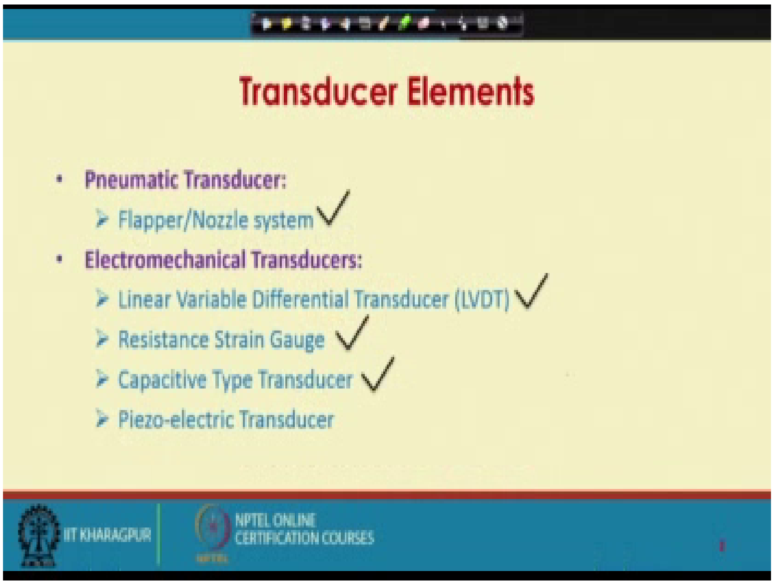
Chemical Process Instrumentation
Prof. Debasis Sarkar
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 20
Transducer Elements (Contd.)

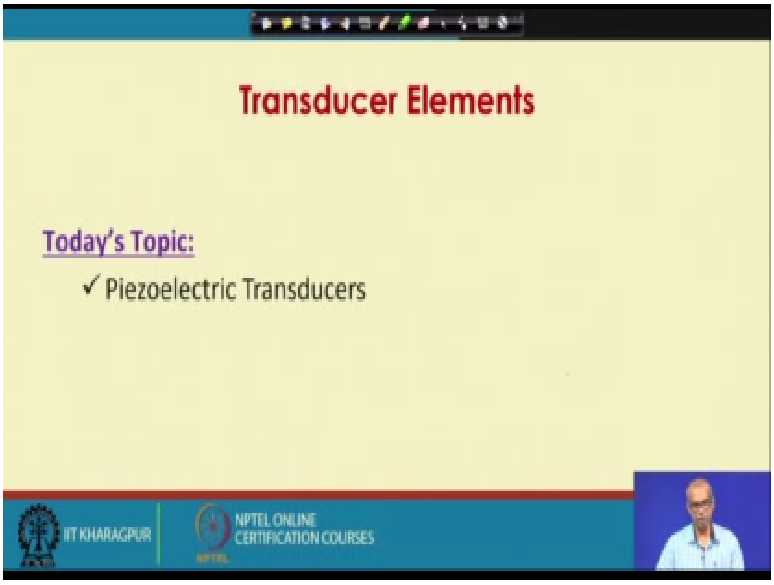
Welcome to lecture 20. So, this is the last lecture of this week and also this is the final lecture for transducer elements.

(Refer Slide Time: 00:33)



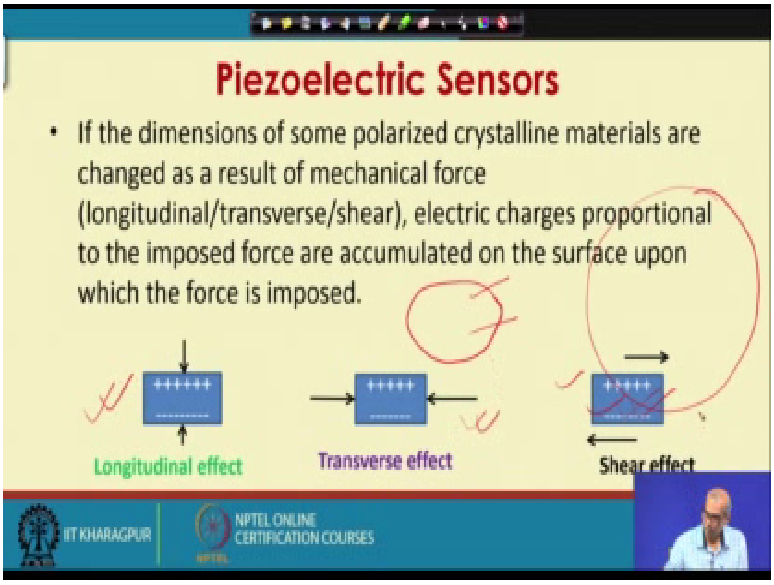
So, as of now we have talked about the pneumatic transducer flapper nozzle system, we have talked about LVDT, we have talked about resistance strain gauge, we have also talked about capacitive type transducer. So, piezoelectric transducer is left.

(Refer Slide Time: 00:57)



And today, we will talk about piezoelectric transducers.

(Refer Slide Time: 01:02)

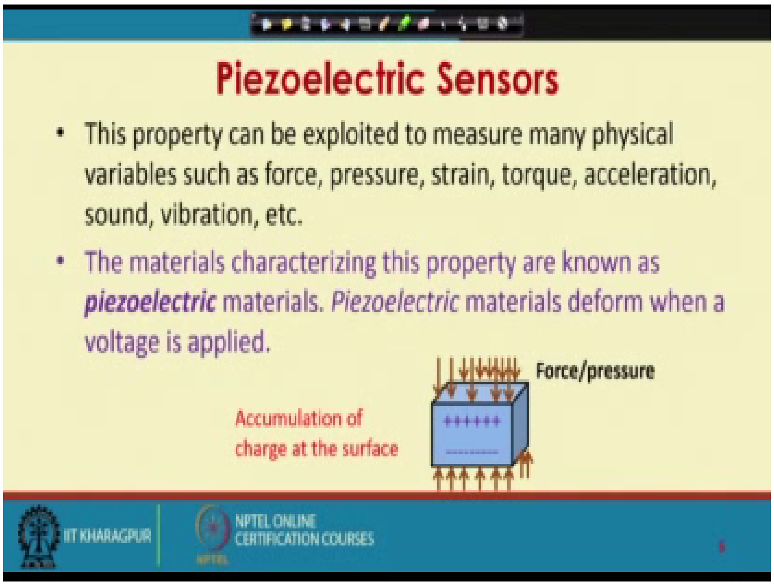


So, let us try to understand what is piezoelectric effect? If the dimensions of some polarized crystalline materials are changed as a result of mechanical force, electric charges proportional to the imposed force are accumulated on the surface upon which the force is imposed.

Say if the dimensions of some polarized crystalline materials are changed as a result of mechanical force, whether it is longitudinal force or transverse force or shear force electrical charges will be accumulated on the surface upon which the forces imposed and the electrical charges accumulated will be proportional to the imposed force, higher are the force more is the charge accumulated.

So, electrical charges are directly proportional to the imposed force. So, this property is seen by some polarized crystalline materials, we call it piezoelectric effect. So, this is schematic of longitudinal effect, transverse effect and shear effect, so under each of this effect there will be accumulation of charges and this accumulated charge is proportional or directly proportional to the imposed force.

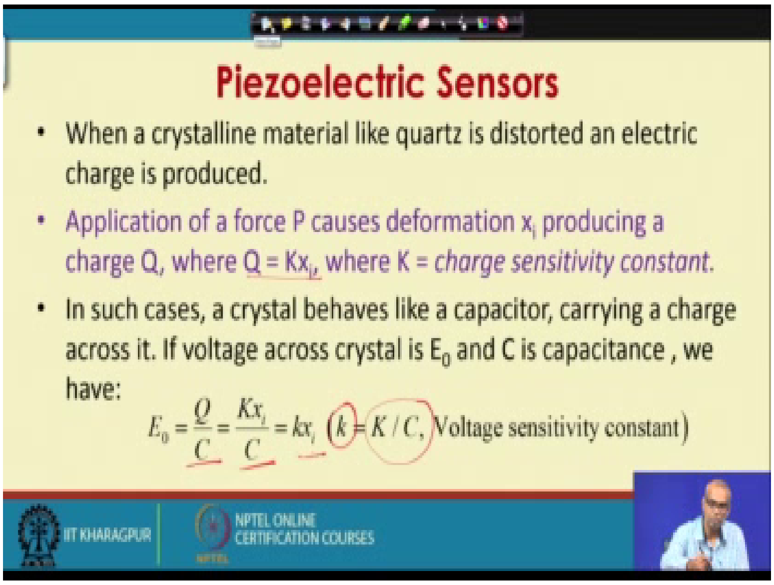
(Refer Slide Time: 03:08)



This property can be exploited to measure many physical variables such as; force, pressure, strain, torque, acceleration, sound, vibration etcetera. The materials characterizing this property are known as piezoelectric materials piezoelectric materials deform when a voltage is applied; that means, these properties invertible, so a piezoelectric material when deform there will be accumulation of surface charges. Similarly when voltage will be applied on the piezoelectric material the piezoelectric material will be deformed, later on will briefly talk about that using this property ultrasonic transmitters can be generated.

So, this schematic shows accumulation of charge at the surface due to application of force or pressure.

(Refer Slide Time: 04:26)

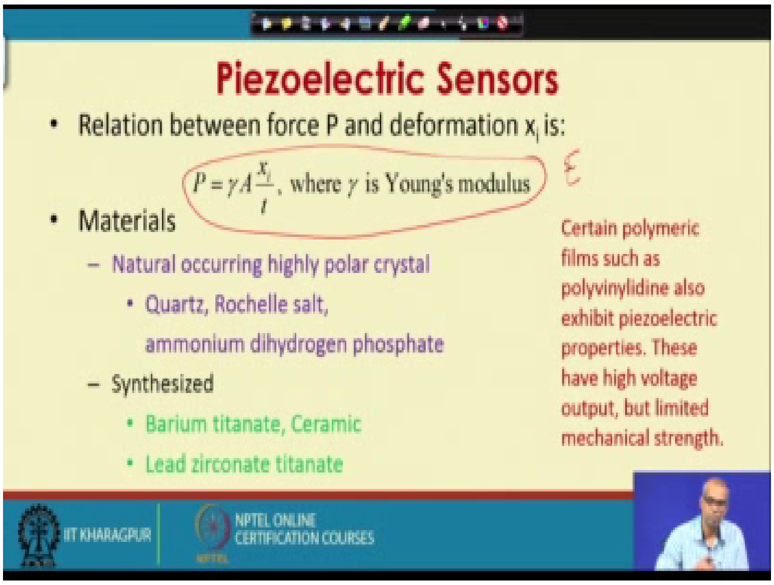


When a crystalline material like quartz is distorted an electrical charge is produced, application of a force P causes deformation x i producing a charge Q, so Q is directly proportional to force P and the deformation is also proportional to amount of force that is being imposed, so you can write charge Q is proportional to the deformation x i, so Q equal to K x i where K is known as charge sensitivity constant.

In such cases; a crystal behaves like a capacitor carrying a charge across it, a voltage across crystal if voltage across crystal is E 0 and C is capacitance, we can write E 0 equal to Q by C, the voltage is charge divided by capacitance the charge Q is charge constant times deformation, so Q by C can be represented as K x i by C; let us define a new constant, which is charged sensitivity constant divided by capacitance which is represented by small k known as voltage sensitivity constant. So, there are two constants charge sensitivity constant and voltage sensitivity constant.

So, the voltage E 0 that is formed across the crystal is equal to the voltage sensitivity constant and multiplied by the deformation x i.

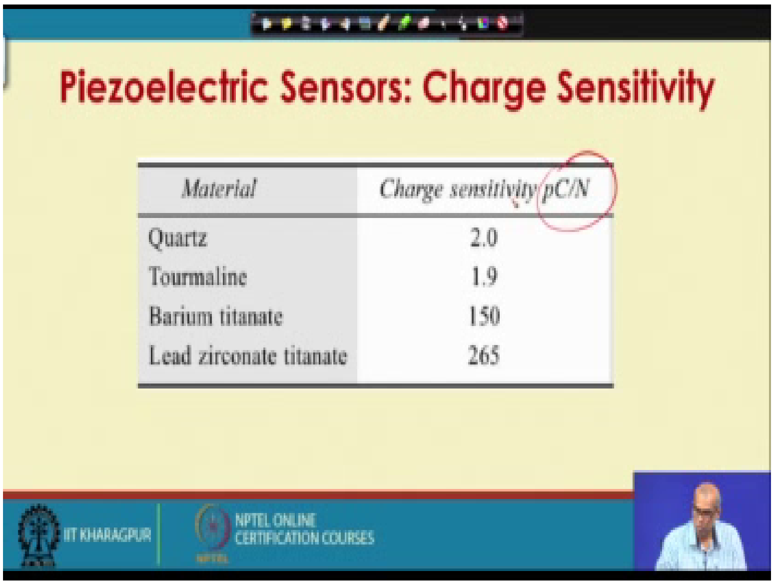
(Refer Slide Time: 06:47)



Relation between force P and the deformation x i can be obtained using this; which says, the force P equal to gamma which is young's modulus you can also write it or represent it by E times area, times deformation divided by t which is thickness of the piezoelectric material.

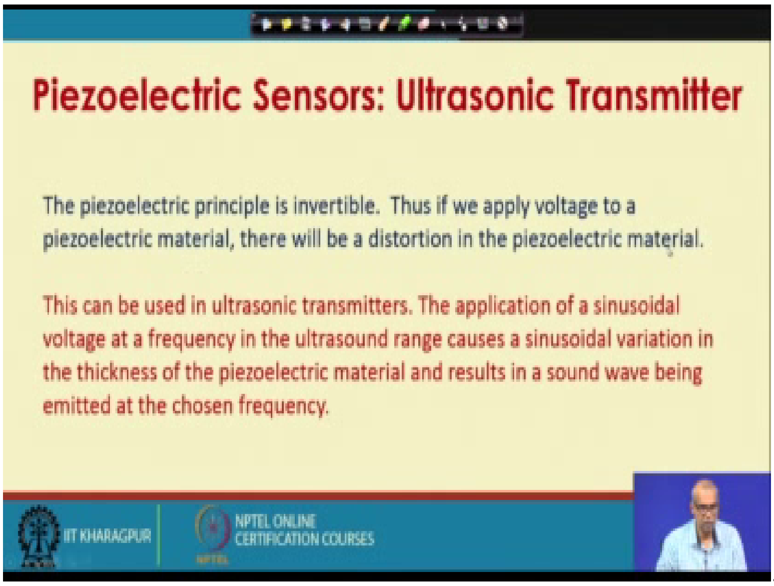
Materials that show piezoelectric effects are naturally occurring as well as we have synthesized materials, so naturally occurring highly polar crystals such as; quartz Rochelle salt, ammonium dihydrogen phosphate, piezoelectric property. Synthesize materials such as; barium titanate, ceramic, lead zirconate titanate, also show piezoelectric properties, certain polymeric films such as polyvinylidine also exhibit piezoelectric properties. Such polymeric materials have high voltage output, so that is an advantage, but they have very limited mechanical strain which is a disadvantage.

(Refer Slide Time: 08:50)



Here I will report some charge sensitivity values for common piezoelectric materials. Note that: The value varies widely. The charge sensitivity expressed as; Pico coulomb per newton, for quartz it is 2 whereas, for Lead zirconate titanate it is 265. Note the unit of charge sensitivity, this is unit of charge divided by unit of force, so coulomb or Pico coulomb divided by newton.

(Refer Slide Time: 10:00)

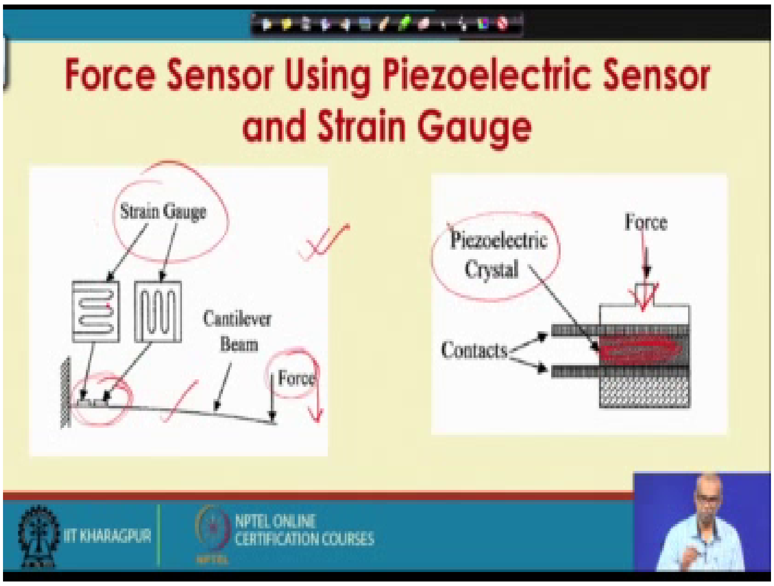


The piezoelectric principle is invertible, thus if we apply voltage to a piezoelectric material there will be a distortion in the piezoelectric material. So, when a force is applied to piezoelectric material, charge is produced or accumulated on the surface it behaves like a capacitor.

Now if I apply voltage to the piezoelectric material there will be a deformation or distortion in the piezoelectric material so the properties invertible, this can be used in ultrasonic transmitter's ultrasonic transmitters generate ultrasound.

The application of a sinusoidal voltage at a frequency in the ultrasound range causes a sinusoidal variation in the thickness of the piezoelectric material and results in a sound wave being emitted at the chosen frequency. So, the application of a sinusoidal voltage at a frequency in the ultrasound range causes a sinusoidal variation in the thickness of the piezoelectric material and results in a sound wave being emitted at the chosen frequency.

(Refer Slide Time: 11:46)

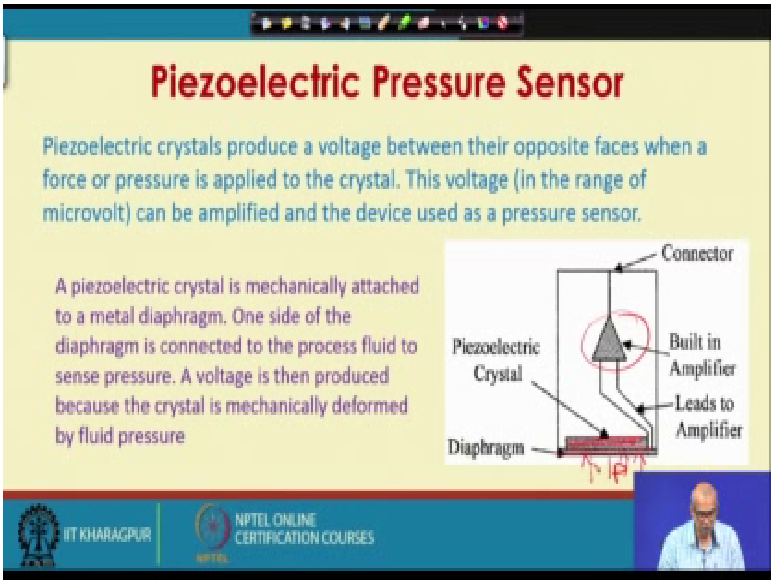


We can, create a force sensor using a piezoelectric sensor; we can also create a force sensor using a strain gauge. Look at this schematic this is cantilever beam I am applying a force on this end of this cantilever beam; I want to measure this force.

So, what I can do is? I can attach strain gauge here; this cantilever is under strain due to application of this force, so when I attach strain gauge the strain gauge wires will also undergo strain. So, there will be change in resistance of the strain gauge wires, this strain gauge will be connected to the Wheatstone bridge and the change in resistance can be measured using the bridge circuit. So, the force can be related to the output voltage from the bridge circuit.

Similarly, I can also make use of piezoelectric sensor to measure force. I take piezoelectric crystal here, so let us imagine between two plates I have taken piezoelectric crystal, now I apply force from one side when we apply force the piezoelectric material or this piezoelectric crystal is deformed, so the surface charge will be accumulated it will behave like a capacitor and I can measure this charge or we can measure the output voltage using a bridge circuit. So, both strain gauge and the piezoelectric crystal can be used to measure force piezoelectric sensors.

(Refer Slide Time: 15:10)



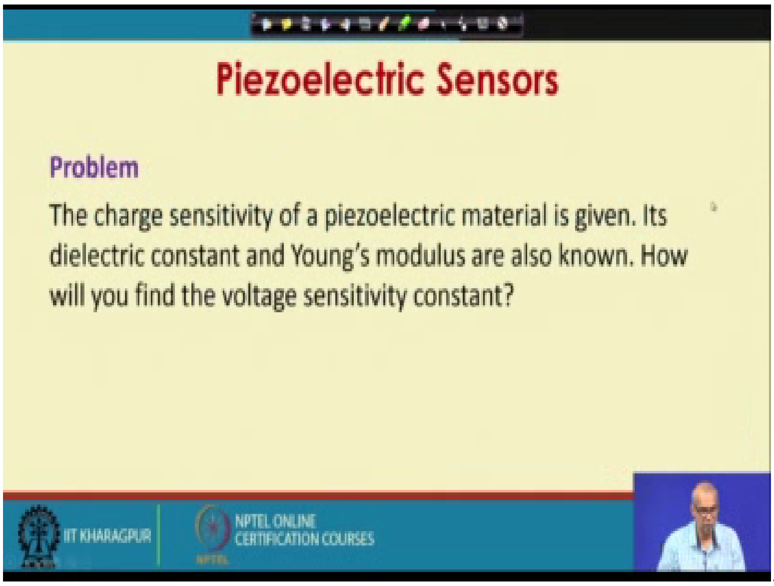
Piezoelectric sensors can also be used to measure pressures, we will call them piezoelectric pressure sensors, piezoelectric crystals produce a voltage between their opposite faces when a force or pressure is applied to the crystal, these voltage which is in the range of microvolt can be amplified and the device can be used as a pressure sensor.

So, the piezoelectric crystals will produce a voltage because the surface charge will be accumulated when we apply pressure, see force and pressure are related. So, when you apply pressure when you apply pressure on the surface of a piezoelectric crystal a force will be deformed develop, so that will deform the piezoelectric crystal surface charge will be accumulated and a voltage between these faces will be develop, this is a very small voltage it is in the range of microvolt, so this can be amplified using suitable amplifier and then the device can be used as a pressure sensor.

So, the pressure can be related to the output voltage. Look at the schematic; so this is the piezoelectric crystal and this is a diaphragm, so piezoelectric crystal is attached to the diaphragm, we apply pressure here the diaphragm this is the pressure it converts the pressure to a force, so piezoelectric crystal is now under force there will be deformation and there will be surface charge accumulated a voltage will be developed with which can be amplified using a built in amplifier and this voltage can be considered as a measure of this pressure.

So, piezoelectric crystal is mechanically attached to a metal diaphragm, one side of the diaphragm is connected to the force to the process way it to sense pressure, a voltage is then produced because the crystal is mechanically deformed by fluid pressure.

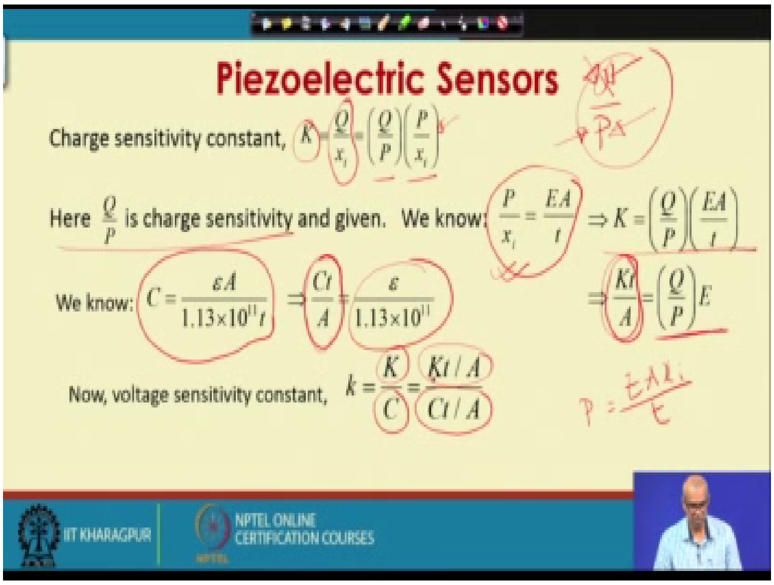
(Refer Slide Time: 18:00)



Let us consider a numerical problem. In fact; there is no data here, but we just show you how will you compute the voltage sensitivity constant if you know the charge sensitivity of a piezoelectric material and also if you know the dielectric constant and young's modulus of the piezoelectric material.

So, the charge sensitivity of a piezoelectric material is given, it is dielectric constant and young's modulus are also known. How will you find the voltage sensitivity constant?

(Refer Slide Time: 19:00)

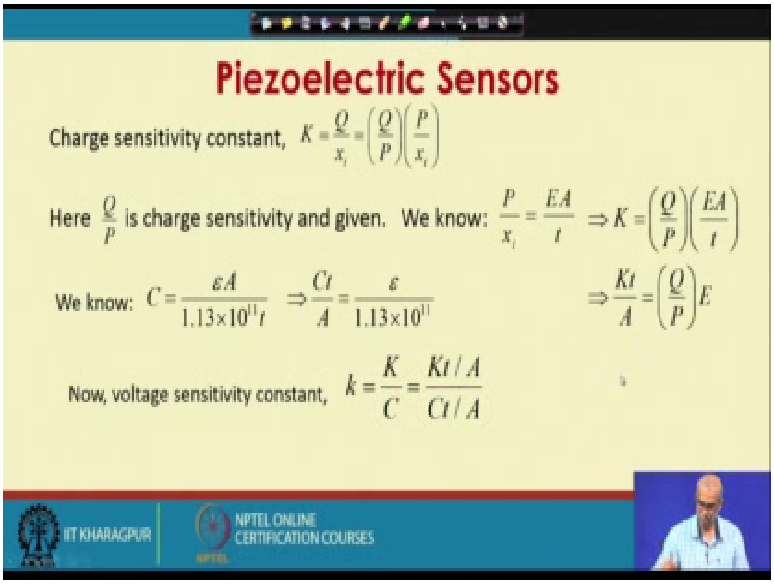


We know the charge sensitivity constant, the charge sensitivity constant K capital K is Q divided by x I, which is charge accumulated divided by the deformation. I can rearrange Q by x i as Q by P into P by x i. Note: Q by P, it is charge accumulated on the surface of the piezoelectric material upon application of pressure or force.

So, Q by P is basically charge sensitivity Q is output P is input, so Q by P is charge sensitivity and is given. Now if we remember P by x i can be computed from; P equal to modulus of elasticity a deformation divided by thickness formula that we talked about. So, I make use of this relationship here, so the charge sensitivity constant K can be written as Q by P into E A by t for P by x i.

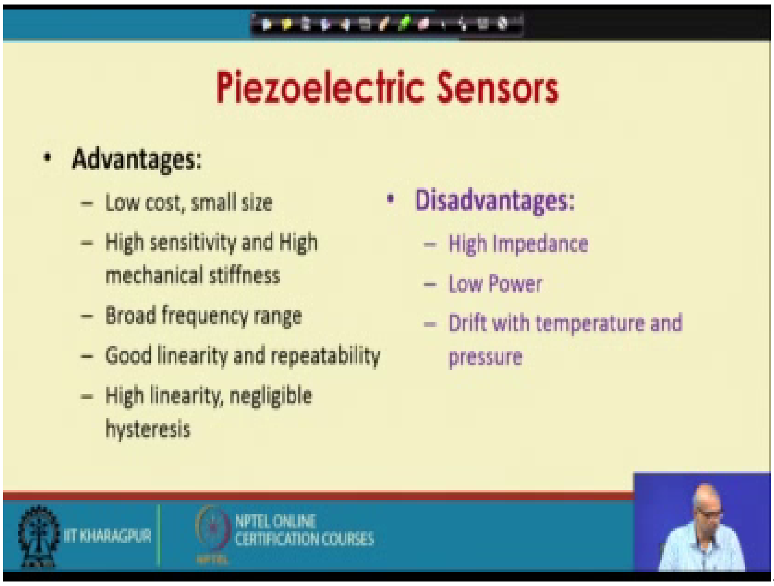
So, K time's thickness of the piezoelectric material divided by area can be written as; Q by P time's modulus of elasticity, similarly we know the expression for charge sorry expression for capacitance. So, from here we can find out capacitance time thickness divided by area as this, now voltage sensitivity constant is charged sensitivity constant divided by capacitance which can be obtained as; K t by A divided by C t by A, so t and A will cancel out which will be capital K by C which way definition is voltage sensitivity constant.

(Refer Slide Time: 23:10)



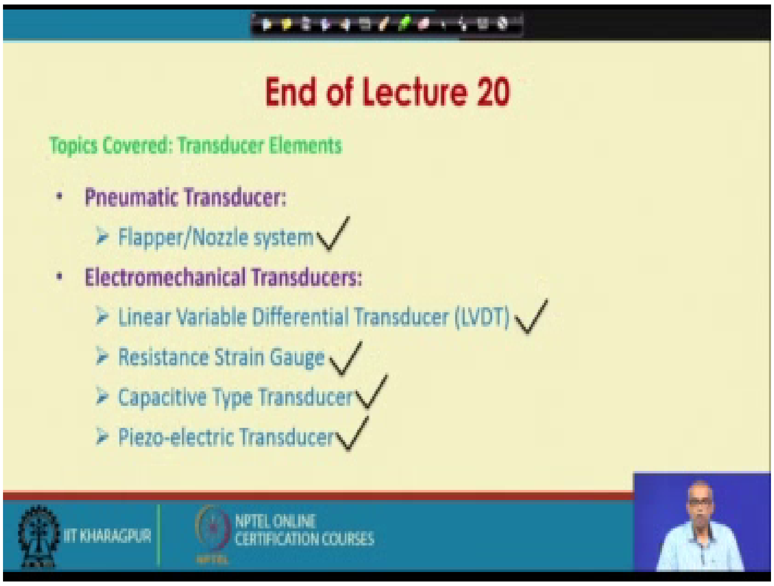
So, if charge sensitivity Q by P is given and you know the modulus of elasticity, you can find out the voltage sensitivity constant.

(Refer Slide Time: 23:14)



Let us look at the advantages of piezoelectric sensors; they are low cost, they are small sizes, they are very high sensitivity and high mechanical stiffness, they have a broad frequency range, they have good linearity and repeatability, they have negligible hysteresis, certain disadvantages are high impedance low power and drift with temperature and pressure. So, there will be error associated with temperature and pressure changes.

(Refer Slide Time: 24:14)



So, this is the end of lecture 2; In this lecture we covered transducer elements as major topic, under transducer elements we talked about pneumatic transducers, flapper nozzle systems and then we talked about various electromechanical transducers, we talked about linear variable differential transformer LVDT, we also talked about potentiometer briefly then you talked about resistance strain gauge, we talked about capacitive type transducers we also talked about piezoelectric transducers. So, this ends our discussion on transducer elements and now you will be given assignments on transducer elements.