UNIT – I

ULTRASONICS

INTRODUCTION

- The human ear can hear the sound waves having frequencies in between 20 Hz to 20 kHz. These frequencies are known as audible frequencies. The sound waves having frequencies less than 20 Hz are known as infrasonic waves
- The sound waves having frequencies greater than 20 kHz are known as ultrasonic waves.
- The wavelength of ultrasonic waves are very much less than the wavelengths of audible sound waves.
- So they applications in non-destructive testing of materials, medical diagnostics, military and marine.
- Ultrasonic method is widely used in industries to find the size, shape, and location of flaws such as cracks, voids, laminations, and inclusions of foreign materials, walls thickness of produced pipes and vessels. The wall thickness measurements are very important in corrosion studies.

PROPERTIES OF ULTRASONIC WAVES

- Ultrasonic waves are high frequency and high energetic sound waves.
- Ultrasonic wave travels longer distances without any energy loss.
- The speed of propagation of ultrasonic waves increases with the frequency of the waves.
- Ultrasonic waves produce cavitation effects in liquids.
- Ultrasonic waves produce acoustic diffraction in liquids.

- Ultrasonic waves cannot travel through the vacuum.
- Ultrasonic waves travel with speed of sound in a given medium.
- Ultrasonic waves require one material medium for its propagation.
- Ultrasonic waves produces heat effect when they passes through the medium.
- Ultrasonic waves obey reflection, refraction, and absorption properties similar to sound waves.
- Ultrasonic waves produce stationary wave pattern in the liquid while passing through it.
- When the ultrasonic wave is absorbed by a medium, it generates heat. They are able to drill and cut thin metals.

PRODUCTION OF ULTRASONIC WAVES

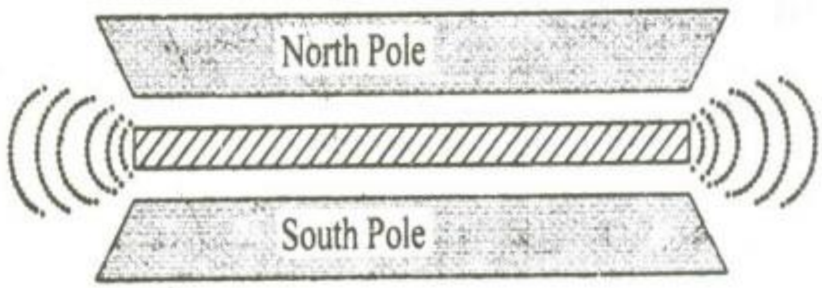
There are three methods for producing ultrasonic waves.

1. Mechanical generator or Galton's whistle
2. Magnetostriction generator
3. Piezoelectric Generator

MAGNETOSTRICTION GENERATOR

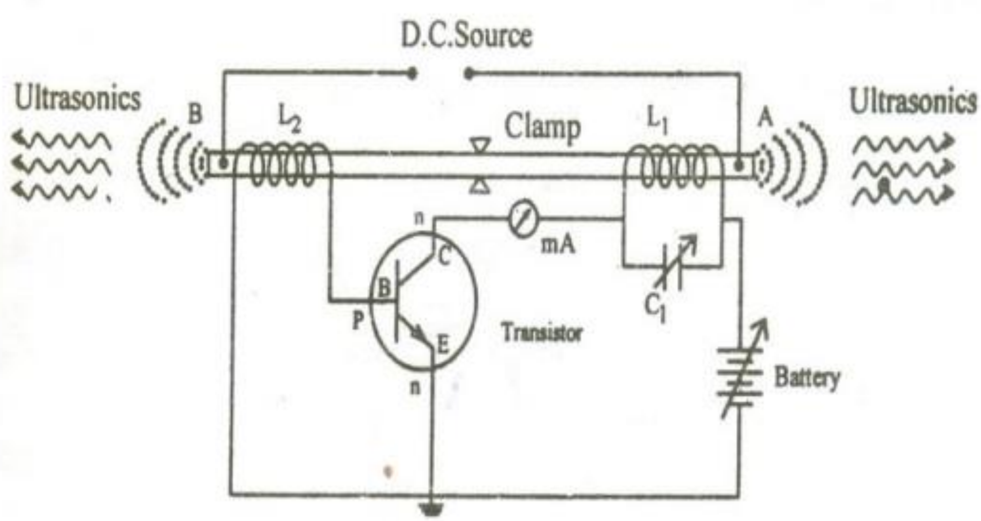
Magnetostriction effect is the principle of producing ultrasonic waves.

Magnetostriction Effect: When a rod of ferromagnetic material like nickel is magnetized. Then the rod is thrown into longitudinal vibrations, thereby producing ultrasonic waves by resonance. This is called Magnetostriction effect.



Construction:

The circuit diagram of magnetostriction ultrasonic generator is as shown in the figure. A short permanently magnetized ferromagnetic rod is clamped at the centre of the rod AB. The two ends of the rod is wound by the coils L_1 and L_2. The coil L_1 is connected to the collector of the transistor and the coil is L_2 connected to the base of the transistor. The frequency of the oscillatory circuit can be adjusted by a condenser(C_1) and the current can be noted by the milli ammeter, connected across the coil L_1. The battery connected between emitter and collector provides necessary biasing, i.e) emitter is forward biased and collector is negative biased for the npn transistor. Hence, current can be produced by applying necessary biasing to the transisitor with the help of the battery.



Working:

When the battery is switched on, current is produced by the transistor. The current is passed through the coil L_1, which causes a corresponding change in the magnetization of the rod. Now the rod starts vibrating due to magnetostriction effect, due to this an emf is induced in the coil L_2.

The induced emf is fed to the base of the transistor, which acts as a feed back continuously. In this way, the current in the transistor is built up and the vibrations of the rod is maintained. The developed alternating current frequency can be tuned with the natural frequency of the rod by adjusting the capacitor. At resonance, the rod vibrates longitudinally with larger amplitude producing ultrasonic waves.

Condition for Resonance:

Frequency of the oscillatory circuit = Frequency of the vibrating rod

$$F = \frac{I}{2\pi\sqrt{L_1C_1}} = \frac{1}{2l}\sqrt{\frac{E}{\rho}}$$

Where

'l' is the length of the rod

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

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

Advantages:

1. It is mechanically versatile
2. Cost is low

3. It can produce large acoustical power with high efficiency.

Limitations

1. It can produce frequencies up to 3MHz only.
2. It is not possible to get a constant single frequency, because it depends on the temperature and the degree of magnetization.
3. Frequency is inversely proportional to the length of the rod, to increase the frequency, the length of the rod should be decreased which is practically impossible.

Piezoelectric Crystals

The crystals which produce piezoelectric effect and converse Piezo electric effect are termed as Piezoelectric crystal.

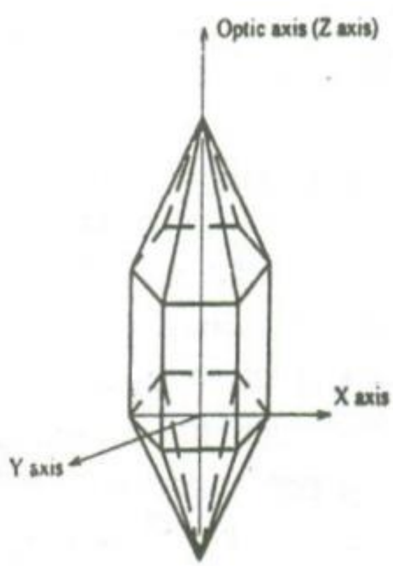
Example: Quartz, Tourmaline, Rochelle Salts etc.

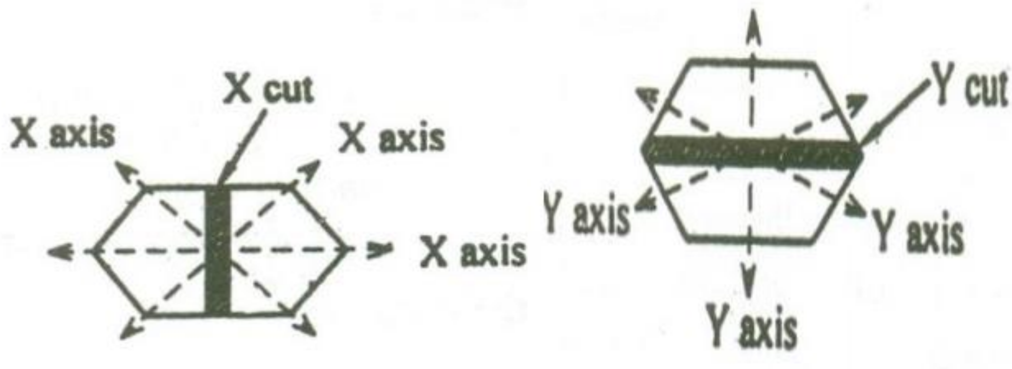
At typical example or a piezoelectric crystal (Quartz) is as shown in the figure. It has an hexagonal shape with pyramids attached at both ends. It consists of 3 axes. Viz.,

(i) Optic Z axis, which joins the edges of the pyramid

(ii) Electrical axis(X axis), which joins the corners of the hexagon and

(iii) Mechanical axis, which joins the center or sides of the hexagon as shown in figure.





X-cut and Y cut crystals

X-Cut crystal:

When the crystal is cut perpendicular to the X-axis, it is called X-crystal.

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

Y-Cut Crystal:

When the crystal is cut perpendicular to the Y-axis, it is called Y-cut crystal.

Generally, Y-Cut crystal produces transverse ultrasonic waves.

Piezoelectric Effect

When a mechanical stress is applied to the mechanical axis with respect to optical axis, a potential difference is developed across the electrical axis with respect to optic axis. This is known as Piezoelectric effect.

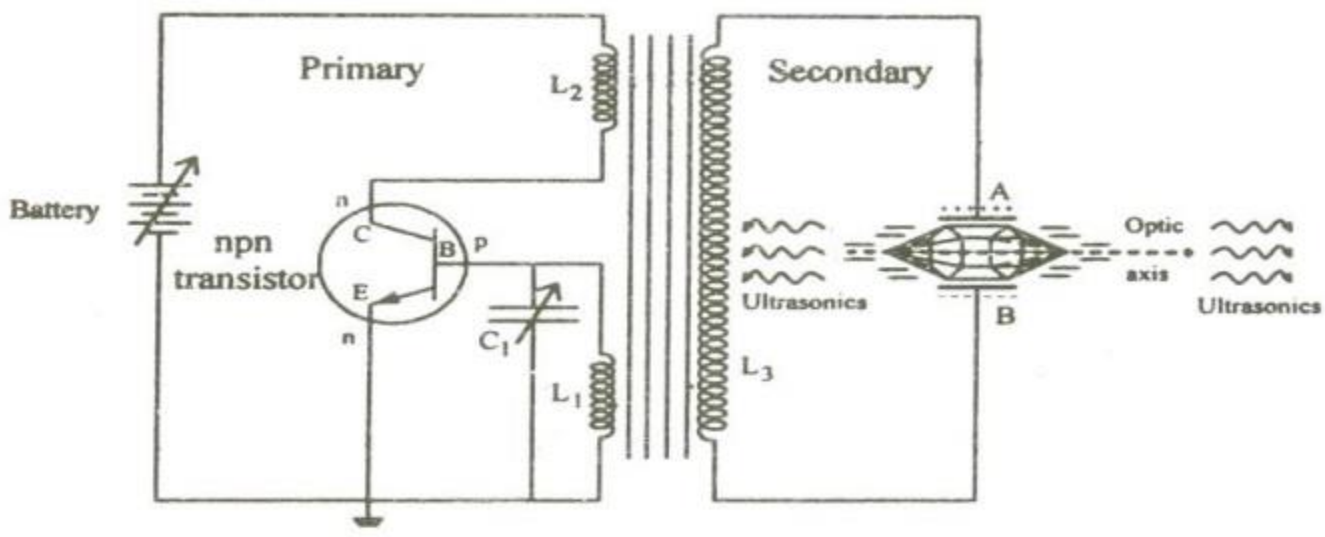
Inverse Piezoelectric Effect:

When an alternating electric field is applied to electrical axis with respect to optical axis, expansion or contraction takes place in the mechanical axis with respect to optical axis. This is known as Inverse Piezoelectric effect.

PIEZOELECTRIC GENERATOR

Principle:

This is based on the **Inverse piezoelectric effect.** When a quartz crystal is



subjected to an alternating potential difference along the electric axis, the crystal is set into elastic vibrations along its mechanical axis. If the frequency of electric oscillations coincides with the natural frequency of the crystal, the vibrations will be of large amplitude. If the frequency of the electric field is in the ultrasonic frequency range, the crystal produces ultrasonic waves.

Construction:

The circuit diagram is shown in the figure. The piezo electric generator consists of primary and secondary circuits. The primary circuit is arranged with coils L_1 and L_2. The coil L_1 is connected to the base of the transisitor and coil L_2 is connected to the collector of the transistor. The capacitor C_1 is used to vary the frequency of the oscillatory circuit[L_1C_1]. The coil L_2 is inductively coupled to the secondary circuit, which comprises of the coil L_3 and two metal plates A and B as shown in figure. The crystal is kept in between the plates A and B for the production of ultrasonics. Emitter is forward biased and collector is reverse biased.

Working

The battery is switched on and hence the current is produced by the transistor in the circuit. The current is passed through the coil L_1 and L_2 of the primary circuit. The current is transferred to the coil L_3in the secondary circuit due to transformer action and is fed to the plates A and B. Now the crystal starts vibrating along the mechanical axis of the crystal. The frequency of the oscillatory circuit is adjusted , when this frequency is equal to the frequency of the vibrating crystal, resonance occurs and ultrasonic waves are produced on both sides of the crystal.

Condition for Resonance:

Frequency of the oscillatory circuit = Frequency of the vibrating crystal

$$F = \frac{I}{2\pi\sqrt{L_1C_1}} = \frac{P}{2l}\sqrt{\frac{E}{\rho}}$$

Where ‘l’ is the length o the rod

‘E’ is the Young’s modulus o the rod

‘ρ’ is the density of the material of the rod.

‘P’ = 1,2,3 …. etc for fundamental, first overtone, second overtone etc respectively

Advantages:

1. It can produce frequency up to 500MHz.
2. It can produce longitudinal as well as transverse ultrasonic waves by properly cutting and shaping the crystal with respect to the optic axis.
4. Independent of termperature. So we can get a stable and constant frequency of ultrasonic waves.

Disadvantages:

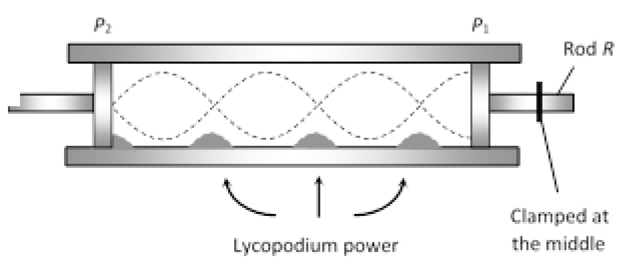
1. The cost of the quartz crystal is very high.
2. Cutting and shaping the crystal is quite complex.

DETECTION OF ULTRASONIC WAVES

Ultrasonic waves propagated through a medium can be detected in a number of ways. Some of the methods employed are as follows:

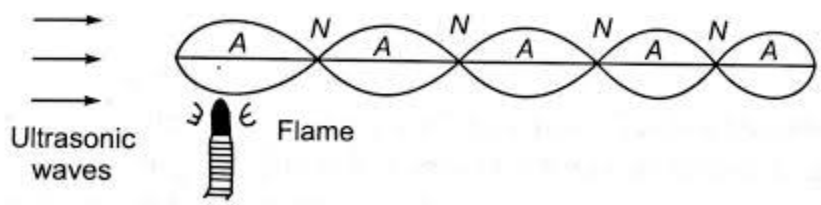
(1) Kundt's tube method:

Ultrasonic waves can be detected with the help of Kundt's tube. At the nodes, lycopodium powder collects in the form of heaps. The average distance between two adjacent heaps is equal to half the wavelength. This method cannot be used if the wavelength of ultrasonic waves is very small i.e., less than few mm. In the case of a liquid medium, instead of lycopodium powder, powdered coke is used to detect the position of nodes.



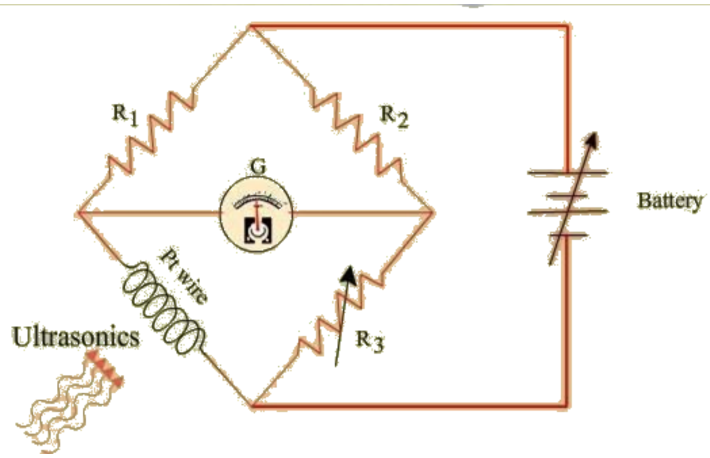
(2) Sensitive flame method:

A narrow sensitive flame is moved along the medium. At the positions of antinodes, the flame is steady. At the positions of nodes, the flame flickers because there is a change in pressure. In this way, positions of nodes and antinodes can be found out in the medium. The average distance between the two adjacent nodes is equal to half the wavelength. If the value of the frequency of ultrasonic wave is known, the velocity of ultrasonic wave propagated through the medium can be calculated.



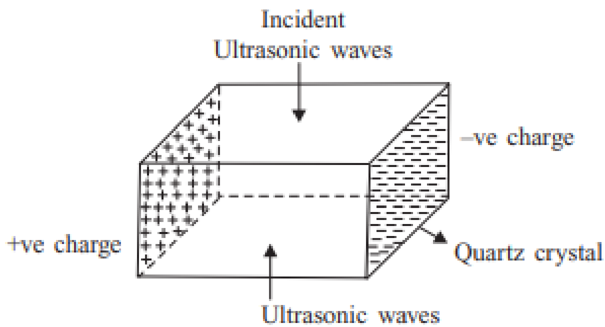
(3) Thermal detectors:

This is the most commonly used method of detection of ultrasonic waves. In this method, a fine platinum wire is used. This wire is moved through the medium. At the position of nodes, due to alternate compressions ad rarefactions, adiabatic changes in temperature takes place. The resistance of the platinum wire changes with respect to time. This can be detected with the help of Callendar and Garrifith's bridge arrangement. At the position of the antinodes, the temperature remains constant. This will be indicated by the undisturbed balanced position of the bridge.



(4) Piezoelectric Detector

Piezoelectric crystals have the ability to develop an electric potential when a stress is applied across certain faces of the crystal. This phenomenon can be used to detect ultrasonic waves. One pair of faces of a quartz crystal (piezoelectric material) is subjected to ultrasonic waves as shown in Figure. An alternating potential then develops across the perpendicular faces. This potential can be amplified and measured to detect the presence of ultrasonic waves.



CAVITATION

Microscopic bubbles with diameters in the range of 10–9 to 10–8 m are generally present in a liquid. A reduction of pressure in regions around these bubbles leads to evaporation and thus results in the growth of the bubbles. This growth, however, is not unlimited. Ultimately, it leads to the collapse of the bubbles. All this happens within a very short span of time, just a few milliseconds. The process of collapse of the bubbles results in the generation of shock waves and the temperature increases manifold in the region of the collapse. Ultrasonic waves passing through a liquid induce alternate regions of rarefaction and compression. Rarefaction regions are local negative pressure regions and result in the process of bubble growth and collapse. This phenomenon is called cavitation. The collapse of bubbles can result in local pressures reaching thousands of atmospheres and local temperatures increasing by as much as 10,000°C. The phenomenon of cavitation can be used for the following applications:

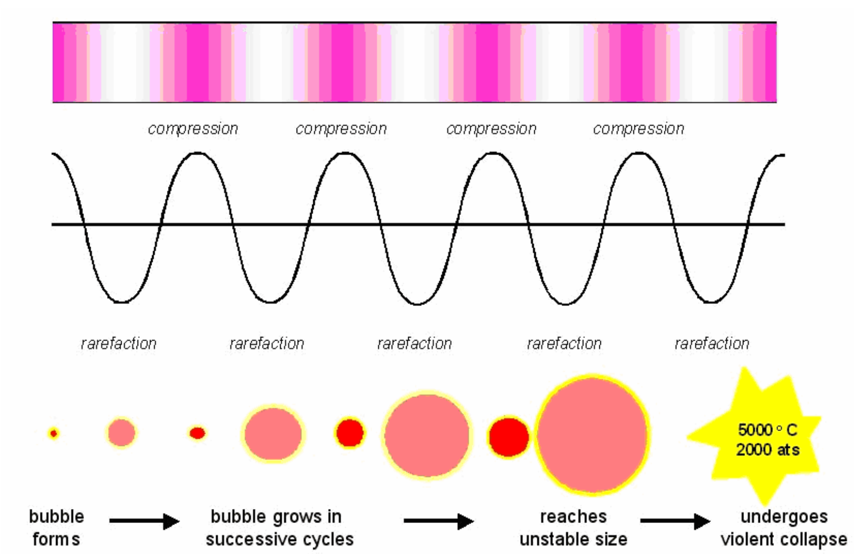
(i) ultrasonic cleaning

(ii) exploration of minerals and oil deposits

(iii) speeding up chemical reactions

(iv) emulsification

(v) formation of stoichiometric alloys and compounds.



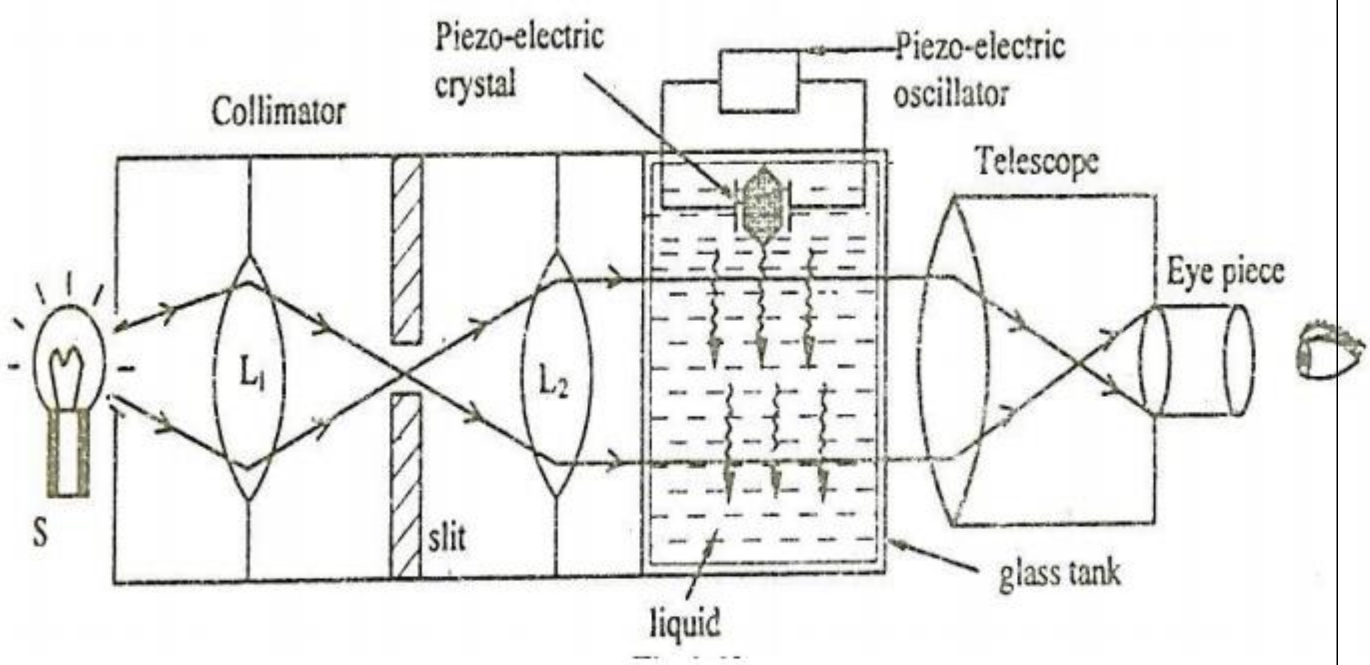
VELOCITY MEASUREMENT USING ACOUSTIC GRATING

Principle:

When ultrasonic waves travel through a transparent liquid, due to alternate compression and rarefaction, longitudinal stationary waves are produced. If monochromatic light is passed through the liquid perpendicular to these waves, the liquid behaves as diffraction grating. Such a grating is known as Acoustic Grating. Here the lines of compression and rareaction act as transparent light waves. It is used to find wavelength and velocity(v) of ultrasonic waves in the liquid.

Construction:

It is consists of a glass tank, filled with the liquid. A piezo-electric (Quartz) is fixed at the top of the glass tank and is connected with piezo-electric oscillatory circuit as shown in the figure.



An incandescent lamp is used as a monochromatic source (S) and a telescope arrangement is used to view the diffraction pattern. A collimator consisting of two lenses L1 and L2 is used to focus the light effectively in the glass tank.

Working

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

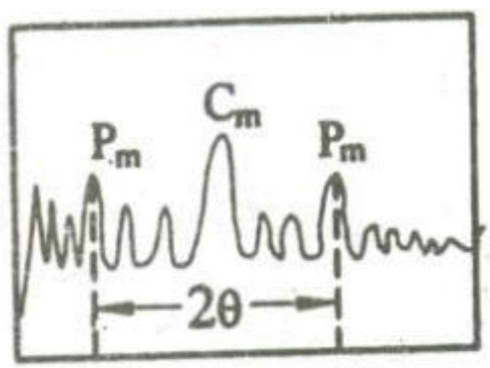
Initially the piezo-electric crystal is kept at rest and the monochromatic at light is switched ON. When the light is focused in the glass tank filled with the liquid, a single imag or a vertical peak is observed in telescope, which shows that there is no diffraction.

(ii) When the piezo-electric crystal is set into vibrations:

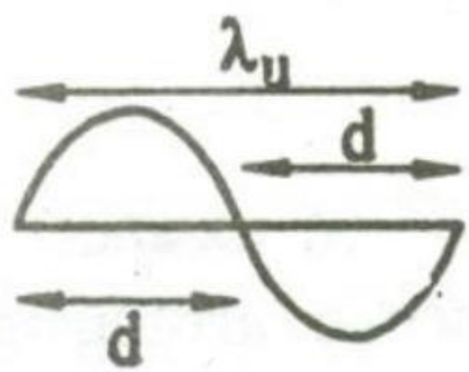
Now the crystal is set into vibrations using piezoelectric oscillatory circuit. At Resonance, Ultrasonic waves are produced and are passed through the liquid. These Ultrasonic waves are reflected by the walls of the glass tank and form a stationery wave pattern with nodes and antinodes in the liquid.

At nodes the density of the liquid becomes more and at antinodes the density of the liquid becomes less. Thus, the liquid behaves as a directing element called acoustical grating element.

Now when the monochromatic light is passed through the acoustical grating, the light gets diffracted and a diffraction pattern consisting of central maxima(C_m) and principle maxima(P_m) on either side is viewed through the telescope as shown in figures.



Diffraction pattern



Calculation of Ultrasonic Velocity

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

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

$$2d\sin\theta = n\lambda \longrightarrow \quad (1)$$

Where, d is the distance between successive node or antinodes.

θ is the angle of diffraction

n is the order of the spectrum

λ_L is the wavelength of the monochromatic source of the light.

If λ_u is the wavelength of Ultrasonics,

If $\lambda_u = 2d \longrightarrow \quad (2)$

Then, equation (1) becomes,

$$\lambda_u \sin\theta = n\lambda$$

Wavelength of Ultrasonic = $\lambda_u = \dfrac{n\lambda}{\sin\theta} \longrightarrow \quad (3)$

We know, Ultrasonic Velocity = Frequency of Ultrasonic $\times$ Wavelength of ultrasonic

$$\boxed{\text{Velocity of Ultrasonic } v = \lambda_u \times \nu_u} \longrightarrow \quad (4)$$

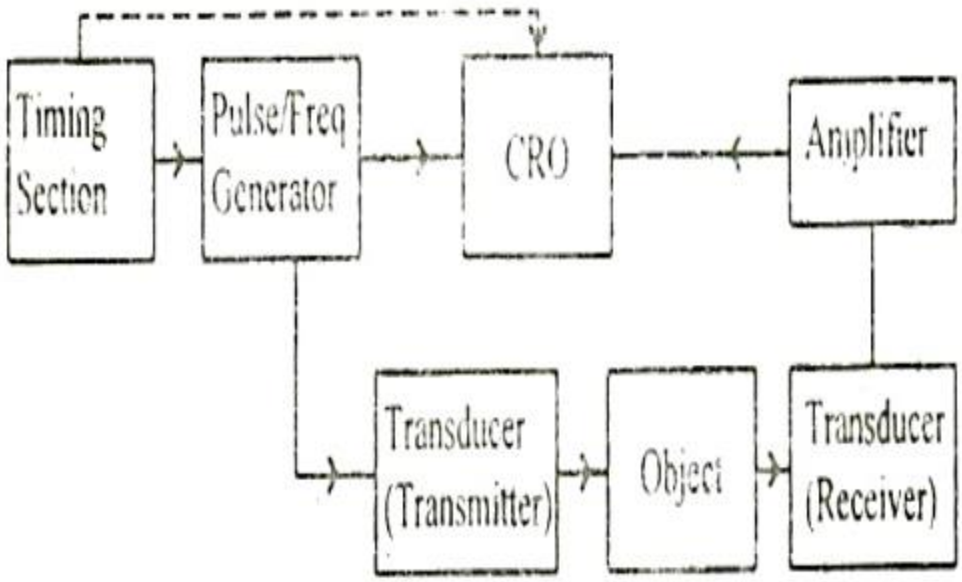
Substituting equation (3) in (4), we get

$$\boxed{\text{Velocity of Ultrasonic } v = \frac{\nu_u n\lambda}{\sin\theta}}$$

SOUND NAVIGATION AND RANGING (SONAR)

Principle:

It is based on the principle of Echo – Sounding. When the Ultrasonic waves are transmitted through water, it is reflected by the objects in the water and will produce an echo signal. The change in frequency of the echo signal, due to Doppler Effect helps us in determining the velocity and direction of the object.



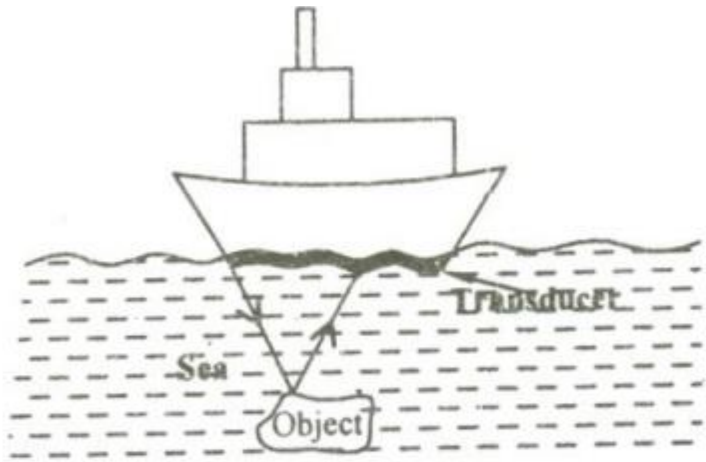
Description:

It consists of timing section which triggers the electric pulse from the pulse generator. This pulse generator is connected to the transducer so that ultra sonic can be produced. The transducer is further connected with the CRO for display. The timing section is also connected to the CRO display or reference of the timing at which the pulse is transmitted as shown in the block diagram(Figure 1.6.1).

Working:

The transducer is mounted on the ship's hull without any air gap between them as shown. The timing at which the pulse generated is recorded at the CRO or reference and this electrical pulse triggers the transducer which is kept in hull of the ship to produce ultrasonic waves due to the principle of inverse piezo electric effect.

These ultrasonic waves are transmitted through the water in sea. On stricking the object the ultrasonic waves (echo pulses) are reflected in all directions as shown in the figure 1.6.2

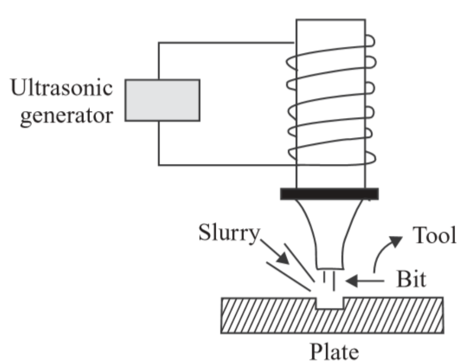


INDUSTRIAL APPLICATIONS

Ultrasonic waves can be used in a variety of industrial applications.

1) Drilling

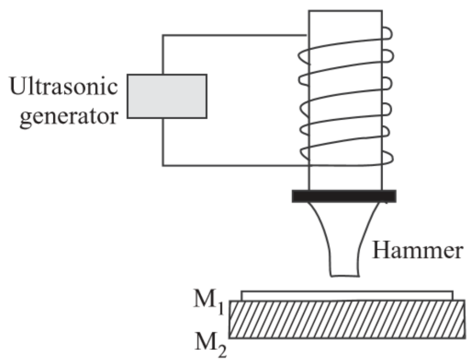
Ultrasonics can be used to drill holes in hard materials like glass and diamond. Schematic diagram of an ultrasonic drilling system is shown in Figure.



The system consists of a tool bit connected to an ultrasonic generator. The tool bit carries out a vertical up–down motion due to the generated ultrasonic waves. Slurry (thin paste of corborundum powder and water) flows in the region between the plate of the material to be drilled and the tool bit. As the tool bit undergoes the vertical motion, the slurry removes material from the plate. Holes with a very good control of dimensions can be obtained using this technique.

2) **Welding**

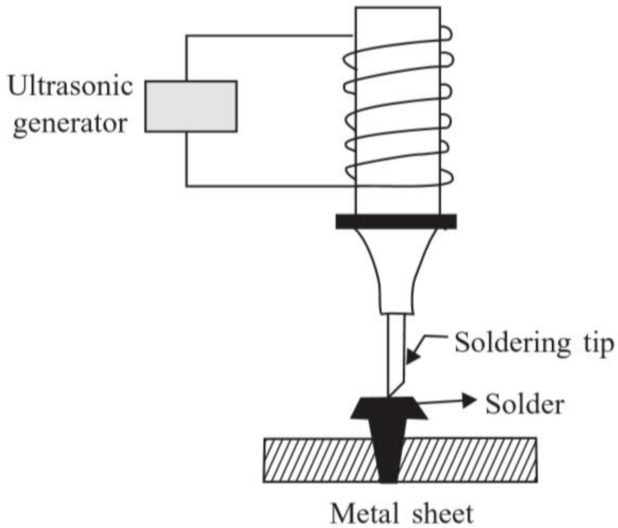
Welding is the process of joining metals. Ultrasonics can be used to carry out welding. Figure 1.8 is a schematic representation of an ultrasonic welding system.



The set-up consists of a hammer connected to an ultrasonic generator. M1 and M2 represent two metal sheets that are to be welded together. The ultrasonic generator makes the hammer vibrate vertically at ultrasonic frequencies, generating pressure on the metal surfaces and causing the molecules of the metals to diffuse into each other. This results in welding of the two metal parts without the need for heating the plates to high temperatures. This process of welding is, therefore, also called cold welding.

3) **Soldering**

Aluminium has diverse industrial applications. However, using the conventional soldering technique, aluminium cannot be soldered without the use of fluxes. Ultrasonic soldering is extremely effective under such conditions. Figure 1.9 shows an ultrasonic soldering system.

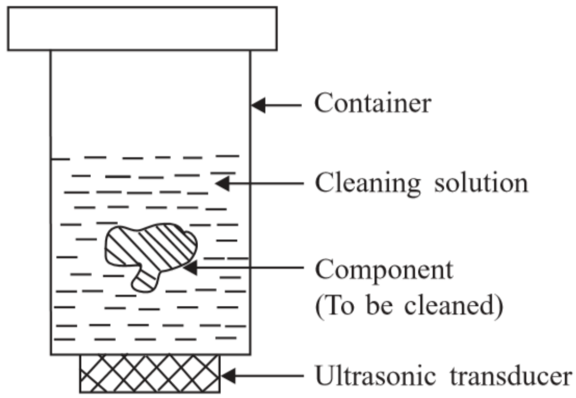


The set-up consists of an ultrasonic soldering iron with a soldering tip at the end. Provision exists for heating the soldering tip. The heated tip melts the solder placed on aluminium and the ultrasonic vibrations of the tip remove the aluminium oxide layer. This results in excellent adhesion of the solder to the aluminium.

4) **Ultrasonic Cleaning**

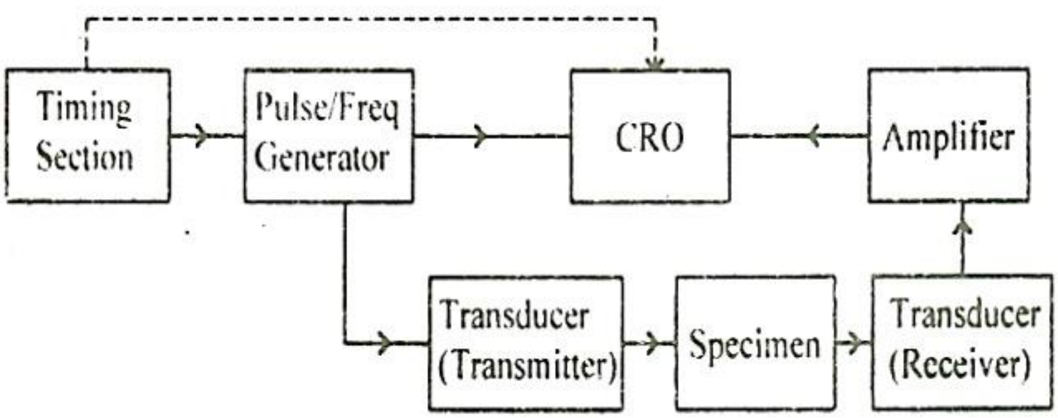
Ultrasonic waves possess high energy and this energy can be used to clean ultensils, clothes, machine parts, etc. Ultrasonic cleaning is an important step in the processing of semiconductor wafers to realize integrated circuits and devices. A schematic diagram of a typical ultrasonic cleaning system is shown in Fig. 1.10. The set-up consists of a transducer that converts electrical energy to mechanical energy. The ultrasonic waves so generated are coupled to the container vessel. This vessel contains the component requiring cleaning, in a suitable cleaning solution.

The high energy of the ultrasonic waves acts on the contaminants to loosen them and thus clean the component.



ULTRASONIC NON DESTRUCTIVE TESTING

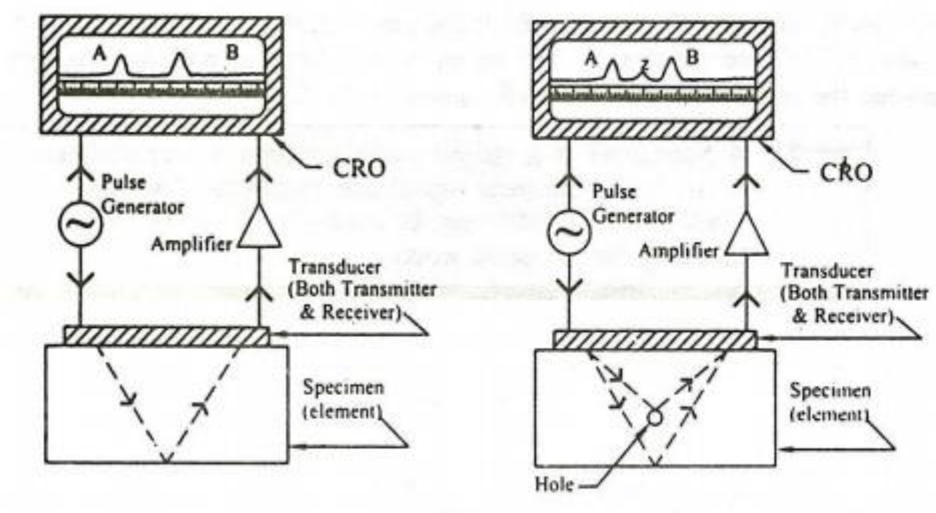
The basic principle behind the ultrasonic inspection is the transmission of the Ultrasound with the medium and the reflection or scattering at any surface or internal discontinuity in the medium due to the change in the acoustic impedance. The Discontinuity means the existence of the flaw,cracks or hole in the material. The reflected or scattered sound waves are received and amplified and hence, the defects in the specimen are suitably characterized.



ULTRASONIC FLAW DETECTOR

Principle:

Whenever there is a change in the medium, then the Ultrasonic waves will be reflected. This is the principle used in Ultrasonic flaw detector. Thus, from the intensity of the reflected echoes, the flaws are detected without destroying the material and hence this method is known as a Non Destructive method.



Working:

- ➢ The pulse generator generates high frequency waves and is applied to the Piezo- electric transducer and the same is recorded in the CRO.
- ➢ The piezo electric crystals are resonated to produce Ultrasonic waves.
- ➢ These Ultrasonic waves are transmitted through the given specimen.
- ➢ These waves travel through the specimen and is reflected back by the other end.
- ➢ The reflected Ultrasonic are received by the transducer and is converted into electric signals. These reflected signals are amplified and is recorded in the CRO.
- ➢ If the reflected pulse is same as that of the transmitted pulse, then it indictes that there is no defect in the specimen.

- On the other hand, if there is any defect on the specimen like a small hole or pores, then the Ultrasonic will be reflected by the holes(i.e.) defects due to change in the medium.
- From the time delay between the transmitted and received pulses, the position of the hole can be found.
- From the height o the pulse received the depth of the hole can also be determined.

ULTRASONIC SCANING METHODS - A, B AND C SCAN DISPLAYS

In the Ultrasonic scanning methods, the principle, construction and working is the same as that of the Ultrasonic law detector. Here, it is based on the position o the transducer and the output displayed in the CRO screen, we can classify the scanning methods into three types

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

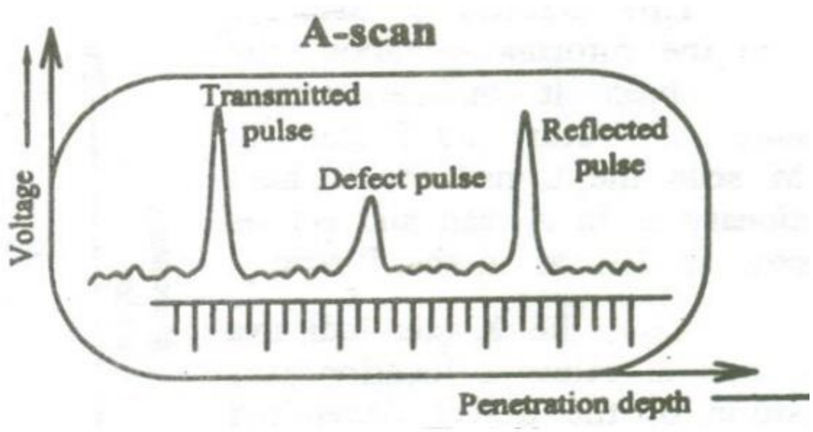
All these three modes of scanning are obtained with respect to the pulses of Ultrasound transmitted into and received from the specimen. The three modes are explained below.

1) A-Scan or Amplitude mode display

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

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

The height of the vertical spikes corresponds to the strength of the echo from the specimen. The position of the vertical spike from left to right along the X-axis corresponds to the depth of penetration. i.e, it gives the total time taken by the Ultrasonic sound to travel from transmitter to the specimen and from the specimen to the receiver.



Figure

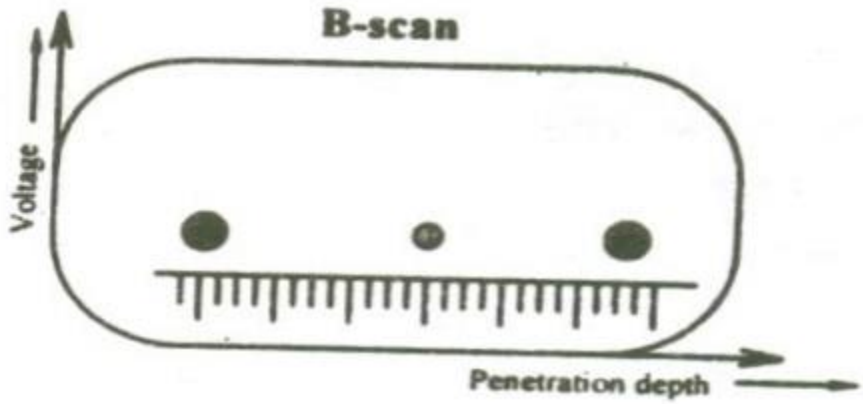
Thus by passing Ultrasonic waves o known velocity and by noting the time delay, we can find the distance at which the detect or flaws are present, by using the formula.

Distance = Velocity x time

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

2) B-Scan or Brightness Mode Scan

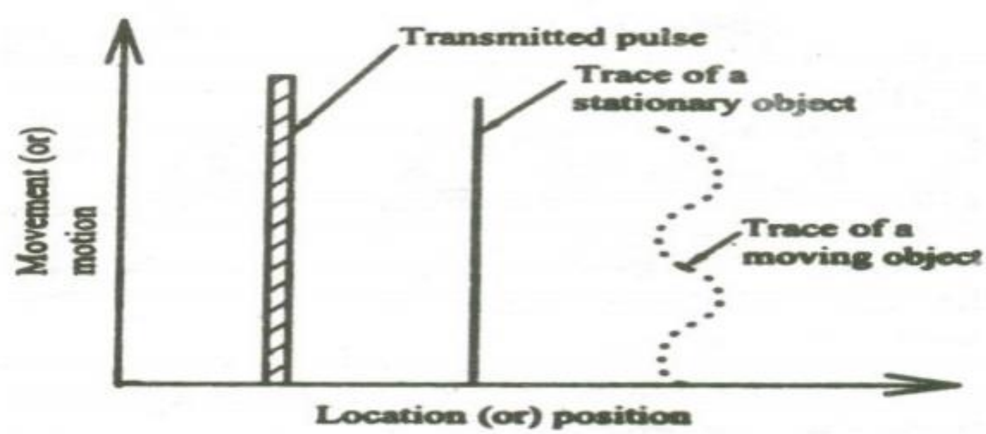
B-scan or Brightness mode display gives a two dimensional image. The principle of the B-Scan is same as that of A-Scan except with a small difference. Here in the B-Scan the transducer can be moved rather than keeping in a fixed position. As a result each echo's are displayed as dots on the screen as shown in the figure 1.10.2.



3) T.M Scan or Time –Motion Mode or C-Scan display

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

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



Figure

scan. Here, the X-axis indicates the dots at the relevant location and Y-axis indicates the movement of the object. Therefore when the object moves, the dot also moves at a low speed. Thus an object with the oscillatory movement will appear as a trace as shown in the figure.