3.1 Introduction

The human ear is sensitive to sound wave in the range of 20 Hz to 20 kHz. Waves are coming in the range of greater than 20 kHz are called ultrasonic waves. And which are coming in the range less than 20Hz frequencies are coming in the range of infrasonic (subsonic) range.

We can describe the sound waves as the vibrations or oscillations of molecules (particles) in solids, liquids and gases.

Hz (hertz) is the unit of frequencies.

1 Hz = 1 Cycle per second

1 kHz = 1 thousand Hz

1 MHz = 1 million Hz

Humans cannot sense the ultrasonic waves, but dogs and other animals has ability of hear the high frequency sounds. The wavelengths of ultrasonic waves are very small that's why they have very wide applications.

They are widely used in marine applications, medical diagnostics and non-destructive testing of new products.

Dolphins and Bats can generate ultrasonic waves and find their path.

3.2 Properties of Ultrasonic waves

Ultrasonic waves have very high frequency.

Ultrasonic waves have very low wavelength.

They have very high penetration power because of higher energy as compared to audible waves. Ultrasonic waves can penetrate through metals and other materials which are opaque to e.m. waves.

They have high energy content.

They can travel over long distances as a high directional ray and without loss of energy.

With increasing of frequency, the speed of propagation in medium of ultrasonic waves is increases.

In ultrasonic waves the diffraction effect is negligible because of the wavelength of ultrasonic is very small

Optical laws like reflection, refraction, diffraction etc. are observed with ultrasonic waves.

Ultrasonic waves produce 'cavitation' effect when made to pass through some solids.

The velocity of the ultrasonic waves depends on the temperature of the medium through which waves propagate.

3.3 Generation of Ultrasonic waves

There are two methods for generation of ultrasonic waves.

Mechanical generator (Galton whistle generator)

Electrical generator (Magnetostriction and piezoelectric generator).

3.4 Magnetostriction Oscillator (Pierce Oscillator)

3.4.1 Principle: Magnetostriction Effect

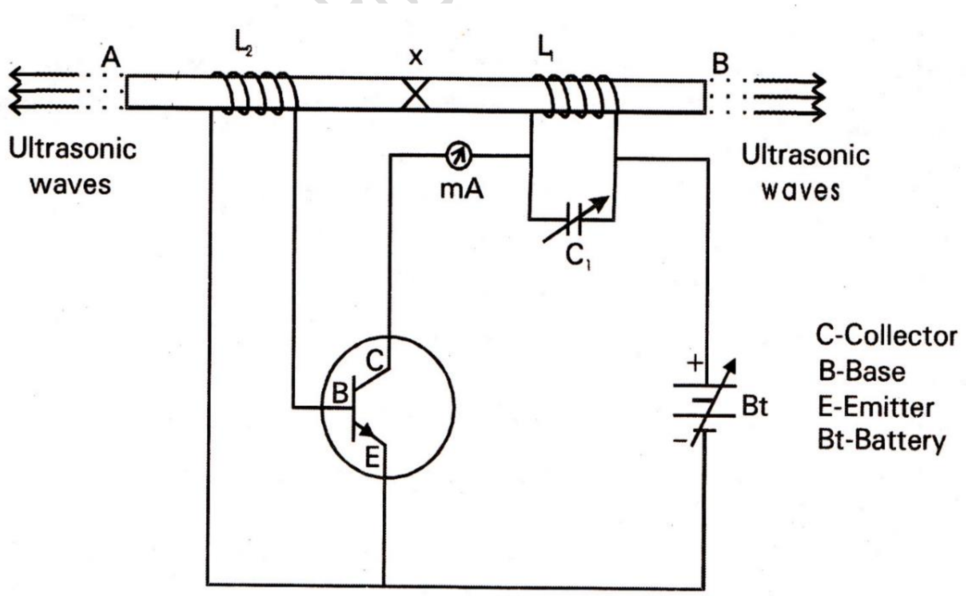
When we put a rod of ferromagnetic material like nickel or iron, in a magnetic field parallel to its length, there is change in length of rod and it depends on the magnitude of the field and nature of the ferromagnetic material. This phenomenon is called magnetostriction effect. This method was discovered by Joule in 1842. Nickel produces the very large magnetostriction effect in compare to other ferromagnetic materials.

If we put a rod in an alternating field of frequency f, in each half cycle rod changes its length. As a result, there is some setup of vibrations in the rod whose frequency is twice the magnetic field frequency. The amplitude of the vibration is small, but when the frequency of the field is set equal to the natural frequency of the rod, resonance occurs and amplitude of the vibrations will be larger. If the frequency of the field comes in ultrasonic range, an ultrasound of frequency 2f will be generated in the medium that is in contact with the ends of the rod.

The frequency of rod is given by

$f = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$ where L is length of the rod, Y is the Young's modulus, ρ the density if the rod.

3.4.2 Construction:



G. W. Pierce was the first to design an ultrasonic oscillator basing on the phenomenon of magnetostriction. Schematic diagram is shown in Figure.

A nickel rod is clamped from the center. Two coils L_1 and L_2 are wound at the ends of the rod. Coil L_1 is connected to variable capacitor and form tank circuit. One end of tank circuit is connected to collector of transistor via milliammeter and other end is connected to emitter of transistor via battery. Ends of L_2 are connected to base and emitter of transistor and form feedback loop.

3.4.3 Working:

When battery is switched on, due to tank circuit alternating current (AC) is generated with frequency

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

Due to this current rod gets magnetized and induce emf in coil L_2. This emf is given back to tank circuit to maintain oscillation.

Also due to this current rod vibrates with frequency

$$f = \frac{1}{2\,l}\sqrt{\frac{Y}{\rho}} \quad \text{where l is length of the rod, Y is the Young's modulus, } \rho \text{ the density if the rod.}$$

With the help of variable capacitor, we can vary the frequency of AC. When frequency of AC becomes equal to natural frequency of the rod i.e., resonance condition is achieved, rod vibrates vigorously and ultrasonic waves are generated. During this milliammeter shows maximum reading. The frequency of generated ultrasonic waves is

$$f = \frac{1}{2\,\pi\,\sqrt{L_1 C_1}} = \frac{1}{2\,l}\sqrt{\frac{Y}{\rho}}$$

3.4.4 Advantages:

The construction is very simple.

The cost of the generator is low.

At low ultrasonic frequencies, a large power output is possible without the any risk of damage of the oscillator circuit.

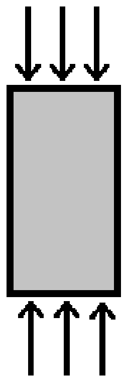
It can generate ultrasonic of frequency till 3 MHz.

3.4.5 Disadvantages:

It cannot generate ultrasonic of frequency above 3 MHz.

The frequency of oscillations depends on temperature. At higher temperatures, the o/p from the oscillator will not be very stable.

3.5 Piezoelectric Effect



When pressure is applied to a pair of opposite faces of crystals like quartz, tourmaline, Rochelle salt etc., cut with their faces perpendicular to its optic axis, equal and opposite charges appears on the other faces as shown in figure. This phenomenon is known as piezoelectric effect.

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

3.6 Piezoelectric Oscillator

3.6.1 Principle: Inverse piezoelectric effect

When an alternating voltage is applied on a pair of opposite faces of piezoelectric crystal (quartz), it starts vibrating at the frequency of the applied voltage.

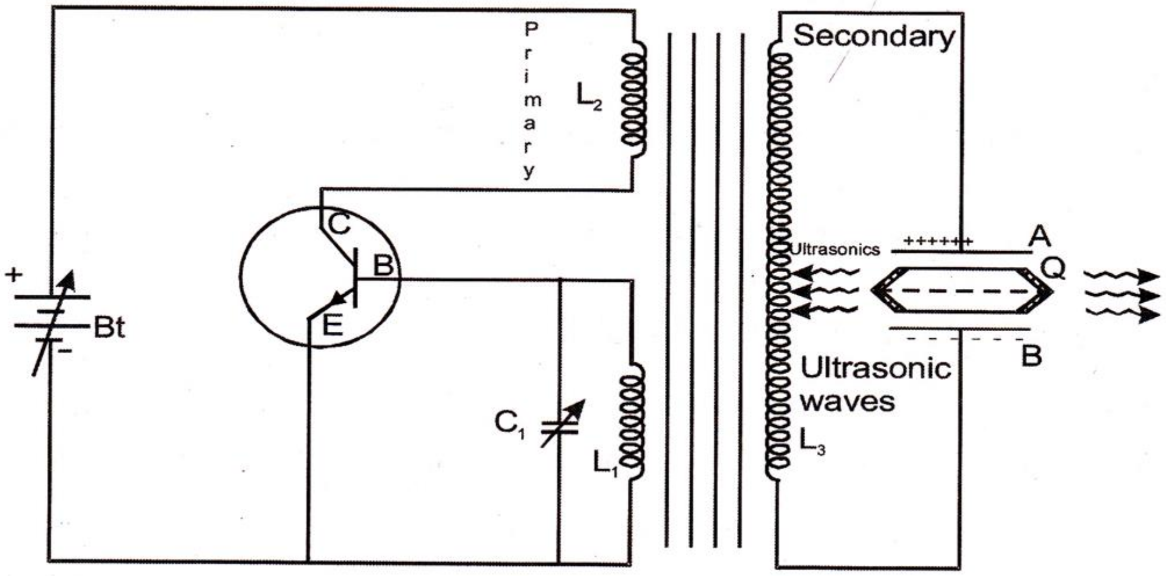
Vibrations occur at maximum amplitude at the natural resonant frequency of the piezoelectric crystal, which is determined by physical dimensions. The frequency of the vibrations is calculated by equation given below

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

where L is the length of crystal plate, Y is the Young's modulus along the appropriate direction, ρ is the density of the crystal and n (number of modes) = 1, 2, 3, …..

3.6.2 Construction:

Paul Langevin developed a method for producing ultrasonic waves using the piezoelectric effect in 1917. It was first observed by Paul-Jacques Curie and Pierre Curie in 1880



The X-cut quartz crystal is placed between two metallic plates A and B which are connected to the coil L_3. Coils L_1, L_2 and L_3 are inductively coupled. Coil L_1 is connected with variable capacitor C to form tank circuit. One end of tank circuit is connected to emitter of transistor and other end is connected to base of the transistor. One end of L_2 is connected to emitter of transistor via battery and other end to collector.

3.6.3 Working:

When battery is switched on, due to tank circuit alternating current (AC) or alternating voltage is generated with frequency

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

Due to this AC, an alternating emf is induced in coil L_3 by transformer action. This emf is imparted on metallic plates. Due to this quartz starts vibrating with frequency,

$$f = \frac{n}{2t}\sqrt{\frac{Y}{\rho}}$$

where, n = 1, 2, 3.. etc. for fundamental mode (first mode), first overtone (second mode), etc. E = Young's modulus of the material, ρ = density of the material and t = thickness of the crystal plate.

With the help of variable capacitor, we can vary the frequency of AC. When frequency of AC becomes equal to natural frequency of the quartz i.e., resonance condition is achieved, quartz vibrates in one of the modes of vibration and ultrasonic waves are generated. The frequency of generated ultrasonic waves is

$$f = \frac{1}{2\,\pi\sqrt{L_1\,C_1}} = \frac{n}{2\,t}\sqrt{\frac{Y}{\rho}}$$

3.6.4 Advantages:

Through this oscillator we can generate ultrasonic waves up to 500 MHz.

It is more efficient then magnetostriction generator.

The ultrasonic generator output (o/p) is very high.

Output does not depend on environmental changes such as temperature and humidity.

3.4.6 Disadvantages:

The cost of the natural piezoelectric crystals is high.

The cutting and shaping of piezoelectric materials is very complex and involve tedious mechanical processes.

3.7 Detection of Ultrasonic waves

The presence of ultrasonic waves is detected in a room by the phenomena of stationary wave method using the Kundt’s tube, or the sensitive flame method or the thermal detectors or the quartz method as was done by Langevin. As ultrasound is beyond audibility, the above indirect methods are used.

3.7.1 Kundt’s tube method

The Kundt’s tube method for the detection of ultrasonic waves is limited to low frequency waves. When ultrasonic waves go through the glass tube filled with light weight power (lycopodium powder) spread in the tube, the powder gets blown off at antinodes and forms heaps at nodes.

The distance between any two nodes is equal to half of the wavelength, i.e. $d=\lambda_{us}/2$. From this equation the wavelength of ultrasonic is estimated. This method, however, fails as the wavelength of ultrasonic is very small as equal to few mm.

3.7.2 Thermal detector method

This method is also used to detect the ultrasonic waves in which a fine platinum wire is moved through the medium. The temperature changes at the nodes and thereby there is a change in the resistance of the platinum wire, whereas the resistance remains constant at the antinodes as the temperature remains constant there. With the help of bridge circuit, the change in resistance of the platinum wire is measured.

The distance between any two nodes is equal to half of the wavelength, i.e. $d=\lambda_{us}/2$. From this equation the wavelength of ultrasonic is estimated.

3.7.3 Sensitive flame method

Ultrasonic waves are detected by moving a sensitive flame in the medium. The stationary positions of flame at antinodes and flicks at nodes will help in finding the exact location of nodes and antinodes and by knowing the mean distance between two consecutive nodes, the ultrasonic wavelength can be determined as usual. However, if the frequency of the ultrasonic wave is known, its velocity through the medium can also be estimated. The distance between any two nodes is equal to half of the wavelength, i.e. $d=\lambda_{us}/2$. From this equation the wavelength of ultrasonic is estimated.

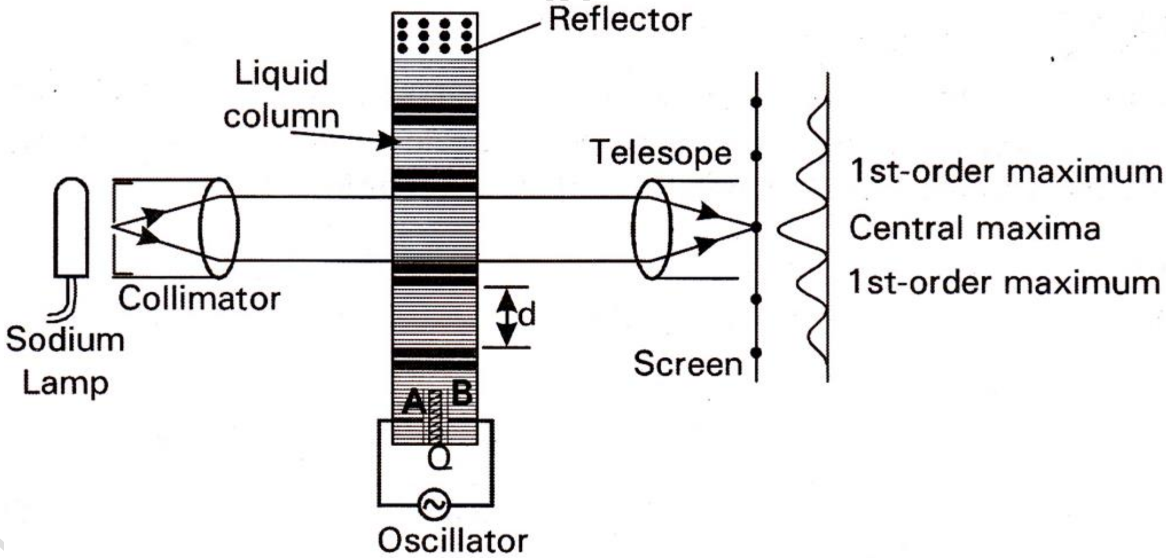
3.7.4 Quartz crystal method

This method of detecting ultrasonic waves depends upon the piezoelectric effect. When one pair of faces of a quartz crystal is exposed to ultrasonic waves, electric charges are developed on the other pair of opposite faces which are perpendicular to the previous one. These charges are amplified and detected by using electronic circuits.

3.8 Determination of Velocity of Ultrasonic waves (Acoustic Grating Method)

When we propagate ultrasonic waves in a transparent liquid medium, after reflection it will superimpose with incident wave and forms stationary waves. At nodes density of the medium becomes maximum and at antinodes density of the medium becomes minimum. Due to this there is periodic variation in density of liquid. It leads to a periodic variation of refractive index of the liquid. Such a liquid column subjected to ultrasonic waves constitutes an acoustical grating. If monochromatic light is passed through the liquid at right angles to the waves, the liquid causes the diffraction of light. Such liquid column subjected to ultrasonic waves is called acoustic grating.

Figure below shows experimental setup for determination of the velocity of ultrasonic waves. Ultrasonic waves are produced in a liquid contained in a glass tube.



The density and hence the refractive index of the liquid is maximum at nodal points and minimum at antinodal points. Therefore, the nodal areas act as opaque regions while antinodal areas act as transparent regions for light. The liquid column thus resembles a ruled grating.

When the crystal is at rest, a single image of the slit is formed in the screen. When the crystal is excited a diffraction pattern is produced. It consist of a central maxima followed is the grating element which is given by $d = \lambda_u / 2$.

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

where λ is the wavelength of monochromatic light beam, n is the order of the maxima.

By using above equation λ_u can be determined. The frequency f of the waves is known from the frequency of the oscillator. The velocity of waves in the liquid can be found from the equation,

$$v = f\lambda_u$$

The above method of determining λ_u and v of ultrasonic waves is known as 'acoustic diffraction method'.

3.9 Applications of Ultrasonics

Ultrasonic is widely used in industry, medicine and marine applications. Here some of the applications is given below,

3.9.1 Echo sounder

Ultrasonic waves can be generated in the form of directed beam like light beam. Further, the ultrasonic waves can travel over long distances in water. As a result, ultrasound is widely used in marine applications. The depth of the ocean can be found by an echo sounder. The ship is equipped at its bottom with a source and a receiver of ultrasound of a specific frequency. The source sends out short pulses of ultrasonic waves and receiver receives reflected pulses. Measuring the time interval between the pulse sent and the pulse received, the depth of the ocean can be computed with the help of the formula

$$d = \frac{v\,t}{2}$$

where, d is the depth, t is the time interval and v is the velocity of ultrasonic wave.

3.9.2 SONAR

The word sonar means Sound Navigation and Ranging. The ultrasonic waves which are highly directional can be used for locating objects and determining their distance in the seas. Sonar can also measure depth of sea, find underwater obstacles like rocks and shipwrecks, locate shoals of fish and trace their movement, help divers and military applications such as finding submarines, mines, enemy ships etc.

3.9.3 Flow measurement

There are various ways to measure the flow velocity in a pipe by measuring its effect on the passage of ultrasonic waves transmitted and received at the outside of the pipe, without disturbing the flow by inserting anything into the pipe.

3.9.4 Material characterization

Ultrasonic velocity and reduction are dependent on material properties which in turn may be related to other characteristics that can be of special interest to the engineer (e.g. breaking strength of cast iron, grain structure of steel).

3.9.5 Detection of cracks or flaw in metals

It there is any hidden flaw or crack in metal, ultrasonic waves can be used to identify these defects by non-destructive testing.

3.9.6 Medical diagnostics

Medical diagnostic is another field of application of ultrasonic waves. This field, on the one hand, mainly consist of examining and anatomical structure of soft tissue or its functioning, while on the other hand it is used for checking the normality of blood flow in various vessels. All these examinations are noninvasive.

3.10 Non Destructive Testing (NDT)

By Non Destructive Testing(NDT), one can detect all microscopic flaws(defects).

Definition: NDT is the method of testing material without causing any damage to it or decreasing their service life.

3.10.1 Difference between DT and NDT

Sr. No.	Destructive Testing	Non Destructive Testing
1.	Measurements are direct and reliable.	Measurements are indirect and reliability has to be verified.
2.	Tests are not made on the objects directly.	Tests are made on objects directly.
3.	Time consumption is generally high.	Time consumption is generally low.
4.	Usually quantitative measurements.	Usually qualitative measurements. But, quantitative measurements can also be done.
5.	In service testing is not possible.	In service testing is possible.
6.	More Costly	Less Costly
7.	It is carried to find properties and behaviour of specimen under different load	It is used to find properties of material and to find out defects.
8.	Specimen is damaged during test	Specimen is not damaged during test
9.	Defects cannot be found using Destructive testing	Defects are found using NDT
10.	Bending Test, Tensile Testing, Compression Testing, Impact testing etc.	Ultrasonic testing, Liquid die penetrant method, eddy current testing.

3.10.2 Objective of NDT

To increase serviceability

To improve production

To increase safety

One can detect defects in crystalline structure

One can test materials properties

Measure a size of cracks & holes of material

To find the composition & their percentage in any material

One can detect Internal stresses & strain with the help of NDT

3.10.3 Methods of NDT

Liquid (Dye) Penetrant Method

Radiography Method

X-ray radiography (OR)

gamma ray radiography

Ultrasonic Inspection Method

Eddy Current Method

Magnetic Particle Method

Thermography

3.10.4 Ultrasonic Inspection Method

It is a form of non-destructive testing used in many industries including aerospace, automotive and other transportation sectors.

Ultrasonic testing is often performed on steel and other metals and alloys, and it can also be used on concrete, wood composites and also rail road, water or oil pipes, aircraft parts.

3.10.4.1 Principle

Ultrasonic is used because of its property to reflect whenever medium is changed.

3.10.4.2 Basic equipment's used in ultrasonic methods:

An electronic signal generator to generate alternating voltage (electrical signal).

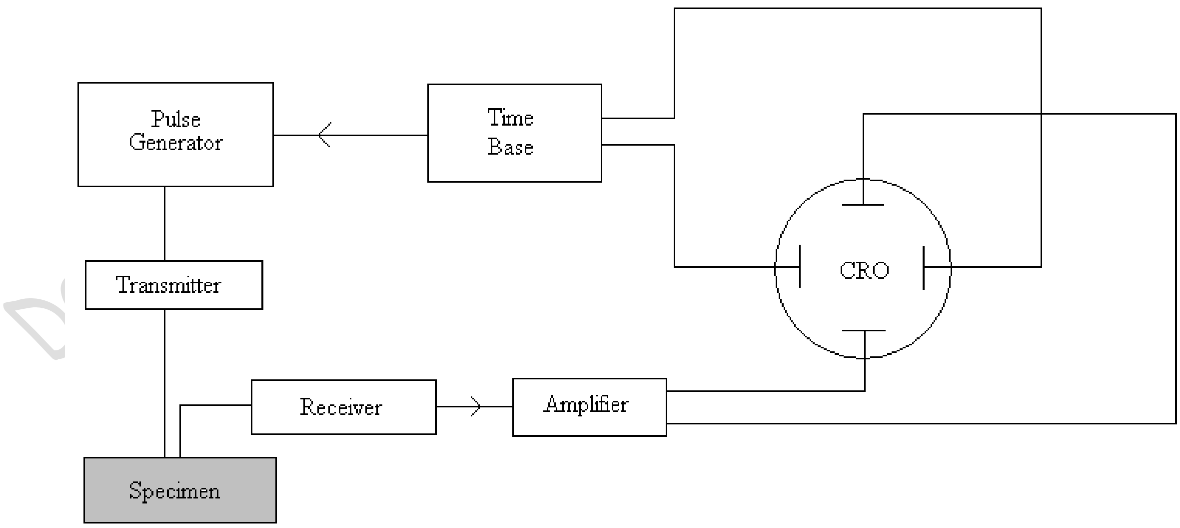
A transmitter (sending transducer) that emits a beam of ultrasonic waves when alternating voltage is applied.

A receiver (receiving transducer) that accepts the ultrasonic waves from the specimen and convert it into electrical signal.

An amplifier to amplify the signal which is received by the receiver.

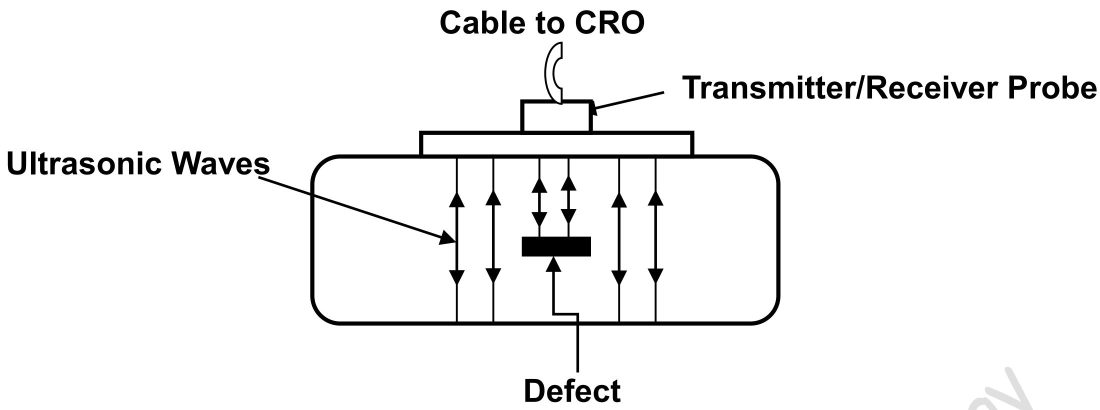
An electronic clock or timer to measure the minute(small) time interval between the sending and receiving of the signal.

3.10.4.3 Block diagram of ultrasonic pulse echo system is shown below.



3.10.4.4 Pulse Echo System:

Only one transducer is used as both transmitter and receiver.



3.10.4.4.1 Working:

In ultrasonic testing, an ultrasound transducer connected to a CRO.

For better contact between the transducer and specimen thin oil and glycerin is used.

Ultrasonic waves can be produced by Piezoelectric effect.

In this method reflection (Pulse-echo) mode is used.

In reflection mode the transducer performs both sending & receiving of the pulse.

When ultrasonic waves are transmitted they will reflect from the surface of the material so we will get transmitted pulse as shown in figure.

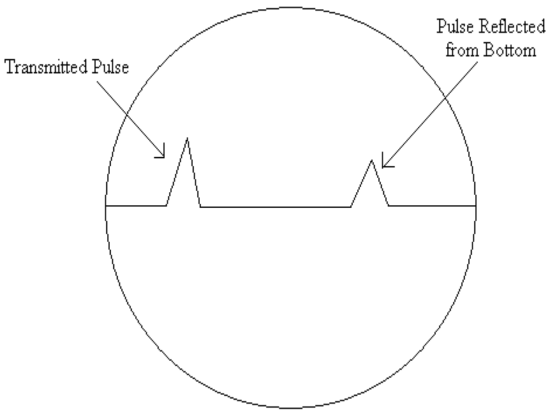


Figure. 1

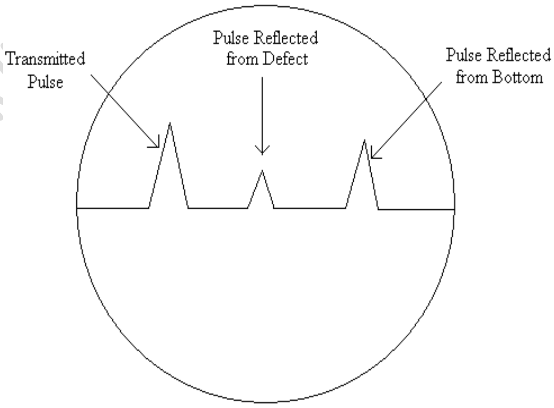


Figure. 2

When no defect is present then we will get transmitted pulse and pulse reflected from bottom as shown in figure 1.

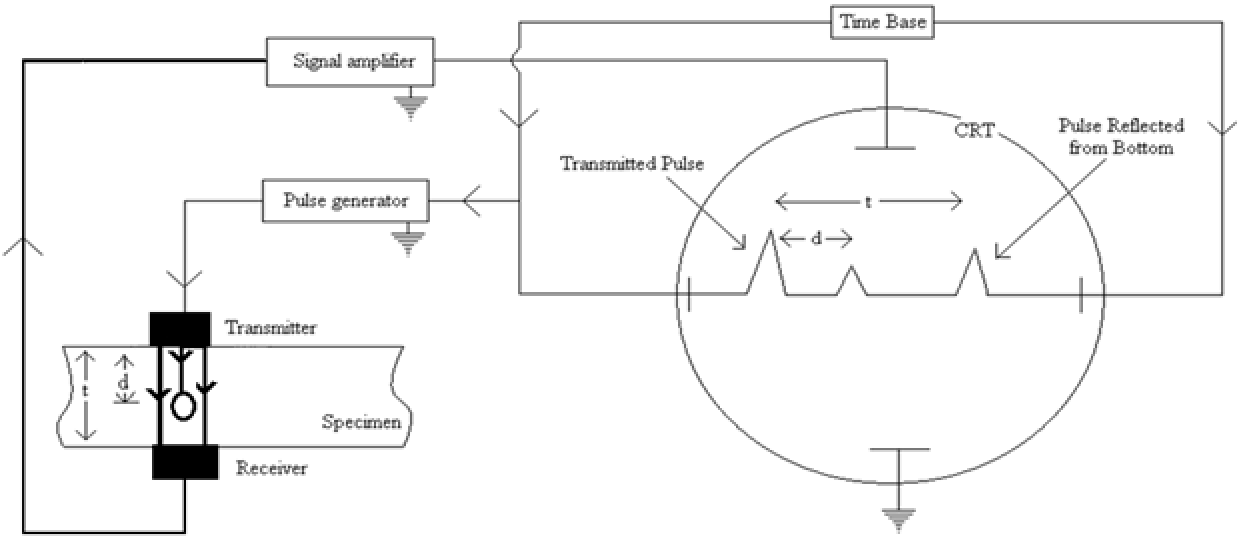
And if there is any defect we will get pulse reflected from the defect along with the other two as shown in figure 2.

If the velocity v of the ultrasonic waves in the specimen is known, the position of the crack can be located by $d=vt/2$.

The exact size and shape of the cavity or crack can be found out by examining the specimen from all directions.

3.10.4.5 Ultrasonic Flaw Detector (Through Transmission System):

Two transducers are used separately as transmitter and receiver.



3.10.4.5.1 Working:

In ultrasonic testing, an ultrasound transducer connected to a CRO.

For better contact between the transducer and specimen thin oil and glycerin is used.

Ultrasonic waves can be produced by Piezoelectric effect.

In this method attenuation (through transmission) mode is used.

In attenuation mode a transmitter sends ultrasound through one surface & separate receiver detect the pulse.

When ultrasonic waves are transmitted, they will reflect from the surface of the material so we will get transmitted pulse as shown in figure.

When no defect is present then we will get transmitted pulse and pulse reflected from bottom.

And if there is any defect we will get pulse reflected from the defect along with the other two as shown in figure.

If the velocity v of the ultrasonic waves in the specimen is known, the position of the crack can be located by d=vt/2.

The exact size and shape of the cavity or crack can be found out by examining the specimen from all directions.

3.10.4.6 Advantages

High penetrating power so we can detect small size defects and deeply seated defects.

It is very cheap and it has high speed of operation.

Greater accuracy.

Capability of estimating the size, orientation & shape of the defects

Not harmful.

Large size specimen can be inspected in a very short duration.

3.10.4.7 Disadvantages

No permanent record of the defect can be obtained.

Manual operation requires careful attention.

Extensive technical knowledge required so only skilled and well trained technicians are required.

Inspected items must be water resistant.

Discontinuities that are present immediately beneath (below) the surface may not be detectable.

3.11 Other applications

1. Science and engineering

Used to detect flaws or defects in metals.

Used to detect ships, submarines, iceberg etc., in the ocean.

Used for soldering aluminium coil capacitors, aluminium wires and plates without using any fluxes.

Used to weld some metals which cannot be welded by electric or gas welding.

Used for cutting and drilling holes in metals.

Used as catalyst to accelerate the reaction.

2. Medicine

Used to remove kidney stones and brain tumours without shedding any blood.

Used to remove broken teeth.

Used for sterilizing milk and for killing bacteria.

Used to study the blood flow velocities in blood vessels of our body.

Used as a diagnostic tool to detect tumours, and also the growth of foetus.