Mechanical Measurement Systems
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Lecture – 32
Piezoelectricity Transducers

Hello. I welcome you all in this course on Mechanical Measurement Systems. Today we will discuss the Piezoelectric Transducers and discussion will focus only on Piezoelectric Transducers.

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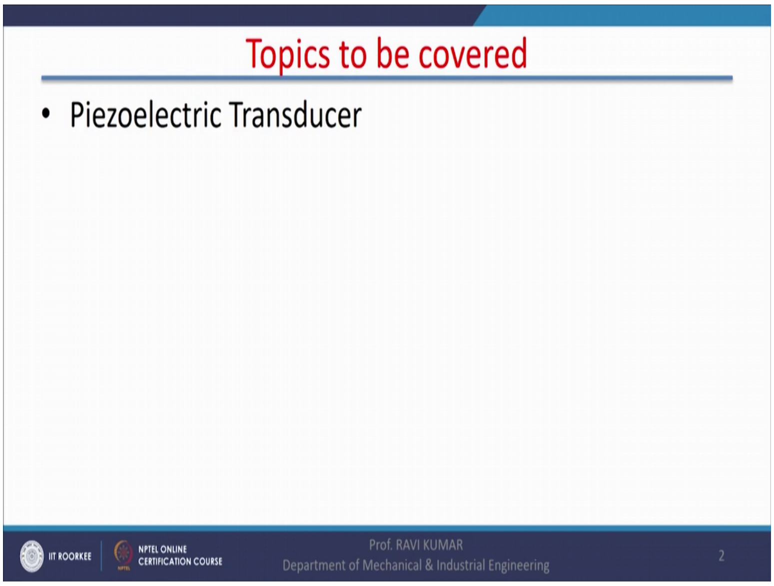

Now, piezoelectric effect is the effect when a substance is.

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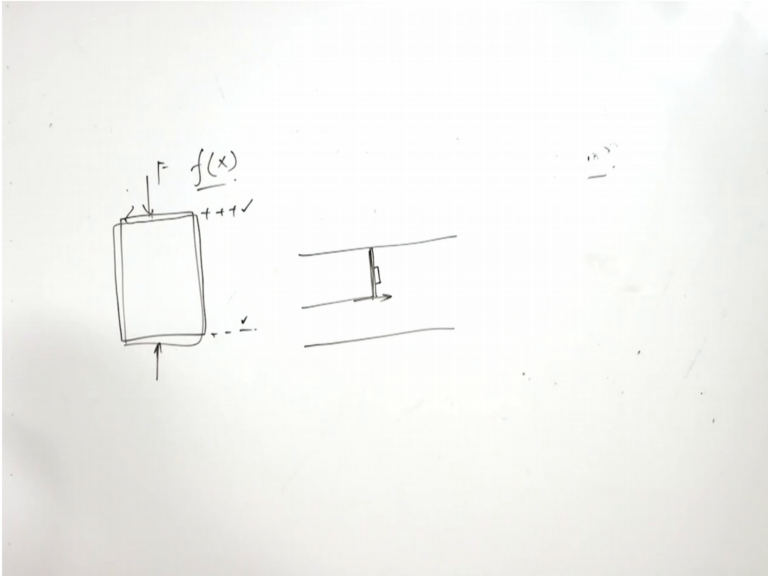

Compressed or expanded or compressed and the force is exerted for compression the force is exerted and some strain volumetric deformation in the substance takes place. Due to this volumetric de deformation, when the opposite phases are charged this is known as piezoelectric effect. So, either we charge opposite faces and deformation takes place or we deform the substance and charging of opposite phase vice versa right. Now we can have relation between the charge developed here and here if the sort of capacitance right. And with the displacement function of displacement. This is the basic working of the piezoelectric transducer, and this property of transducers is for many users I mean not only it is used as a sensor.

Even in wrist watches also there is piezoelectric transducers, even in the pressure gauges or pressure measurement there are piezoelectric transducers. So, they have variety of applications like strain gauges. Now for example, let us take example of strain gauge, suppose there is a flow in a channel right and if we insert a vertical with a strain gauge fixed and this is a flexible type of thing.

So, this fluid will push this cantilever in this direction and strain will be developed. So, not only strain gauge can be used for measurement of; this strain it can be used for the measurement flow as well. Similarly here for piezoelectric transducers not only they are used as a sensor for measuring the force or the strain, they have they can have variety of a applications right. Quartz is essentially is piezoelectric substance.

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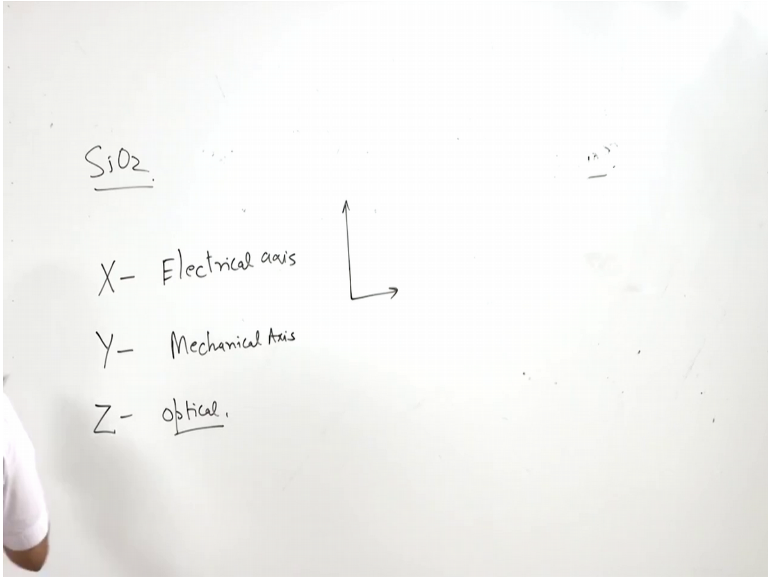

If quartz is silicon dioxide this is quartz it is available in nature in abundance. Now every piezoelectric crystal let us talk in terms of crystal has three axises right one is X axis which is called electrical axis another is Y axis, which is called mechanical axis and there is a Z axis which is known as optical axis.

So, suppose this is X axis, this is Y axis and opposite to the board it is Z axis right and there are two effects in transducers one is longitudinal effect.

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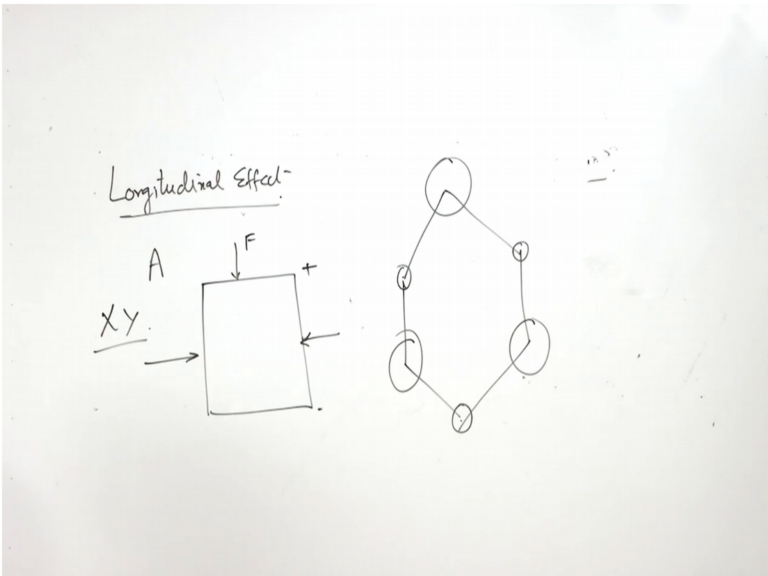

In longitudinal effect suppose this is X direction and force is applied here and deformation takes place. The charge will be developed here or the opposite phases of the crystal, and this is known ad longitudinal effect and it is independent of the area, it is not dependent upon the area and thickness of the crystal in this direction X direction right. It is mainly it depends dependent on the force applied on the crystal right. So, this is the longitudinal effect, another is transfer effect and the transfer effect where the force is applied in this direction either of the direction I mean either from this direction or this direction, definitely this from here we are getting the reaction force. And then charge is developed in the opposite phases this is known as longitudinal effect and it is depended upon the X and Y direction of the length.

So, there are two effects in transducers one is longitudinal effect, another is transversal effect the effect. Now if you look at the arrangement of the silicon crystal, it is arrangement is like this there is a hexagonal arrangement of atoms. So, this silicon and smaller one let us say oxide and hexagonal is the prism hexagonal arrangement and the bottom side also be more oxygen are attached to each it is structure of a crystal it is not atomic structure it is a structure of a crystal of silicon right. Now if length and L and b.

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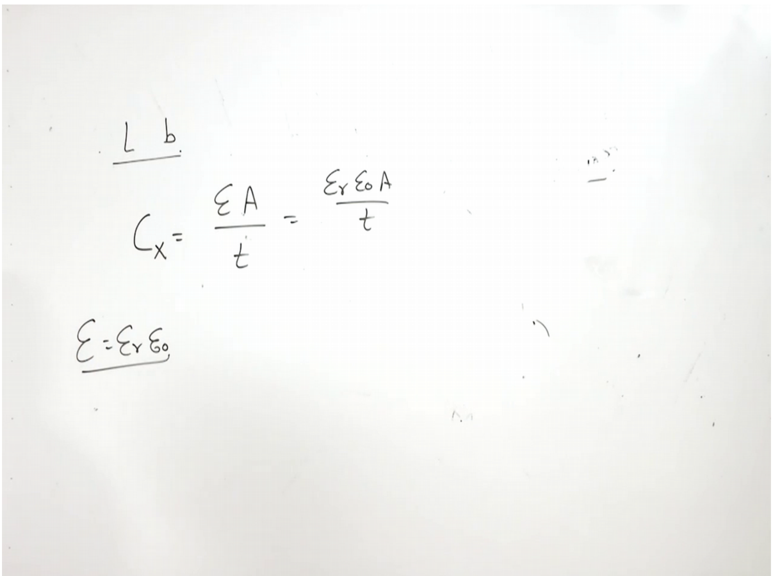

L and b are the length and breadth of the surfaces right in that case the capacitance because of opposite phases charge is developed. So, some charge developed because it will work as a capacitor. So, capacitance is Cx is equal to epsilon A by t, t is the thickness of crystal and this epsilon is permittivity and epsilon is relative permittivity multiplied by absolute permittivity or we can write as epsilon r epsilon o A by t ok. Now voltage because charge is difficult to measure, but once we can easily mea measure the voltage of runs two phases it is easier to measure.

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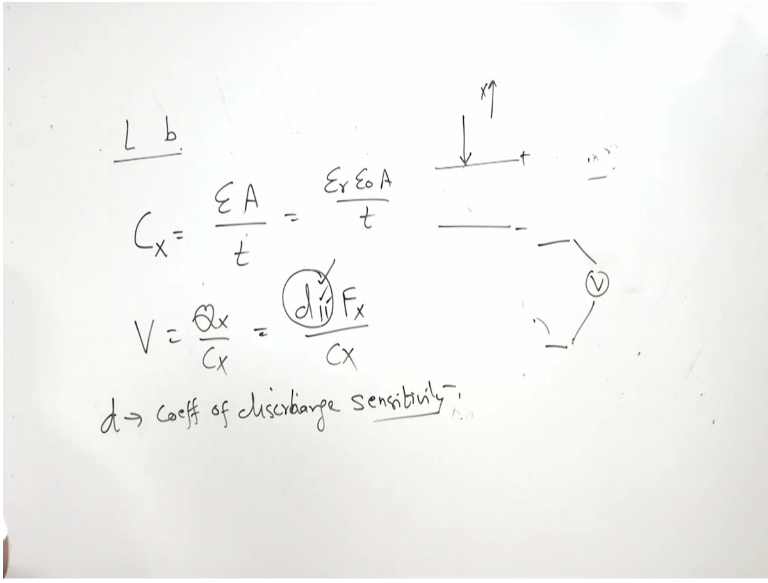

So, V is equal to Qx by Cx right and it is equal to d 11 F x by C x. Now there is a parameter which is d 11 and has come to the picture this is discharge coefficient, this is unique for every material for a particular crystal, these coefficient of discharge sensitivity d is coefficient of dis charge coefficient of discharged sensitivity. Now it has two subscripts 11. 11 means first subscript is electrical effect and second subscript is mechanical effect, it means if force x it is x axis

So, force and charging are on the same axis right. So, it is charging effect and force effect. So, first subscript direction of electrical effect and second for mechanical also so mechanical effect and effect electrical effect are on the same axis. If it is d 12 it means electrical effect in this axis mechanical effect is in this axis. Suppose we charge crystal in like positive and negative the d 12 will indicate the mechanical effect of charge in this axis it will swell or it will shrink. So, here we are taking d 11, it is coefficient of discharge sensitivity.

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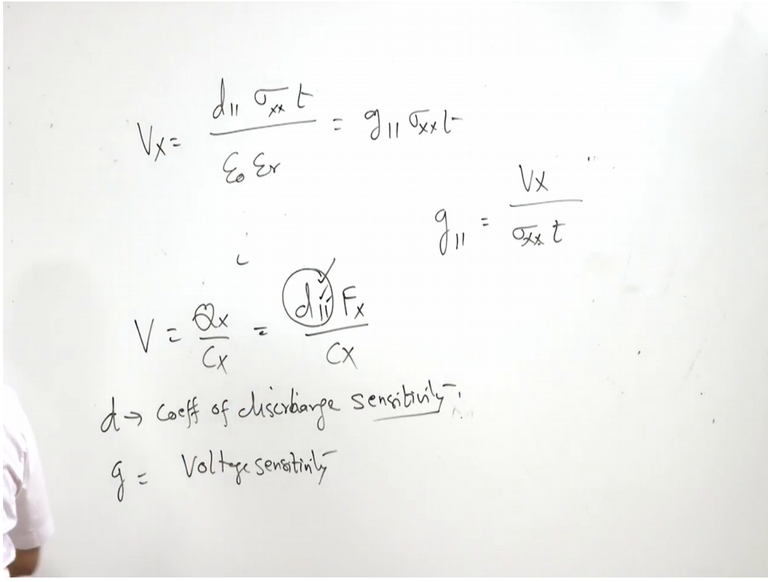

Now once we have coefficient of discharge sensitivity Vx can be written as d 11 sigma t divided by epsilon naught epsilon r now this is V x across x is it clear because sigma is f by a.

So, this epsilon this a this a divided by a that is how we are getting sigma axis and t is already there right. Now it can be replaced by g 11 sigma xxt now there is a another term g 11. So, g 11 is g is voltage sensitivity, it is voltage sensitivity and g 11 is g 11 is equal to V x by sigma xx t right and we are concerned with voltage sensitivity. Now for force in y direction suppose now we have taken force n electric axis and mechanical same you are taking d 11 sorry d 11.

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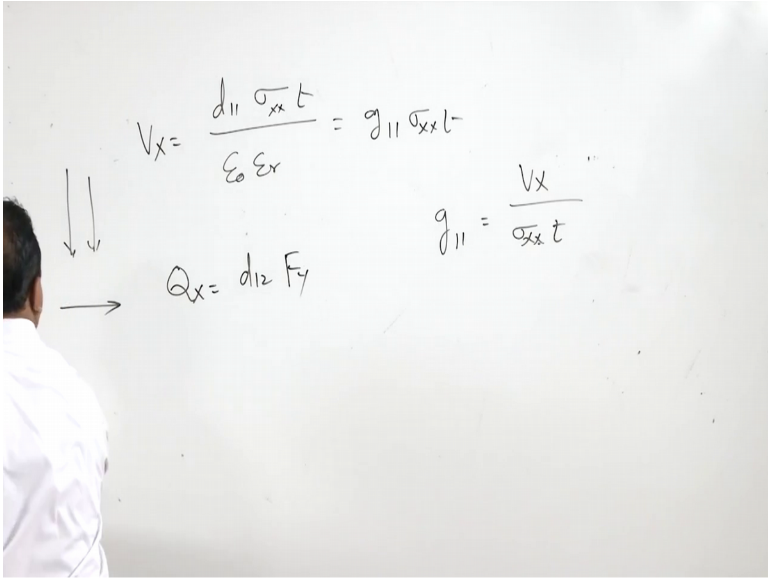

Now in the second case when force is applied in Y axis, charge will charging will be there in the x axis force is applied in the y axis. When the force is applied on the y axis then Qx is equal to d 12 y sorry Fy Fy or.

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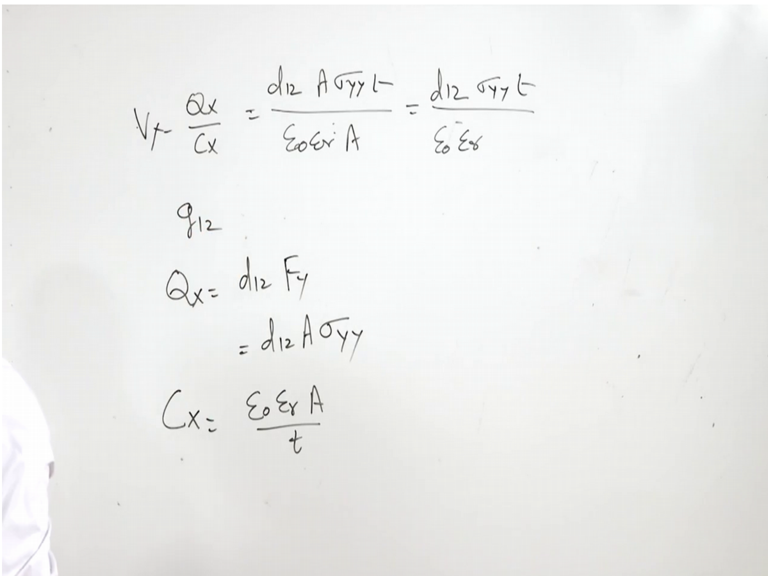

D 12 a sigma yy because the stress is replaced by sigma sorry the force is replaced by stress multiplied by the area. Now Cx is again epsilon naught epsilon r A by t this is formula for Cx. Now V x is equal to again Qx by C x and again d 12 A sigma yy t by epsilon naught epsilon r divided by A then a and a will be considered out and it will be d 12 sigma yy t divided by epsilon naught epsilon r that is it.

Now, from here we can find the value of g 12.

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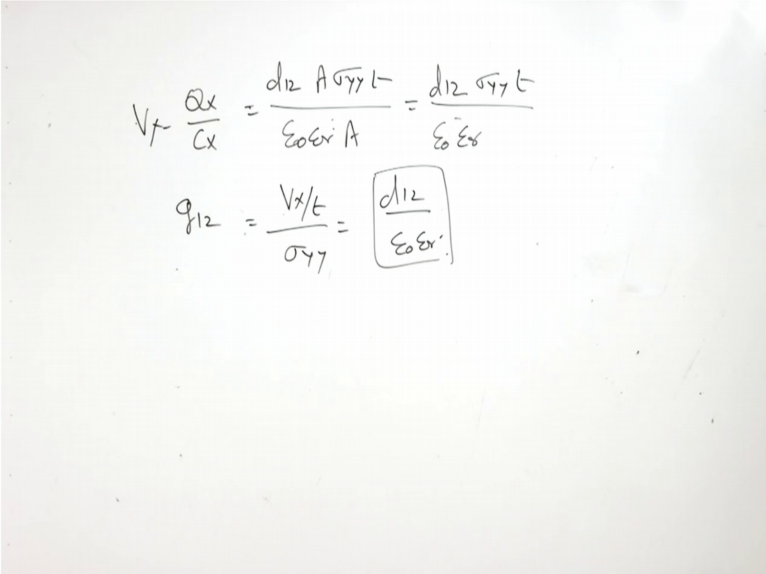

Now g 12 is equal to Vx by t divided by sigma yy and is equal to d 12 divided by epsilon naught epsilon r right; now we will go in the next step we will go for the first rest order, I saw because it is a first order system. So, if we want to have response of piezoelectric crystal, because it is known for a very quick response piezoelectric crystal is known for a very quick response. So, we will do the first order analysis of piezoelectric crystals.

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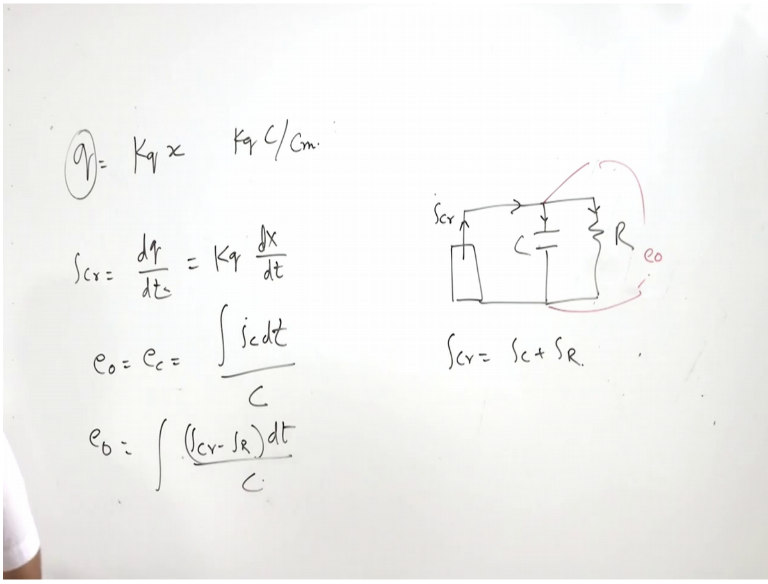

Now Q is equal to K q x where K q is c by d this is the charge c by pulse centimeter q is the charge right and in Piezoelectric system. It is not only crystal now the crystal is collected to a charge amplifier a high impedance amplifier, crystal is also having high impedance, and the cables which are connecting if the cable is quite long, then it will also have certain order of or substantial c or capacitance in it. So, it is a I mean if we want to finalize.

So, a circuit for a piezoelectric transducer, it is going to be like this is current in crystal and that it is it is that RC circuit R and C because there is a capacitance in the cables and then it goes to the amplifier and amplifier is also I mean high impedance amplifier not for the [FL] say amplifier is the a high impedance amplifier impedance of this is also is high capacitance is here. So, we will take current suppose this is crystal current I cr. So, i c r will be divided in two parts one part is will be going into. This another part will be going to. So, this i c r is equal to IC plus IR right.

So, part of the current is going to the capacitance and part of the current is going to the resistance. Now i c r is equal to dq by dt this q because this is the charge which is developed on the crystal. So, this dq by dt is nothing, but K q dx by dt or current is a function of rate of change of the displacement dx by dt. Now here we have emf which is same this is eo which is same ac across three this one this one and C and R. So, eo is equal to ec. Let us take voltage drop across the capacitance this is equal to integral of ic dc divided by c because q is equal to cv it has come from q is equal to cv. So, if you want to have v then q is divided by c and q is integral of ic sorry not dc it is dt ic dt divided by C.

Now this ic dt can further be replaced by eo is equal to ic is i c r and minus ir i c r minus ir multiplied by dt or. So, ir dt divided by c ic minus IR dt divided by c.

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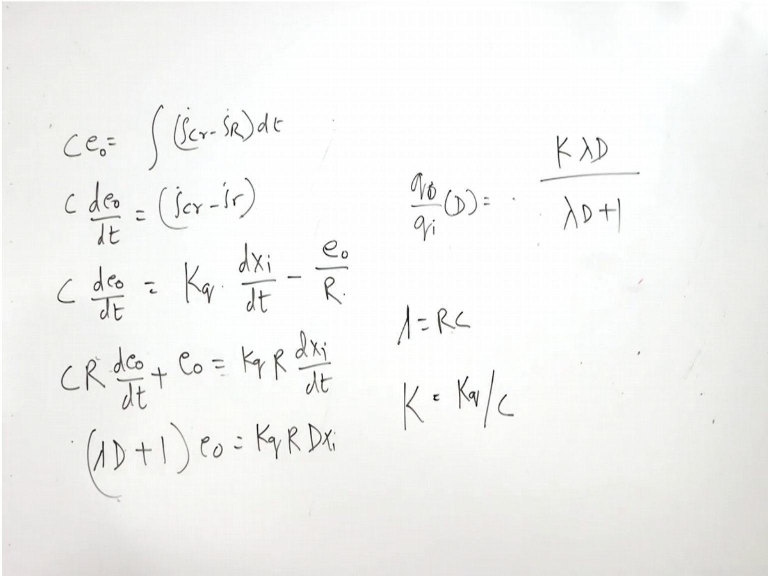

Now we can say that C eo is equal to index integral of i c r minus i R dt now if you differentiate this C eo C e deo by dt is equal to i c r minus ir right i c r is K q dxi by dt this is input displacement dxi minus ir. Ir is again eo by R. Now we are formatting the first standard equation now this is going to be C deo by dt. Now we multiply this by r and will take this to this side then C R deo by dt plus eo is equal to K q R dxi by dt now this cr or rc. So, we can write this as a lambda d plus one eo is equal to K q R Dxi right and if you want to have solution for this then qo by qi output by input, output by input is going to be [FL] K lambda D divided by lambda D plus 1 where lambda is Rc and k and static sensitivity K, K is equal to K q by C because this is because lambda is there.

So, lambda is replaced by this lambda is replaced by c r by c r by c ok. So K q lambda is K q lambda sensitivity k q lambda K q lambda k and lambda now k lambda is replaced by r by cr we are getting this. Now here if you want to have frequency response because not only we require this transient response, we need the frequency response also. So, for the frequency response for the first order system in this case is going to be qo by qi omega lambda whole square divided by 1 plus omega lambda whole square

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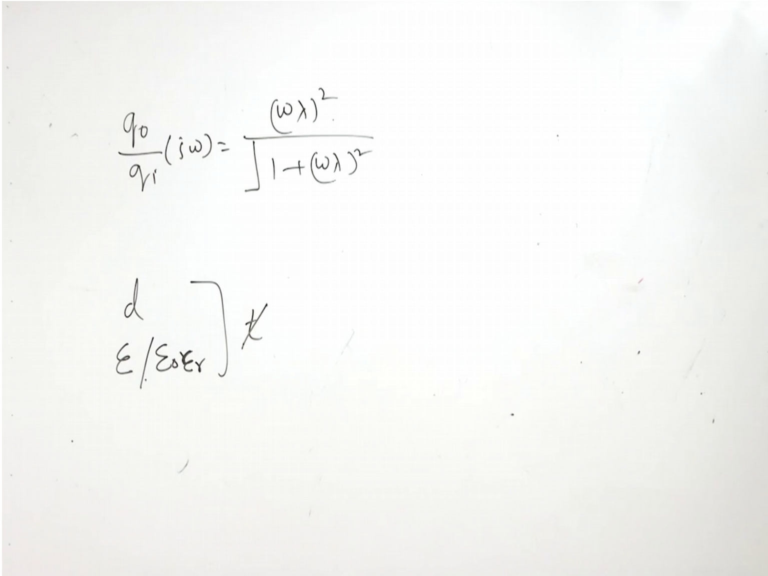

This is going to be the frequency response of this electric piston piezoelectric material. So, in a piezoelectric crystal first of all the charge sensitivity d and per permittivity this or epsilon naught r whatever you want to take epsilon naught r they are not affected by temperature they are not affected by the temperature (Refer Time: 22:12) is; the only material that exhibit large sensitivity in volume expansion mode in z axis and is useful temperature is up to 1000 degree centigrade there is a crystal made of Rochelle salt, because there is another piezoelectric material, which is largely produced for in old age it was used as a pressure pic or pick up for not pressure pickup pick up for the gramophones nowadays a for silicon microphones this salt is being used and they are number of materials piezoelectric materials.

We can have piezoelectric material like eh barium titanate, barium titanate that can also be made eh piezoelectric as a very good piezoelectric response, but if you take the quartz crystal, quartz is quite liable we want to make temperature measurement for the measurement of the temperature it is a quite reliable and for suppose, because temperature measurement in piezoelectric crystal is done with the frequency response right.

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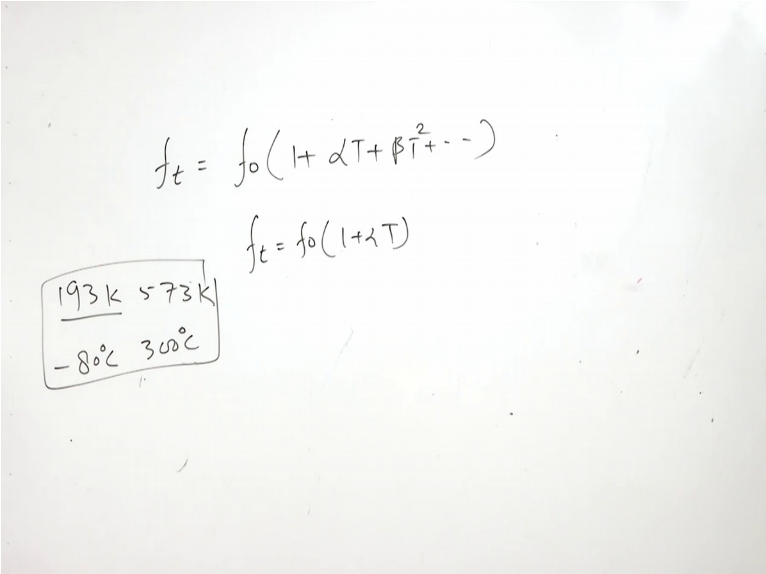

For example, this is the fundamental frequency of the piezoelectric crystal, this is 1 plus alpha T plus beta T square and so on. But if you take the quartz right if you take the quartz it is highly linear in a range of 1 9 in a range of 193 Kelvin to 573 Kelvin or 193 Kelvin means minus 80 degree centigrade to 300 degree centigrade. So, quartz crystal is quite linear and change the frequency is rated with the temperature in the case of quartz crystal and say; if I said linear and it is going to be right fundamental frequency, f is the fundamental frequency temp t is the temperature t is the temperature in degree centigrade.

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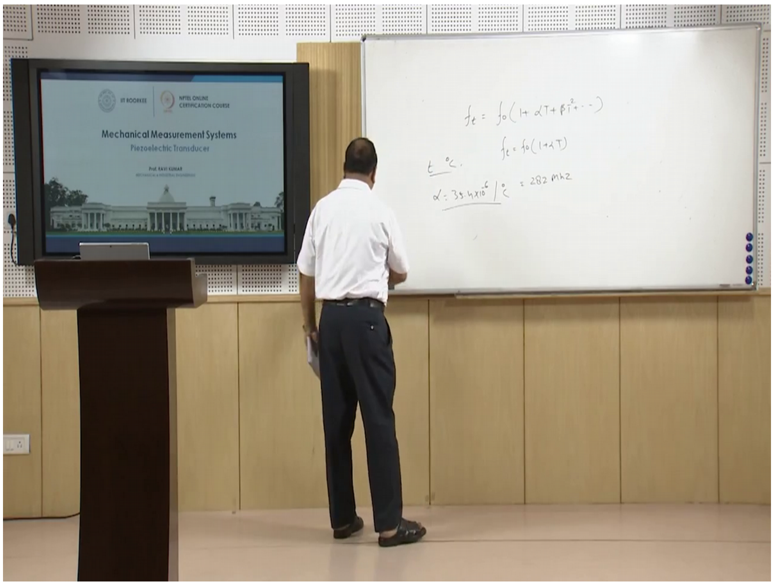

It is not in Kelvin though it is capital pr or written capital, but in temperature and degree centigrade and alpha the value of alpha for quartz is 35.4 into 10 to the power minus 6 per degree centigrade that is the value of alpha for quartz; now for 1 degree centigrade for temperature.

Suppose I want to change temperature by 1 degree centigrade fundamental frequency is 28.2 megahertz that is fo.

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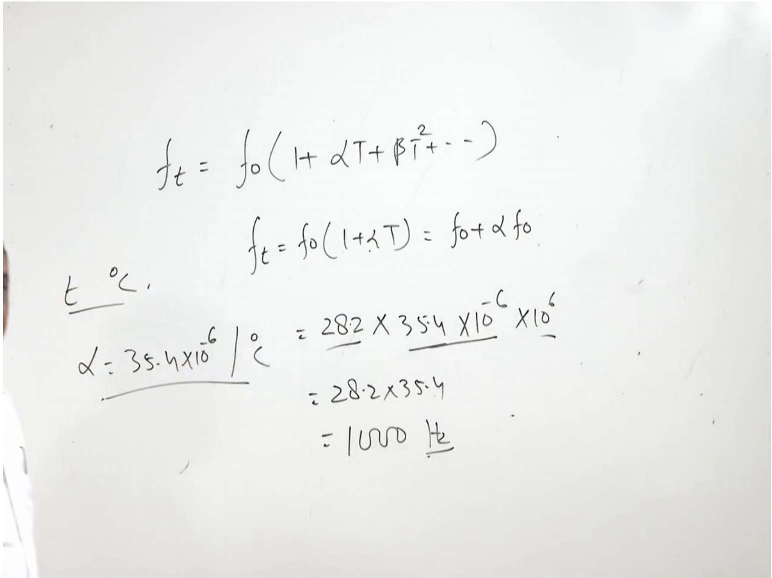

So, fundamental frequencies 28.2 megahertz multiplied by 1 plus alpha t. So, 1 plus alpha t because there is a change in the temperature, we are saying the change in temperature is one degree centigrade. So, the difference change in the frequency or the change in the frequency is going to be multiplied by 35.4 into 10 to the power minus 6 and this is also 28.2 megahertz.

So, it is 10 to the power 6 now I am repeating frequency at a particular temperature is fundamental frequency plus 1 plus alpha T, where T is in degree centigrade. Now suppose there is a change in temperature by 1 degree centigrade. The moment the temperature changes one degree centigrade it becomes fo plus alpha fo right for 1 degree centigrade temperature. Now if you take the difference, then the difference is going to be the alpha fo right.

So, this is basic frequency 28.2 megahertz if we are converted into a hertz, 35.4 is value of alpha into 10 to the power minus 6. If we take multiplication of this 2 28 into and 35.4 it is 998.28 approximately it is 900 or approximately it is 1000 hertz. So, in a piezoelectric crystal is silicon or the silicon oxide or quartz crystal if there is a change in the one degree centigrade temperature, the change in the frequency is 1000 hertz or if we take if 5 digital display, it can give it can read accuracy of measurement as 0.001.

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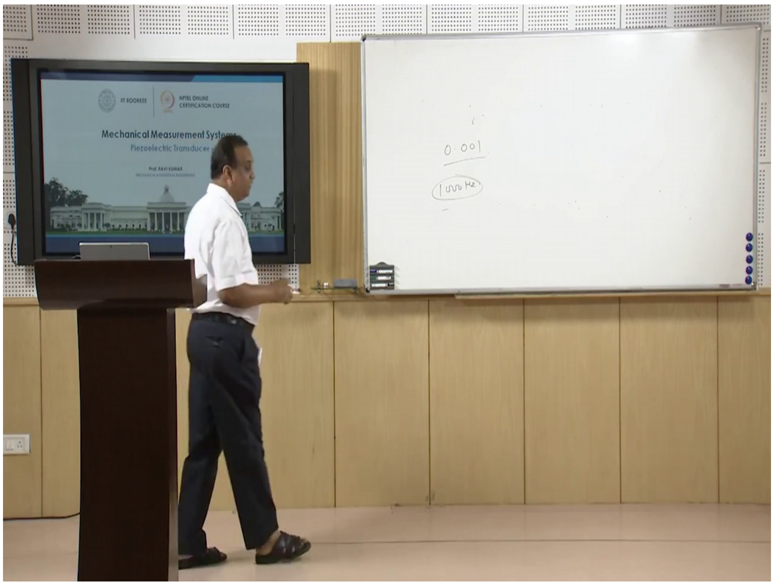

So, with the help of the quartz crystal, we can have the temperature measurement up to the order of because the frequency is changes of frequency is 1000 hertz right. So, we can go up to the temperature measurement or accuracy measurement up to 0.001 degree centigrade.

So, that is the benefit of the quartz crystal we can go for a very high accuracy or temperature measurement of temperature measurement. In addition to their there are many applications for these crystals, not only in the area of instrumentation measurement in physical systems also many places the quartz this property of quartz is used is specially for actuation, actuation of the wrist watch or actuation in many of the mini or micro machines. Now the qa quartz crystal is minus 40 2 to 250 degree centigrade temperature.

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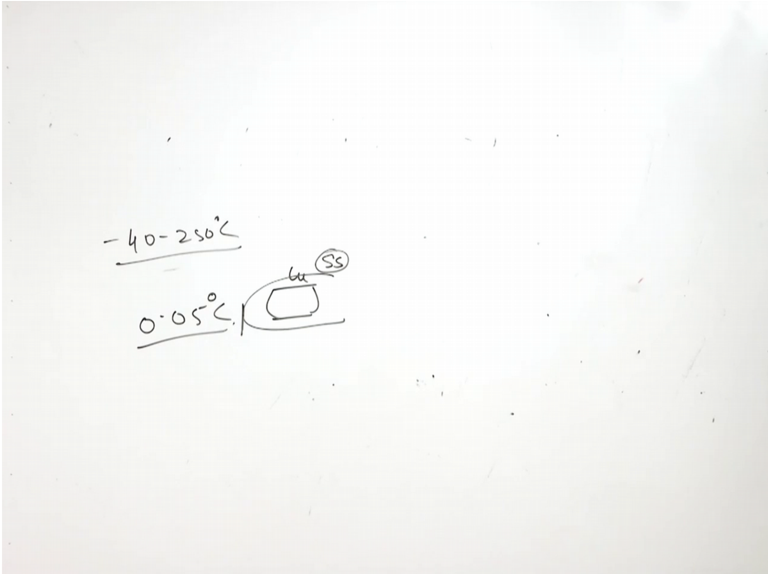

The measurement it is the deviations of the linearity is 0.05 degree centigrade. So, it is quite linear eh as far as the temperature measurement is concerned in and the quartz crystal is placed it is not it does not coming to the direct point of measuring, it is put in a capsule or a cylinder of copper and this cylinder is again put in a tube of stainless steel and this stainless steel tube surface comes into the picture of the measuring. If now we can have bank of piezoelectric effect also if we put two piezoelectric materials or two piezoelectric vapors in series right then they become bimorph.

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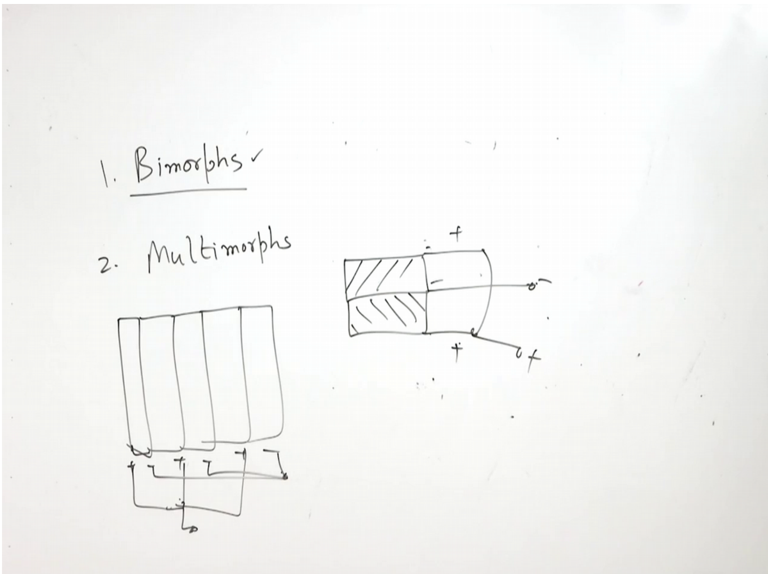

Bimorphs there is one thing and another reason multi morphs bimorph means there are two slices of crystal and they are put side by side mechanically they are in series ok, and they are of two different piezoelectric material. They can be connected in mechanically also they can be I mean electrically also they can be connected in series or they can be connected in this is connected in series eh or they can be connected in parallel then this is this collection and they can be connected in series and they can be connected in this is positive.

So, this is one terminal and this is another terminal. So, this is negative this is positive this is how they are connected in parallel. So, this is a parallel arrangement mechanically they are one by one right one over other. And so, but they can have parallel connection also and they can have series connection also multi morphs, they are number of piezoelectric crystals they are laid side by side and these crystals are connected in parallel. So, all this is plus plus minus plus minus plus minus. So, all plus are connected at one place, and all negative terminals are connected at one place.

So, this is the arrangement of bi morphs and multi bimorphs and multi morphs in piezoelectric crystals that is all for today.

Thank you very much.