# Ultrasonics

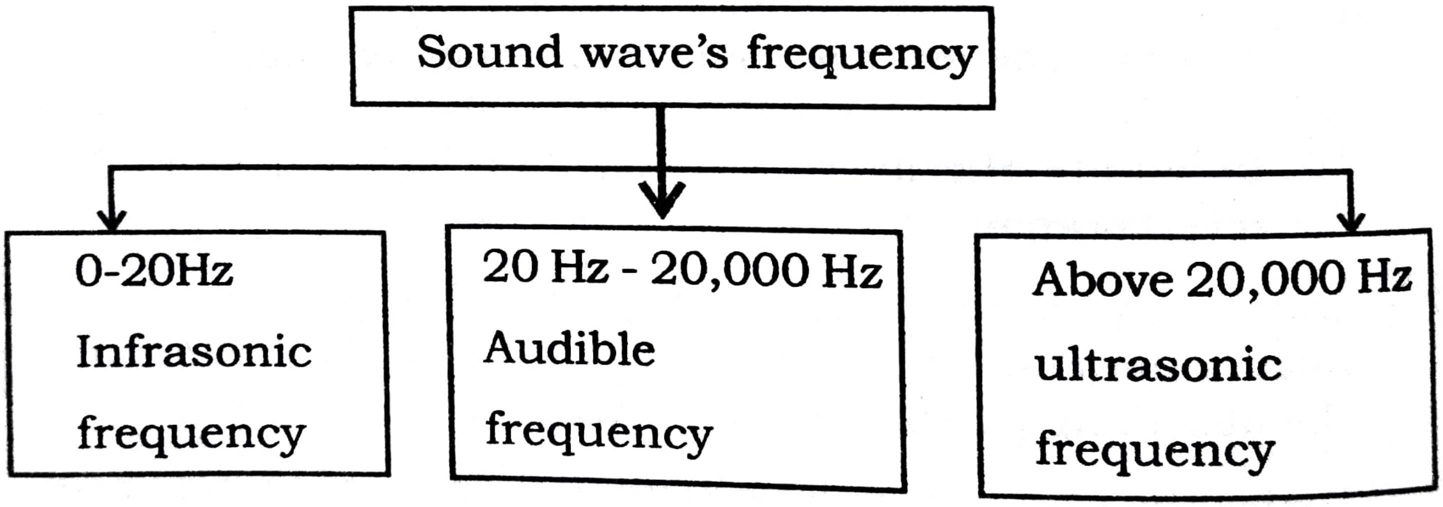
## Introduction

A normal human ear can hear the sound waves of frequencies ranging from 20 Hz to 20,000 Hz. This frequency range is called as audible range.

Sound waves of frequencies above the audible range (above 20,000 Hz or 20 kHz) are known as ultrasonic waves or simply ultrasonics. These sound waves are not audible to human ear.

Ultrasonic waves are also known as high-frequency sound waves or ultrasound etc. Although, human ear cannot hear ultrasonic waves, surprisingly bats and some animals are capable of hearing this sound.

Sound waves of frequencies less than 20 Hz are called Infrasonic waves.




The smaller wavelength of ultrasonic waves is mainly responsible for many of their interesting applications.

## General Properties of Ultrasonics

1. Ultrasonic waves are acoustic waves with a frequency greater than 20 kHz. They travel through any medium like solid liquid and gas. But they cannot travel thorough vacuum.

2. They are high energetic waves

3. The speed of ultrasonic waves in a thin rod or Crystal is given by

   $v = \sqrt{\frac{Y}{\rho}}$ where Y is the Young's modulus of the material and $\rho$ its density.

   Its speed in a liquid is given by $v = \sqrt{\frac{K}{\rho}}$ where K is the bulk modulus of liquid and $\rho$ is its density. Its speed in a gas is given by $v = \sqrt{\frac{\gamma p}{\rho}}$ where P is the pressure of gas, $\rho$ its density and $\gamma$ is the ratio of specefic heats of gas.

4. Their speed depends on frequency. Greater the frequency, higher the velocity.

5. Ultrasonic waves can travel through any medium with different modes. They can be propagated as longitudinal waves or compressional waves, producing alternate compressions and rarefactions. They can also be propagated as transverse waves or shear waves so that the particles of the medium vibrate in a

## Production of Ultrasonics

There are number of ways to generate ultrasonic waves. The method to be used depends upon the frequency range and power output required.

In general, there are three methods to produce ultrasonic waves.

(a) Magnetostriction generator or Magnetostriction oscillator

(b) Piezo-electric generator or Piezo-electric oscillator

(c) Mechanical generators Galton's whistle and siren)

## Piezo-Electric Method

The piezo-electric method is more efficient than magnetostriction oscillator method. Ultrasonic waves of frequencies as high as 500 MHz ($500 \times 10^6$ Hz) can be produced by this method.

**Piezo - electric effect**

When a mechanical stress is applied to one pair of opposite faces of a quartz crystal, then equal and opposite electrical charges are developed on the other pair of opposite faces of the crystal. This is known as direct piezo-electric effect.

The piezo-electric effect is reversible.

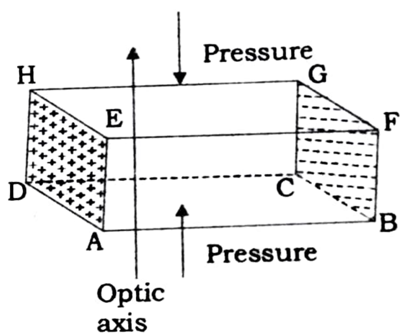
**Inverse Piezo-Electric Effect**

When an electric field is applied to one pair of opposite faces of a quartz crystal, expansion or contraction (mechanical stress) is developed across the other pair of opposite faces of the crystal. This is called as inverse piezo-electric effect.

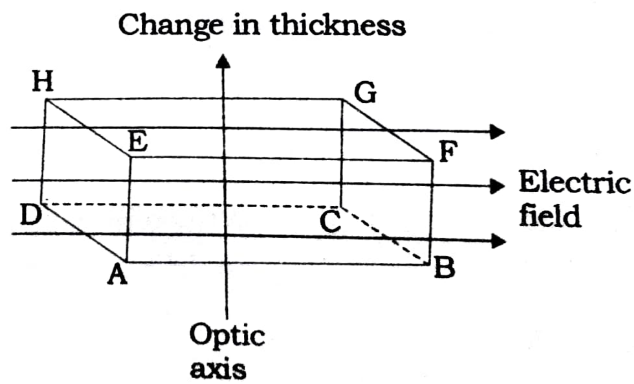
**Explanation**

A rectangular slab is cut from a quartz crystal such that two opposite faces ABCD and EFGH are perpendicular to optic axis. The other two opposite faces AEHD and BFGC are parallel to optic axis.

When the mechanical stress is applied to two opposite faces ABCD and EFGH, then opposite electrical charges are developed on the other pair of opposite faces AEHD and BFGC. This is known as piezoelectric effect.




When the electrical field is appllied across the opposite faces parallel to optic axis AEHD and BFGC, then thickness of the crystal (faces ABCD and EFGH) along the optic axis changes. This is called as inverse piezo-electric effect.




- The amount of electric charges developed are directly proportional to the amount of stress applied.

- Piezo-electric effect is best exhibited on natural crystals cut in a suitable direction.
- The direction of the cut of the crystal with reference to optic axis is most important.

**Piezo Electricity**

Electricity produced by means of piezo - electric effect is called piezo-electricity.

**Piezo-electric materials**

The materials which exhibit piezo-electric effect are known as piezo-electric materials. Quartz, rochelle salt, tourmaline and zinc blende are the best examples for piezo electric materials.

**Principle**

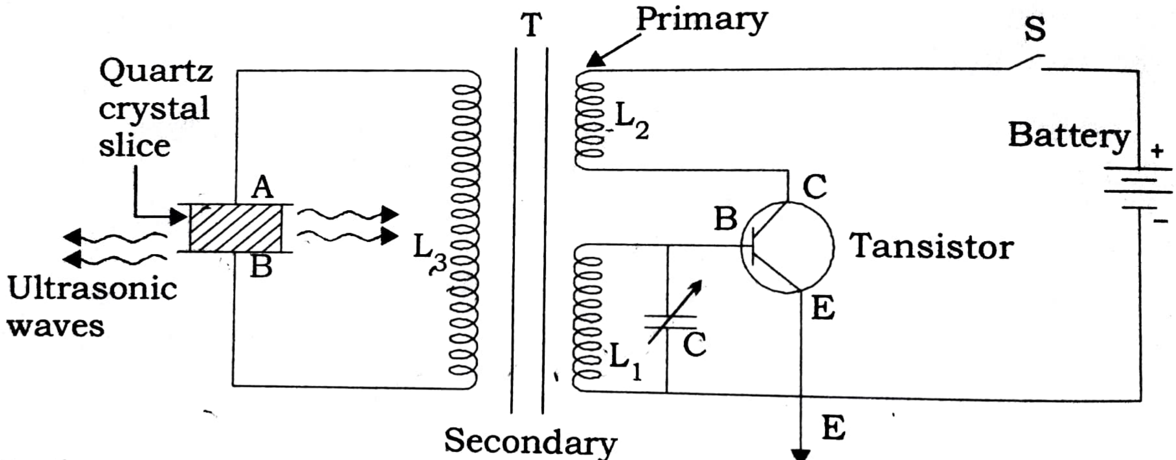
This method of producing ultrasonic waves is based on inverse piezo electric effect.

When an alternating voltage is applied to one pair of opposite faces of a quartz crystal, then alternative mechanical contractions and expansions are produced on the other pair of opposite faces of the crystal. Thus, the crystal is set into mechanical vibrations and it produces ultrasonic waves at resonance.

**Construction**

The circuit diagram of a piezo electric oscillator is shown in figure.

It consists of a transformer with primary and secondary circuits. The coils $L_1$ and $L_2$ of primary are connected to base and collector circuit of a NPN transistor. The variable capacitor C is used to vary the frequency of the oscillatory circuit. The coil $L_2$ is inductively coupled to secondary circuit. This circuit consists of the coil $L_3$ and two metal plates A and B. The piezo - electric crystal is kept in between these plates.




**Working**

When the battery is switched on, the electronic oscillator produces alternating voltages with frequency

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

Where $L_1$ - Inductance of the coil

C - Capacitance of the variable capacitor

An alternating e.m.f. is induced in the coil $L_3$ due to transformer action. This e.m.f is applied to the crystal. Now, the crystal expands and contracts alternately due to inverse piezo-electric effect. Thus it is set into mechanical vibrations. The capacitance of the variable capacitor C is adjusted such that the frequency of the applied AC voltage is equal to the natural frequency of the crystal. Now the resonance condition occurs.

The crystal vibrates with large amplitude.When the frequency of oscillator lies in ultrasonic frequency range, ultrasonic waves are produced from the crystal.

The natural frequency of the crystal is given by $n = \frac{P}{2l}\sqrt{\frac{E}{\rho}}$

where p = 1, 2, 3 ... (stands for fundamental, 1st overtone, 2nd overtone,. etc.)

$l$ - Length or thickness of crystal plate.

$\rho$ - Density of the crystal

E - Modulus of Elasticity

For solids E = Y, Young's modulus of the material of crystal

$$n = \frac{P}{2l}\sqrt{\frac{Y}{\rho}}$$

**Advantages**

1. It is more efficient than magnetostriction generator.
2. Ultrasonic frequencies as high as 500 MHz ($500\times 10^6$) can be obtained with this generator.
3. The natural frequency of the crystal is not affected by temperature and humidity.

**Disadvantages**

1. The cost of piezo-electric quartz is very high
2. Its cutting and shaping are very complex and difficult.

Nowadays, cheaper synthetic piezoelectric crystals are available.

**Applications**

This generator is used for low power applications such as flaw detection and medical applications.

## Velocity and wavelength of ultrasonics using ultrasonic diffractometer

When a quartz crystal Q placed between two metal plates in a liquid is set into vibrations using an R.F.oscillator, ultrasonics are produced. When these ultrasonics are reflected by a reflector, longitudinal stationary waves are produced in the liquid. As a result, alternate nodal planes and antinodal pulses are formed. At nodal planes, the layers are crowded together (compressions or condensations) and density is maximum. At antinodal planes, the layers are separated (rarefactions) and density is minimum. This setup of nodal planes and antinodal planes behaves like slits and



opaque spaces of a plane grating. Such an arrangement is called acoustic grating. Using this acoustic grating, velocity 'V' and wavelength '$\lambda$' of ultrasonics can be determined.

A parallel beam of monochromatic light from a sodium vapour lamp is collimated and is allowed to fall normally on this acoustic grating.Diffraction takes place and the diffracted beam is observed through the telescope of a spectrometer.On either side of the central maximum various orders of principal maxima are obtained.If $\theta$ is the angle of diffraction for a principal maximum, then

Fig. →

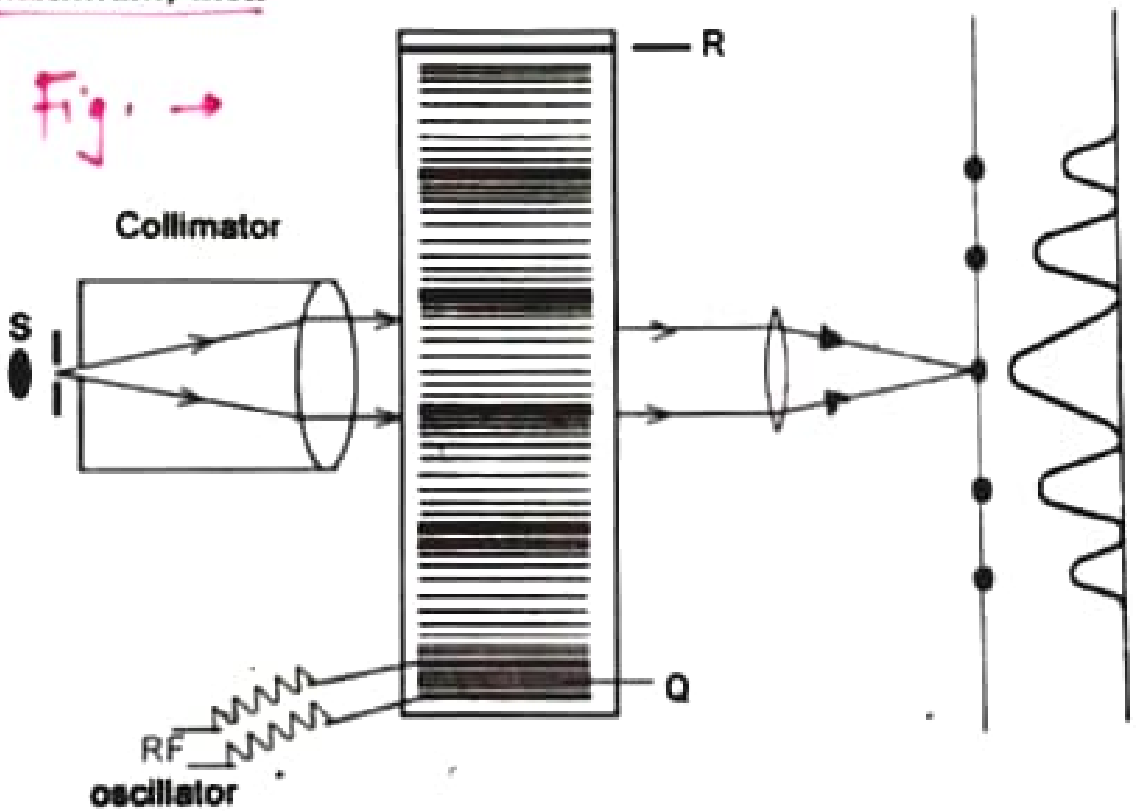



*Fig. 8.6*

$\boxed{d\sin\theta = n\lambda}$ ——>(1) where 'd' is the distance between two consecutive nodal planes or two consecutive anti nodal planes, n is the order of spectrum and '$\lambda$' is the wavelength of monochromatic light.d can be calculated from this grating equation.But $d = \frac{\lambda_a}{2}$ or $\lambda_a = 2d$ or $\boxed{\lambda_a = 2d}$ ——>(2) where

$\lambda_a$ is the wavelength of ultrasonic wavo in the liquid.

But $\boxed{V = \upsilon . \lambda_a}$ where $\upsilon$ is the frequency of oscillations of the crystal and V is the velocity of ultrasonic wave in the liquid.

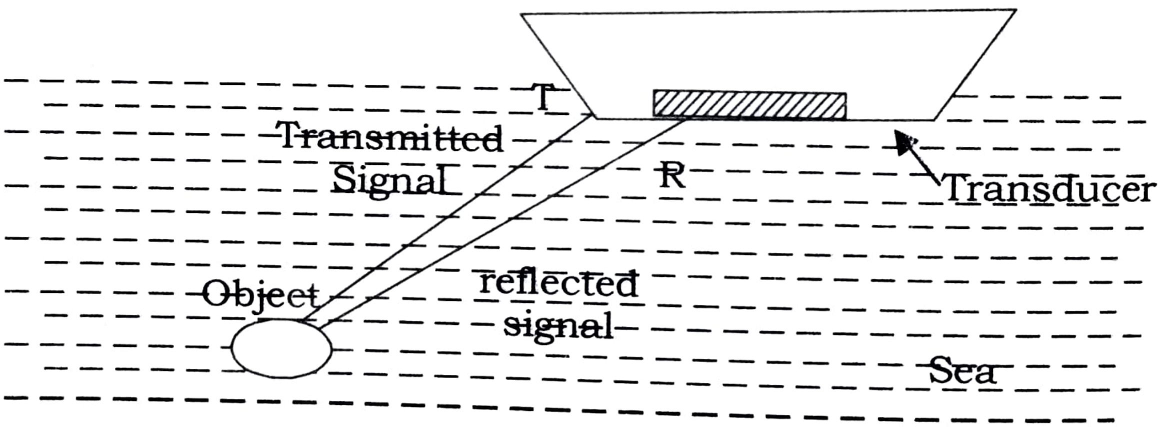
## 5. Sonar

SONAR stands for Sound NAvigation and Ranging. It uses highly directional ultrasonic waves for locating objects and determining their distance in the sea.

It is based on the principle of echo sounding technique.

### Basic concept of SONAR

Piezo electric transmitter in the sonar generates short pulses of ultrasonic waves. These sound pulses travel through the water and strikes the object. The sound pulse is reflected back and it is received by the ultrasonic receiver.




The time interval ($t$) between transmitted and received signals is noted by the cathode ray oscilloscope (CRO)

By knowing the velocity (v) of sound in sea water, distance of the object (d) from the surface of water is calculated by using relation,

$$d = \frac{vt}{2} \qquad \text{(distance = velocity × time = } v \times t/2\text{)}$$

Thus, the position (distance and direction) of the moving object can be determined.

**Applications and Uses**

1. Sonar is used to locate shipwrecks and submarines in the bottom of the sea.

2. It is used in fish finding applications and detection of fish shoals.

3. It is used in all merchant and military ships.

4. It is used for seismic survey.

5. It is used to measure the depth of the sea.

**Advantages**

1. ultrasonics waves cannot be confused with engine noise or other sounds produced by the ship. It is because the ultrasonics waves cannot be heard by human.

2. ultrasonics waves has high frequency and it is confined to a narrow beam. This allows ultrasonic beam to penetrate through a long distance in sea water without much loss of energy due to scattering.

**6. Non - Destructive Testing (NDT) - Ultrasonic Inspection**

NDT is a method of testing the material without destructing or damaging the material by just passing X- rays or ultrasonics or any other radiations through the material.

**Ultrasonic Flaw Detection**

Ultrasonic flaw detection is one of the most widely used non-destructive testing methods. High frequency ultrasonic sound waves are used in this method.

It is the property of ultrasonic waves that it gets reflected whenever there is a change in medium.

This method is used for the detection of defects like cracks, blow holes, porosity etc. in the internal structure of a material.

**Basic Ultrasonic Testing systems**

There are three basic ultrasonic testing systems that are commonly used in industries. They are

(i) Pulse echo system

(ii) Continuous transmission system and

(iii) Resonance system.

# Applications of Ultrasonics

## (1) Non Destructive testing of materials (NDT)

Non Destructive Testing (NDT) is a new method of testing of materials without any destruction of the materials and without any obstruction of their further uses and services.The present condition and quality of the materials can be examined using NDT without destroying their properties.High reliability, safety, further usefulness etc. are some of the benefits.

Ultrasonics can be used to detect the imperfections like the flaws, cracks, breakings, cavity, airpockets, discontinuities



etc. in materials like metals.Any defects in weldings and castings can be exactly located with the help of ultrasonics.Continuity of reinforced plastics and adhesive bondings can be tested.Aircrafts have to undergo such ultrasonic testings before their flight.

Fig.

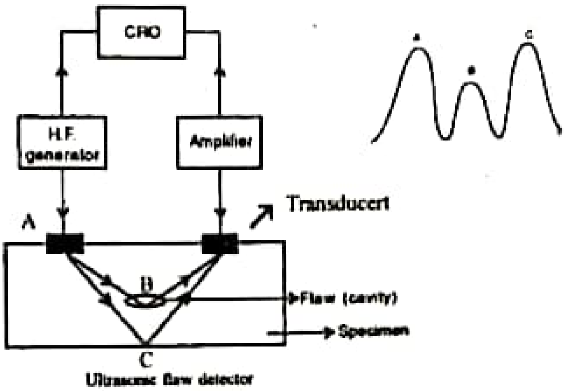



*Fig. 8.8*

A flaw or a crack in metal block produces a change in the medium which causes reflection of waves. When ultrasonic waves pass through a flaw, it is partially reflected from it and partially transmitted through it. The transmitted beam is again reflected from the bottom side of the metal block.

When ultrasonic beam is incident on the interface between two media, it is partly reflected and partly transmitted. The intensity of the reflected and the transmitted beam is decided by the acousitc impedences of the media. This is the principle of the ultrasonic testing. The intensity of the reflected ultrasonic wave from the cavity is examined using a C.R.O. Due to the change in the acoustic impedence, the echo pulse will be weak.

The incident pulse A, echo pulse B from the cavity and the reflecrted pulse C from the other side are seen on the screen of C.R.O. If the specimen does not contain any defects, the pulse A



and C alone are seen, The pulse B reveals the presence of a defect. The position of this pulse B and its distance from A give the nature of the flaw or cavity and its location.

## Advantages

1. It is a fast and reliable method of non-destructive inspection
2. This method of locating flaws within metal objects is more sensitive than radiography.
3. Location, nature and size of a defect can be accurately determined.
4. Operation is simple and elegant.
5. Ultrasonic inspection involves low cost and high speed of operation.

## Limitations of ultrasonic testings

1. No permanent record (photograph) of the flaw can be obtained, as it can only be observed on the screen of CRO.
2. Only skilled and well trained technicians can perform this testing.
3. There should be good mechanical coupling between the piezoelectric crystal (called probe) and specimen to be tested.

## Applications

1. Ultrasonic inspection is used for quality control and material inspection in all major industries.
2. Inspection of large castings and forging for internal defects, before carrying our expensive machining Operations.
3. Inspection of moving strip or plate (for laminations) as regards its thickness.

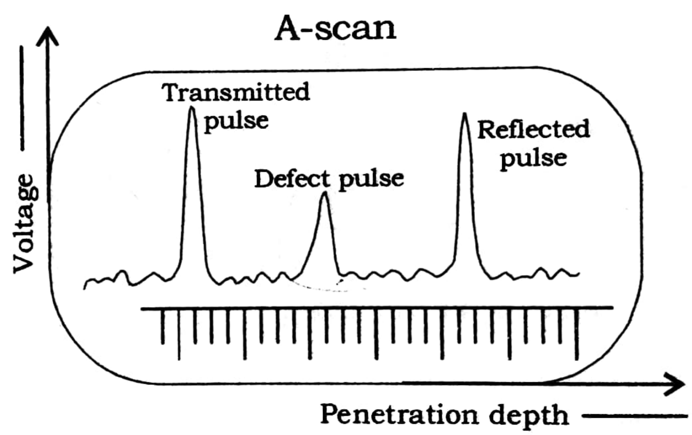
## 1. Ultrasonic Imaging-Ultra sonic scanning methods

In the ultrasonic scanning methods, the principle, construction and working is the same as that of the ultrasonic flaw detector. There are several modes of display to visualize the received information on the CRT screen. The most commonly used methods are A scan, B scan and time position (M mode) displays. Let us discuss the above display methods in details.

### (a) A - scan (Amplitude mode display)

Amplitude mode display gives only the one dimensional information about the specimen. In this, a single transducer is used to transmit and receive the pulses from the specimen.

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




The height of the vertical spikes corresponds to the strength of the echo from the specimen. The position of the vertical spike from the 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 the ultrasonics 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 given formula.

Distance = velocity × time

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

**Examples**

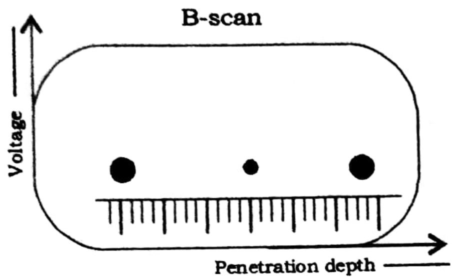
Echo - opthalmoscope and eco encephalograph.

**Applications**

1. It is used determine the position of the midline of the brain in the case of accident or disease.
2. It is used to measure accurately the foeful head size.
3. It is used to measure the internal dimensions of the eye.

**(b) B-Scan (or) Brightness mode display**

B-Scan (or) Brightness mode display gives a two dimensional image. The principle of B-scan is same as that of the A-scan except with a small difference, i.e. Here in 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.




The brightness and size of the dot depends on the intensity and strength of the reflected echo pulses respectively. The distance between the two dots gives the penetration depth. Thus, B-scan provides exact information about the internal structures of the specimen.

**Example**

Ophthalmic scan

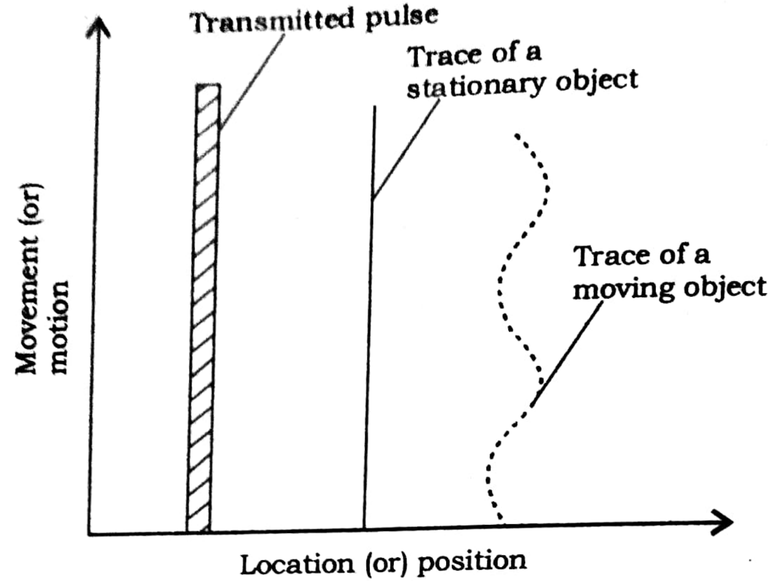
**Applications**

1. It is used to study the abdomen and to detect pregnancy.
2. It is used to visualize the various structures of the body like breasts, kidneys and soft tissues of the abdomen.
3. It is used to detect the multiple foetusses, the age of the foctus, position of the placenta etc.
4. It is also used for scanning of the eye.

**(c) T.M.Scan (or) Time-motion mode (or) C-Scan display**

This method is used to obtain the information about the moving object. It combines certain features of A-scan and B-scan. In T-M scan the transducer is held stationary as in A-scan and echoes appear as dots as in the B-scan.

Here, the X-axis indicates the dots at relevant location (or) position of the defect depending on the depth of the reflection.




The Y-axis indicates the movement of the object. Therefore when the object moves, the dots also moves at a low speed. Thus an object with oscillatory movement will appear as a trace.

**Example**

Echocardiogram. (ECG).

**Applications**

1. This type of display is very much useful in obtaining the pulsating structure such as heart and valves of the heart system.
2. It is used to measure the movement of the mitraval value related to various period of the heart cycle, etc.

2. A quartz crystal of length 1 mm is vibrating at resonance. calculate the fundamental frequency.

(Assume Y for quartz = $7.9 \times 10^{10}$ $Nm^{-2}$ and $\rho$ for quartz = 2650 kg $m^{-3}$

Length of the iron rod ($l$) = 1mm = $1 \times 10^{-3}$m

Density of quartz crystal ($\rho$) = 2650 kg/$m^3$

Young's modulus of the quartz (Y) = $7.9 \times 10^{10}$ N/$m^{-2}$

$$n = \frac{p}{2l}\sqrt{\frac{Y}{\rho}} \qquad p = 1$$

$$n = \frac{1}{2 \times 1 \times 10^{-3}}\sqrt{\frac{7.9 \times 10^{10}}{2650}} = 2.73 \times 10^{6} \text{ Hz}$$

3. Calculate the frequency of the fundamental note emitted by a piezo electric crystal of vibrating length 3mm. Young's modulus = $8 \times 10^{10}$N/$m^2$ and density = 2500kg/$m^3$

Vibrating length ($l$) = $3 \times 10^{-3}$m

Density of crystal ($\rho$) = 2500 kg/$m^3$

Young's modulus of the quartz (Y) = $8 \times 10^{10}$ N/$m^{-2}$

$$n = \frac{p}{2l}\sqrt{\frac{Y}{\rho}} \qquad p = 1$$

$$n = \frac{1}{2 \times 3 \times 10^{-3}} \sqrt{\frac{8 \times 10^{10}}{2500}} = 9.43 \times 10^{5} \text{ Hz}$$

$= 943$ kHz

4. An ultrasonic interferometer is used to measure the velocity in sea water. If the distance between two consecutive antinodes is 0.55mm. Compute the velocity of the waves in the sea water. The frequency of the crystal is 1.5 MHz.

Distance between two antinodes

$$\frac{\lambda}{2} = 0.55 \text{ mm} = 0.55 \times 10^{-3}\text{m}$$

$\lambda = 2 \times 0.55 \times 10^{-3}\text{m} = 1.1 \times 10^{-3}\text{m}$

Frequency of the crystal = 1.5 MHz = $1.5 \times 10^6$ Hz

Velocity of ultrasonics = Frequency × wave length

$= 1.5 \times 10^6 \times 1.1 \times 10^{-3} = 1650$ m/s

5. An ultrasonics 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 wave length o pulse.

Frequency of ultrasonic source = 0.09 MHz = $0.09 \times 10^6$ Hz

Time taken $t = 0.55$ seconds

Velocity of sound in water v = 1800 $\text{ms}^{-1}$

$$\text{depth of the sea } d = \frac{vt}{2} = \frac{1800 \times 0.55}{2} = 495\text{m}$$

Wavelength of the ultrasonic pulse is

$$\lambda = \frac{v}{f} = \frac{1800}{0.09 \times 10^6} = 20000 \times 10^{-6} = 0.02\text{m}$$

6. Given that the velocity of ultrasonic waves in sea water is equal to 1440 m/s. Find the depth of a submerged submarine if an ultrasonic pulses reflected from the sub-marine is received 0.33 sec afetr sending out ultrasonic waves.

Velocity of ultrasonics in sea water v = 1440 m/s

Time elapsed between emission and reception of ultrasonics t

= 0.33 second

Total distance travelled by ultrasonics = $v \times t$

= $1440 \times 0.33 = 475.2$m

Total distance travelled by ultrasonics waves in going from source to submarine and back after reflection is equal to twice the depth of submarine.

∴ Depth of submarged submarine (d) is half of the total distance travelled by ultrasonics

$$d = \frac{475.2}{2} = 237.5\text{m}$$

(Also we can solve directly using the equation $d = \frac{v \times t}{2}$)

7. Given that the velocity ultrasonic waves in sea water is equal to $1440\text{ms}^{-1}$. Find the depth of a submerged if an ultrasonic pulse reflected from the submarine is received 0.33 second after sending out the ultrasonic waves.

Ultrasonic velocity in sea water (v) = $1440\text{ms}^{-1}$

Time (t) = 0.33 second

Depth of the submerged submarine $d = \frac{v \times t}{2}$

$$= \frac{1440 \times 0.33}{2} = 237.6\text{m}$$

8. Longitudinal standing waves are set up in quartz plate with anti-nodes at opposite faces. The fundamental frequency of vibration is given by $F_1 = 2.87 \times 10^3 / l$, where $l$ is the thickness of the plate in metre and $F_1$ is in Hz. The denisty quartz crystal is $2660\text{kgm}^{-3}$. Determine, (i) young's modulus of the quartz plate and (ii) thickness of the plate for a frequency of vibration 1200 k Hz.

(i) Fundmaental frequency $F_1 = 2.87 \times 10^3 / l$

Density of quartz crystal ($\rho$) = $2660\text{ kgm}^{-3}$

$$2F_1 l = \sqrt{\frac{Y}{\rho}}$$

$$Y = (2F_1 l)^2 \rho$$

$$= \left(2 \times \frac{2.87 \times 10^3}{l} \times l\right)^2 \times 2660$$

$$= 8.76 \times 10^{10} Nm^{-2}$$

(ii) Fundamental frequency $F_1 = 1200kHz$

$$1200 \times 10^3 = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

$$\text{Thickness } (l) = \frac{1}{2 \times 1200 \times 10^3}\sqrt{\frac{8.76 \times 10^{10}}{2660}}$$

$$= 2.39 \times 10^{-3} m = 2.39 mm$$

QUESTIONS

## QUESTIONS AND ANSWERS

1. **Define the term reverberation time. What is the unit of reverberation time?**

The time required for the intensity of the sound pulse to fall below the audible limit after the source is cut off is known as the reverberation time. Thus by Sabine's law, it is defined as the time taken by sound to fall to one millionth of its original intensity after the source of sound is cut-off. The unit of reverberation time is second.

2. **Name three sound absorbing materials used is an auditorium (or) Give the names of few materials which absorb sound to the maximum.**

i. Fibrous (Straw) Plaster Material ii. Wood
iii. Cork iv. Rubber Tile

3. **What is meant by resonance effect in acoustics?**

Hollows and crevices select their natural frequencies from the sound produced in the hall and reinforce them there by producing resonance. This creates a jarring effect and non-uniform distribution of sound energy in the hall. This is called resonance effect in acoustics.

4. **What is meant by structure-borne noise?**

Structure borne noises are the noises produced inside the structure of hall or working machine and are conveyed through the structure. Any loose fittings or sliding one surface with the other surface of various machine parts produce structure borne noises. Further drilling, hammering and working of machinery inside the building also produce structure borne noise. For the reduction of these noises, working machineries are placed on absorbent pads and the walls, floors and ceilings of the building are padded with sound absorbing materials.

5. **What is air-borne noise?**

The noise carried by air that enters into ears directly or from outside through open windows of the hall is called air-borne noise. The ascending and decending aeroplane, siren or any moving vehicle are the main sources of air-borne noise. To reduce air borne noise, it is better to use ear muffs or ear plugs when we walking on the road and to construct air conditional halls or rooms.

6. **What do you meant by acoustics of buildings?**

Design of the building to provide good uniform intensity of audible sound to every audience in the building is called acoustics of buildings or architectural acoustics.

7. **What are the requirements for good acoustics?**

i. The hall should have proper reverberation time about 1.1 to 1.5 second.

ii. No echo should be present.

iii. Resonance effect (jarring effect of sound) should be avoided.

iv. There should be no echelon effect.

v. There is no path for entering of outside noises.

vi. The loudness of the sound should be uniform throughout the hall.

8. **Give the units for intensity of sound, intensity level of sound, loudness, loudness level, sound pressure and sound pressure level.**

| | |
|---|---|
| Intensity of sound | - $W/m^2$ |
| Intensity level of sound | - dB |
| Loudness | - sone |
| Loudness level | - phon |
| Sound pressure | - Pa or $Nm^{-2}$ |
| Sound pressure level. | - dB |

9. **What is Echelon effect?**

The sound waves reflected from the flight of steps with equal width in a room will consist of echoes with regular phase difference. These echoes which produce a separate musical note. So far a listener, this creates confusion. To eliminate this effect, steps should be made of unequal width or the steps should be covered with sound absorbing material.

10. **Distinguish between loudness and intensity of sound.**

**Loudness**

It is the amount of sensation produced in the ear and hence it depends upon the listener.

It is not a purely physical quantity but it subjective in nature. Loudness is measured in sones.

**Intensity**

It is the quantity of sound energy flowing across unit area per second. Hence it depends on the source of sound and does not depend upon the listener.

It is a pure physical quantity

Intensity is measured in $Wm^{-2}$