Wave and Its Applications

Periodic Time (T): Time required to complete one complete oscillation is known as Periodic time.

It is denoted by T.

Its unit is $s(second)$.

Frequency (f): the number of oscillations performed in one second is known as frequency.

It is denoted by f.

Its unit is $Hz \; or \; s^{-1}$.

Wave length (λ): the distance between two particles having same phase is known as wavelength.

It is denoted by λ.

Its unit is m.

For longitudinal wave, it is the distance between two consecutive compression (or rarefaction) is known as wavelength.

For transverse wave, it is the distance between two consecutive crests (or troughs) is known as wavelength.

Amplitude (A): the maximum displacement performed by the particle in any one direction along the propagation is known as amplitude of the wave.

It is denoted by A.

Its unit is m.

Wave velocity (v): the displacement of wave done in unit second is known as wave velocity.

If the wave travels λ distance in time T then wave velocity is,

$$v = \frac{\lambda}{T} = \lambda \times \frac{1}{T}$$

But $f = \frac{1}{T}$ so,

$$v = f \cdot \lambda \Leftrightarrow f = \frac{v}{\lambda} \Leftrightarrow \lambda = \frac{v}{f}$$

It is denoted by v.

Its unit is m/s.

Type of Waves according to requirement of medium

Mechanical waves: A wave which require a medium to propagate is known as mechanical wave.

Sound wave, string wave are the examples of mechanical wave.

Non-Mechanical wave: A wave which does not require a medium to propagate is known as non-mechanical wave.

Light wave (Electromagnetic radiation) is the example of non-mechanical wave.

Type of Waves according to propagation

Longitudinal wave: If the direction of oscillation of particles is same as the direction of wave propagation, then such type of wave is known as Longitudinal wave.

Sound waves is an example of longitudinal wave.

Transverse wave: If the direction of oscillation of particles is perpendicular to the direction of wave propagation, then such type of wave is known as Transverse wave.

String waves, light waves are the example of Transverse waves.

Longitudinal wave	Transverse wave
In Longitudinal wave, the direction of oscillation of particles is same as the direction of wave propagation.	In Transverse wave, the direction of oscillation of particles is perpendicular to the direction of wave propagation.
Longitudinal wave cannot pass through vacuum.	Transverse wave can pass through vacuum.
Velocity of Longitudinal wave is lesser in air.	Velocity of Transverse wave is higher in air.
Longitudinal wave can pass through solid, liquid and gas medium.	Transverse wave can pass through only solid and liquid.
Longitudinal wave cannot be polarized.	Transverse wave can be polarized.
Longitudinal wave can propagate only in one direction.	Transverse wave can propagate in two or three directions.
During the propagation of Longitudinal wave, the density of medium does not change.	During the propagation of Transverse wave, the density of medium does change.
With increase in density of the medium, the velocity of Longitudinal wave also increases.	With increase in density of the medium, the velocity of Transverse wave decreases.
Propagation of Longitudinal wave occurs via compression and rarefaction.	Propagation of Transverse wave occurs via crest and troughs.
Sound waves, tuning fork waves, Ultrasonic waves, P-waves of earthquake are the most common examples of Longitudinal wave.	String waves, Light waves and S-waves of earthquake are the most common examples of Transverse wave.

Ultrasonics – Definitions

1. **Audible sound:** A sound which has frequency ranging from 20 Hz to 20,000 Hz is known as audible sound. Humans can listen only this range of frequency.
2. **Infrasonic Sound**: A sound which has frequency less than 20 Hz is known Infrasonic Sound. Human cannot hear this sound.

   Elephants, Blue Whales and some other creatures can hear infrasonic sound.

   The sound produced during Vulcanic eruptions, Tornado, Tsunami waves are in the range of Infrasonic sound.
3. **Ultrasonic Sound**: A sound which has frequency greater than 20,000 Hz is known as ultrasonic sound. Bats, Dogs, Mosquitos, dolphins and some bugs can listen ultrasonic sound.

ULTRASONICS – APPLICATIONS

Medical field:

1. Ultrasonic Angiology: Used for detection of arterial and venous diseases.
2. Cardiology: Ultrasonic is also used to check heart rate and rhythm.
3. Gastroenterology: Ultrasonic is used to diagnose stomach and intestinal disorders.
4. Cancer: Ultrasound is used to detect cancer in the thyroid gland.
5. Neurology: Ultrasound is used to examine the internal nerves of the brain, blood flow in its arteries and internal bleeding.
6. Obstetrics: Ultrasound is used to check fetal growth and defects during pregnancy.
7. Musculoskeletal: Ultrasonic is used as a good alternative to X-ray for bone fracture, muscle, joint examination in children.
8. Cataract Surgery: Ultrasonic waves are used for cataract and other eye surgeries.
9. Liposuction: Ultrasonic is also used to remove excess fat from the body.
10. Dentistry: Ultrasonic is used in teeth for gum treatment and cleaning.
11. Lithotripsy: Ultrasonic is used to break up kidney (bladder) stones.
12. Sterilization: Ultrasonic is used to sterilize instruments used in surgery.

Industrial Field:

1. NDT (Non-Destructive Testing): Ultrasonic is used to detect internal cracks in oil carrying pipes, boilers etc. without causing any damage.

2. SONAR (Sound and Navigation Ranging): SONAR is used to determine the location of underwater objects or water bodies. Ships or submarines floating in the sea can determine the position of other ships or submarines and know their speed through this method.

3. USID (Ultrasonic Identification): Ultrasonic is used to check the illegal presence of an unknown object in a fixed area.

4. Cleaning: Usually cleaning is done with soap or detergent. But very small and irregularly shaped items, parts of the rod, some spare parts of the engine etc. cannot be cleaned by hand or brush. Hence such items are placed in a container filled with a solution. By passing the ultrasonic waves in this vessel, the debris or oily substance like grease on these objects is dislodged from the objects and mixed into the solution. And things are thoroughly cleaned.

5. Drilling: A simple drill cannot work for drilling in glass, fiber or metals. Hence, a metal rod is attached to an ultrasonic vibrator and the rod is agitated with ultrasonic frequency. Hence these rods act like a hammer.

6. Welding: Welding of materials like plastic cannot be done with conventional welding equipment. The surface of materials such as plastics can be melted and welded with high-frequency ultrasonic waves.

7. Emulsion: Normally oil and water are immiscible. Water and oil can be combined with ultrasonic extraction. E.g., Usually, honey crystallizes

after some time. Ultrasonically treated honey does not develop this problem.

Food Industry:

1. Quality Control: Ultrasonic is used for checking the quality of food products being prepared and also for detection of inedible substances mixed in food products.

2. Cold Pasteurization: Pasteurization is usually used to sterilize food by killing some of the microorganisms and bacteria that are useful to the body. After keeping the juice of the fruits for some time, the juice floats separately on the upper side and the pulp below. In contrast, cold pasteurized juice and pulp remain intact for months. High Power Ultrasonic (HPU) is used for this.

3. Irradiation: Pesticides sprayed on fruits and vegetables are extremely harmful to health. Normal washing with warm water does not remove the pesticides. Irradiate with ultrasonic waves to remove harmful insects and pesticides from fruits and vegetables.

4. Tenderization: Ultrasonic waves are used to soften food items such as meat in the food industry to make them easier to cook and digest before packing.

5. Ripening: Ultrasonic waves are used to ripen unripe fruits.

6. Ultrasonic waves are used for mixing, dispersing, equilibrating, dissolving, crystallizing and preserving some foods.

Biomedical Field:

1. Cell Destruction: Bacteria attacking living cells form a protective shield around themselves. This protective shield is formed when ultrasonic waves are applied to bacteria living in tissue that are kept in specific chemicals, which is used in medicines.

2. Solution maker: While making some medicines some chemicals are not soluble in its solution. Hence, they can be easily dissolved in solution with the help of ultrasonic waves.

3. Activation of Enzymes: In some biochemical processes ultrasonic waves are used for activation or inactivation of enzymes to speed up the process.

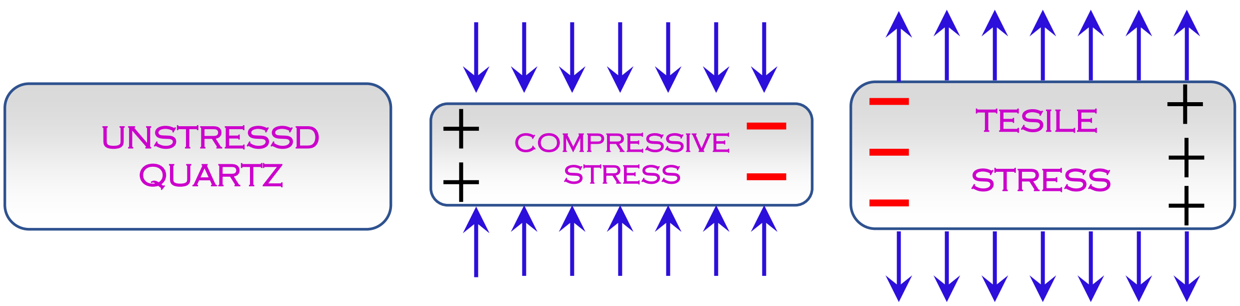
4. To make milk-cream from animal products like milk, ultrasonic waves are used to release only the fat.

5. Ultrasonic waves are used to break apart the cells of living cells and release the cellular fluid needed to make biochemical substances from them.

Piezoelectric effect

When crystals like quartz or tourmaline are stressed along any pair of opposite faces, electric charges of opposite polarity are induced in the opposite faces perpendicular to the stress. This is known as Piezoelectric effect.

Piezoelectric effect- Mechanism:



Piezoelectric and inverse piezoelectric effects are only exhibited by certain crystals which lack center of symmetry.

In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed, so that the crystal overall is electrically neutral.

Each of these sides forms an electric dipole and dipoles near each other tend to be aligned in regions called Weiss domains.

The domains are usually randomly oriented, but can be aligned by strong electric field applied across the material.

When a mechanical stress is applied, this symmetry is disturbed, and the charge asymmetry generates a voltage across the material.

For example, a $1\ cm^3$ of quartz with $2000\ N$ of correctly applied force can produce a voltage of $12{,}500\ V$.

Piezoelectric materials also show the opposite effect, called converse (inverse) piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal.

Inverse piezoelectric effect:

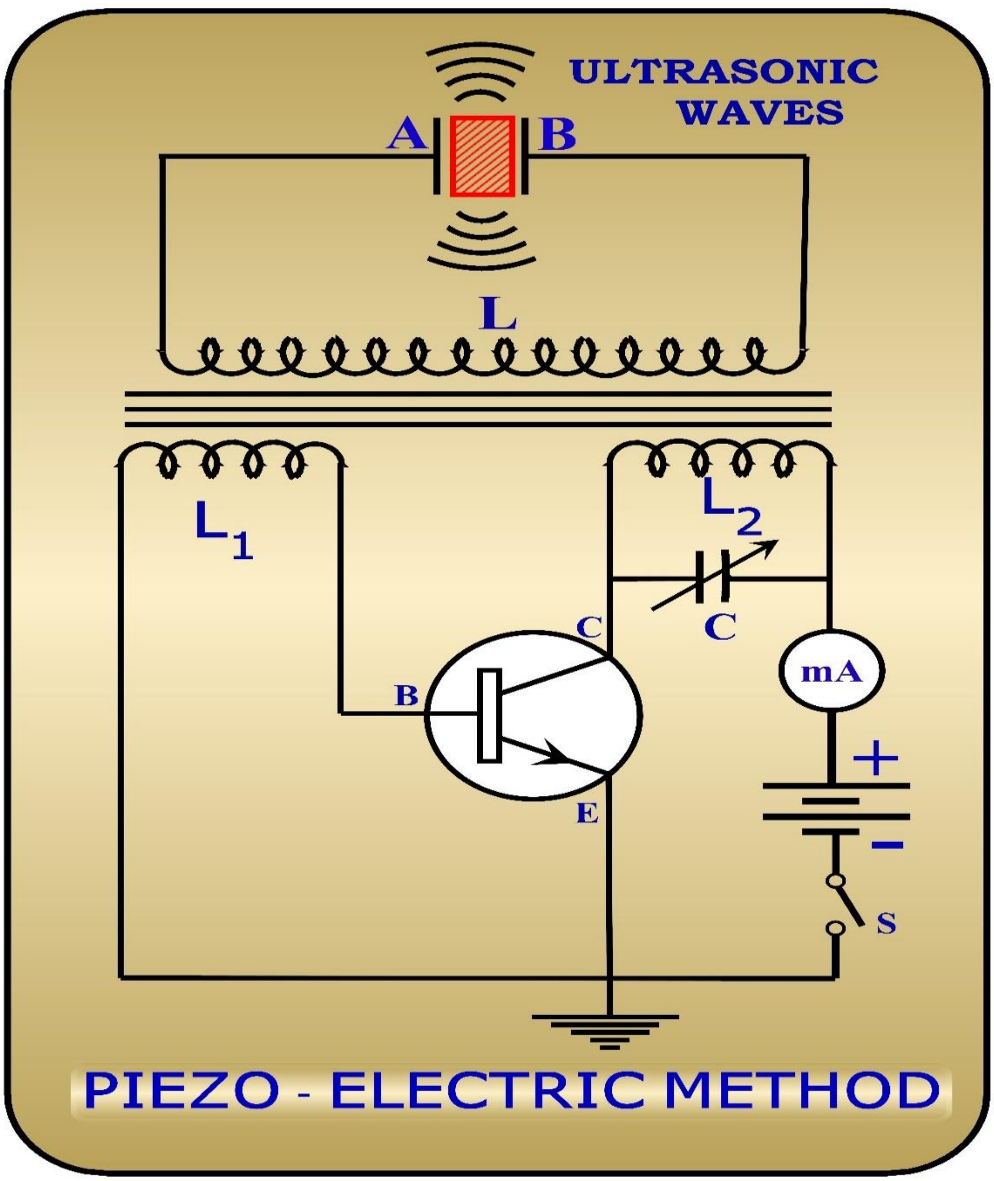
When an alternating e.m.f is applied to the opposite faces of a quartz or tourmaline crystal it undergoes contraction and expansion alternatively in the perpendicular direction. This is known as inverse piezoelectric effect. This is made use of in the piezoelectric generator.

PIEZOELECTRIC GENERATOR

PRINCIPLE: When an alternating e.m.f is applied to a crystalline material like quartz or tourmaline, the crystal undergoes contraction and expansion simultaneously in the perpendicular direction.

CONSTRUCTION:

- As shown in circuit diagram, L_1 coil is connected to base terminal of transistor.



- A tank circuit is made by connecting a variable capacitor with coil L and one end of thank circuit is connected with collector terminal of transistor.
- Other end of tank circuit is connected to series connection of mA and battery.
- A parallel plate capacitor AB is made using piezo-electric crystal Q and it is connected with secondary coil L_2.

WORKING:

- The tank circuit has a variable capacitor 'C' and an inductor 'L' which decides the frequency of the electrical oscillations.
- When the circuit is closed current rushes through the tank circuit and the capacitor is charged, after fully charged no current passes through the same. Then the capacitor starts discharging through the inductor and hence we get electrical oscillations in the tank circuit.
- With the help of the other electronic components including a transistor, electrical oscillations are produced continuously.
- These electrical oscillations are fed to the piezoelectric crystal via secondary coil L_2 and the piezoelectric crystal starts vibrating.
- As this crystal is continuously subjected to alternating electric field it produces sound waves. The frequency of this crystal is known as natural frequency.
- of the piezoelectric slab then it will vibrate with maximum amplitude. The frequency generated is given as follows:

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

where, $t = Thickness\ of\ crystal\ slab$

$Y = Young's\ Modulus$

$\rho\ =\ Density$

$$k = 1, 2, 3, \ldots (Integer\ Multiple)$$

- Now with the help of variable capacitor, the frequency of tank circuit is adjusted so that $f = f_0$, which is necessary condition for resonance.
- At the time of resonance, the crystal oscillates with high amplitude, hence ultrasonic waves are produced.

ADVANTAGES:

1. Ultrasonic frequencies as high as 500 MHz can be generated.
2. The output power is very high.
3. It is not affected by temperature or humidity.
4. It is more efficient than the Magnetostriction oscillator.
5. The breadth of the resonance curve is very small. So, we can get a stable and constant frequency of ultrasonic waves.

DISADVANTAGES:

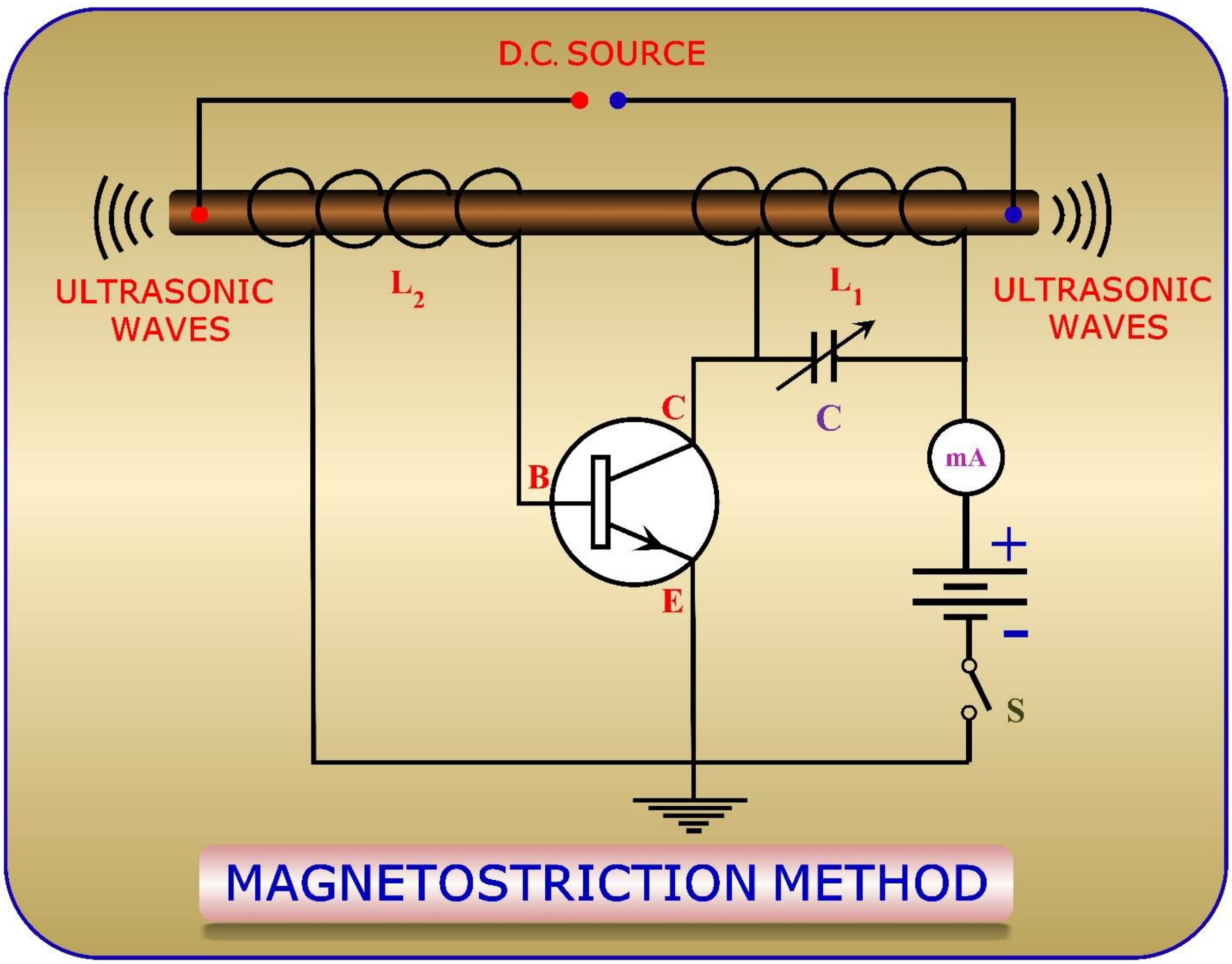
1. The cost of the quartz crystal is very high.
2. Cutting and shaping the crystal is quite complex.

MAGNETOSTRICTION METHOD

PRINCIPLE: When an electric field is applied parallel to the length of a ferromagnetic rod, the entire length of the rod changes and when the electric field is removed, the rod regains its original length.

CONSTRUCTION:

- As shown in figure a ferromagnetic (Fe, Co, Ni, Cr) rod is clamped between two turns L_1 and L_2 of conducting wire.
- This rod is connected to an D.C. electrical source in the rod, hence D.C. current pass through this rod.



- The inductor L_1 is connected to a variable capacitor which forms an LC resonance tank circuit.
- One end of the coil L_2 is connected to the base (B) of the transistor and the other end is connected to the emitter (E).
- One end of the coil L_1 is connected to the collector (C) of the transistor and the other end to one end of the battery.
- The emitter (E) terminal of the transistor is grounded in the common emitter (CE) connection.

PROCEDURE:

- Charging and discharging of L_1 and the capacitor coiled with the battery and this tank circuit produces oscillations (waves) of frequency f.
- Frequency of oscillations

$$f = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$

- These oscillations are imparted to the rods. Hence longitudinal waves are generated in the rod due to which the rod contracts and expands along its length.
- A change in the length of the rod changes the flux associated with L_1 which results in an emf (e.m.f) in L_1.
- This electric force (e.m.f) is amplified while passing through the collector (C) to the base (B) terminal of the transistor and goes to L_2.
- Feedback is given to L_2 by the LC tank circuit as a result of which the LC tank circuit maintains oscillations.

- The value of the variable capacitor C is kept in such that when the frequency of oscillations produced by the circuit is equal to the natural frequency of the rod, due to resonance, the rod oscillates with the maximum amplitude at which ultrasonic waves are generated.
- Natural frequency of the rod at resonance,

$$f_0 = \frac{n}{2l}\sqrt{\frac{Y}{\rho}}$$

where, $l = thickness\ of\ crystal$

$Y = Young's\ modulus$

$\rho = density$

$n = 1, 2, 3, \ldots (whole\ multiples)$.

- Now with the moving capacitor the frequency f of the tank circuit is kept such that $f = f_0$ which is a very necessary condition for resonance.

Advantages:

1. Magnetostrictive materials are cheap.
2. Its structure is very simple.
3. Waves of large amplitude can also be generated with it.
4. Efficiency is good.
5. It can generate high power waves.

Disadvantages:

1. It cannot generate waves with frequency higher than 3 MHz.
2. Its oscillations are temperature dependent.
3. Energy is lost in hysteresis and eddy currents.
4. It does not produce waves having a single constant frequency.
5. Since the frequency is inversely proportional to the length of the rod, in order to obtain a large frequency, the length of the rod must be made very small, which is often impossible in practice.