Unit 2. Wave and Oscillations

2.1 Introduction :

The longitudinal waves can be divided in to three categories on the basis of frequency as follows :

1. **Audible Waves :** The sound wave having frequency between 20 Hz to 20 KHz can heard by the human ear. Hence it is called audible waves. These sound waves originate in vibrating string (e.g. violin, guitar, sonometer etc.), vibrating membranes (e.g. loudspeakers, drum etc.) and vibrating air column (e.g. flute, clarinet etc.)

2. **Infrasonic :** The sound wave having frequency lower than the audible range (i.e. below 20 Hz) are called infrasonic. These waves are produced by large vibrating bodies, e.g. during an earthquake, vibrations of pendulum. These waves are insensitive to human ears.

3. **Ultrasonic Waves :** The sound wave having frequency higher than the audible range (i.e. above 20 KHz) are called ultrasonic waves. The frequency of these waves are higher than the normal limit of audibility by the human ear. The animals like dogs, birds and bats are sensitive to a particular range of these waves. Bats are almost blind but can locate objects and navigate obstacles by producing ultrasonic waves (by their inborn trait) and receiving the echo.

These waves travel in air with the same speed as that of audible waves and exhibit the properties of audible sound waves. The wavelength of ultrasonic waves is smaller therefore it has great penetrating power. The ultrasonic waves are not electromagnetic waves.

2.2 Generation of Ultrasonics :

The ultrasonic generators can be divided into two groups :

(a) Mechanical generators and (b) electrical generators.

(a) Mechanical Generators :

The mechanical generators may be subdivided into two groups :

(i) Gas Driven: These are simple devices to produce ultrasonic of frequencies up to 30 Khz, such as Galton's whistle and siren etc.

(ii) Liquid Driven: These are transducer type of devices which convert energy from one form to another, such as vibrating blade transducer and hydrodynamic oscillators. A carbon microphone is also an example of a transducer in audible range.

(b) Electrical Generators :

The electrical generators may be subdivided into two categories :

(i) **Piezoelectric Generator :** When certain crystal like quartz, tourmaline and Rochelle salt are subjected to pressure (either compression or expansion), they exhibit opposite electrical charges on their opposite faces and produce potential difference to the faces. This phenomenon is known as piezoelectric effect. Similarly, if the opposite sides of these crystals are maintained at different electric potentials by applying a voltage, then the crystal slice expands or contracts. This phenomenon known as converse piezoelectric effect. The piezoelectric generator is utilized to produce ultrasonic waves of high frequency.

(ii) **Magnetostriction Oscillator :** When ferromagnetic material like nickel, cobalt, iron in form of a rod placed in a magnetic field parallel to its length then length of rod changes. This phenomenon is called magnetostriction effect. This phenomenon can be used to produce ultrasonic waves.

2.3 Piezoelectric Effect :

The 'Piezo' is a Greek word. Its meaning is pressure. Hence the translation of Piezoelectric would be pressure electricity.

The certain crystals like quarts, tourmaline etc. have the property to produce a voltage when pressure is applied to them. The crystal can change the shape on application of charge. Depending on applying pressure, the electric potential developed from a fraction of a volt to several thousand volts. The Piezoelectricity is one of the phenomenon of nature which changing one form of energy to another. Here, the mechanical energy is converted to electrical potential energy as shown in figure 2.1

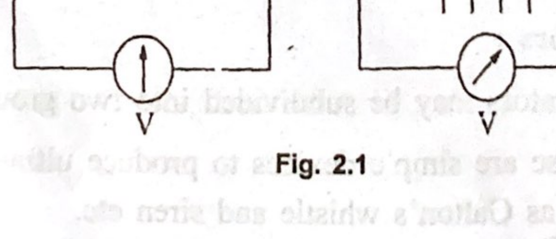

Fig. 2.1

The opposite effect also occurs. The material changes their dimensions when an electrical potential is applied as shown in figure 2.2.

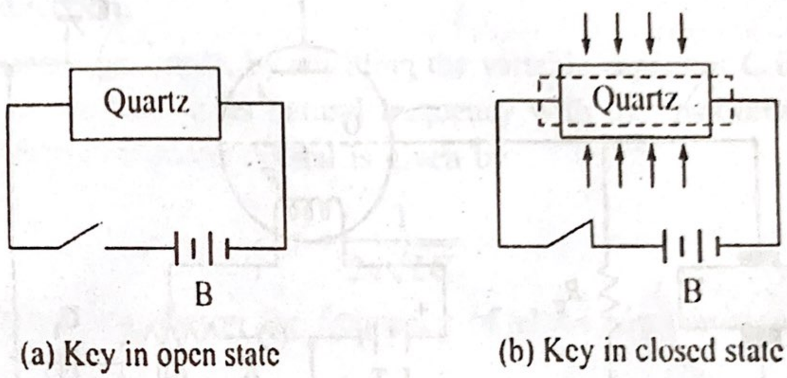

Fig. 2.2

The above two effects are the basis of piezoelectricity. In 1880, Pierre Curie and Jacques Curie first discovered the piezoelectric effect in the substance like quartz, tourmaline and Rochelle salt crystals. The quartz is found as colourless silicon dioxide (SiO_2), while tourmaline is a red, pink, green, blue, yellow, brown, black or colourless silicate. Rochelle salt can be crystalized from a solution of potassium sodium tartrate.

If an alternating voltage is applied across a slice of quartz crystal, it becomes alternately contract and expand. Hence the quartz crystal start vibrating. If the frequency of applied voltage becomes equal to natural frequency of the quartz crystal then resonance occur and produce ultrasonic waves.

2.4 Piezoelectric Generator :

Construction : In 1917, Langevin developed a method for producing ultrasonic wave using the piezoelectric effect. The valve oscillator is used to produce an alternating potential difference as shown in figure 2.3. In this method, X-cut quartz crystals are used to produce ultrasonic waves because they produce longitudinal waves. The Y-cut crystal produce shear waves which can travel only in solids.

The X- cut quartz crystal Q is placed between two metallic foils which are connected to the anode A and grid G of a triode valve. The LC oscillator tuned circuit is connected to anode A. The high tension battery H.T. is shunted by a by-pass capacitor C_1 to prevent high frequency currents from passing through the battery. A grid leak resistor R_g is used to regulate the action of the grid.

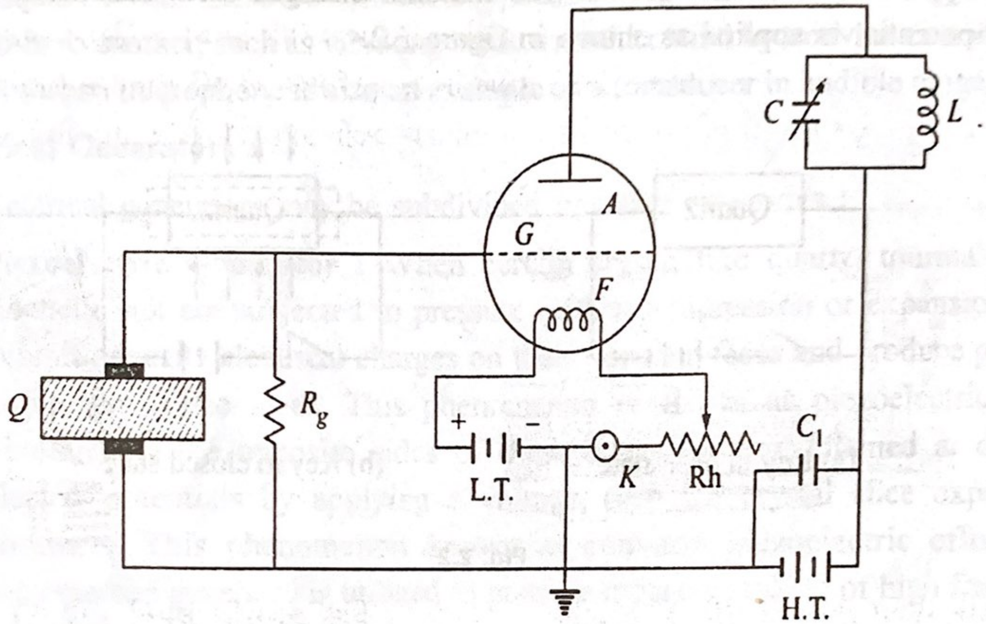

Fig. 2.3

Working : When a high frequency current flows in the anode circuit, an alternating potential difference of the same frequency is applied to the faces of the crystal. Hence, the crystal undergoes linear expansions and contractions and it is set in to mechanical vibrations. The frequency can be varied by varying the capacitance of capacitor C. When this frequency becomes equal to the fundamental natural frequency of the crystal, the crystal is set into resonant mechanical vibrations, and producing ultrasonic waves.

The expression of ultrasonic frequency is given by

$$f = \frac{P}{2t}\sqrt{\frac{E}{\rho}} Hz \qquad \ldots\ldots\ldots (2.1)$$

Where, P = 1,2,3 etc. for fundamental modes

E = Young's modulus of the material (For quartz, E = 7.9×10^{10} N/m^2)

ρ = density of the material (For quartz, ρ = 2.65×10^4 Kg/m^3)

t = thickness of the crystal slice

With a suitable slice of quartz crystal, ultrasonic waves of frequencies 5.4×10^5 Hz can be produced. The tourmaline plates can be used to produce ultrasonic waves up to the frequency 1.5×10^8 Hz.

In above equation (2.1), the term $\sqrt{\frac{E}{\rho}}$ is equivalent to the velocity of longitudinal wave along X- direction.

In a piezoelectric generator, by adjusting the variable capacitor C in tank circuit, the crystal is made to oscillate at its natural frequency with the maximum efficiency. The frequency of vibration of quartz crystal is given by

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \text{... ... . (2.2)}$$

This is required expression for frequency of ultrasonic waves using piezoelectric generator.

2.5 Advantages of Piezoelectric Generator :

There are following advantages of piezoelectric generator

(i) One can generate ultrasonic waves whose frequencies are up to 500MHz

(ii) A wide range of frequencies can be generated at lower cost using synthetic materials.

(iii) The ultrasonic generator output is very high and does not depend on environmental changes such as temperature and humidity.

Limitations :

(i) The cost of the natural piezoelectric crystals is high.

(ii) The cutting and shaping of piezoelectric materials involve tedious mechanical processes.

2.6 Magnetostriction Effect :

When the ferromagnetic material placed in a magnetic fields parallel to its length, the length of material changes. This effect is called magnetostriction effector Joule effect. The change in length is independent of the field and this change may be either increasing or decreasing depends on nature of ferromagnetic material. The change in length is very small. It is of the order of 1 part in a million.

The change in length of material against magnetic field if shown if figure 2.4.

Fig. 2.5 shows that the length of nickel and annealed cobalt metal decreases as increase in magnetic field. This phenomenon is reversible. If a magnetic rod of nickel is stretched then the magnetization of the rod decreases and compression of the rod along the length increases the magnetization. Hence, if a coil is wound around a rod, any elastic deformation of the rod induces a voltage in the rod.

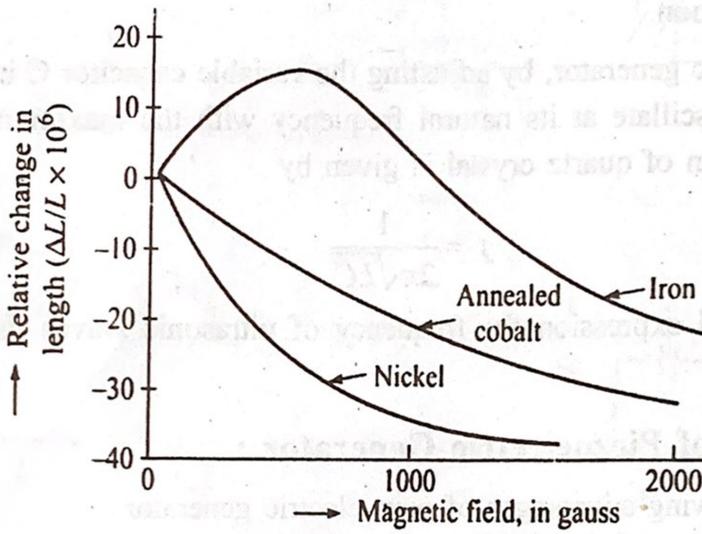

Fig. 2.4

If a nickel rod is brought into alternating magnetic field, the length of rod changes periodically. The frequency of vibration is same as an alternating magnetic field due to resonance. The frequency of the rod is given by

$$f = \frac{1}{2t}\sqrt{\frac{E}{\rho}}\ Hz \qquad \ldots\ \ldots\ \ldots . (2.3)$$

Where E is the Young's modulus of the material and ϱ is its density.

For a nickel rod of length 12.5 cm, the frequency produced by this method is 20.4 KHz.

2.7 Magnetostriction Oscillator :

Principle : This oscillator generates ultrasonic based on megnetostriction phenomenon

Construction : It is designed by G.W. Pierce. A nickel rod is clamped in the middle and two coils L_1 and L_2 are wound round at its two ends as shown in figure 2.5. The coil L_1 is connected to the plate circuit and L_2 in the grid circuit of a triode oscillator. The two coils are indirectly coupled.

Working : When the circuit is closed the rod gets magnetized by the plate current passing through coil L_1. The change in plate current will change in the magnetization of

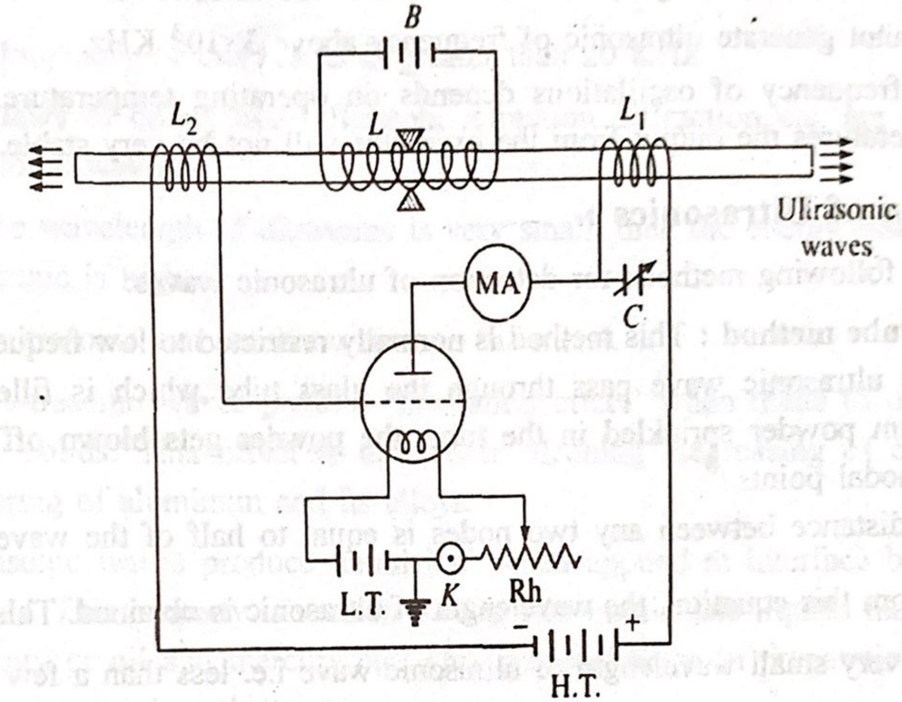

Fig. 2.5

the rod and hence change in the length of the rod. This change in length gives rise to a change in the flux linked with grid coil L_2. Hence, inducing an emf in it. This emf is amplified and passed on to the plate circuit so that oscillations are maintained. The frequency of oscillations, $f = \dfrac{1}{2\pi\sqrt{L_1 C}}$ is controlled by the variable capacitor C. If this frequency becomes equal to the natural frequency of the longitudinal vibrations of the rod, then resonance occur. The variations in the deflection of the milliammeter (MA) will give the indication of the resonance.

It should be noted that the best effect is obtained when the nickel bar is previously magnetized by a second coil L wound over it and carrying a direct current.

2.8 Advantages and Disadvantages of Megnetostriction Oscillator :

The merits of the magnetostriction oscillator are as follows :

(i) The construction is very simple.

(ii) The cost of generator is low.

(iii) At low ultrasonic frequencies, a large power output is possible without the risk of damage of the oscillatory circuit.

The drawbacks of the magnetostriction oscillator are as follows:

(i) It cannot generate ultrasonic of frequency above 3×10^3 KHz.

(ii) The frequency of oscillations depends on operating temperature. At higher temperatures the output from the oscillator will not be very stable.

2.9 Detection of Ultrasonics :

There are following methods for detection of ultrasonic waves:

(i) **Kundt's tube method :** This method is normally restricted to low frequency waves. When the ultrasonic wave pass through the glass tube which is filled with the hycopodium powder sprinkled in the tube, the powder gets blown off and forms heaps at nodal points.

The distance between any two nodes is equal to half of the wavelength, i.e. $d = \frac{\lambda}{2}$. From this equation, the wavelength of ultrasonic is obtained. This method is failed for very small wavelength of ultrasonic wave i.e. less than a few mm.

(ii) **Thermal detector method :** In this method a fine platinum wire is moved through the medium where ultrasonic waves travelling. Due to compression and rarefaction, the temperature changes at nodes and antinodes. Therefore, the resistance of the platinum wire will change. The resistance remains constant at antinode because there is no change in temperature at that point.

With the help of the Callender and Griffith bridge, the change in the resistance of the platinum wire is measured at the nodes. At antinodes there is no change in temperature and hence its resistance is indicated by null deflection in the bridge circuit.

(iii) **Sensitive flame method :** In this method, a sensitive flame is moving in the medium of ultrasonic. The flame will stationary at antinode and flickering at nodes. From exact location of nodes and antinodes can be determined by the motion sensitive flame.

By knowing the mean distance between two consecutive nodes, the wavelength of ultrasonic can be determined. If the frequency of the ultrasonic wave is known, its velocity through the medium can also be estimated.

(iv) **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 charge are developed on the other pair of opposite faces. These charge are amplified and detected by using electronic circuits.

2.10 Properties of Ultrasonics :

1. The frequency of this waves is greater than 20 KHz.
2. The laws of optics like reflection, refraction diffraction etc. are observed in ultrasonic waves.
3. As the wavelength of ultrasonic is very small, then the energy associated with ultrasonic is high.
4. The ultrasonic can penetrate through the metal.
5. The ultrasonic waves produce 'cavitation effect' when made to pass through some solids. This effect is utilized in cleaning, degreasing of components, soldering of aluminum and its alloys.
6. Ultrasonic waves produce 'emulsion' when applied at interface between two liquids. This property is used in mixing two immiscible liquids like water and mercury or oil and mercury etc. This property helps in preparation of paints, cosmetics, food products etc.
7. When an ultrasonic wave incident at surface of separation between two media, it undergoes reflection.
8. Ultrasonic waves can be focused by lenses made by plastics and metals.
9. When ultrasonic waves passes through some liquid, the chemical reaction will occur. In some cases the chemical reactions are accelerated by the application of ultrasonic waves. These properties are utilized in 'depolymerization' etc.
10. When an ultrasonic wave meets an obstacle it may be reflected depending upon the nature of obstacle and its size. If the obstacle is large, there is reflection and shadow is observed. However, if the obstacle is very small, there will be no reflection and no shadow.
11. The ultrasonic luminescence is observed in liquids like water under certain special condition.
12. The ultrasonic waves can be propagated through elastic bodies like liquids, solids, gases or vapours.
13. In liquids and gases, there exists no shear elasticity because tangential stress cannot be generated. There is only longitudinal wave propagation is possible.
14. In solids there exists tangential shear stresses due to deformation of shape and hence both longitudinal and transverse waves propagation are found.

15. The velocity of ultrasonic waves depends on the temperature of the medium through which waves propagates. The velocity decreases as increase in temperature. This effect is opposite in water, i.e. the velocity increases with the increase in temperature. However, the increase in velocity is maximum between the temperature interval 75 – 85°C.

2.11 Applications of Ultrasonics :

1. In the study of structure of matter :

The ultrasonic is used for determination of many thermodynamical parameters of the medium such as compressibility, inter-molecular free length, absorption coefficient, specific heat etc.

2. Elastic symmetries of crystals :

When ultrasonic waves are applied to certain crystal. The crystal acts like grating for light waves. From the diffraction pattern produced by the crystal grating, the elastic constants and hence the elastic symmetries of the crystal are determined.

3. Direction signaling and depth sounding :

Due to very small wavelength of ultrasonic, it has small diffraction effects. Hence it is travel long distance without spread. Hence, like radar waves, ultrasonic waves may also be used for signaling in any particular direction.

These waves are also used for the determination of depth of sea, lakes etc. which is known as echo depth sounding. A piezoelectric quartz oscillator is used. The ultrasonic waves transmitted by the crystal are directed toward the bed of the sea and the waves are reflected back from it. The echo is detected by the crystal itself. The time interval between transmitted and reflected echo is determined with the help of an oscilloscope. If v is the velocity of the waves through sea water, the depth of sea is given by $d = \frac{v \times t}{2}$

4. SONAR (Sound Navigation And Ranging) :

The relationship of SONAR to underwater acoustics is like that of RADAR to electromagnetics. The SONAR can measure the depth of water, find underwater obstacles such as rocks and shipwrecks, locate shoals of fish and trace their movement. The SONAR helps divers and military applications such as finding submarines, mines, enemy ships, and so on. Targets can be displayed in a pictorial manner showing their positions and distances as on a RADAR screen.

5. Flow measurement :

There are various methods 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.

6. Material characterization :

The ultrasonic velocity and attenuation are dependent on material properties which may be related to other characteristics like breaking strength of cast iron or porcelain, quality of concrete, grain structure of steel etc.

7. Stress under load and residual stress :

Stress under load and residual stress can be determined by very accurate (1 in 10^4) shear wave velocity measurements.

8. Temperature of hot gases :

The temperature of hot gases can be measured by pulse transit time measurement between two ultrasonic probes protected by such delay rods as fused quartz. This technique has been applied to measure temperature in an internal engine chamber and in a plasma jet.

9. Detection of cracks and flows in metals :

If there is any flaws or cracks in a metal, the ultrasonic waves can be used to identify these defects by non-destructive testing.

10. Mechanical effects and industrial uses :

A glass rod oscillating with ultrasonic frequency can drill a hole in a piece of steel or glass plate. The dust particles can be removed from the surface. The ultrasonic waves are used for cleaning cloths specially woolens, silk fabrics and objects such as parts of watches etc. They are also used for dispersing fogs at airports and in textile industry to improve the dyeing properties of dye suspensions.

11. Medical diagnostics :

Medical diagnostics is another major field of application of ultrasonics. This field mainly consist of examining the anatomical structure of soft tissue or its functioning, while on the hand it is used for checking the normality or abnormality of blood flow in various vessels. All these examinations are noninvasive.

The ultrasonic waves are used to examine soft tissue. It is possible to detect disorders in pregnancy. Tumors, cysts, abscesses and many other disorder can be found and recognized in many organs using ultrasound. Normal or diseased functioning of the heart valve can also be visualized.