Engineering Physics 1
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Module-02
Lecture-03
Ultrasonics

In the last lecture which was the second one of the series on acoustics, we considered principle of superposition. You see this proves still to be operative because the wave equation is the linear and homogeneous. We use this principle to investigate formation of beats. You see, the beats are produced when two progressive waves of slightly different frequencies are moving in the same direction.

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>
> In the present lecture we shall consider ultrasonic sound waves, their production and applications.

They overlap and the result is that the resulting amplitude varies with time becomes large, becomes very small. This waxing and waning of sound is called beats. The number of beats per second is given by the difference in frequencies. We also studied stationary waves and their properties. These waves are formed a very incident progressive wave and the reflected wave; they overlap in some region.

As the name suggests, the stationary waves do not transfer energy to one side or the other like progressive waves. The whole region gets divided into segments by nodes.

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Nodes are the points where the particles have 0 amplitude. They are permanently at rest all the particles in a segment are in the same phase. Those in the adjacent segments are in opposite phase. In the middle of the segment there is a point called antinode. Here, the amplitude is maximum; the distance between a node and anti-node is a quarter wavelength, lambda by 4. We studied all these properties.

Now in the present lecture, we shall consider ultrasonic sound waves, the methods of production and applications. The applications are quite varied in nature.
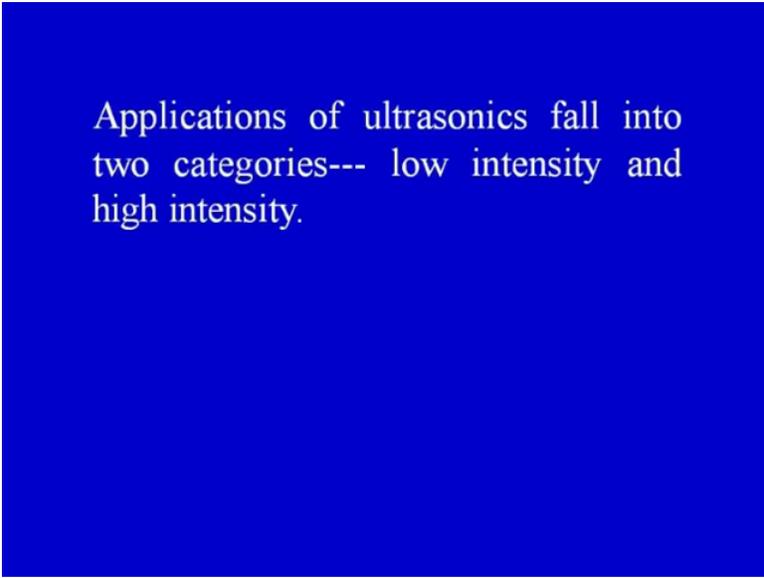
VII. Ultrasonics

Ultrasonics deals with acoustics beyond the audio frequency limit of 20 kHz. The wavelengths of ultrasonic waves are very small as compared to audible sound.

Most of the applications of ultrasonic waves have been possible on account of their small wavelength.

Ultrasonics deals with acoustics as a name suggests beyond the audio frequency limit of 20 kilo Hertz. If the human ear is insensitive to sound frequencies above about 20 kilo Hertz, the wavelengths of ultrasonic waves are very small naturally, because the frequency is very high, as compared to audible sound. Most of the applications of ultrasonic waves have been possible on account of their small wavelength.

You see, because of small wavelength diffraction effects are very little and we can have well defined beams of acoustic waves.

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Applications of ultrasonics fall into two categories--- low intensity and high intensity.

Applications of ultrasonics proudly fall into two categories. Low intensity applications and high intensity applications. Low intensity applications carry the purpose of simply transmitting energy through a medium in order to obtain information about it or to convey information through the medium.

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Non-destructive testing, medical diagnostics, acoustical holography and measurements of elastic properties of materials fall under this category of low intensity applications.

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Marine applications are also included in this category, despite large energy input into operating sonar submarine detectors and depth Sounders.

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High intensity applications deliberately affect the propagation medium through which the waves are passing or its contents. Users of high intensity include medical therapy and surgery atomization of liquids, machining of materials, cleaning, welding of plastics, disruption of biological cells and homogenization of materials.

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Let us continue the production of ultrasonic waves. These waves cannot be produced by the usual method of a diaphragm loudspeaker, supplied with an alternating current, coming from some electronic oscillator. This is due to defect that at very high frequencies, the inductive effects of the loudspeaker coil is so large; when impedance of the coil becomes so large that practically no current passes through it.

 Moreover, the diaphragm of a loudspeaker which is just a sheet, cannot vibrate at such high frequencies. Therefore, other methods are used for the production of ultrasonic waves.

There are two main methods namely magnetostriction method and piezoelectric method which are mostly used. These methods fall under the general category of electromechanical methods. Magnetostriction method is used when frequencies up to 100 kilohertz are needed, while piezoelectric generator is used mostly for frequencies above this limit of about 100 kilohertz.

VII.1(a) Magnetostriction method

This method is based on the phenomenon of magnetostriction. It occurs prominently in ferromagnetic materials such as iron, nickel, and cobalt.

This method is based on the phenomena of magnetostriction. You see, we have all heard the humming sound which comes from a transformer or from the choke of evolution light tube. That is just a very common manifestation of magnetostriction. The humming sound has a frequency double that of the line frequency that is tuned 2 x 50 cycles per second. Now, this magnetostriction phenomena occurs prominently in ferromagnetic materials such as iron, nickel, cobalt etc.

According to it and a rod a ferromagnetic material such as iron, nickel or cobalt is placed in a magnetic field longitudinally.

According to it when a rod of a ferromagnetic material, such as iron or nickel, is placed in a magnetic field parallel to its length, a small extension or contraction occurs.

This change of length is independent of the sign of the field and depends only upon the magnitude of the field and nature of the material.

Parallel to its length, a small extension or contraction occurs. You see the magnet, the ferromagnetic materials have an internally domain structure. Within a domain, the magnetic field is strong and uniform. When an external magnetic field is applied, these domains within ferromagnetic material they move, they rotate to change their orientation. And the result of these internal changes is that there is a dimensional change in the longitudinal direction.

That is along the direction of the magnetic field. As the processes isochoric there is an opposite change in the orthogonal direction. See, the magnetostriction depends on temperature. Actually, it reduces with increase in temperature becomes zero at Curie temperature and amongst various materials for a pure element. Cobalt has the highest magnetostriction coefficient. Now, this change of length which occurs when the material is put in a magnetic field, this is independent of the sign of the field.

The change of sign does not change the extension to contraction; depends only upon the magnitude of the field naturally and nature of the material.

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If the rod is placed inside a coil carrying an alternating current, then it suffers the same change in length for each half cycle.

This results in setting up vibrations in the rod whose frequency is twice that of the alternating current.

If the rod is placed inside the coil carrying an alternating current, this means if this rod fills an alternating magnetic field, then, it suffers the same change length for each half cycle. You see that is interesting, same change length for each half cycle. This results in setting up vibrations in the rod whose frequency is twice that of the alternating current.

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The wave form of the strain thus caused occurs as a rectified sine curve, with the result that unwanted harmonics may be generated.

The wave form of the strain thus caused occurs as a rectified sine curve as if it is coming from a full wave rectifier. With the result that unwanted harmonics may be generated;

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A purely sinusoidal wave corresponding to the frequency of the applied field, along with a markedly increased energy output, will be obtained if the bar is polarized.

This is achieved by simultaneously applying the alternating field and a direct magnetic field of sufficiently high intensity for the value of the resultant field to remain above zero all the time.

A purely sinusoidal wave corresponding to the sinusoidal wave is coming from the applied field, corresponding to the variation of the magnetic field. Along with a markedly increased energy output will be obtained if the bar is, if that bar of the parametric material is polarized. This polarization of the body is achieved by simultaneously applying the alternating field as before.

And a direct magnetic field of sufficiently high intensity for the value of the resultant field to remain above 0 all the time the magnetic field now does not change sign. Essentially, now it varies from 0 to twice the earlier value.

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Ordinarily, amplitude of the vibrations of the rod is small.

If, however, the frequency of the alternating current is same as the natural frequency of the rod, given by

$$f_r = \frac{1}{2L}\sqrt{\frac{Y}{\rho}}$$

then, resonance occurs and the amplitude of vibrations is considerably increased.

Here Y is the Young's modulus for the rod material, ρ is the density of the material and L is the length of the rod.

Because there is no change in sign no crest will be produced and we expect harmonics will also be much less and we get a much larger magnetostriction signal. Ordinarily amplitude of the vibrations of the rod is small. If however, the frequency of the alternating current is same, as the natural frequency of the rod, which is given by 1 over 2L square root of Y over Rho. Then, resonance occurs.

This means the natural frequency of vibration of the rod and the frequency of the magnetic field they are equal. The amplitude of the vibration is considerably increased. Here while Young's modulus for the rod material, Rho is the density, L is the length of the rod. So, when the amplitude becomes pretty large, ultrasonic waves are now emitted from the ends of the rod.

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Ultrasonic waves are now emitted from the ends of the rod.

It is assumed here that the rod is clamped in the middle. This point is a node.

It is assumed here that the rod is clamped in the middle. This point is a node; the free ends are the antinodes.

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Magnetostriction oscillator is used extensively in industry when high power is required. It can produce ultrasonic waves up to a frequency of 100 Kilo Hertz. Oscillations at different frequencies if you want to vary the frequency, this they can be obtained by adjusting the length of the rod.

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Piezoelectric method: this method is based on piezoelectric effect which is a reversible effect and represents a linear electromechanical interaction. Actually this effect is a combination of two effects: the elastic property of the material defined by Hookes law which gives the relation between stress and strain involving the Young's modulus of the material in the electrical property, defined by the relation between the electric displacement.

And the external field involving the electric permittivity of the material according to it, according to the piezoelectric effect, when certain crystals like quartz are compressed or stretched along certain direction, the along certain axis, these are known as mechanical axis an electrical potential difference is produced, along a perpendicular direction along a perpendicular axis. These are known as electric axis. The converse of this effect is also true.

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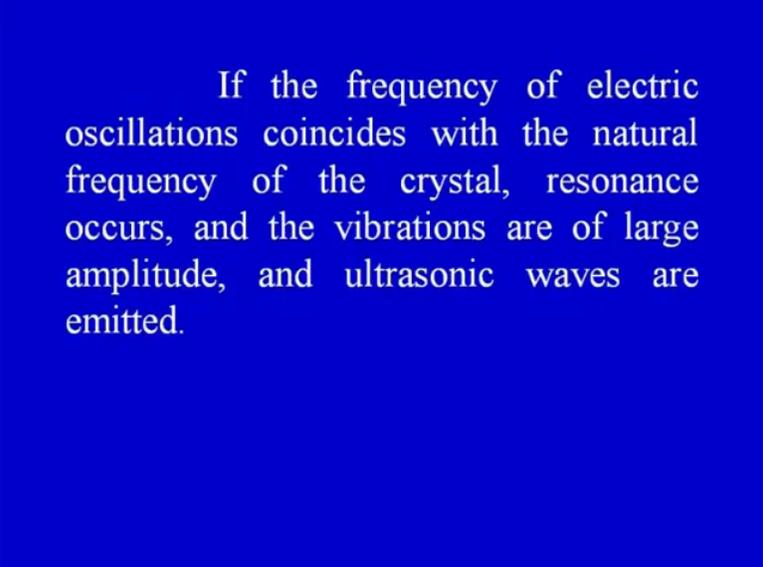
If the frequency of electric oscillations coincides with the natural frequency of the crystal, resonance occurs, and the vibrations are of large amplitude, and ultrasonic waves are emitted.

Now, if the frequency of electric oscillations coincides with the natural frequency of the crystal, resonance occurs, a resonance is naturally and the vibrations are of much larger amplitude and ultrasonic waves are emitted.

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Apart from quartz, there are several other substances which exhibit piezoelectric effect. These are Rochelle salt, tourmaline, ammonium di hydrogen phosphate, barium titanate, potassium zirconium titanate, etc. Out of these substances, Rochelle salt is the most active crystal, generating greatest potential difference for a given mechanical stress.

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However, quartz is almost universally used because it is hard, reasonably strong and most interestingly has a small temperature coefficient of expansion. Since quartz is chemically silicon dioxide, silica. The quartz crystal is essentially an arrangement of three silicon atoms and six oxygen atoms. The charges on the atoms gets cancelled out. That is the effect of the crystal structure.

But when these atoms are pressed from outside, this cancellation gets disturbed or the electrical neutrality gets disturbed and the charges appear on the electrodes. The converse is also true if an electric field is applied on the electrodes, one side is upon giving a positive potential, other side giving a negative potential, the items the silicon and oxygen atoms move and there is a change in dimensions. If the external potential is oscillating, varying with time, then, these internal changes also vary with time.
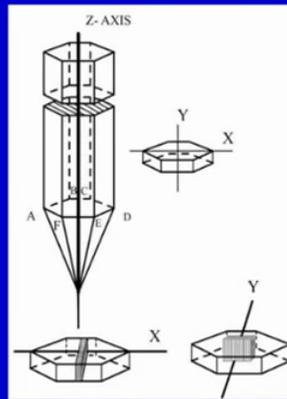
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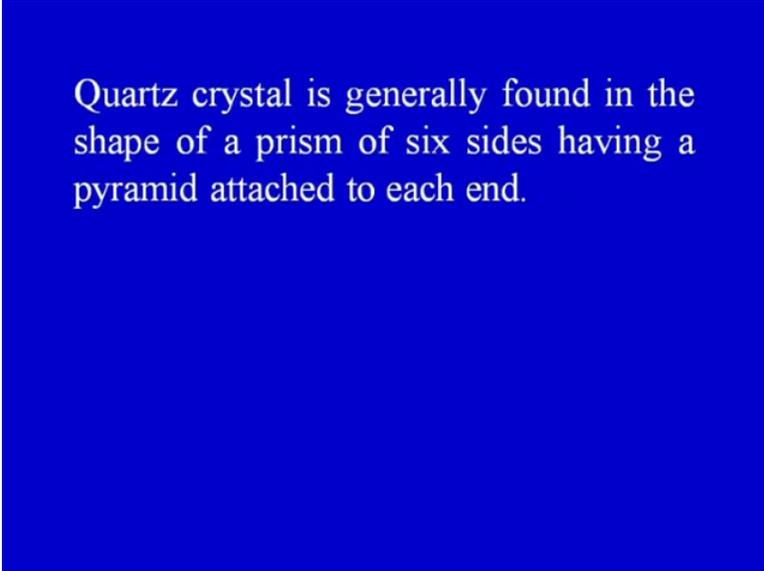
Quartz crystal is generally found in the shape of a prism of six sides having a pyramid attached to each end.

Quartz crystal is generally found in the shape of a prism of six sides having a pyramid attached to each end.

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This figure shows naturally occurring quartz crystal and various cuts.

This figure shows naturally occurring quartz crystal and various cuts one of the parameters has been removed. The line joining the two vertices of the pyramid is the non-polar optic axis. This is a symmetry axis denoted by the z axis in the figure.

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The line joining the two vertices of the pyramid is the nonpolar optic axis, denoted by the z-axis in the figure.

Let a hexagonal plate (slice), as shown, perpendicular to the z-axis be taken out from the original crystal.

Let a hexagonal plate slice as shown in the figure, perpendicular to the z axis be taken out from the original crystal. This is a hexagonal slice.

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The axes joining opposite edges of the hexagon are designed as x axis. There are three of them corresponding to six corners of a hexagon and the associated axes which are perpendicular to these and joining opposite phases are termed y axis. These are also three.

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The x and y axes are called polar axis and the slabs cut with their faces perpendicular to them perpendicular to x axis, perpendicular to y axis, manifests the piezoelectric effect.

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Crystals that are cut with their faces perpendicular to an x axis are called x cut crystals. Or similarly, those cut with their faces perpendicular to the y axis are called y cut crystals. And these are shown at the bottom of the figure.

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Applying an electric field along the x axis yields a compression in that direction, while an expansion occurs simultaneously, along the y-direction. It is a phenomenal isochoric, if there is a compression in one direction, there is a corresponding expansion in the other direction.

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If the direction of the field is reversed, an expansion occurs along the x-axis with an associated compression along the y-axis.

No strain, however, occurs along the z-axis.

In the direction of the field is reversed, in place of that compression, now an expansion occurs along the x axis, with an associated compression now along the y axis. You see all these changes are taking place along the x direction or the y direction. This means in a plane perpendicular to the z axis, perpendicular to these symmetric axes, perpendicular to the optic axis, no strain occurs along the z axis along that direction.

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If a pair of surfaces normal to either of the polar axes (x- and y-axes) are coated with a conducting material to form electrodes, small amplitude oscillations will result when an alternating voltage is applied across them.

Now, if you a pair of surfaces normal to either of the polar axis x or y axes are coated with a conducting material or polished with the conducting material are some conducting foil is attached to it to form electrodes small amplitude oscillations will result when an alternating

voltage is applied across the two foils or across the two plates those two plates that put in an electronic oscillator.

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When the frequency f of the alternating voltage equals one of the natural frequencies of mechanical vibration for a particular axis, resonance occurs, and the response amplitude jumps to a considerably higher value.

When the frequency of the alternating voltage equals one of the natural frequencies of mechanical vibration for a particular axis, resonance occurs and the resonance amplitude jumps to considerably higher value.

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Crystals are generally operated at resonant frequencies for either 'length' or 'thickness' vibrations, as denoted by the resonance occurring in the direction parallel to or normal to the radiating surfaces., respectively.

See, the crystals are generally operated at resonant frequencies for either length of vibrations or thickness vibrations as denoted by the resonance occurring in the direction parallel to the length

then it is the length of vibrations or normal to the radiating surface then they are thickness vibrations.

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The fundamental frequency of thickness vibration is given by the expression –

$$n_1 = \frac{1}{2t}\sqrt{\frac{c_{11}}{\rho}} \quad \text{for } x-\text{cut crystal}$$

$$n_2 = \frac{1}{2t}\sqrt{\frac{c_{44}}{\rho}} \quad \text{for } y-\text{cut crystal}.$$

The fundamental frequency of thickness vibration is given by the expression is given by 1 over 2t square root of c 11 by Rho for x cut crystals. And the frequency is given by 1 by 2t square root of c for 4 by Rho for y cut crystals.

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Here $c_{11} = 8.75 \times 10^{11}$ dynes/cm² and $c_{44} = 5.73 \times 10^{11}$ dynes/cm² are the elastic constants for x- and y- cut crystals respectively, $\rho = 2.654$ gm/cm³ is the density of quartz crystal and t is the thickness of the plate.

Here, c 11 = 8.75 into 10 11 dynes per square centimeter and c 44 = 5.73 into 1011 dynes per square centimeter. They are the elastic constants for x and y cut crystals respectively. Remember, crystal is an isotopic; that is why these constants are not same. Rho = 2.654 grams per cc, the

density of quartz crystal and t is the thickness of the plate. It is the crystal usually in the form of a plate.

As the natural frequency for mechanical vibrations is proportional to the inverse of the dimension along which they occur,

so it becomes obvious that lower frequencies are generated by 'length' vibrations along the direction of the longer dimension while the higher frequencies are produced by 'thickness' vibrations along the direction of the smaller dimension.

As the natural frequency for mechanical vibrations is proportional to the inverse of the dimension along which they occur. So, it becomes obvious lower frequencies are generated by length vibration that is along the longer dimension of the plate. While higher frequencies are produced by thickness vibration that is along the direction of a smaller dimension.

Actually the thickness vibrations are used for producing longitudinal ultrasonic waves in the medium in contact with the crystal plate. Y cut crystals are usually used to produce shear waves in solid medium. So in the solids can support shear waves?

Maximum acoustic intensities are obviously obtained by operating at the fundamental natural frequencies.

Now, another feature we know that maximum acoustic intensities are obviously obtained by operating these crystals at the fundamental natural frequency.

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To obtain higher frequencies, material constraints come in the way as the thickness of the crystal slab has to be reduced.

For example, an *x*-cut quartz plate can be only 0.15 mm thick in order to generate a fundamental 'thickness' mode of 20 MHz.

To obtain higher frequencies, material constants come in the way as the thickness of the crystal slab has to be reduced. You know, the frequency depends on 1 over t. For example an x cut quartz plate can be only 0.15 millimeter thick in order to generate the fundamental thickness mode of 20 megahertz.

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Such a quartz plate is extremely brittle and it can shatter under the impulse of an exceedingly high applied voltage, or its dielectric properties may break down.

Now, such a thin quartz plate is extremely brittle and it can shatter under the impulse of an extraordinarily high applied voltage or its dialectic properties may break down.

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Higher harmonics are, therefore, used to obtain higher frequencies. It is customary to use thicker slabs of crystals with lower resonance frequencies and operate at one of the upper harmonics.

An example is the vibration of a 1-cm thick quartz crystal at its 191st harmonic to generate 55 MHz ultrasound.

So, something else has to be done. The thickness of the crystal just cannot be reduced. The method therefore is has the higher harmonics are used. This is the method which is used to obtain higher frequencies. The crystal is, we are not working on the fundamental but basically, on higher harmonics. It is customary to use thicker slabs of crystals with the lower resonance frequency so the crystal is better take but operate at one of the upper harmonics.

As an example let us consider this one. The vibrations of a1 centimeter thick quartz crystal 1 centimeter thick, was quite thick. But working at if 191st harmonic to generate very high pretty high 55 megahertz ultrasound.

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Note that piezoelectric effect occurs only when opposite charges appear on the electrodes, and for that reason, only *odd* harmonics should be generated.

Remember, piezoelectric effect occurs only when opposite charges appear on the two electrodes and for that reason only odd harmonics should be generated.

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At the nth harmonic, the thickness of the crystal is divided into n equal segments with compressions and expansions alternating in adjacent sections as shown in the figure.

We know at the nth harmonic, the thickness of the crystal is divided into n equal segments with compressions and expansions, alternating in adjacent sections as shown in the figure.

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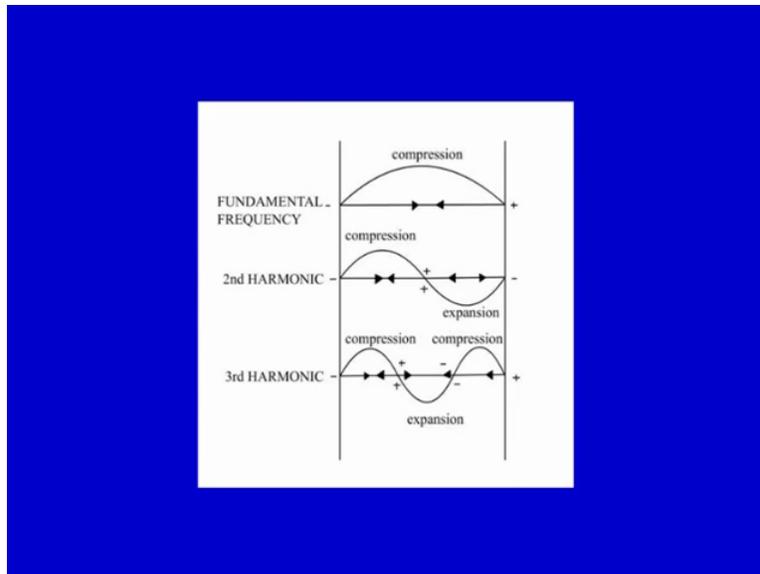
This figure shows the fundamental mode are the second harmonic and the third harmonic, there is only one segment in the fundamental mode, two segments in the second harmonic, three segments in the third harmonic. And the segments are in opposite phase interlinked, compression in one then expansion in the other.

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For even harmonics in the nth mode, compression occurs in n by 2 segments expansion occurs in the other n by 2 segments with the result that there is no net strain. The result is there will not be any piezoelectric effect.

When n is odd, the (n − 1)/2 compressions offset the same number of expansions, leaving either a compression or an expansion in the remaining segment and piezoelectric effect occurs.

When n is odd, then, n - 1 by 2 compressions offset the same number of expansions mutually canceling out, leaving either a compression or an expansion in the remaining segment and piezoelectric effect occurs. So, that is the technique of working on a high hard harmonics one can generate ultrasounds of pretty high frequencies.

VII.2 Applications of ultrasonic waves

(1) Detection of flaws in metals: Ultrasonic waves can be used to detect flaws in metals. A flaw produces a change in the medium due to which reflection of ultrasonic waves takes place.

The reflected pulses are picked up by a receiver and are fed to a CRO. The position of this peak on the time-base of the CRO will give location of the flaw.

Okay, Let us now come to the applications of ultrasonic wave. These are quite varied and many different areas of outcome of our life, I mean, in industry, in medicine, I mean, in many, many areas. Let us see that. Number one: Detection of flaws in metals: this is an application in an industry. The waves can be used to detect flaws in metals. If the flaw produces a change in the

medium, due to which reflection of ultrasonic waves take place, the reflected pulses are picked up by a receiver and are fed to a cathode ray oscilloscope.

The position of this peak on the time base of the CRO, will give location of the flaw. Number 2: Detection of submarines etcetera in the ocean difference application:

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The sharp ultrasonic beam was directed in various directions, into the sea, the reflection of waves from any direction shows the presence of some reflecting body. Number 3: Depth of sea: This is a geological application. We know that the ultrasonic waves are highly energetic.

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And show little diffraction effects because of its small wave length. Thus they can be used for finding the depth of the ocean. The time interval between sending the wave and the reflected wave from the sea is recorded.

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(4)Cleaning: Both cavitation and the agitation of the fluid by the waves are entailed in the process of ultrasonic cleaning. Most cleaning applications are executed in the frequency range of 20 – 40 kHz.

The workpiece being cleaned is immersed in a tank containing a liquid selected on the basis of its detergent properties, ability to degrease, and so on.

Trichloroethylene and cyclohexane are among the most satisfactory fluids used for ultrasonic cleaning.

Number 4: Cleaning: There is a very special type of application, let us see that. Both cavitation and agitation of the solute by the waves are entailed in the process of ultrasonic cleaning. Most cleaning applications are executed in the frequency range of 20 to 40 Kilo Hertz. The workpiece being cleaned is immersed in a tank containing a liquid selected on the basis of its detergent properties its ability to degrease and so on.

Trichloroethylene and cyclohexane are among the most satisfactory fluids used for ultrasonic cleaning.

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Cleaning application includes the removal of lapping paste from lenses without scratching after grinding the flush out of grease and machining particulates from small crevices and engine components removal of blood and other organic material from surgical instruments after use. Number five: Directional signaling:

Ultrasonic waves can be concentrated into sharp beam due to a small wavelength and very little spreading and hence can be used for signaling in a particular direction.

(6)Formation of alloys: The constituents of alloys, having widely different densities can be kept mixed uniformly by a beam of ultrasonic waves. Thus they are used to get an alloy of uniform composition.

Number six: There is a metallurgical application, formation of alloys: The constituents of alloys, having widely different densities can be kept mixed uniformly by a beam of ultrasonic waves. Thus they are used to get an alloy of uniform composition.

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(7)Ultrasonic mixing: A colloidal solution or emulsion of two non-miscible liquids like oil and water can be formed by simultaneously subjecting them to ultrasonic waves.

These days most of the emulsions like polishes, paints, food products and pharmaceutical preparations are produced by ultrasonic mixing.

Ultrasonic mixing a gradual solution or emulsion of two non miscible liquids like oil and water can be formed by simultaneously subjecting them to ultrasonic waves. These days most of the emulsions like polishes, paints, food products, pharmaceutical preparations are produced by ultrasonic mixing.

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(8)Coagulation and crystallization: The particles of a suspended liquid can be brought quite close to each other by ultrasonic waves, so that coagulation may take place. The crystallization rate is also affected by ultrasonic waves.

Coagulation and crystallization: The particles of a suspended liquid can be brought quite close to each other by ultrasonic waves, so that coagulation may take place. The crystallization rate also affected.

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(9)Ultrasonic waves in metallurgy: Ultrasonic waves are used to irradiate molten metals which are in the process of cooling so as to refine the grain size and to release trapped gases.

Ultrasonic waves in metallurgy: Another use there, ultrasonic waves are used to irradiate molten metals which are in the process of cooling so as to refine the grain size and to release trapped gases.

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(10)Detection of abnormal growth:
Abnormal growth in the body and certain tumors can be detected by ultrasonic waves.

(11)Treatment of neurological pain:
The body parts affected due to neurological or rheumatic pain get great relief from pain on being exposed to ultrasonic waves.

Number 10: Detection of abnormal growth: That is medical science. Abnormal growth in the body and certain tumors can be detected by ultrasonic waves. Number 11: Treatment of neurological pain: Another medical use. The body parts affected due to neurological a rheumatic pain get great relief from pain on being exposed to ultrasonic waves. It is a gist of applications not completed.

There many, many applications are very varied applications and quite interesting. Okay, with this, we have just come to the end of this lecture.