Ultrasonics

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Ultrasonics

The word **ultrasonic** combines the Latin roots ultra, meaning '**beyond**' and sonic, or **sound**.

Ultrasonic refers to any study or application of sound waves that are higher frequency than the human audible range.

Classification of sound:

(i)	Infrasonic	~20 Hz	(Inaudible)
(ii)	Audible	~20 to 20,000Hz	(Music and Noise)
(iii)	**Ultrasonic**	**20,000Hz**	**(Inaudible)**

Generally these waves are called as **high frequency waves**.

Ultrasonics

Bats use ultrasonic frequencies up to 100 kHz for locating their food sources and navigating.

Ultrasonics

Rhinoceroses use infrasonic frequencies as low as 5 Hz to call one another.

Ultrasonics

Table 2-2 Range of Hearing for a Variety of Species

Humans	20–20,000 Hz
Cats	100–32,000 Hz
Dogs	40–46,000 Hz
Horses	31–40,000 Hz
Elephants	16–12,000 Hz
Cattle	16–40,000 Hz
Bats	1000–150,000 Hz
Grasshoppers	100–50,000 Hz
Rodents	1000–100,000 Hz
Whales, Dolphins	70–150,000 Hz

Properties of ultrasonic waves

- They have a high energy content.
- Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed.
- They shows negligible diffraction due to their small wavelength. Hence can be transmitted over large distances without any appreciable loss of energy.
- Intense ultrasonic radiation has a disruptive effect in liquids by causing bubbles to be formed.
- If an arrangement is made to form stationary waves of ultrasonic in a liquid, it serves as a diffraction grating (called acoustic grating)

Applications of ultrasonic waves

- The broad sectors of society that regularly apply ultrasonic technology are the medical community, industry, and the military.

- The field of ultrasonic have applications for
  - imaging
  - Detection
  - Navigation

Ultrasonics Production

Ultrasonic waves are produced by the following methods.

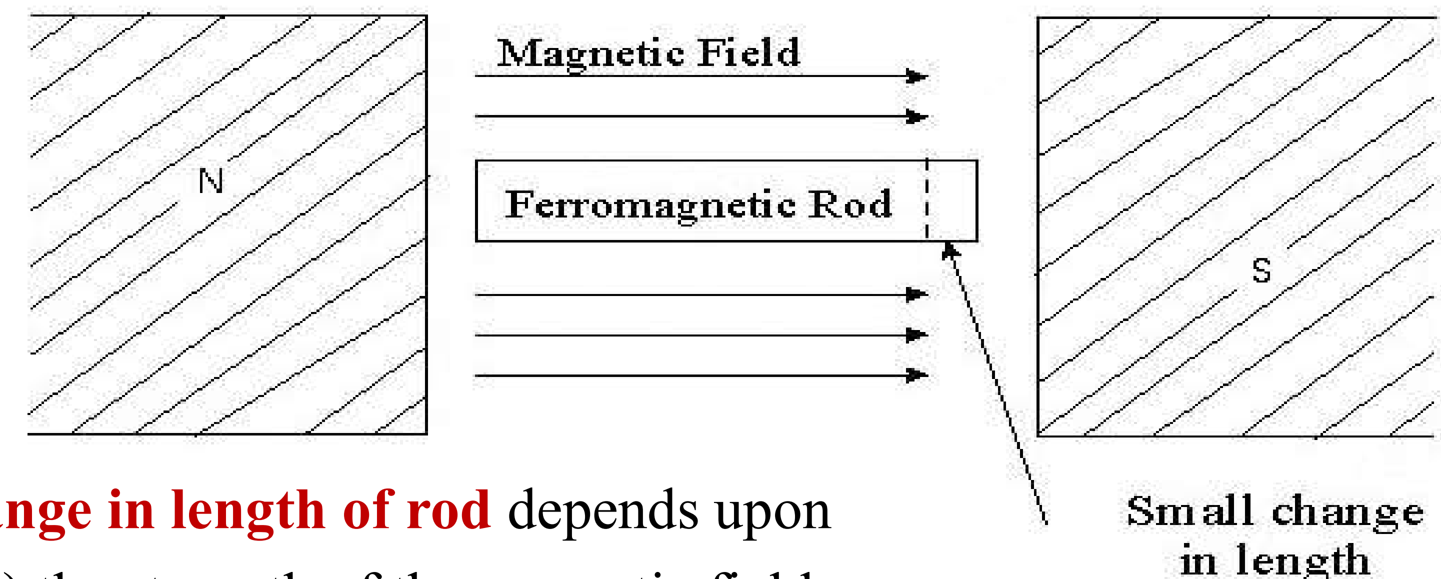
(1) Magnetostriction method

(2) Piezoelectric method

Magnetostriction method

Principle: Magnetostriction effect

When a magnetic field is applied parallel to the length of a ferromagnetic rod made of ferromagnetic materials such as iron or nickel, a **small elongation or contraction** occurs in its length.



The **change in length of rod** depends upon

i) the strength of the magnetic field,

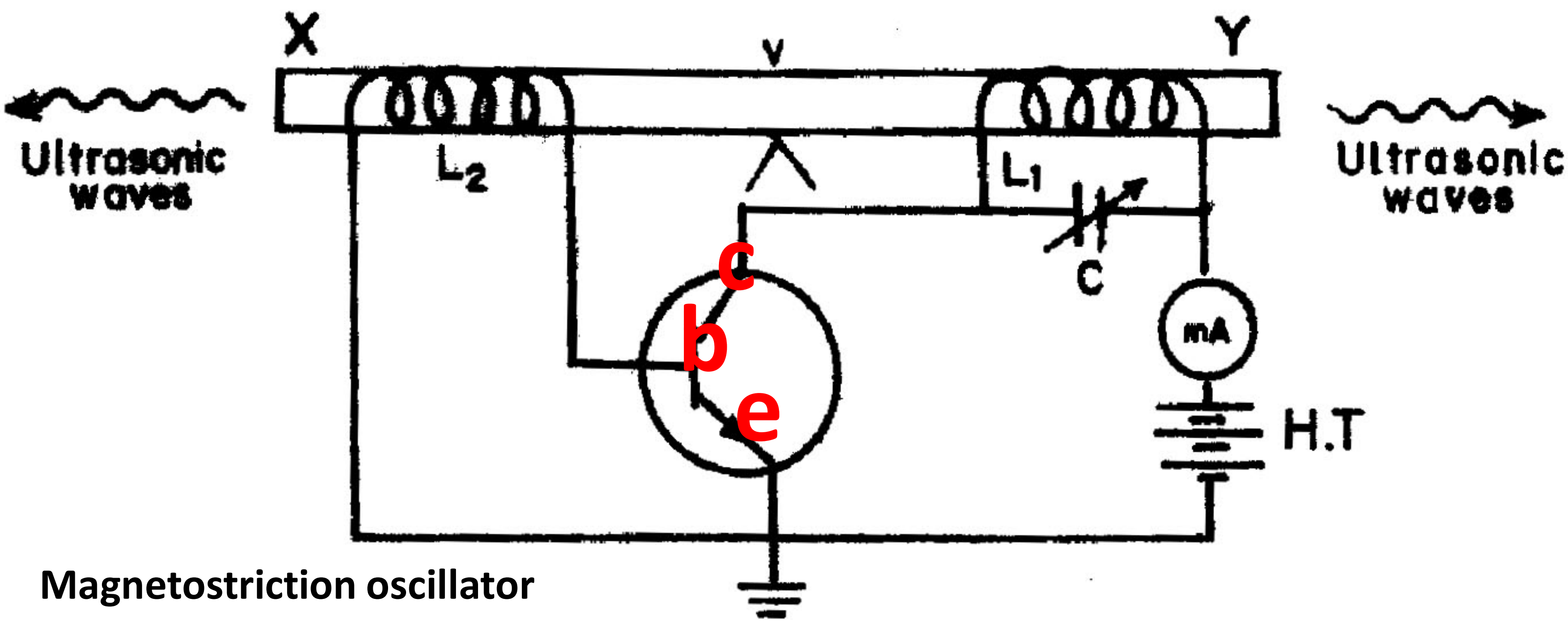
ii) the nature of the ferromagnetic materials

iii) does not depend of the direction of the field if rod is not already magnetised .

Magnetostriction method

Used to produce low frequency Ultrasonics

- XY is a rod of ferromagnetic materials Fe or Ni. The rod is clamped in the middle.
- The alternating magnetic field is generated by electronic oscillator.
- The coil L_1 wound on the right hand portion of the rod along with a variable capacitor C.
- This forms the ***resonant circuit*** of the collector tuned oscillator. The frequency of oscillator is controlled by the variable capacitor.
- The coil L_2 wound on the left hand portion of the rod is connected to the base circuit. The coil L_2 acts as ***feed –back loop.***



Magnetostriction oscillator

Magnetostriction method

Working

- When High Tension (H.T) battery is switched on, the collector circuit oscillates with a frequency,

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

- This alternating current flowing through the coil L_1 produces an alternating magnetic field along the length of the rod. The result is that the rod starts vibrating due to magnetostrictive effect.

Magnetostriction method

The frequency of vibration of the rod is given by

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

where l = length of the rod

Y = Young's modulus of the rod material and

ρ =density of rod material

- The capacitor C is adjusted so that the frequency of the oscillatory circuit is equal to natural frequency of the rod and thus resonance takes place.
- Now the rod vibrates longitudinally with maximum amplitude and generates ultrasonic waves of high frequency from its ends.

Magnetostriction method

Advantages

1. The design of this oscillator is very simple and its production cost is low
2. At low ultrasonic frequencies, the large power output can be produced without the risk of damage of the oscillatory circuit.

Disadvantages

1. It has low upper frequency limit and cannot generate ultrasonic frequency above 3000 kHz (i.e. 3MHz).

2. The frequency of oscillations depends on temperature.

3. There will be losses of energy due to hysteresis and eddy current.

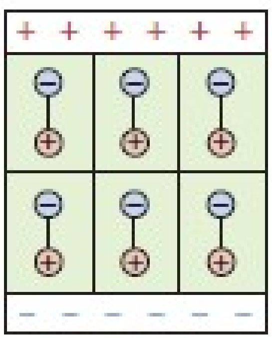
Piezo-Electric method

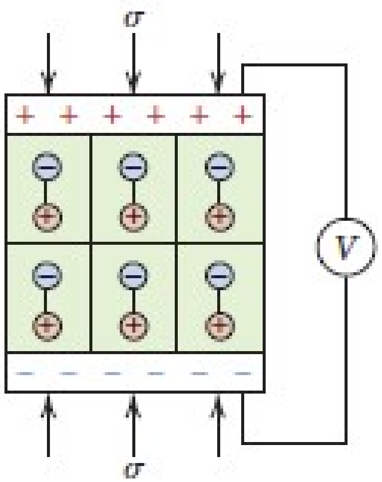
This is based on the Inverse piezo electric effect

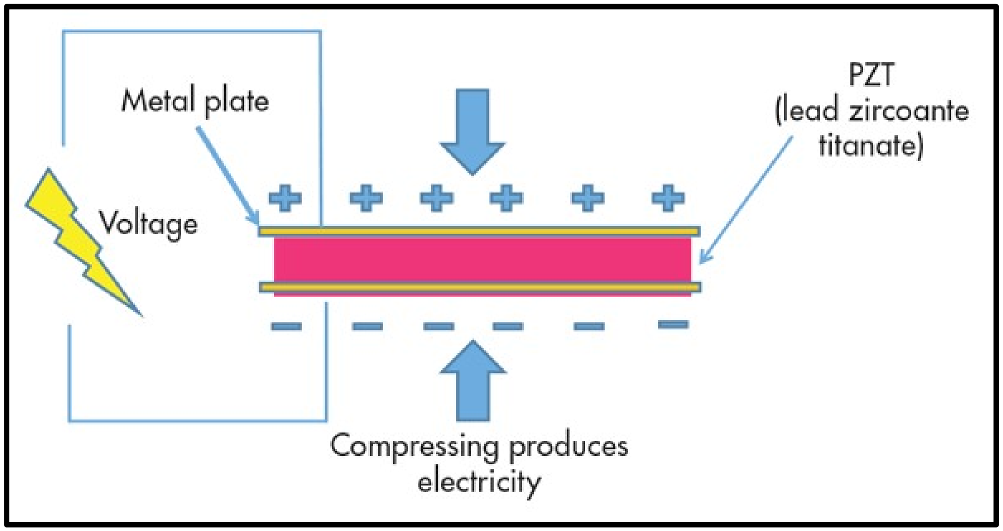
PIEZOELECTRIC EFFECT

If mechanical pressure is applied to one pair of opposite faces of certain crystals like quartz, equal and opposite electrical charges appear across its other faces. This is called as piezo-electric effect.

The converse of piezo electric effect is also true. If an electric field is applied to one pair of faces, the corresponding changes in the dimensions of the other pair of faces of the crystal are produced. This is known as ***inverse piezo electric*** effect or ***electrostriction***



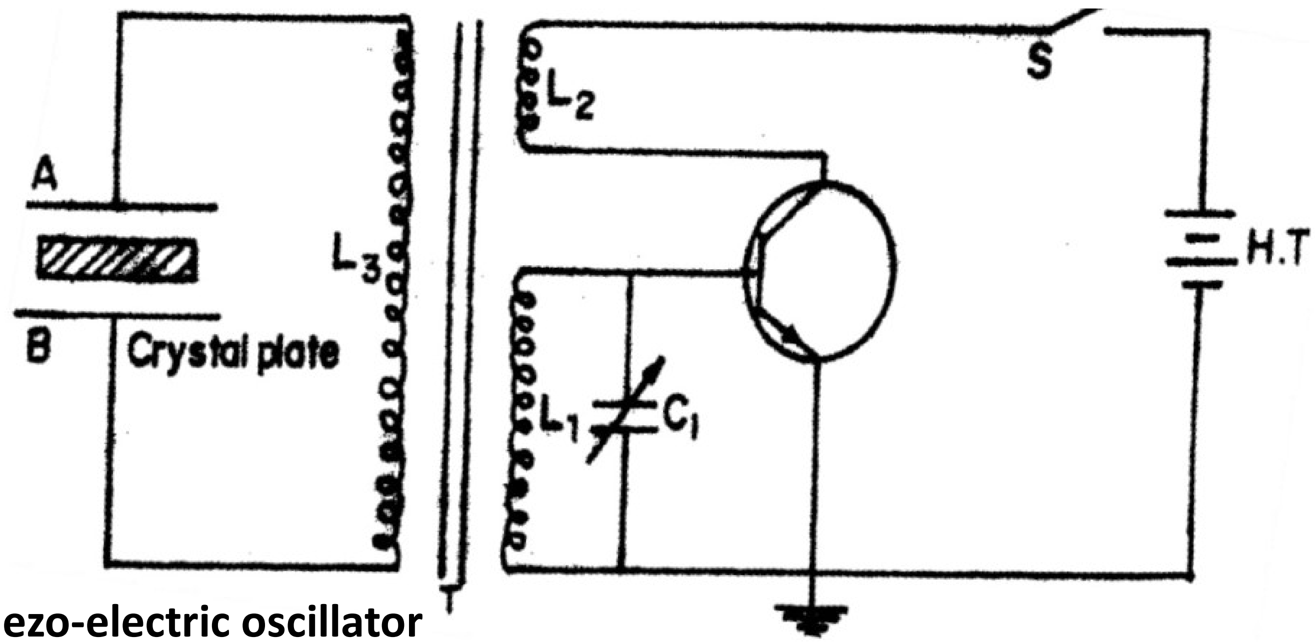




Piezoelectric materials: titanates of barium and lead, lead zirconate ($PbZrO_3$), ammonium dihydrogen phosphate ($NH_4H_2PO_4$), and quartz (natural crystal).

Piezo-Electric method

- The quartz crystal is placed between two metal plates A and B.
- The plates are connected to the primary (L_3) of a transformer which is inductively coupled to the electronics oscillator.
- The electronic oscillator circuit is a base tuned oscillator circuit.
- The coils L_1 and L_2 of oscillator circuit are taken from the secondary of a transformer T.
- The collector coil L_2 is inductively coupled to base coil L_1.
- The coil L_1 and variable capacitor C_1 form the *tank circuit* of the oscillator.



Piezo-electric oscillator

Piezo-Electric method

Working

- When H.T. battery is switched on, the oscillator produces high frequency alternating voltages with a frequency.

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

- Due to the transformer action, an oscillatory e.m.f. is induced in the coil L_3. This high frequency alternating voltages are fed on the plates A and B.
- Inverse piezo-electric effect takes place and the crystal contracts and expands alternatively. The crystal is set into mechanical vibrations.
- The frequency of the vibration is given by

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

Where l = thickness of the crystal
Y = Young's modulus of the crystal axis chosen
ρ = density of the crystal.

Piezo-Electric method

Advantages

- Ultrasonic frequencies as high as 500 MHz can be obtained with this arrangement.
- The output of this oscillator is very high.
- It is not affected by temperature and humidity.

Disadvantages

- The cost of piezo electric quartz is very high
- The cutting and shaping of quartz crystal are very complex.

Numerical

A quartz crystal of thickness 1 mm is vibrating at resonance. Calculate the fundamental frequency. Given Y for quartz = 7.9×10^{10} Nm^{-2} and ρ for quartz = 2650 kg m-3.

$$f = \frac{1}{2 \times 0.001} \sqrt{\frac{7.9 \times 10^{10}}{2650}}$$

$$= 2.72998 \times 10^{6} \text{ Hz}$$

The fundamental frequency of the quartz crystal

$= 2.730 \times 10^{6}$ Hz = **2.73MHz**

Numerical

What should be the minimum length of an iron rod to generate ultrasonic wave of frequency 0.03 MHz? Given Y for iron = 1.15×10^{11} Nm^{-2} and ρ of iron = 7.23×10^{3} kg m^{-3}.

Answer = 0.067 m = 6.7 cm

Ultrasonics Production

Ultrasonic waves are produced by the following methods.

(1) Magnetostriction method

(2) Piezoelectric method

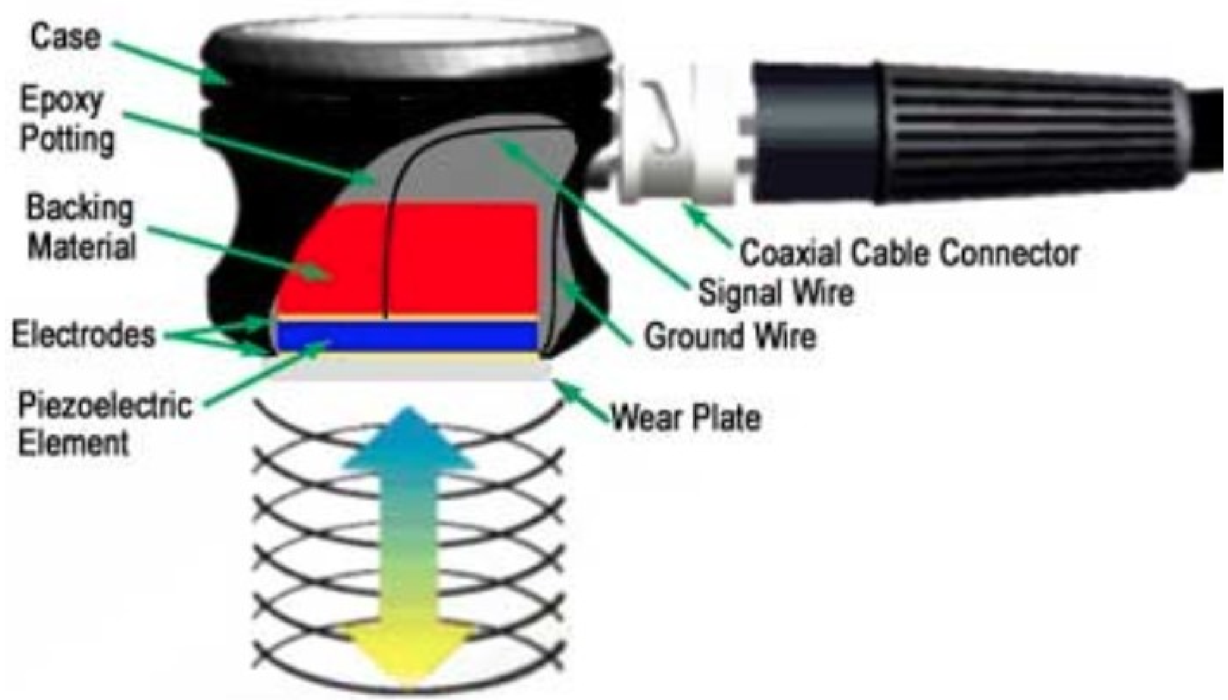
The frequency of vibration of the rod is given by

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

Detection of Ultrasonic Waves

1. Piezoelectric Detector

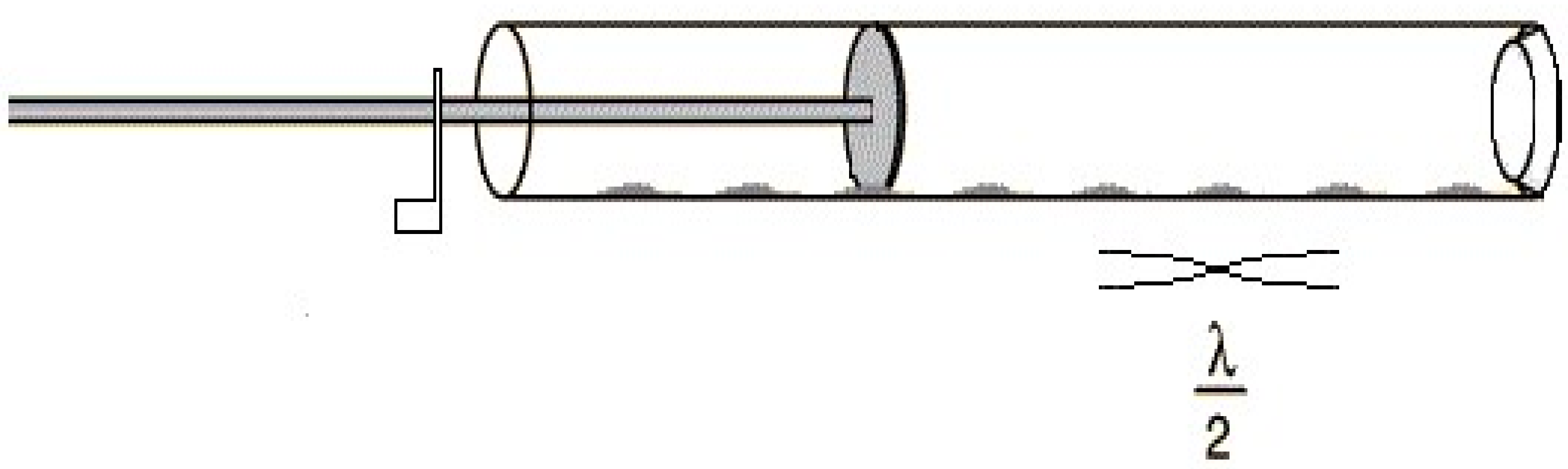
Piezoelectric effect can also be used to detect ultrasonics. If ultrasonics comprising of compressions and rarefactions are allowed to fall upon a quartz crystal a certain potential difference is developed across the faces which after amplification by a value amplifier can be used to detect ultrasonics.



Detection of Ultrasonic Waves

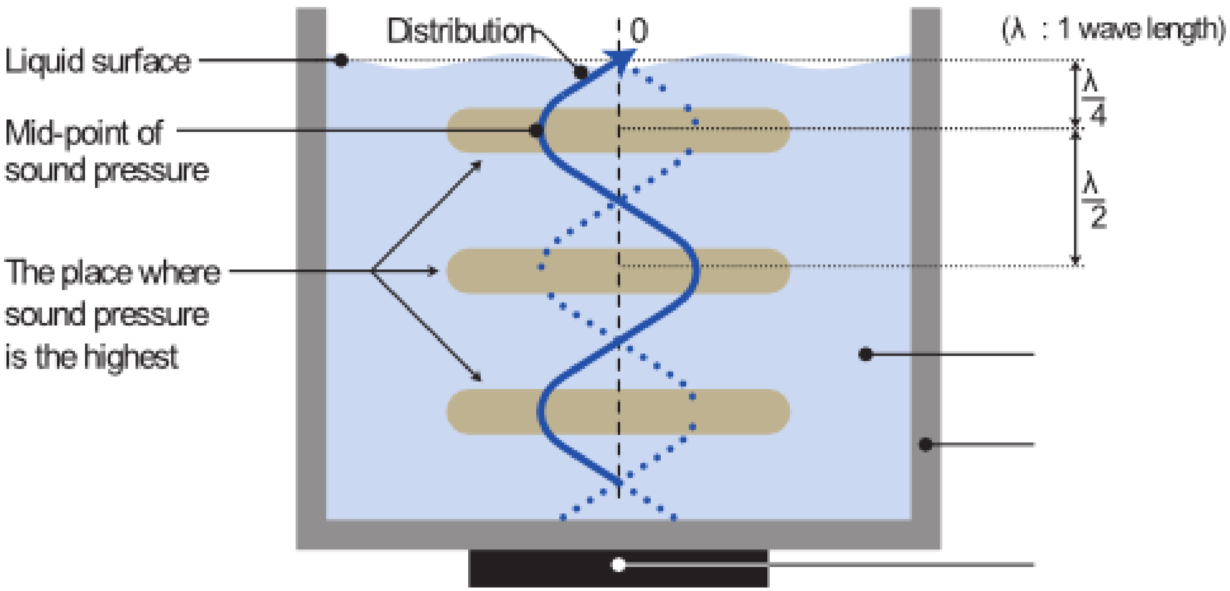
2. Kundt's Tube Method

Kundt's tube is a long glass tube supported horizontally with a air column in it when the ultrasonic waves are passed the Kundt's tube, the lycopodium powder (flash powder) sprinkled in the tube collects in the form of heaps at the nodal points and is blown off at the antinodal points.



3. Sensitive flame Method

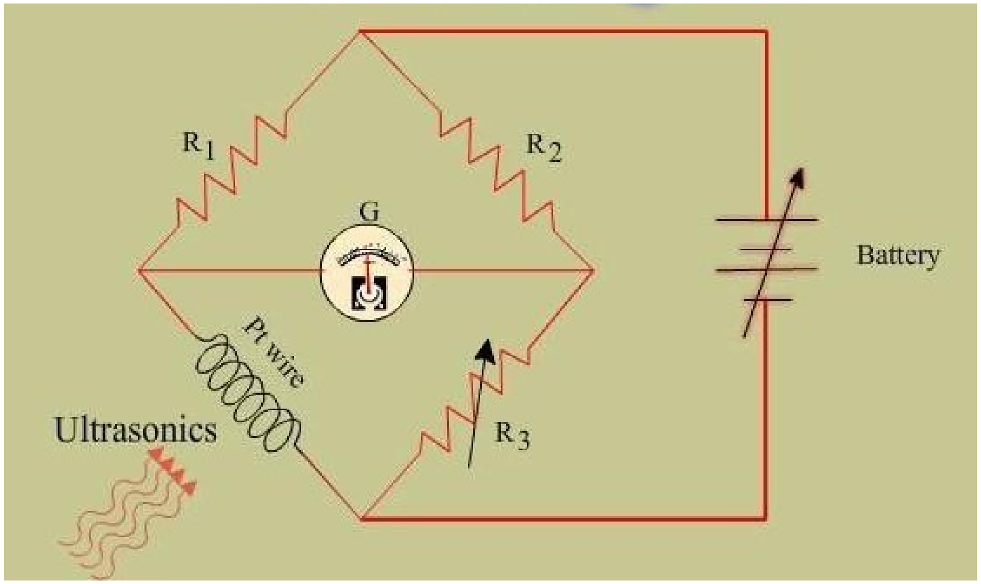
When a narrow sensitive flame is moved in a medium where ultrasonic waves are present, the flame remains stationary at antinodes. At the positions of nodes, the flame flickers because there is a change in pressure. In this way, positions of nodes and antinodes can be found out in the medium. The average distance between the two adjacent nodes is equal to half the wavelength.



The most suitable spot to remove dirt is $\frac{\lambda}{4} + \frac{\lambda}{2}$

4. Thermal Detector

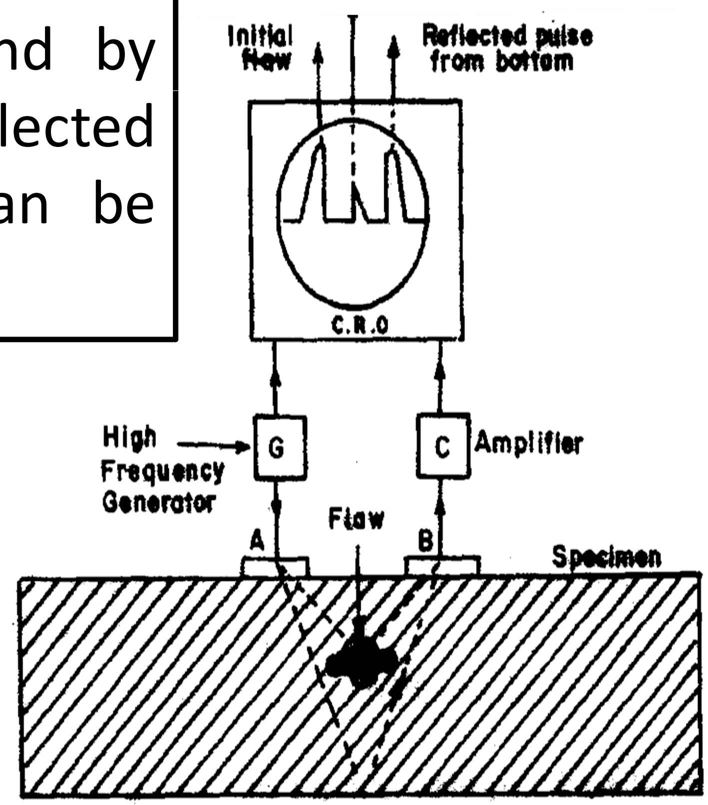
This is the most commonly used method of detection of ultrasonic waves. In this method, a fine platinum wire is used. This wire is moved through the medium. At the position of nodes, due to alternate compressions and rarefactions, adiabatic changes in temperature takes place. The resistance of the platinum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



Applications of Ultrasonic Waves

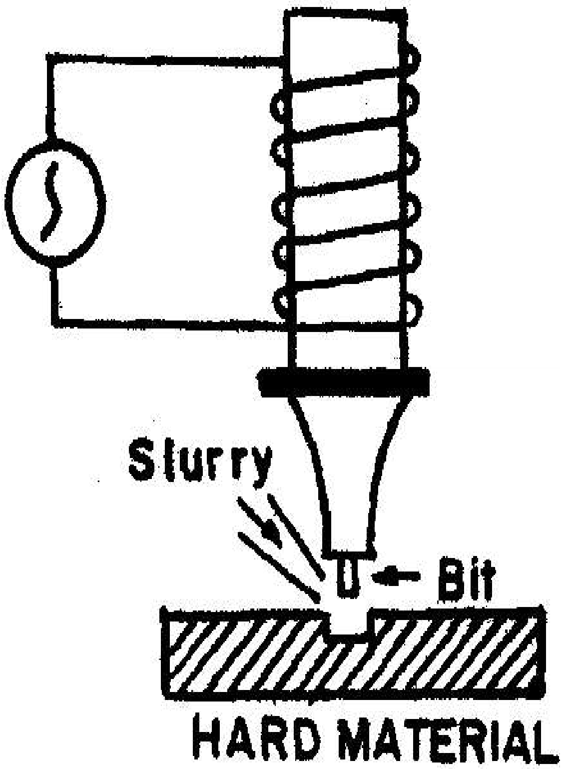
1. Detection of flaws in metals (Non Destructive Testing –NDT)

- Ultrasonic waves are used to detect the presence of flaws or defects in the form of **cracks, blowholes porosity etc.**, in the internal structure of a material.
- By sending out ultrasonic beam and by measuring the time interval of the reflected beam, flaws in the metal block can be determined.



(2) Ultrasonic Drilling

- Ultrasonics are used for making holes in very hard materials like glass, diamond etc.
- For this purpose, a suitable drilling tool bit is fixed at the end of a powerful ultrasonic generator.
- Some slurry (a thin paste of carborundum powder and water) is made to flow between the bit and the plate in which the hole is to be made
- Ultrasonic generator causes the tool bit to move up and down very quickly and the slurry particles below the bit just remove some material from the plate.
- This process continues and a hole is drilled in the plate.



(3) Ultrasonic soldering

- Metals like aluminium cannot be directly soldered. However, it is possible to solder such metals by ultrasonic waves.
- An ultrasonic soldering iron consists of an ultrasonic generator having a tip fixed at its end which can be heated by an electrical heating element.
- The tip of the soldering iron melts solder on the aluminium and the ultrasonic vibrator removes the aluminium oxide layer.
- The solder thus gets fastened to clear metal without any difficulty.

(4) Ultrasonic cleaning

It is the most cheap technique employed for cleaning various parts of the machine, electronic assembles, armatures, watches etc, which cannot be easily cleaned by other methods.

(5) SONAR

- SONAR is a technique which stands for ***Sound Navigation and Ranging***.
- It uses ultrasonics for the detection and identification of under water objects.
- The method consists of sending a powerful beam of ultrasonics in the suspected direction in water.
- By noting the time interval between the emission and receipt of beam after reflection, the distance of the object can be easily calculated.
- Measuring the time interval (t) between the transmitted pulses and the received pulse,

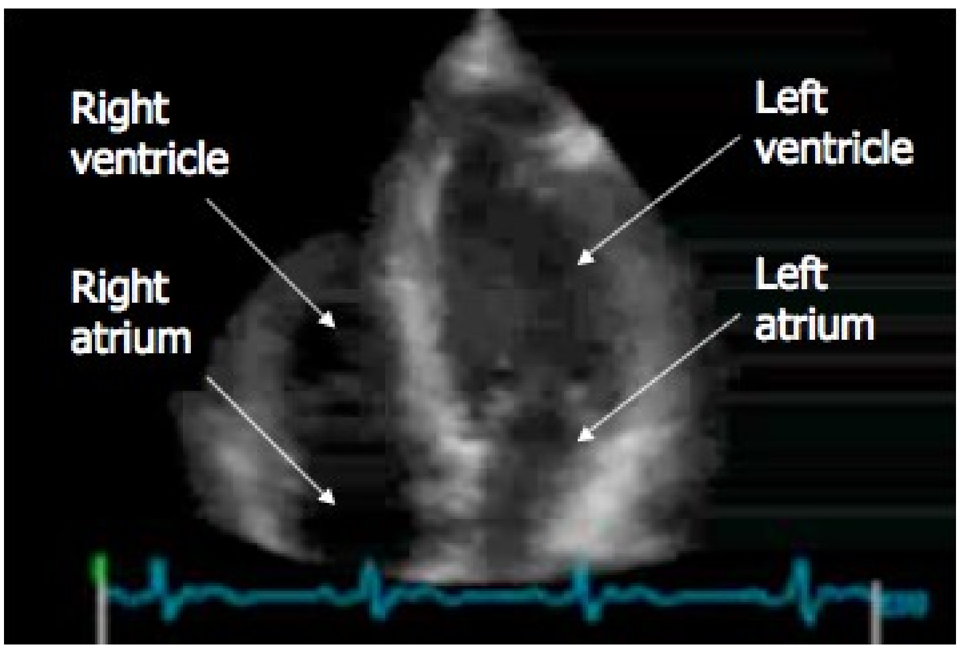
$$d = \frac{vt}{2}$$

- the distance between the transmitter and the remote object is determined using the formula., where v is the velocity of sound in sea water.

6. Ultrasonics in Medicine

Diagnostic sonography

Medical sonography (ultrasonography) is an ultrasound-based diagnostic medical imaging technique used to visualize muscles and many internal organs, their size, structure and any pathological lesions.



7. Car airbag sensor

Powerful US waves detect intensity of the shock and send an electrical signal to trigger the airbag.

8. Dispersion of fog

Fog is defined as a mass of water vapour condensed into small water droplets on powery materials made from smoke, tyres etc. When US waves directed towards fog, they being longitudinal in nature, get reflected from its constituents and form stationary waves. The stationary waves, comprising of high and low density points, help coagulate the liquid and solid particles in the fog turning them into big particles. These particles fall on ground due to the gravity resulting in dispersal of fog

9. Green Energy

Piezoelectricity being non-polluting is called green energy. It can be an alternative green energy source in providing piezoelectric flooring at places such as floors, airports, shopping malls, train stations or places where heavy foot traffic is available.