3 Ultrasonics

(1) INTRODUCTION

"A wave, that is transmitted through a solid, liquid or a gas as a result of mechanical vibrations of the particles of the medium is called Acoustic wave or mechanical wave". These waves cannot propagate through vacuum. Acoustic waves are elastic in nature and as these waves travel through a medium, there is elastic deformation of the medium.

"Acoustic waves of frequency lying in the range 20 Hz to 20 kHz are called Sound Waves as human ear can perceive these waves." These waves are also called audible waves.

"Accoustic waves of frequency less than 20 Hz are called Infrasonic waves."

"Ultrasonic waves are acoustic waves whose frequency is more than 20 kHz". They travel with the speed of sound. Hence their wave length is smaller than $\frac{33200 \text{ cms}^{-1}}{20000 \text{ Hz}} = 1.66 \text{ cm}$ $\left(\because \lambda = \frac{V}{\nu}\right)$. These waves possess a number of properties of sound waves and exhibit some new phenomena also.

(2) TYPES OR MODES OF ULTRASONIC WAVES

Ultrasonic waves can propagate through a medium as stress or strain waves depending upon the elastic properties of medium. Based on particle displacement of the media, these are classified into four categories (modes) :

(*i*) **Longitudinal or Compressional or Pressure Waves.** In these waves particles of medium vibrate back and forth parallel to the direction of propagation of wave. These waves propagate through the medium as a series of alternate compression and rarefaction. These waves are most widely used in the ultrasonic inspection of materials. This mode is exhibited when medium of propagation has no boundaries *i.e.* it has infinite span. Due to propagation of these waves both pressure and density of medium fluctuate periodically.

(*ii*) **Transverse or Shear Waves.** In these waves particles of the medium vibrate perpendicular to the direction of wave propagation. In this case the medium undergoes shear deformations periodically. These waves can propagate through thin rods.

(*iii*) **Surface or Rayleigh Waves.** These waves travel along the flat or curved surface of thick solids without influencing the bulk of medium below the surface. The depth to which these waves propagate below the surface with considerable intensity is approximately equal to wavelength of the wave. Practically all of its energy is attenuated within this depth. These waves are used to detect cracks or flaws on or near the surface of test objects. During the propagation of surface waves, the particles of medium describe elliptical orbits.

(*iv*) **Lamb or Flexural or Plate Waves.** These are produced in thin metal, whose thickness is comparable to the wavelength of ultrasonic wave.

(3) PROPERTIES OF ULTRASONIC WAVES

(*i*) These waves cannot travel through vacuum.

(*ii*) These waves travel with speed of sound in a given medium. The speed of ultrasonics in gases is given by the expression

$$V_g = \sqrt{\frac{\gamma P}{\rho}} \qquad ...(1)$$

Here $\gamma = \frac{C_p}{C_v}$ is the ratio of specific heats of gas.

P = pressure, ρ = density.

At NTP, for air $\gamma = 1.4, \rho = 1.3\ \text{kg m}^{-3}$, $P = 1\ \text{atm} = 1.01325 \times 10^{-5}\ \text{Nm}^{-2}$

Put in (1), we get

$$V_g = 332\ \text{ms}^{-1}$$

Expression (1) is called Laplace formula. It is derived on the fact that acoustic waves travel adiabatically through gases.

In case of liquids the expression for speed of ultrasonic waves (or acoustic waves) is given as

$$V_l = \sqrt{\frac{K}{\rho}} \qquad ...(2)$$

where K = Bulk modulus of elasticity of liquid.

ρ = density of liquid.

At room temperature, density of water is $\rho = 10^3\ \text{kg}\ m^{-3}$ and $K = 2 \times 10^9\ \text{N}m^{-2}$

$\therefore$ equation (2) gives us $V_{water} = 1440\ \text{ms}^{-1}$

In case of solid media, the speed of acoustic waves is given by the expression

$$V_s = \sqrt{\frac{Y(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}} \qquad ...(3)$$

where Y is Young's modulus of elasticity, σ is Poisson's ratio and ρ is density of the solid.

If the solid is in the form of thin rod, then $\sigma = 0$. Hence above expression becomes

$$V_{\text{thin rod}} = \sqrt{\frac{Y}{\rho}} \qquad ...(4)$$

The speed of ultrasonic waves in iron at 20°C is 5130 m/s.

Their velocity remains constant in homogeneous media.

(*iii*) These waves can weld certain plastics, metals etc.

(*iv*) These can produce emulsion of two immiscible liquids.

(*v*) These waves can produce vibrations in low viscosity liquids.

(*vi*) These waves are reflected and refracted just like light waves. *i.e.* (*a*) Angle of incidence is equal to angle of reflection.

(*b*) Incident ray, reflected ray and normal lie in same plane.

(*c*) If i is angle of incidence, r is angle of refraction, V_1 is velocity of ultrasonic waves in incident medium and V_2 in refracted medium then

$$\frac{\sin i}{\sin r} = \frac{V_1}{V_2} \qquad ...(5)$$

This is called Snell's law of refraction.

(*viii*) The speed of ultrasonic waves/acoustic waves is more in more dense media *i.e.* $V_g < V_l < V_s$. If ultrasonic waves enter from rarer medium to dense medium, then $V_1 < V_2$ so equation (5) gives $\frac{\sin i}{\sin r} < 1 \Rightarrow i < r$. Thus ultrasonic waves will bend away from normal. Similarly when ultrasonic waves enter from denser to rarer medium, then they bend toward normal. This property is just opposite to that of light.

(*ix*) **Attenuation.** We know that ultrasonic waves cannot travel through vacuum. Thus if these waves travel through a non- homogeneous medium, then at each discontinuity (flaw, crack or change in density or presence of impurity etc.), the amplitude and hence intensity of ultrasonic waves decreases by some amount. "This decrease in intensity of ultrasonic waves as these travel through a medium is called Attenuation." The vacuum in the material causes strong reflection of ultrasonic waves while impurities or discontinuity cause the scattering of ultrasonic waves leading to net decrease in intensity. The attenuation is increased with increase in frequency of ultrasonic waves for a given medium. The intensity of ultrasonic waves decreases exponentially according to the relation

$$I = I_0 e^{-\alpha x} \qquad ...(6)$$

where I_0 = Intensity at surface

I = Intensity at depth x inside the sample.

α is called Monochromatic Attenuation coefficient. Its value is different for different media and for a given medium, its value is different for different frequencies/wavelengths. With increase in frequency of ultrasonic waves, value of α also increases. If we put $\alpha = \frac{1}{x}$ in (6), we get

$$I = \frac{I_0}{e}.$$

"Thus monochromatic attenuation coefficient at a given wavelength is equal to the reciprocal of the thickness of medium, which will reduce the intensity of ultrasonic waves to $\frac{1}{e}$ times the intensity at surface". Unit of α is m^{-1} or cm^{-1}.

(4) ACCOUSTIC IMPEDANCE AND MODE CONVERSION

Accoustic Impedance is defined as the complex ratio of the alternating sound pressure to the rate of volume displacement of the surface, that is vibrating to produce sound.

$$\text{Accoustic Impedance (Z)} = \frac{\text{sound pressure}}{\text{rate of volume displacement}}$$

$$= \frac{\text{sound pressure}}{\text{area of surface} \times \text{particle velocity}} \qquad \left(\because \frac{\text{volume}}{\text{time}} = \text{area} \times \text{velocity}\right)$$

For a surface producing sinusoidal sound, the acoustic impedance can be expressed as

$$Z = R + iX \qquad ...(7)$$

Where Z = acoustic impedance

R = acoustic resistance

X = Acoustic reactance

$$i = \sqrt{-1}$$

The magnitude of Z is $|Z| = \sqrt{R^2 + X^2} = \rho V$ ...(8)

Where ρ is density of the medium and V is velocity of ultrasonic waves in the medium. If medium dissipates energy then R is non zero and if medium is non dissipative, then R is zero. Unit of Z, R, X is kg m^{-2} s^{-1}. The accoustic impedance is analogous to refractive index of a transparent medium for light. Thus acoustic impedance is an important parameter for making ultrasonic lenses, mirrors, prisms etc.

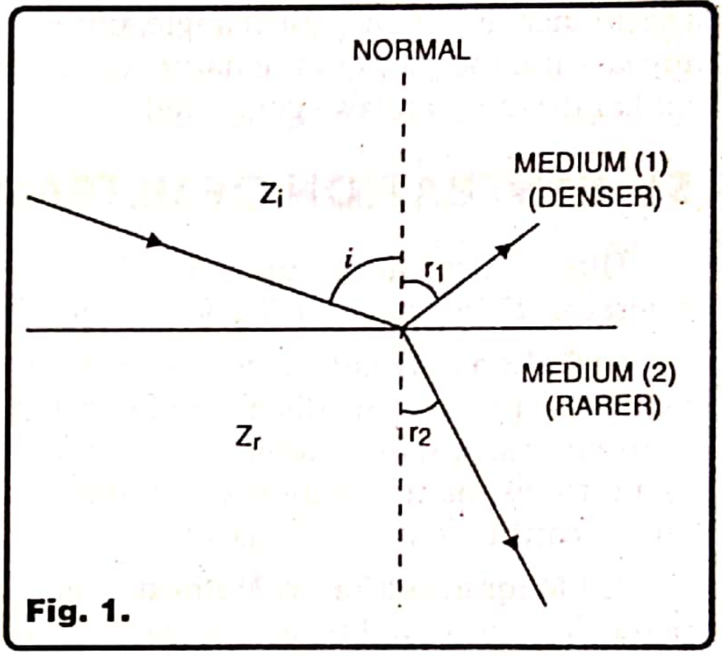

Fig. 1.

When ultrasonic waves strike an interface between two media then these are partially reflected and partially transmitted. Let Z_i, Z_r be the acoustic impedance of incident and refracting medium respectively. Then "reflection coefficient is defined as ratio of amplitude of reflected wave to amplitude of incident wave."

$$\text{Reflection coefficient } (r) = \frac{\text{Amplitude of reflected wave}}{\text{Amplitude of incident wave}}$$

Expression of r is given as $r = \dfrac{Z_r - Z_i}{Z_r + Z_i}$ ...(9)

Similarly transmission coefficient (t) is defined as the ratio of amplitude of transmitted wave to amplitude of incident wave.

$$\text{transmission coefficient } (t) = \frac{\text{Amplitude of transmitted wave}}{\text{Amplitude of incident wave}}$$

A detailed anPalysis leads to following expression for transmission coefficient

$$t = \frac{2Z_r}{Z_i + Z_r} \qquad ...(10)$$

Both r and t are dimensions less quantities.

When ultrasonic wave strikes an interface between two media having different acoustic impedances at oblique incidence, then some of its energy is converted into modes of vibration other than the incident mode. This is called Mode Conversion. *e.g.* Incident wave may be longitudinal, while reflected (or transmitted) wave may be containing longitudinal as well as shear waves. For any angle of incidence other than normal incidence (in which case $i = 0$), every longitudinal wave has a reflected and refracted components of both longitudinal and shear waves.

When ultrasonic waves enter from rarer to denser medium, then they bend away from normal. If angle of incidence is increased then angle of refraction also increases $\left(\because \frac{\sin i}{\sin r} = \frac{V_1}{V_2} = \text{constant}\right)$. At some angle of incidence i_{c_1} called first critical angle, the angle of refraction for Longitudinal waves become 90° *i.e.* refracted longitudinal wave travels along the interface of two media. If angle of incidence is more than i_{c_1} then longitudinal wave is totally reflected back into rarer medium and no longitudinal mode exists in denser medium. If we continue to increase angle of incidence, then at some value i_{c_2} called second critical Angle, angle of refraction for shear waves become 90°. For angle of incidence $i > i_{c_2}$, even shear waves are reflected back into rarer medium. As a result there will be no shear mode in denser medium. Same discussion can be applied in the case when incident wave is shear wave. Thus for angle of incidence less than critical angle, both shear and longitudinal modes are produced at the interface independent of the nature of incident wave. Besides these, it is found that Rayleigh and Lamb waves are also generated.

(5) GENERATION OF ULTRASONIC WAVES

Ultrasonics can be produced by means of (*i*) Galton's Whistle (*ii*) Magnetostriction Generator (*ii*) Piezoelectric Generator or Oscillator.

(*i*) **Galton's Whistle.** It consists of essentially a short cylindrical pipe blown in the form of an annular nozzle. The distance of nozzle from the edge of pipe can be varied by turning a micrometer screw. By suitable adjustment of this distance and the pressure of air blast, the pipe is set into resonant vibration at a frequency depending on length and diameter of pipe. This method can be used to produce ultrasonic waves of low frequency upto 100 kHz.

(*ii*) **Magnetostriction Method.** When magnetic field is applied across the length of a ferromagnetic rod such as Nickel, then change in the length of rod is observed. This is called Magnetostriction. The charge in length is proportional to the strength of magnetic field. The humming sound of transformer is due to this property. The increase in length is very small in practice. Amongst all ferromagnetic substances, increase in length is maximum for Nickel.

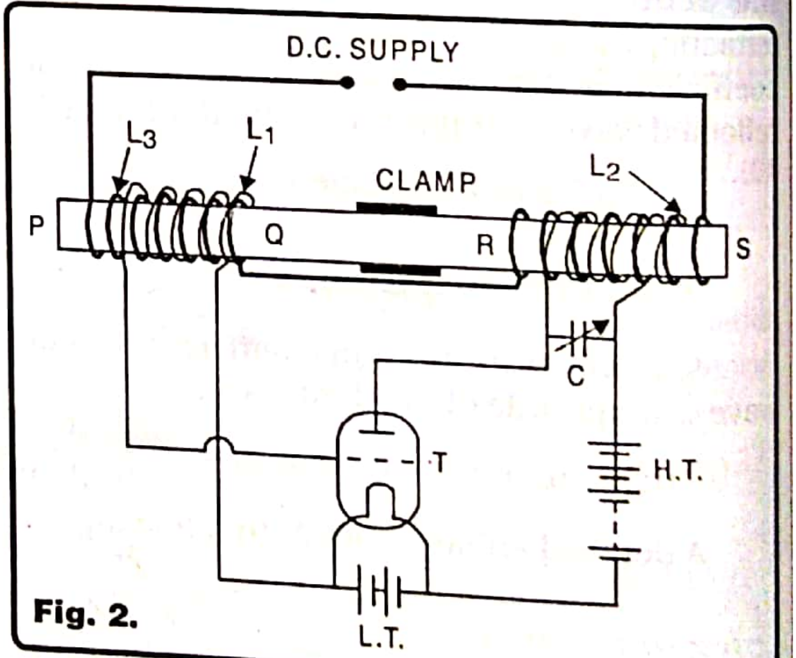

Fig. 2.

Experimental arrangement to produce Ultrasonic Waves by magnetostriction method is shown in fig. (2). Here PS is a rod of nickel, which is clamped in the centre. Here T is a valve oscillator. One coil L_1 (shown with thin line) in the grid circuit of value oscillator is wound on one side of the rod and another L_2 (also shown by thin line) in the anode circuit of valve is wound on other side of the rod. The coil L_2 and variable capacitor C from a tank circuit, which produces electronic oscillations of frequency

$$\nu = \frac{1}{2\pi\sqrt{L_2 C}} \quad \text{...(11)}$$

Due to this a longitudinal alternating magnetic field is produced around the rod. The frequency of oscillation of magnetic field is also ν as given in (11). Since capacitor C is variable capacitor. Hence by adjusting value of C, we can adjust the frequency of alternating magnetic field produced around the nickel rod. However the oscillations of magnetic field should be sustained (*i.e.* amplitude of magnetic field should not change with time). For this the feed, back is provided by voltage induced on L_1 connected in the grid circuit of valve oscillator. Whenever the magnitude of alternating magnetic field increases, the length of nickel rod also increases independent of direction of magnetic field, provided it should be parallel to length of rod). Thus alternating magnetic field sets up vibrations in the nickel rod such that frequency of vibration of rod is double of frequency of oscillation of magnetic field. This situation is unwanted as amplitude of vibrations of rod will be very small in this case because the two kinds of vibrations are non resonant. To avoid this another coil L_3 (shown by thick line) is wound over the rod and connected to a Polarizing d.c. supply. This produces a permanent and steady magnetic field along one direction parallel to the length of rod. By changing current through D.C. supply, strength of steady magnetic field can be adjusted to a suitable value. When these two magnetic fields (one alternating and other steady) are super imposed, then half part of alternating magnetic field is cancelled by steady magnetic field. In this case the frequency of vibration of nickel rod will be same as that of frequency of alternating field. Thus whatever is frequency of a.c. field, same is frequency of vibration of rod.

By changing the capacity of capacitor and by taking suitable length of nickel rod, we can produce alternating magnetic field, whose frequency matches with natural frequency of vibration of nickel rod. Due to this nickel rod shows resonant vibrations of maximum amplitude and produces ultrasonic waves of the frequency at which it is vibrating. In the fundamental mode, clamped end of nickel rod acts as node and the ends of rod act as antinodes. We know that distance between a node and antinode is $\frac{1}{4}$ of wavelength. Hence if length of rod is L, then wavelength of ultrasonic waves is given by

$$\frac{L}{2} = \frac{1}{4}\lambda$$

$$\Rightarrow \quad \lambda = 2L \qquad ...(12)$$

The speed of ultrasonic waves in the rod is given by

$$V = \sqrt{\frac{Y}{\rho}} \qquad ...(13)$$

where Y = Young's modulus, ρ = density of nickel

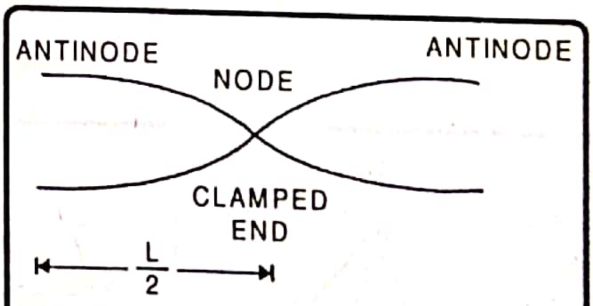

Fig. 3.

The frequency of ultrasonic waves produced is given by

$$\nu = \frac{V}{\lambda} = \frac{1}{2L}\sqrt{\frac{Y}{\rho}} \qquad ...(14)$$

Note that since rod is vibrating in resonance, hence frequency given by (14) and (11) are identical.

By varying the length of rod high frequency oscillations can be obtained. A nickel rod 10 cm long gives out ultrasonic waves of frequency $\approx$ 24 kHz.

A bundle of the insulated wires of nickel or a cylinder with alternate layers of nickel and paraffin wax is usually employed to avoid eddy currents in the rod.

A magnetostriction generator can produce ultrasonic waves of comparatively low frequency. For generating high frequency ultrasonic waves, piezoelectric generator is used.

(iii) Piezoelectric Generator. It is observed that when pressure or compression is applied on two opposite faces of a quartz crystal, then charges are produced on a set of opposite faces which are perpendicular to the faces at which pressure is applied. The magnitude of charge developed is proportional to the amount of pressure applied. Charge produced on one face is +ve and on other face is negative. Further more, if instead of compression, the faces of crystal are subjected to some tension, then nature of charges developed also gets reversed. "The process of appearance of charges on transverse faces of certain crystals when subjected to external stress is called Piezoelectric effect."

Alternatively "if an electric field is applied across two opposite faces of a Quartz crystal, then extension or compression is produced in the crystal in a direction transverse to the direction of electric field. This effect is called Antipiezoelectric Effect." The extent of compression or extension is proportional to the strength of electric field.

If applied electric field is alternating in nature then quartz crystal starts vibrating at the frequency of electric field and hence produces acoustic waves in air. If the frequency of electric field is same as natural frequency of the crystal, then amplitude of crystal oscillations is quite large. This property of Quartz crystal is used for producing ultrasonic waves. Apart from Quartz, other materials showing this property are Rochella salt (Sodium potassium tartrate), tourmaline etc. The effect is best in Quartz cut in a particular manner.

Fig. (4) (*a*) shows a Quartz crystal. ZZ′ axis the optic axis of crystal. If the crystal is cut perpendicular to this axis, then the section obtained is a hexagon. A line joining its two opposite corners (*e.g.* Q and T) is called X-axis (see fig. (4)(*b*)). And a line perpendicular to this (*e.g.* joining A & B) is called Y-axis. A strip of quartz crystal cut along ZZ′ axis and perpendicular to XX′ axis (see fig. (4) (*b*)) is called X-cut quartz crystal. Such a crystal is used in piezoelectric oscillator to generate ultrasonic waves. Its end faces are silvered to ensure proper contact and alternating electric field is applied by means of metallic plates pressing against the faces. The alternating electric field is applied along XX′ axis. The crystal vibrates with a frequency

$$\nu = \frac{272500}{l} \text{ (Hertz)} \qquad \ldots(15)$$

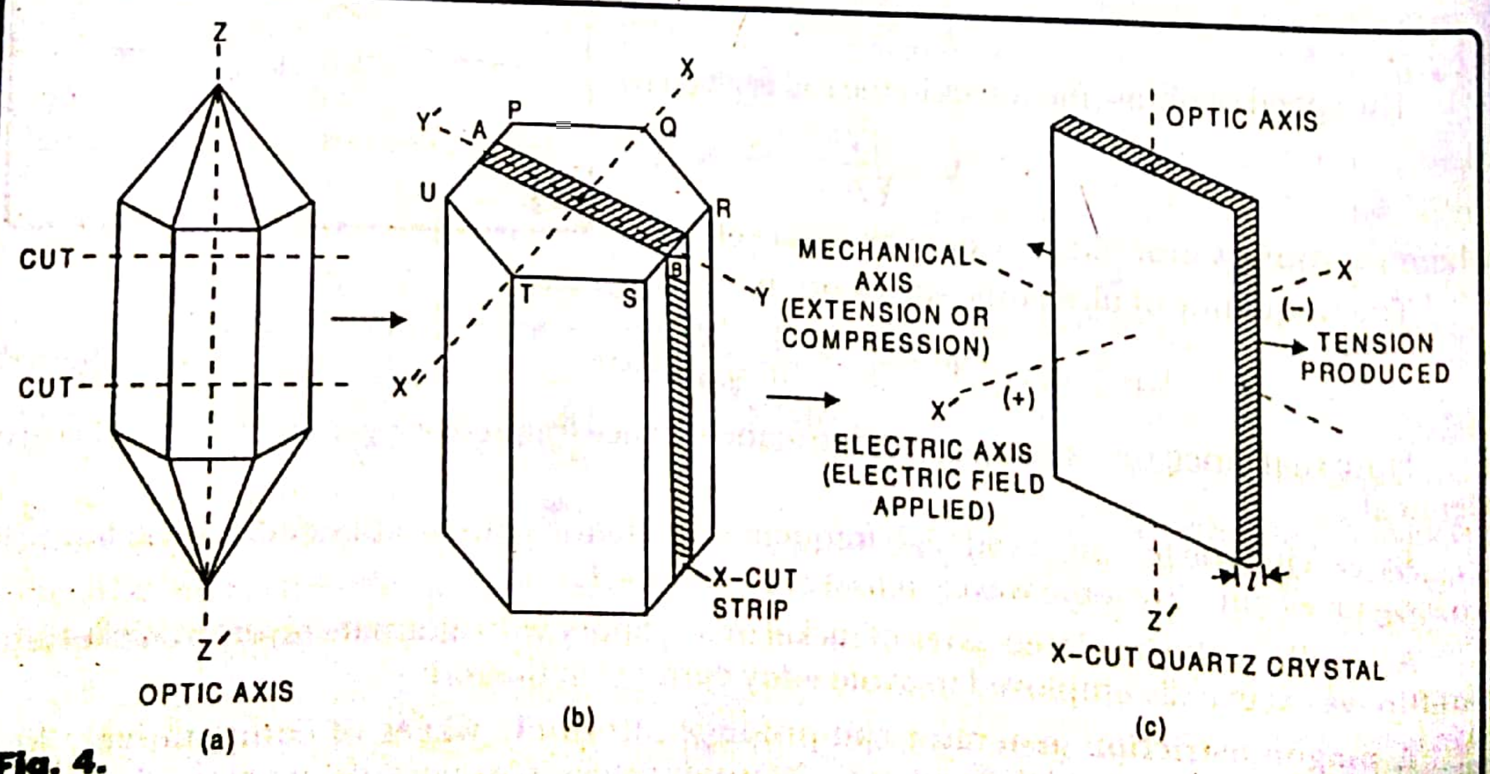

Fig. 4.

Where l is the thickness of the X-cut quartz crystal expressed in millimeters. Experimental arrangement to produce ultrasonic waves by piezoelectric method is shown in fig. (5). Inductor L_1 and capacitor C form the tank oscillator in the grid circuit and produce electric oscillations of frequency.

$$\nu = \frac{1}{2\pi\sqrt{L_1 C}} \qquad ...(16)$$

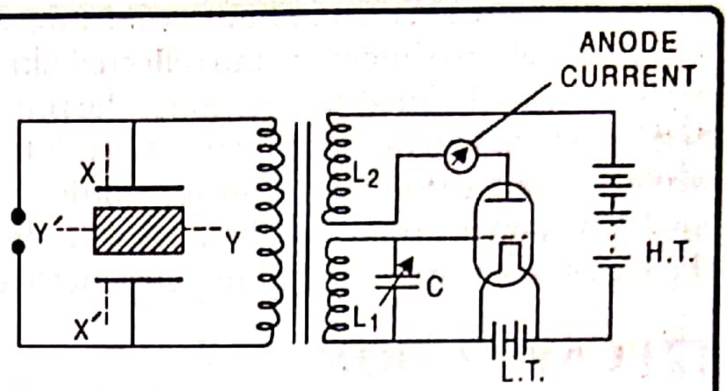

Fig. 5.

These vibrations are sustained by voltage induced across L_2, which provides necessary feed back. Hence electric field of constant frequency and amplitude applied across the crystal produces ultrasonic waves of high frequency due to vibrations shown by quartz crystal. In order to avoid sparking at the quartz plate, a spark gap is put parallel to it. It should be noted that by adjusting the value of capacitor C, the frequency of electric field can be matched with natural frequency of vibration of the quartz crystal so that resonant vibrations of maximum amplitude are observed. For obtaining powerful ultrasonic waves at a point, quartz plate of the shape of concave mirror is used. This arrangement concentrates the ultrasonic waves at a point.

(6) DETECTION OF ULTRASONIC WAVES

(*a*) Ultrasonic waves can be detected using Radiometer. In this method ultrasonic beam is made to fall on a thin mica fan suspended by a thin wire carrying a small mirror from one end of a light rod. Due to pressure exerted by ultrasonic waves the fan gets deflected along with the mirror. The deflection can be noted by a lamp and scale arrangement. A beam of light is made incident on the mirror and reflected beam falls back on the origin of scale attached to lamp. When mirror shows deflection by angle θ, then reflected beam on the scale defects by angle 2θ. Since 2θ can be noted from scale, hence deflection of mirror can be found. The deflection is directly proportional to the intensity of ultrasonic waves. Hence we can calculate the intensity of ultrasonic waves with this method.

(*b*) Kundt's tube filled with lycopodium powder can also be used for detecting ultrasonic waves whose wavelength is of the order of a few millimeters. When ultrasonic waves pass through tube then stationary waves are formed due to super position of incident and reflected waves. Heaps are formed at the position of nodes. The distance between adjacent nodes is calculated, which is equal to half the wavelength of ultrasonic waves. Hence with this method wavelength of ultrasonic waves can be calculated.

(*c*) Ultrasonic waves can also be detected after amplification using a cathode ray oscilloscope.

(*d*) when ultrasonic waves pass through a medium, then alternative compressions and rarefactors are formed. At compression, particles of medium are brought closer and collisions between them increases. As a result of this the temperature of medium increases at compressions. On the other hand, the temperature of medium decreases at rarefaction due to the fact that particles of medium go move away from each other and frequency of collisions is decreased. Thus if we introduce a platinum resistance thermometer in the path of ultrasonic waves in a medium, and move the thermometer along the direction of propagation of waves then temperature reading of thermometer changes alternatively confirming the presence of ultrasonic waves in the medium. Some times stationary waves are formed in the medium due to superposition of incident and reflected ultrasonic waves. In such a case nodes and antinodes are formed in the medium. At nodes the pressure varies alternatively resulting in cooling and heating effect. Thus a platinum resistance introduced at nodes will store change in temperature, while no change in temperature is recorded at antinodes. Thus if we move thermometer in the medium, then resistance of platinum wire of thermometer will change alternatively confirming the ultrasonic waves in medium. This method of detection is called Thermal Method.

(7) CAVITATION

It is the formaton of vapour bubbles of a flowing liquid in a region where the pressure of liquid falls below its vapour pressure. Cavitation is usually of two types namely inertial (or transient) cavitation and non inertial cavitation. Inertial cavitation is the process where a bubble in a liquid rapidly collapses and produces a shock wave. Such cavitation often occurs in control valves, pumps, propellers and in the vascular tissues of plants. Non inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in shpe or size due to some form of energy input such as accoustic field using ultrasonic waves. Such kind of non inertial cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps and propellers etc.

Since shock waves formed by cavitation are strong enough to damage the moving parts, cavitation is an undesirable phenomenon in many applications of industry. It is specificdly avoided in the design of machines such as turbines and propellers and eliminating cavitation is a major field in the study of fluid dynamics.

(8) APPLICATIONS OF ULTRASONIC WAVES

A few important applications of ultrasonics are discussed below :

(*i*) **Ultrasonic Cleaning.** Ultrasonic cleaning is powered by Ultrasonic energy. When an ultrasonic wave is projected in liquid, negative pressure is created and causes the liquid to fracture. This process is called cavitation. Cavitation creates bubbles that oscillate with the projected ultrasonic waves. As ultrasonic waves continue, these bubbles grow larger and become very unstable and eventually collapse in a violent implosion. The implosions radiate high power shock waves that dissipate energy repeatedly at a rate of 25 kHz – 30 kHz. These implosions can create temperature of the order of 1000°F and enormous pressure. This cavitation implosion effect can be used to clean objects to high degree. The cleaning is speedy and more effective as compared to other conventional methods.

(*ii*) **Determination of speed of sound (ultrasonic waves) in a liquid using accoustic grating.** An X-cut quartz crystal is placed just above the open surface of a liquid column. When connected to radio frequency oscillator (see Fig. (6)), the crystal produces ultrasonic waves which travel in the liquid column and get reflected from opposite end of the column. The incident and reflected wave super impose to produce stationary wave in the liquid as shown in figure (6) (*a*). At nodes the liquid density is maximum and at antinodes the liquid density is minimum. The wavelength of ultrasonic waves (λ_u) is equal to distance between consecutive odd (or even) numbered nodes.

We know that light can pass easily through less dense transparent medium as compared to more dense transparent medium. Hence when light is made to pass through the liquid column, then nodes behave as opaque points in liquid and antinodes as transparent points.

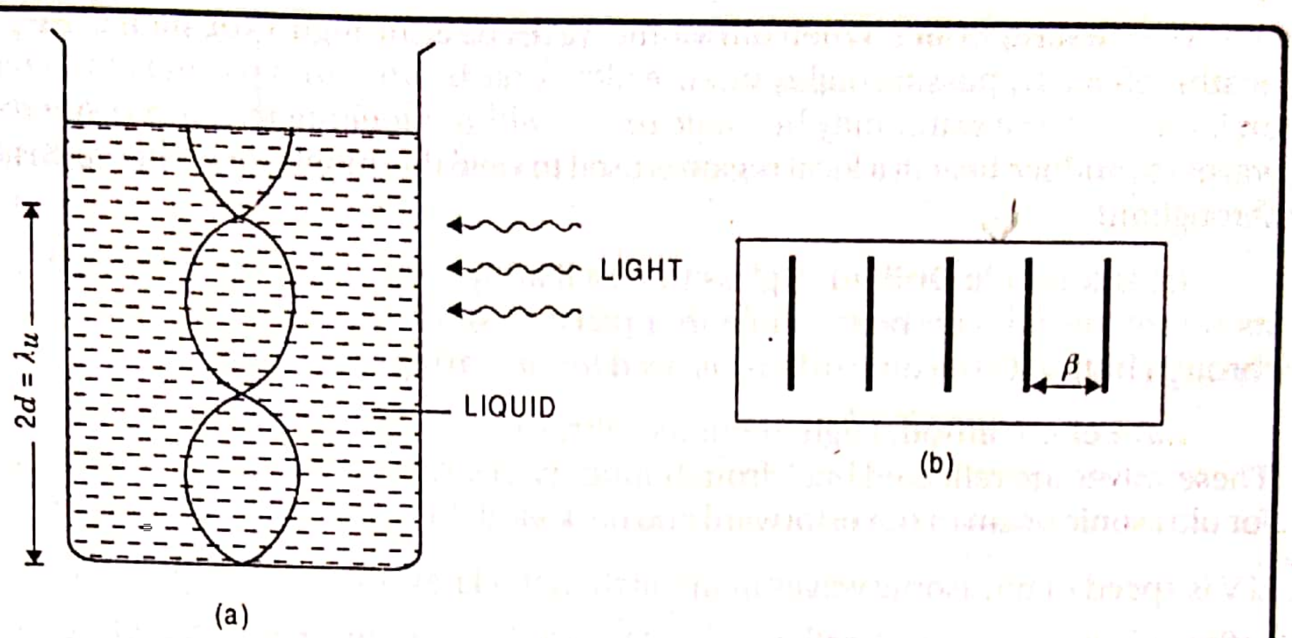

Fig. 6.

Hence liquid acts like a diffraction grating called ultrasonic diffraction grating such that grating element d is equal to distance between two adjacent nodes *i.e.*

$$d = \frac{\lambda_u}{2} \qquad ...(17)$$

When light passes through liquid column, it diffracts and diffraction pattern is recorded on screen. Here lines show maxima and centre of space between them is a minimum. For n^{th} order diffraction, the equation is given as

$$d \sin\theta = n\lambda$$

or

$$\frac{\lambda_u}{2} \sin\theta = n\lambda \qquad ...(18)$$

Here λ = wavelength of light used.

Let D = distance of screen from liquid column

β = fringe width

Then angle of diffraction θ is given as

$$\tan\theta = \frac{\beta}{D} \qquad (\text{for } n = 1) \qquad ...(19)$$

Value of β can be calculated directly from screen using a millimeter scale. Hence using equation (19), we can find θ (for $n = 1$). Then using value of θ in (18) and putting $n = 1$, we can find λ_u. The speed of sound (or ultrasonic waves) in liquids is given as

$$V = \nu\lambda_u \qquad ...(20)$$

Equation (20) can be used to find speed of sound in a liquid.

(*iii*) **SONAR.** Ultrasonic waves from piezoelectric quartz crystal oscillator are used for sending ultrasonic waves in water. These waves are reflected back from submarine or an obstacle coming in its way and reflected beam is again detected by a quartz receiver. The time of ultrasonic beam t from transmitter to obstacle and back to receiver is noted. If V is speed of ultrasonic waves in water then distance of obstacle is given as $d = \frac{Vt}{2}$. This method of determining distances of various objects in sea water using ultrasonic waves is called Sound Navigation And Ranging (SONAR).

(*iv*) **Heating Effect.** When ultrasonic waves pass through a substance, they cause intense heating effect. By passing highly intense ultrasonic beam through water at 0°C with ice floating on its surface, the water may be made to boil without melting ice. This property of ultrasonic waves to produce heat in a local region is used to weld thermoplastics. The weld is homogeneous throughout.

(*v*) **Ultrasonic Drilling.** A glass rod oscillating with ultrasonic frequency combined with its rotary motion can bore a hole in a piece of steel. It passes through steel just like knife through butter. Ultrasonic drilling is used for preparing teeth for filling.

(*vi*) **Echo Method.** High frequency ultrasonic waves are projected into thin metal strips. These waves are reflected back from boundary of strip and detected by the receiver. The time for ultrasonic beam to travel forward and backward through metal strip is noted down. Let it is t. If V is speed of ultrasonic waves in metal then thickness of metal strip is given by $d = \frac{Vt}{2}$. The reflected sound signal is called Echo. Due to this, the method is called Echo Method. This method is used to measure thickness of steel from 0.01 to 4 cm with great deal of accuracy.

(*vii*) When highly intense beam of ultrasonic waves is passed through milk or water it destroys unicellular organisms and bacteria. Hence ultrasonic waves can be used to sterilise water or milk.

(*viii*) **Ultrasonic Welding.** Ultrasonic welding of metals can be performed at room temperature, without the need of any special surface preparation.

In this technique the two pieces to be welded are held togetehr in good contact using external mechanical forces and high intensity ultrasonic waves are passed through them. Due to compressive forces generated by ultrasonic waves, the temperature is increased and atoms/molecules of two surfaces diffuse into each other and result in strong joint between them. This technique in limited to welding of thin metal sheets and foils and is ideal for welding of plastic materials. During ultrasonic welding, there is practically no deformation of work piece. Since only local heating takes place during this process, so this method is also called cold welding.

(*ix*) **Ultrasonic Soldering.** When metal wires/contact are soldered together, then we apply soldening flux along with solder. This flux is used to dissolve oxide film which normally covers the metal surfaces to be welded together and hence helps in forming a firm joint. However soldering flux cannot be applied to active metals like aluminium because they react chemically with flux at high temperature. Such kind of metals can be soldered without flux using ultrasonic waves. In this case just like ultrasonic welding, the two surface/metal contacts are held together firmly and a special iron rod, through which intense ultrasonic waves are passing is brought in contact with metal. The compressive forces produced in iron rod due to ultrasonic waves melts the iron rod, which diffuses and then settles in between the two metal contacts and thus forming a firm joint.

(*x*) **Non Destructive Testing (NDT).** "Non destructive testing is the technique to examine a material for imperfections, various mechanical properties or quality in such a way that material does not lose its usefulness after being tested."

Ultrasonic waves can be used for Non Destructive Testing of materials to check the flaws, cracks or discontinuities in the material. NDT using ultrasonics is based on the principle that cracks or flaws in the material strongly reflect the ultrasonic waves. There are three different types of ultrasonic testing systems :

(a) **Pulse Echo System.** In this method short pulses of ultrasonic waves are projected into the specimen using a single transducer T as shown in fig. (7). The same transducer acts as receiver of reflected ultrasonic waves.

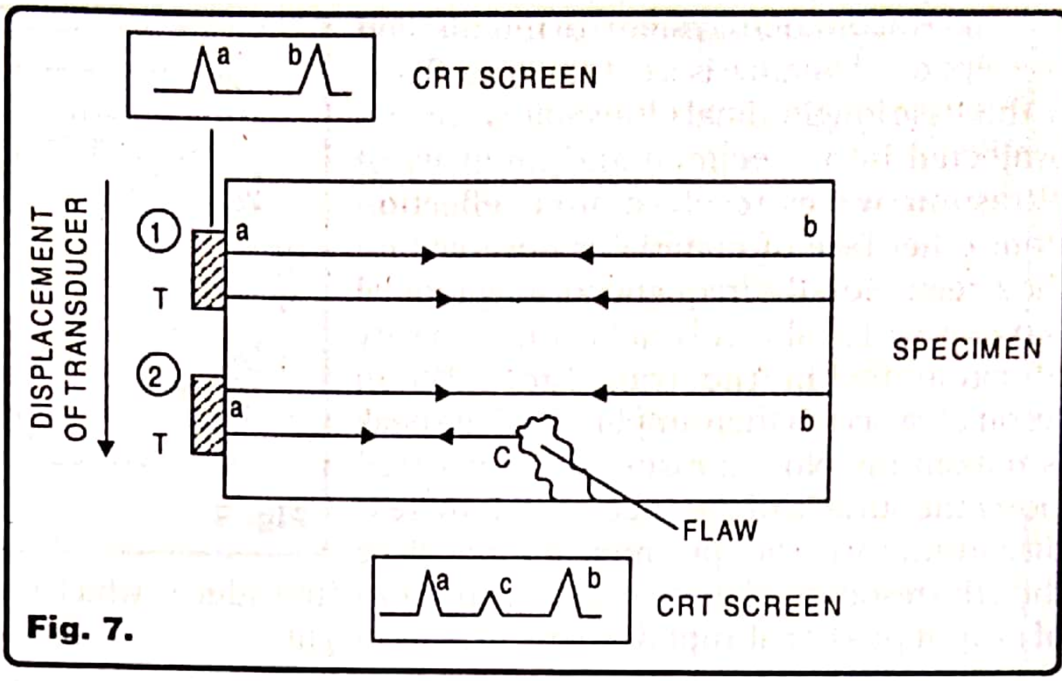

Fig. 7.

The received echoes (reflected ultrasonic waves) are displayed on the cathode ray tube (CRT). Initially transducer is at position (1). When ultrasonic waves enter the material, then some reflection of ultrasonic waves take place at face '*a*'. Hence an echo is recorded by transducer T, due to which a peak (designated as '*a*') is observed on screen of CRT. The ultrasonic waves entering into the medium are again reflected from face '*b*' of specimen. Due to this a second echo of almost same intensity as corresponding to '*a*' is recorded by transducer (∵ metals donot produce much attenuation of ultrasonic waves). Hence another peak '*b*' is obtained on CRT. Now transducer is displaced along the face '*a*' of specimen. Let there be a crack at position '*c*' as shown in the figure. When transducer comes in front of crack then an additional peak on CRT is observed (shown as '*c*') which is due to echo sent by the crack to the transducer. The size of crack decides the heights of the peak '*c*'. Conversely by noting the height of peak '*c*' from CRT, one can find out the size of crack. Further location of crack '*c*' from face '*a*' can be found by proper calibration of CRT on time scale. If t_1, t_2 correspond to times for peaks at '*a*' & '*c*' and V is speed of ultrasonics in the metal, then the distance of the crack from the face '*a*' is given as $d = V(t_2 - t_1)$.

(b) **Pulse Transmission System.** In this method two different transducers are used. One transmits the ultrasonic waves from one side and other receives them from opposite side. The quality of material is determined by the change in intensity of ultrasonic waves as they travel from one end to other end of the specimen. For material free from any discontinuity the intensity of ultrasonic waves at entering the specimen and at the time of coming out of it are almost same. Hence peak height for input and output will be same. On the other hand if there is some discontinuity in the material then height of peak obtained at output will be smaller than peak height at input.

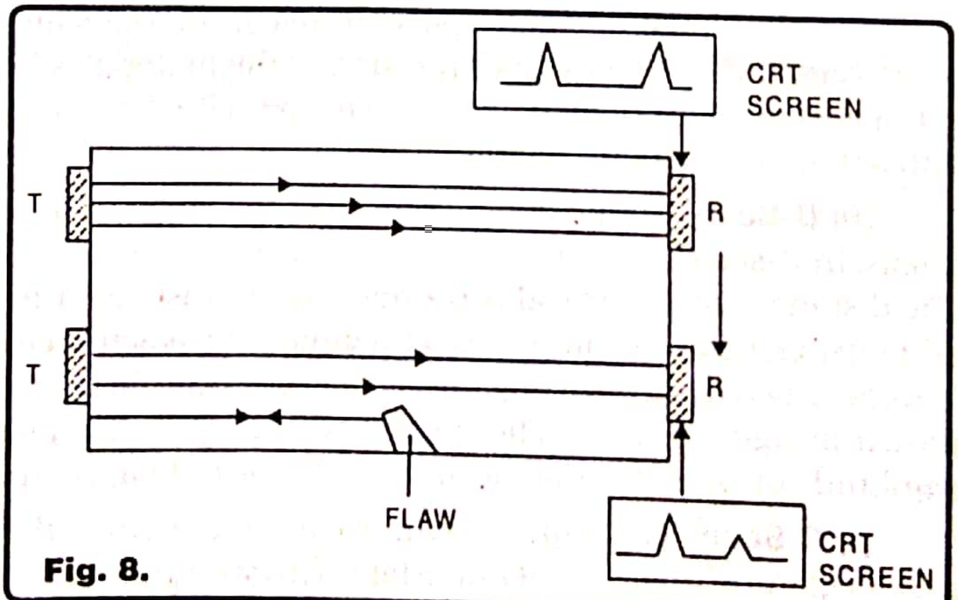

Fig. 8.

(*c*) **Resonance System.** In this method concept of resonance is used to detect flaws. In this case longitudinal ultrasonic waves are projected into specimen and intensity of ultrasonic waves received after reflection from other face of material is observed on the screen. Now the frequency of longitudinal waves is varied slowly by adjusting capacity of capacitor in the transducer. When resonance occurs then amplitude of the peak is maximum. Now transducer is displaced along the surface of the specimen. If there is discontinuity in the specimen at some place then the resonance is broken at that position of transducer, which is indicated by disappearance of output peak or abrupt decrease in peak height.

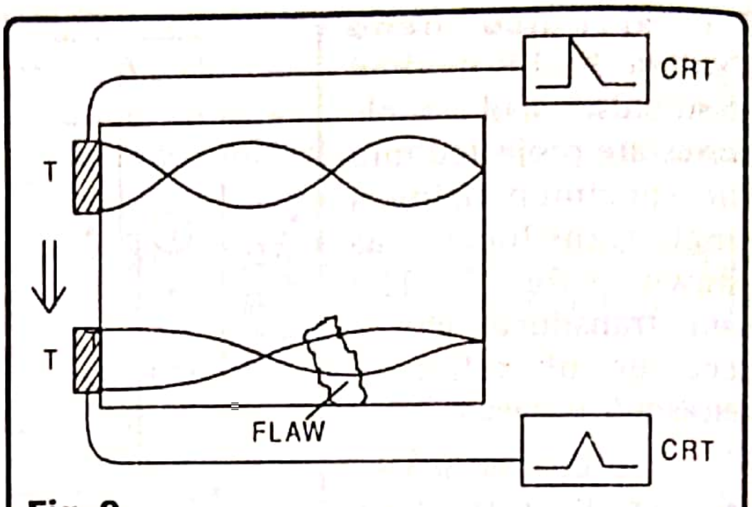

Fig. 9.

(*xi*) **Medical Applications.** Ultrasound waves have been widely used for examining the shape and movement of organs within the body. Normally ultrasound is transmitted in short burst at a repitition rate of 1 kHz to 12 kHz. The images of ultrasonic waves, that are reflected from the boundaries of the organs are obtained. The ultrasonic waves reflected from moving objects such as red blood cells exhibit a doppler shift, which is used to estimate the speed of blood flow. This technique is allowed to monitor the motion of heart valves. The density of tumor and surrounding organs is slightly different, which can be measured using ultrasonic waves. Hence we can use ultrasound to locate the position and estimate the size of a tumor. Ultrasonic imaging is used to produce image of various organs inside our body. There are mainly three types of techniques or scans for construction of ultrasound image. These are described briefly as follows :

(*a*) **A-Scan.** For scanning a part of body ultrasonic waves are sent into the body of person and reflected ultrasound is recorded as described in pulse echo system. In A-scan the amplitudes of received echoes are plotted on the vertical axis of display. The horizontal axis indicates time taken by echo pulse to reach the transducer. In this scan, the transducer is stationary. If the velocity of ultrasound in the material is known, then horizontal axis can be calibrated in terms of distance travelled by echo. Thus A-scan can be coverted electronically into a thickness gauge. Diagramatic representation of A-Scan is shown in figure 10(*a*).

(*b*) **B-Scan.** Suppose direction of propagation of ultrasonic waves is taken to be along Z-axis. In B-scan, the horizontal axis of display indicates the distance Z in the organ of body. The distance along vertical is proportional to distance *y* in the organ normal to direction of propagation of ultrasonic waves. This dimension is achieved by moving the transducer laterally or sweeping it in an arc using phased array of transducer elements. A typical B-scan display is shown in figure (10)(*b*). The display is in grey scale and brightness is proportional to the amplitude of any reflection occuring in YZ co-ordinate of the organ.

(*c*) **C-Scan.** This type of scan is carried out when the actual depth information of the affected parts of organ is not important. This scan gives only the distribution of defects (affected part) perpendicular to a particular direction. In the C-scan, the transducer is swept rapidly back and forth in the X-direction while being stepped in the Y-direction after each sweep. The repitition rate of pulse is rapid compared with X-sweep rate. Thus in the sweep squence the complete volume of organ is scanned.

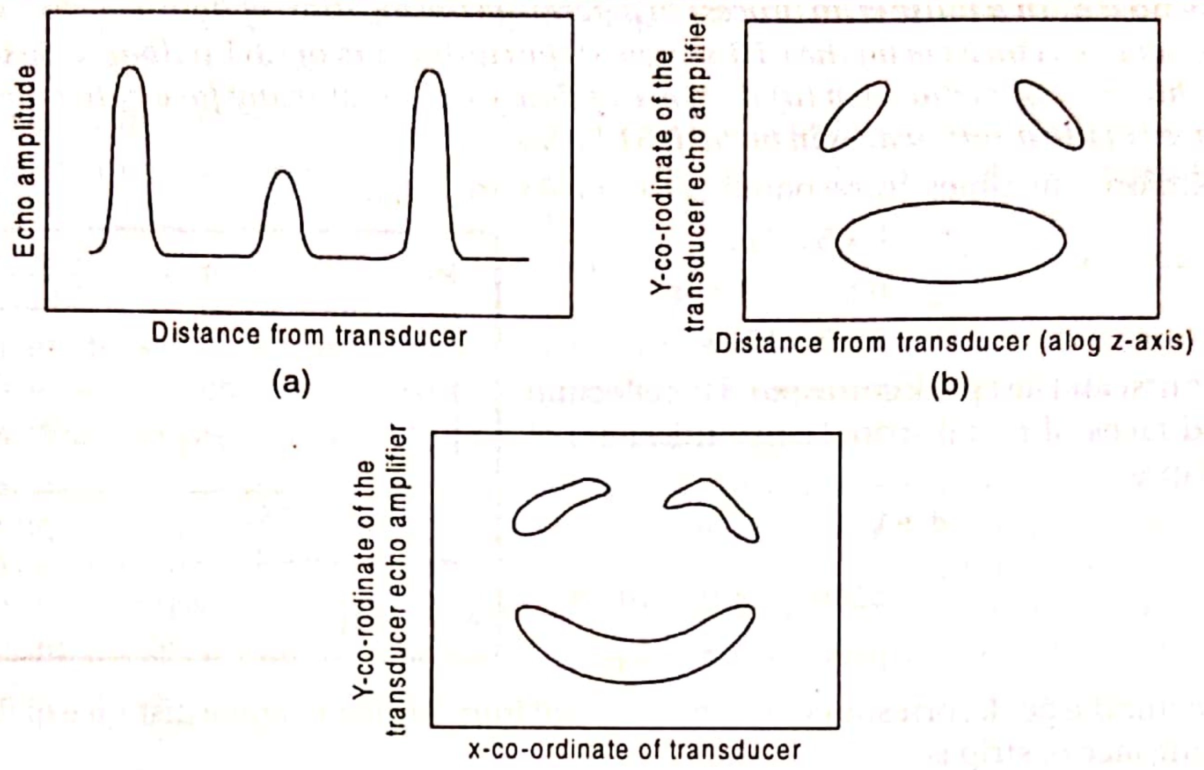

Fig. 10.

Example 1. *The value of Young's Modulus, Poisson ratio and density of silver are 7.25×10^{11} dyne cm^{-2}, 0.39 and 10.5 g cm^{-3} respectively. Find speed of ultrasonic waves in silver.*

Solution.

$$V = \sqrt{\frac{Y(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}}$$

$$= \sqrt{\frac{7.25 \times 10^{11}\ (1-0.39)}{10.5\ (1+0.39)\ (1-2\times 0.39)}}$$

$$= 371125 \text{ cm}/s = 3711.25\ m/s$$

Example 2. *An X-cut quartz crystal of 3mm thickness is used in piezoelectric resonator. Calculate the frequency of ultrasonic waves produced.*

Solution.

$$\nu = \frac{272500}{l}\ (\text{H}_z)$$

$$= \frac{272500}{3} = 90833 \text{ Hz}$$

Example 3. *Light waves of wavelength 6000 Å are made to pass through a liquid column which is under ultrasonic resonance. The angle of diffraction for second maximum is found to be 2°. Find the wavelength of ultrasonic waves in the liquid.*

Solution.

$$\frac{\lambda_u}{2} \sin\theta = n\lambda$$

$$\therefore \quad \lambda_u = \frac{2n\lambda}{\sin\theta}$$

$$= \frac{2\times 2\times 6000 \times 10^{-10}}{\sin 2^\circ} = 6.88 \times 10^{-5}\ m$$

Example 4. *In a pulse echo process to determine the location of flow, we observed three peaks at 0 cm, 0.5 cm, 2 cm on the CRT screen. If the calibration of CRT is done at 5μs/cm, find (i) total thickness of metal strip (ii) distance of flaw from the starting face of the metal strip. Given speed of ultrasonic waves in metal is 5130 m/s.*

Solution. The times corresponding to 3 peaks are given as

$$t_1 = 0 \times 5 = 0\,\mu s$$
$$t_2 = 0.5 \times 5 = 2.5\,\mu s$$
$$t_3 = 2 \times 5 = 10\,\mu s$$

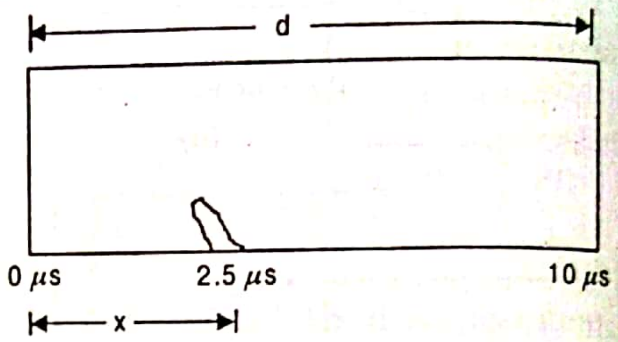

Fig. (11)

The first and last peak correspond to reflection from end faces of metal strip. Hence thickness of metal strip is

$$d = V(t_3 - t_1)$$
$$= 5130\frac{m}{s} \times 10 \times 10^{-6}\,s$$
$$= 0.0513\,m = 5.13\text{ cm}$$

The middle peak correspond to echo received from the flaw. Hence distance of flaw from the starting face of strip is

$$x = V(t_2 - t_1)$$
$$= 5130\frac{m}{s} \times 2.5 \times 10^{-6}\,s$$
$$= 0.0128\,m = 1.28\,cm$$

Exercise 1. *Young's modulus of Nickel is 200 G Pa and its density is 8.9 g cm^{-3}. A rod of length 10 cm is used in magnetostriction method. Find (i) frequency of ultraronics generated. (ii) Capacity of capacitor required to obtain resonance oscillations. Given Induction used in tank circuit is 0.5 mH.*

[Ans. (*i*) 23.7 *k*Hz (*ii*) 90*n*F]

Exercise 2. *Calculate speed of sound in iron. Given value of Y, σ and ρ for iron are 190 G Pa, 0.27 and 7.87 g cm^{-3} respectively.*

[Ans. 5492 *m/s*]

SHORT ANSWER TYPE QUESTIONS

Q. 1. What properties are required by a medium to allow propagation of acoustic waves through it?

Ans. A medium must possess properties of elasticity and inertia so that acoustic waves can propagate through it.

Q. 2. What is ultrasound or ultrasonography?

Ans. It is a medical imaging technique, that uses high frequency ultrasonic waves (1MHz – 5MHz) and their echoes. These ultrasonics pulses travel into human body and hit a boundary between tissues. Due to this some part is reflected back to the transducer, while remaining part goes to the next tissue and get reflected at its boundary and so on. The reflected waves are picked up by transducer and relayed to machine. The machine calculates the distance of tissue from probe. The distances and intensities of echoes are displayed on a screen forming a two dimensional image. This helps in studying the internal parts of body more apparently.

Q. 3. What are disadvantages of Ultrasonics?

Ans. (*i*) Ultrasonic devices are very expensive.

(*ii*) The ultrasonic devices are very complex in their design.

(*iii*) In medical examination of human using ultrasound, tissues or water absorb ultrasound energy, which increases their temperature locally.

(*iv*) During passage of ultrasonics through liquids, dissolved gases may come out of it due to cavitation.

(*v*) Bats, dogs and some other animals are capable of perceiving ultrasonic waves. Hence if ultrasonic waves are sent around in open, it causes rest lessness amongst some animals & birds.

Q. 4. What do you mean by Acoustical Holography?

Ans. By illuminating an object with pure tones of ultrasonic waves instead of a beam of coherent light, one can create a three dimensional image of object when viewed with a laser light. This 3-D picture is called Acoustical Hologram and the technique is called Acoustical Holography. The medical applications of acoustic holography are in imaging internal organs. This is because light cannot pass through rigid objects whereas sound can pass more easily. In industry accoustical holography is used to reveal how materials are manufactured, welded or to find out the quality of a product.

QUESTIONS

1. What is Piezoelectric Effect? Explain with a circuit diagram, the generation of ultrasonic using Piezo electric oscillator.
2. Discuss the applications of ultrasonic waves in medical field.
3. Discuss non destructive testing of materials using ultrasonic waves. Explain the applications of non destructive testing of materials.
4. Define ultrasonic waves. Describe its production by magnetostriction method.
5. Write down advantages of using ultrasonic waves in comparison to electromagnetic waves for Non destructive testing of materials.
6. Define acoustic impedance. Write an expression for it.
7. What are various types of ultrasonic waves?
8. Explain a few ways to detect ultrasonic waves.
9. Which method would you choose to produce ultrasonic waves of high frequency ?
10. Write down applications of ultrasonics in industry.
11. Discuss medical applications of ultrasonic waes.