, shown in Figure . .9, consists of a long glass tube of more than 1m length and 5 cm in diameter kept horizontally with two supports on a wooden base board. One end of the tube is fitted with an adjustable piston rod with cork. A quartz crystal placed in between the two metal plates is placed at the mouth of the other end of the tube.

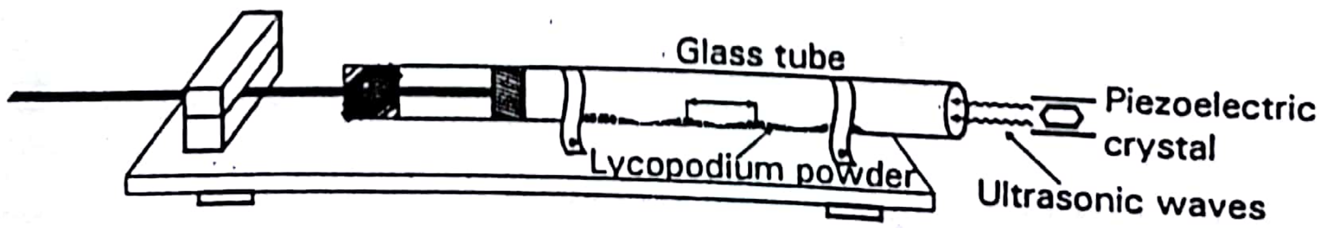

Figure . .9: Kundt's tube method

Example ..2

Find the frequency of the first and second modes of vibration for a quartz crystal of piezoelectric oscillator. The velocity of longitudinal waves in quartz crystal is $5.5 \times 10^3\ ms^{-1}$. Thickness of quartz crystal is 0.05 m.

Solution:

Given, $v = 5.5 \times 10^3\ ms^{-1}$; $t = 0.05$ m ; $\nu_1 = ?$; $\nu_2 = ?$

In the lowest mode of vibration, the distance between the two faces of the crystal of thickness t will be $\lambda/2$.

Therefore, $$t = \frac{\lambda}{2}$$

or $$\lambda = 2t = 2 \times 0.05$$

$$\lambda = 0.1 \text{ m}$$

Therefore, the frequency in the first mode of vibration

$$\nu_1 = \frac{v}{\lambda} = \frac{5.5 \times 10^3}{0.1}$$

$$\nu_1 = 5.5 \times 10^4 \text{ Hz}$$

The frequency in the second mode of vibration is

$$\nu_2 = 2\nu_1 = 2 \times 5.5 \times 10^4$$

$$\therefore \quad \nu_2 = 110 \times 10^3 \text{ Hz}$$

.5 APPLICATION OF ULTRASONIC WAVES—SONAR

SONAR is a device which stands for SOund NAvigation and Ranging.

It is based on the principle of echo sounding. In this acoustical technique highfrequency ultrasonic waves are used. When ultrasonic waves are transmitted through water, they get reflected by the objects under water. The change in frequency of the echo signals due to the Doppler effect helps us to determine the velocity, distance and the direction of objects.

In the absence of an obstacle the ultrasonic waves do not get reflected to the receiving transducer. But in the presence of an obstacle the ultrasonic waves get reflected and are picked up by the receiving transducer. Knowing the velocity of ultrasound and the elapsed time, the distance of the object can be determined.

Using SONAR, the distance and direction of submarines, depth of sea, depth of rocks in the sea, the shoal of fish in the sea, etc., can be determined.

.5.1 Determination of Depth of Sea

The ultrasonic waves can be used to find the depth of the sea. It is based on the principle of echo sounding.

Figure .1 illustrates the use of ultrasonic to find the depth of the sea.

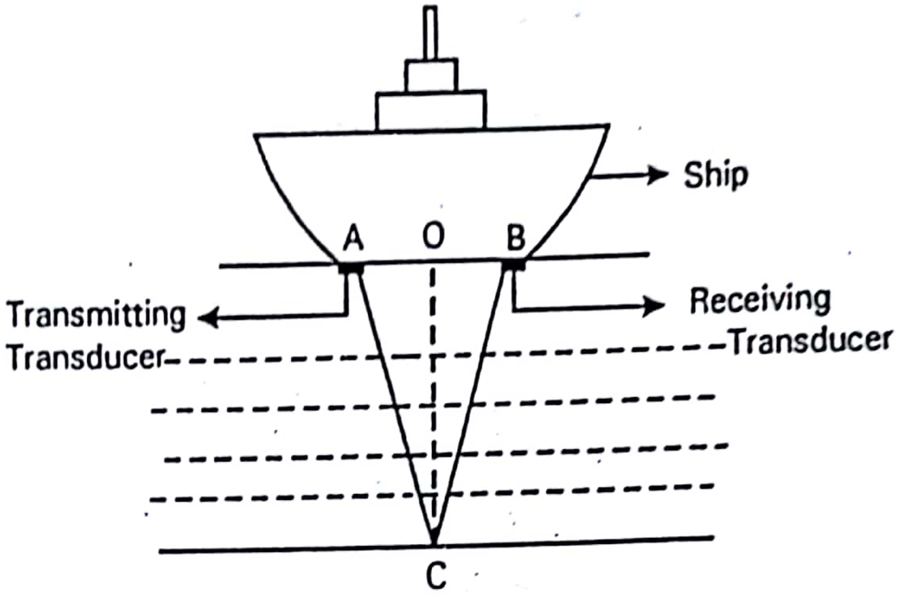

Figure . 11: Determination of depth of sea

The ultrasonic waves sent from point A travel through sea water and get reflected from the bottom of the sea. The reflected waves are received at point B.

The time t taken for the ultrasonic wave to travel to the bottom of the sea and to get reflected back to the top surface is noted using a CRO. If the velocity v of the ultrasonic wave is already known, then

$$\text{Velocity } v = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$v = \frac{AC \quad CB}{t} \simeq \frac{2CO}{t}$$

$$\therefore \quad CO = \text{Depth of the sea} = \frac{vt}{2}$$

Thus, the depth of the sea can be calculated using this formula.

Fathometer or Echometer is a device which is directly caliberated to determine the depth of the sea.

Example . 3

An ultrasonic source of 0.09 MHz sends down a pulse towards the seabed which returns after 0.55 sec. The velocity of sound in water is 1800 m/s. Calculate the depth of the sea and wavelength of pulse.

Solution:

Given, $f = 0.09 \text{ MHz} = 0.09 \times 10^6 \text{ Hz}$; $t = 0.55$ sec; $v = 1800 \text{ ms}^{-1}$

depth of the sea $= ?$; $\lambda_u = ?$.

$$\text{depth of the sea } d = \frac{vt}{2} = \frac{1800 \times 0.55}{2}$$

$$\therefore \quad \mathbf{d = 495 \text{ m.}}$$

The wavelength of the ultrasonic pulse is

$$\lambda_u = \frac{v}{f} = \frac{1800}{0.09 \times 10^6}$$

$$\therefore \quad \lambda_u = 0.02 \text{ m.}$$

5.2 Cavitation

One of the major application of high power and low frequency ultrasonic sound waves is ultrasonic processor and cleaner. *In a processor and cleaner, the principle of cavitation is used.*

What is cavitation?

When high frequency sound waves are passed into a solution, it produces mechanical vibration effect within the liquid. Thus, the violent disturbance in the liquid results in the formation of minute vaccum bubbles (also called microscopic cavities or voids). This process of bubble formation and its subsequent collapse is known as cavitation.

As the sound waves continuously propagate through the liquid, each point in the liqiud is subjected to alternate negative and positive pressure at the compressions and rarefactions of the sound waves. The bubbles are grown at the microscopic level during rarefaction and it becomes very larger during compression phase. As the bubbles grow larger, they become very unstable and eventually collapse in a violent implosion releasing a shock wave of energy. The resulting shock wave provide the necessary energy used to assist cleaning.

The implosion radiate high powered shock waves that dissipate repeatedly at a rate of 25,000 ~ 30,000 times per second. The implosions of cavitation bubbles generate temperature of 10,000°F and pressure that exceed 10,000 Pa. Ultrasonic cleaning and processor uses this cavitation implosion effect for cleaning.

Applications

1. The ultrasonic processor is used for emulsification of immiscible liquids, disruption and killing of micro-organisms etc.
2. The ultrasonic cleaner is used to clean semiconductor components, PCB's, switches, tools, moulds, casting, gears, ball-bearings, jewelleries, coins, precious stones, surgical instruments, camera lenses etc.

5.3 Ultrasonic Cleaning

The ultrasonic cleaning system consists of an ultrasonic generator, a transducer and a tank filled with the required cleaning solution as shown in Figure ?.12.

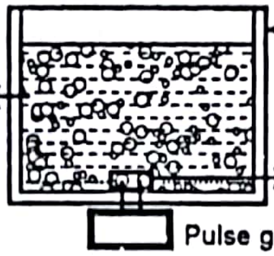

Figure ·.12: Ultrasonic cleaning system

The tank is made up of stainless steel. The ultrasonic transducer is mounted at the bottom of the tank. The size and frequency of the transducer selection depend on the capacity of the tank. The tank is filled with the cleaning liquid which may be either aqueous or solvent.

When the ultrasonic generator is switched on, it provides a suitable a.c. signal to the transducer and thus, the transducer generates the ultrasonic waves of desired frequency. These sound waves pass into the liquid medium within the tank and the process of cavitation occurs within the liquid. Due to this cavitation process fine particles on objects are pulled into the space releasing them from the object and they become suspended in the liquid by the soap.

To increase the effect of the ultrasonic cleaning, the cleaning medium should have low surface tension, low viscosity etc.

Advantages of ultrasonic cleaning

1. Environmentally pollution free and less cost.
2. Enhanced cleaning speed for both solvent and aqueous medium.
3. Cleaning is consistency and of higher quality.
4. High safety with less complaints.
5. It occupies less space and reduces labour.

·.5.4 Ultrasonic Drilling and Cutting

Ultrasonics are used for making holes in very hard materials such as glass, diamond, gems, ceramics etc., possessing high impact brittleness.

In this drilling technique, a tool bit (drilling device) driven by a suitable ultrasonic generator is used. Abrasives like boron carbide or silicon carbide are used. An ultrasound produced by the generator makes the tool bit to move up and down very quickly and forces the abrasive particles against the material to be cut thereby removing some material from the plate. This process continuous until the desired depth of a hole is formed over the plate. The same action takes place in ultrasonic cutting.

· 5.5 Ultrasonic Welding (Cold Welding)

Ultrasonic welding is a solid state phenomena of producing a metallurgical bond between the materials without melting.The ultrasonic welding is also known as a cold welding technique. This is because, during a conventional welding process properties of some metals may get changed on heating. Therefore, they cannot be welded by electric or gas welding. In such cases, the metal sheets can be welded together at room temperature using ultrasonic waves.

Process - The surfaces of the work pieces are cleaned and held together. In ultrasonic welding, the bonding between the welding pieces is produced due to the local application of high frequency vibratory evenly by keeping the work pieces together under pressure.

Using an ultrasonic generator the ultrasonic vibrations are transmitted into the work piece through a coupling system or sonotrode which is resting over one of the work piece. The anvil is used to support the welding pieces and opposes the clamping forces as shown in Figure 2.13.

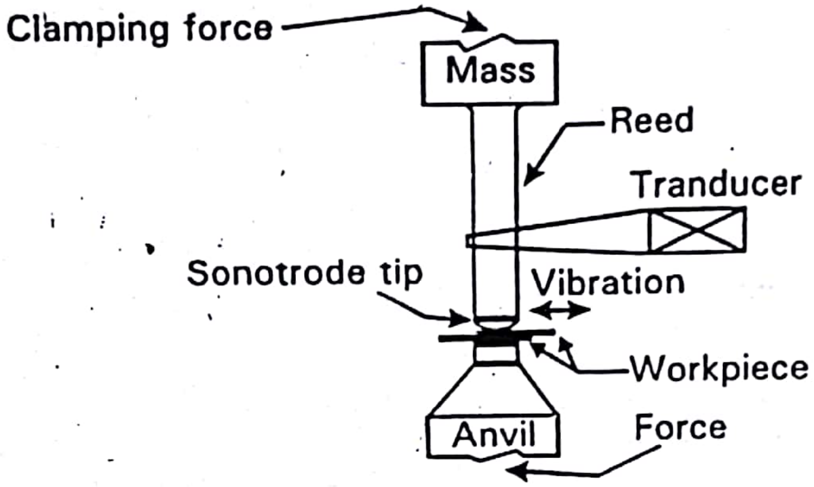

Figure 2.13 : Ultrasonic spot welding system - wedge reed type

A static clamping force is applied perpendicular to the interface between the work pieces. At the same time, the sonotrode tip oscillates parallel to the interface of the work pieces. Due to the combination of static and oscillating shear forces, an internal stress is created in the work piece. As long as the internal stress is below the elastic limit, the metal deforms elastically. But, when the stress exceeds the threshold value a high localised interfacial slip occurs. As a result, the breaking and dispers of the surface film takes place which produces metal to metal contact at any point.

Due to friction arising between the srufaces, a rise in temperature of surface layer exceeds the recrystallisation point, the layers melt and bond together to form a strong joint.

Note:

- Sonotrode is an acoustic term for the electrode used in welding. It consists of wedge and a reed.

Applications of ultrasonic welding

1. It is used in variety of packaging application such as soft foil packet, pressurised cans etc.
2. It is used to weld electronic components such as
   (a) wires and ribbons to the thin films
   (b) diodes and transistors to substrates
   (c) Aluminium wires to semiconductor devices etc.

3. In a solar cell, as the connections between photovoltaic modules are made using ultrasonic welding, they are much useful in reducing the fabrication cost of solar energy system.
4. It is used for encapsulating the materials which are sensitive to heat or electrical current.

Advantages of ultrasonic welding

1. Ultrasonic welding are made without melting the material.
2. It is used to join a wide variety of dissimilar metals.
3. The welding time is very short and is also a safe method.

5.6 Ultrasonic Soldering

In the conventional method of soldering; prior to soldering, the surfaces are to be cleaned with active fluxes to remove the contaminants, grease, oxide films etc., because, such films may prevent the formation of a good joint. The fluxes when heated dissolves unwanted contaminant and oxide films. As a result of this, the surface readily allows the molten solder to form a firm joint.

Using this type of conventional soldering, aluminium foil condensers, aluminium wires and plates cannot be soldered. Hence, to solder these type of materials ultrasonic soldering technique (a process of soldering metals without fluxes) can be used.

An ultrasonic soldering iron consists of an ultrasonic generator having a tip fixed at its end which can be heated by an electrical heating element. The tip of the soldering iron melts the solder on the aluminium (soldering piece) and the ultrasound removes the oxides and other contaminants over the surface and allows the solder to fasten.

5.7 Other Applications of Ultrasonics

The ultrasonic waves find a wide application in many fields. Some of the important applications are listed below.

5.8 Science and Engineering

1. It is used to detect flaws or cracks in metals.
2. It is used to detect ships, submarines, iceberg, etc., in the ocean.
3. It is used for soldering aluminium coil capacitors, aluminium wires and plates without using any fluxes.
4. It is used to weld some metals which cannot be welded by electric or gas welding.
5. It is used for cutting and drilling holes in metals.
6. It is used to form stable emulsions of even imiscible liquids like water and oil or water and mercury which finds application in the preparation of photographic films, face creams, etc.
7. It acts like a catalytic agent and accelerates chemical reactions.

:.5.9 Medicine

1. It is used to remove kidney stones and brain tumours without shedding any blood.
2. It is used to remove broken teeth.
3. It is used for sterilizing milk and for killing bacteria.
4. It is used to study the blood flow velocities in blood vessels of our body.
5. It is used as a diagnostic tool to detect tumours, breast cancer and also the growth of foetus.

SUMMARY

- Ultrasonics are the sound waves with frequency greater than 20 KHz.
- They have small wavelength, higher frequency and higher energy.
- Ultrasonic waves are produced by piezoelectric and magnetostriction methods.
- The piezoelectric method of generation is superior to magnetostriction method in a number of ways.
- When an ultrasonic wave meets a surface of seperation between any two media, it gets reflected in the same medium through which it propagates. This property is used in acoustical grating to measure the wavelength and frequency of ultrasonics.
- The application of ultrasonic comprises SONAR, cutting, drilling, welding, soldering, cleaning, etc.
- One of the important applications of ultrasonics is related to non-destructive testing of materials.

PART - A

Questions with Answers

1. What are ultrasonic waves?
   Sound waves having frequency greater than 20 kHz are called ultrasonic waves.
2. Why are ultrasonics not produced by passing high-frequency alternating current through a loud speaker?
   At high frequencies, the inductive effect of a loud speaker coil is so huge that practically no current passes through it. Moreover, the diaphragm cannot vibrate at such high frequencies.
3. Explain magnetostriction effect. or what is magnetostriction effect?
   When a rod of ferromagnetic material like iron, cobalt and nickel is magnetized longitudinally, the rod undergoes a small change in length. This is called magnetostriction effect.
4. What is piezoelectric effect?
   When pressure is applied to one pair of opposite faces of crystals like quartz, tourmaline, rochelle salt, etc., cut with their faces perpendicular to its optic axis, equal and opposite charges appear across its other faces. This is known as piezoelectric effect.
5. What is inverse piezoelectric effect?
   If an alternating voltage is applied to one pair of opposite faces of the crystal, mechanical contractions and expansions are produced across the other opposite faces. This phenomenon is known as inverse piezoelectric effect.