Chemical Process Instrumentation
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Lecture – 19
Transducer Elements (Contd.)

Welcome to lecture 19. We are talking about transducer elements. In last 3 lectures we have talked about flapper nozzle systems which are a pneumatic transducer, then we talked about LVDT or Linear Variable Differential Transformer which is electromechanical displacement measuring transformer or transducer and then in our previous lecture, we talked about strain gauge which is again electromechanical transducer which measures strain or displacement or force torque etcetera. Today we will talk about another electromechanical transducer.

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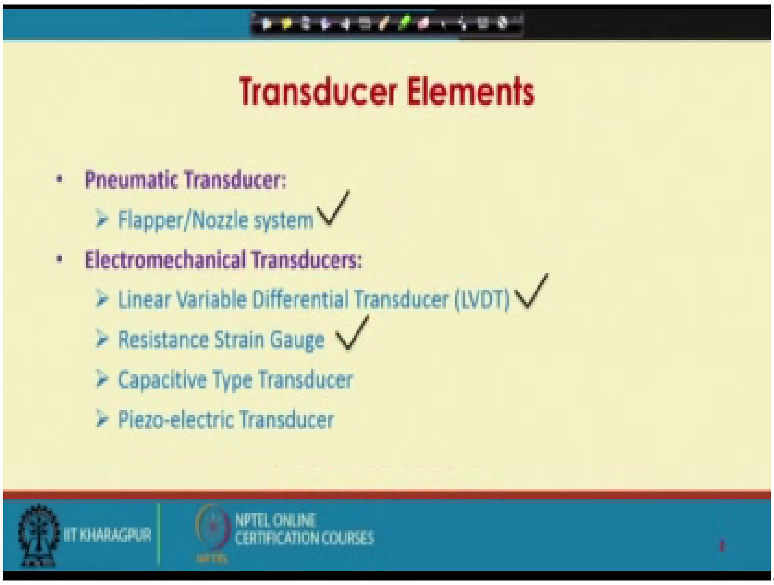

So, these tic marked are the items we have covered. So, the remaining is capacitive type transducer and Piezo-electric transducer.

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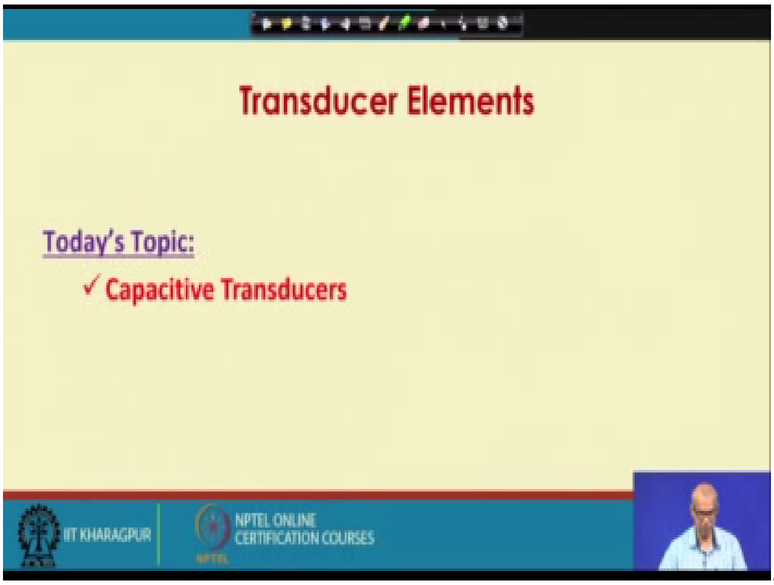

So, today we will talk about capacitive transducers.

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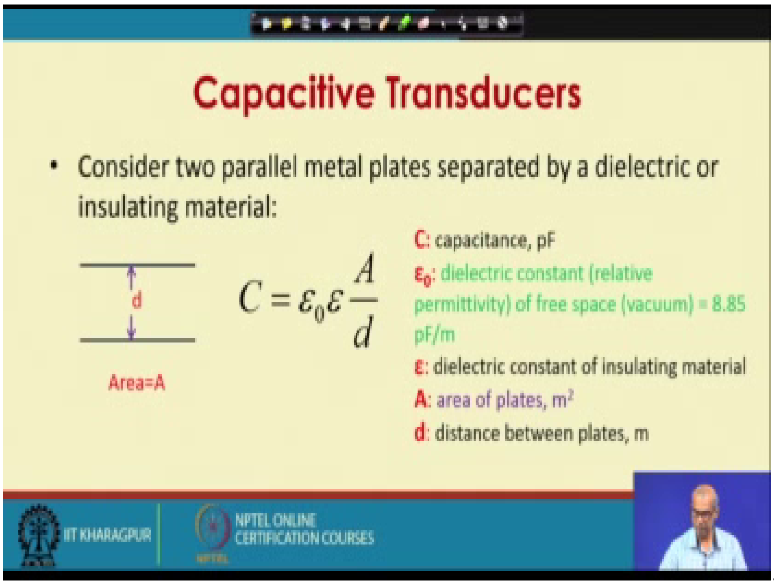

Consider 2 parallel metal plates separated by a dielectric or insulating material. So, there are 2 metal plates, they are separated by a distance d, this area equal to A and they are separated by a dielectric or insulating material. So, a dielectric or insulating material is in between these 2 plates. The capacitance under such circumstances you know can be expressed as the equation shown, where C is capacitance in picofarad epsilon 0 is dielectric constant or relative permittivity of free space or vacuum it is 8.85 picofarad per meter, epsilon is dielectric constant of insulating material, A is area of plates expressed in meter square and d distance between plates, meter.

So, there will be a capacitance when 2 parallel metal plates are separated by a dielectric on insulating material and the capacitance depends on the dielectric material, it depends on the area of plates and it also depends on the distance by which these 2 plates are separated.

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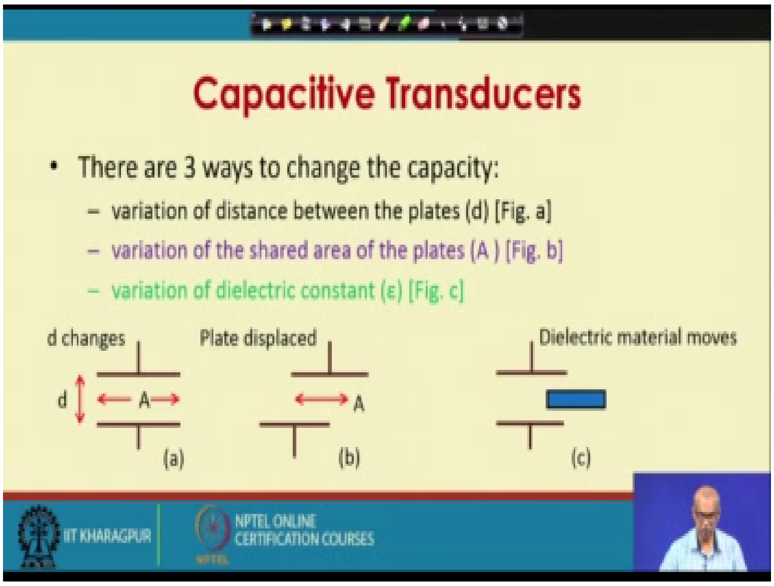

There are 3 ways to change the capacity; variation of distance between the plates, so, if you change d the capacitance will change. Variation of the shared area of the plates, so, if you change A by displacing the plates there will be change in the capacitance. You can also change the capacitance by variation of dielectric constant. So, take different dielectric or insulating material between the plates there will be different capacitance. So, by adopting any of these 3, we can change the capacitance.

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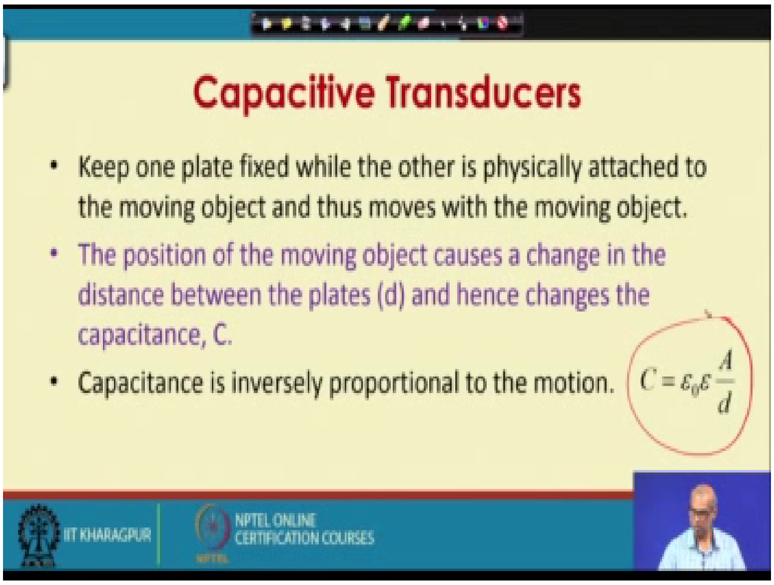

So, if we keep now one plate fixed while the other is physically attached to the moving object, the plate will also move with the moving object. The position of the moving object causes a change in the distance between the plates and hence changes the capacitance. As we have seen the capacitance depends on the distance that exists between these 2 metal plates. So, if I now keep one plate fixed and attach the moving object with another plate with change in the moving object; that means, change in the location of the moving object or it is change in the motion, the moving object will change it is location. As the moving object change changes it is location the distance between the fixed plate and the moving plate will be different. Accordingly, a capacitance will be changing.

So, by measuring the capacitance it should be possible to measure the distance between the 2 plates. In other words this becomes or change in the capacitance becomes a measure of the displacement. Capacitance is inversely proportional to the motion. Note that; capacitance is inversely proportional to the distance between the 2 plates and the distance between these 2 plates is determined by the displacement of the motion of the moving object. So, that is why you write capacitance is inversely proportional to the motion.

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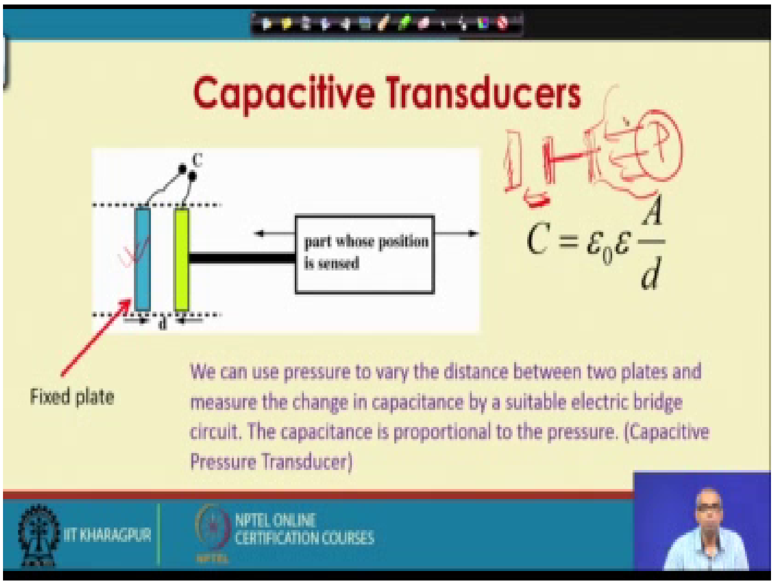

So, this is represent as schematically. So, this is one plate, this is another plate. Let us keep this plate fixed and this plate be attached to the moving object. So, as the object moves in this direction the distance between the 2 plates represented as d increases. So, as d increases, the capacitance decreases. As the moving object moves in this direction, the distance between the fixed plate and the moving plate decreases. As d decreases, the capacitance increases. Note here, that these terms are not changing for this 2 metal plates or capacitors. What we can also do is, we can apply pressure onto this plate. I keep this plate fixed as we discussed now, instead of connecting these with a moving object let us say, I connect this to a fluid source whose pressure needs to be measured.

So, that can be done let us say this is my fixed plate and this is the moveable plate and this is say connected to a diaphragm like this and here I apply fluid pressure. So, as I apply pressure this force as I apply pressure here on to this diaphragm surface a force will be developed that force will be transmitted by this connecting rod and that will cause this moveable plate to change its position. In other words, when I apply higher pressure, this will come forward closer to the fixed plate. If I now decrease the pressure it will go away from the fixed plate. In other words by changing the pressure here, I can change the distance d between the fixed plate and the movable plates. So, accordingly a capacitance will be formed. So, the change in capacitance can be considered as a measure of pressure.

So, this now becomes capacitive pressure transducer. So, we can use pressure to vary the distance between 2 plates and measure the change in capacitance by a suitable electric bridge circuit. The capacitance is proportional to the pressure. We will call such an arrangement Capacitive Pressure Transducer.

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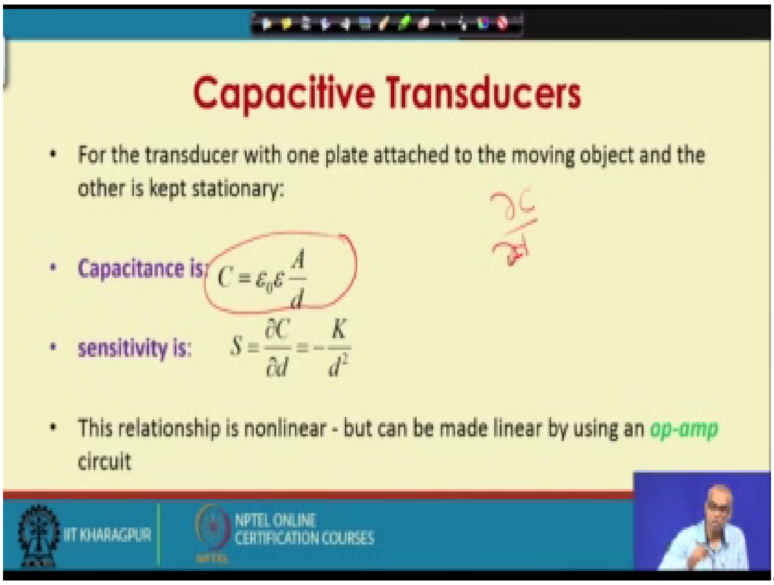

For the transducer with one plate attached to the moving object and the other is kept stationary we can express the capacitance by this expression. Now, the sensitivity if you remember, it is the change in output divided by change in input. Output from the capacitance, output from the capacitive transducer is capacitance and the input is let us say, the distance between these 2 plates. So, a measure of sensitivity will be change in capacitance with respect to change in distance between these 2 plates.

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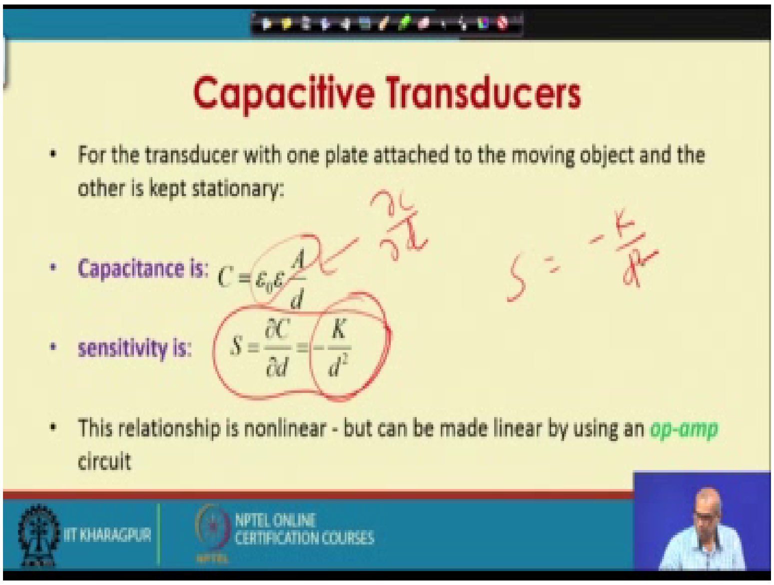

So, the measure of sensitivity is del C del d. So, if you take del C del d, you will get minus K by d square, where minus K incorporates all these parameters. Please note that, the sensitivity relationship is non-linear with distance. S is some constant minus some constant divided by d square. So, it is a non-linear relationship, but it can be made linear by using an op-amp circuit, operational amplifier circuit.

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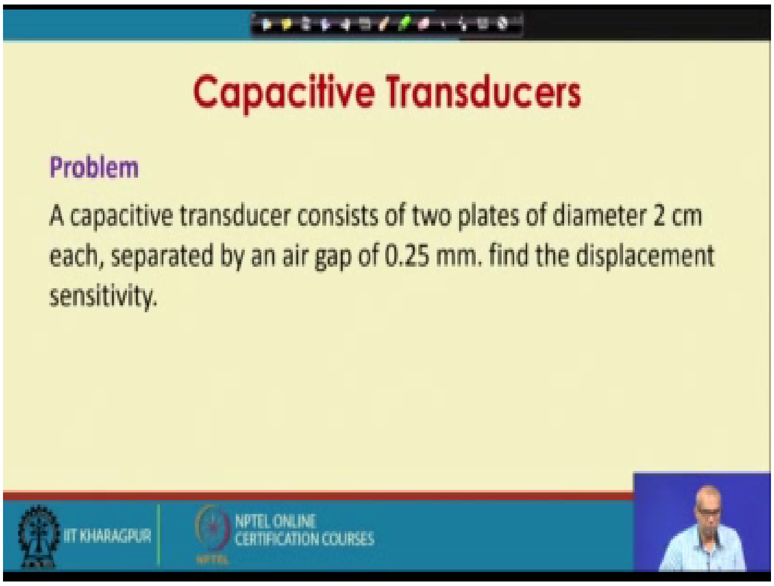

Now, let us consider a very simple problem. I have a capacitive transducer consists of 2 plates of diameter 2 centimetre each, separated by air gap of 0.25 millimetre. Find the displacement sensitivity. So, basically you have to find out del C del d. So, we have a capacitive transducer which consists of 2 plates of diameter 2 centimetres each. So, this statement will allow you to find out area. These 2 plates are separated by an air gap of 0.25 millimetres. Find the displacement sensitivity.

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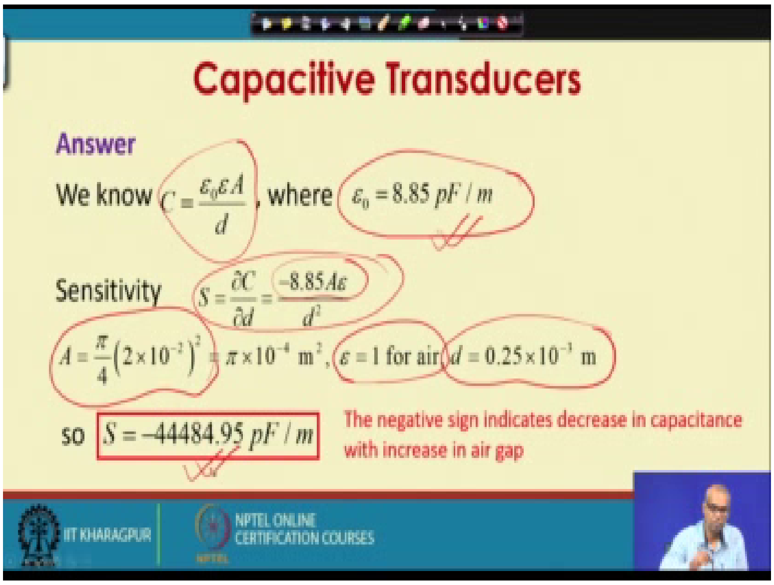

So, you know this expression for capacitance. We need to know this epsilon 0 is 8.85 picofarad meter, sensitivity is del C del d. So, you remember we wrote minus K by d square. So, that K is minus epsilon 0 epsilon into A, so, minus 8.85A into epsilon. So, you need to know epsilon is 1 or 1.0006 for air; epsilon 0 is this is for vacuum, this is for air and A can be computed as pi d square by 4 the distance between these 2 plates are given. If I put all these values to this expression for sensitivity I get the sensitivity as minus 44484.95 picofarad per meter. The negative sign here indicates that the capacitance will decrease with increase in air gap because the relationship is inverse.

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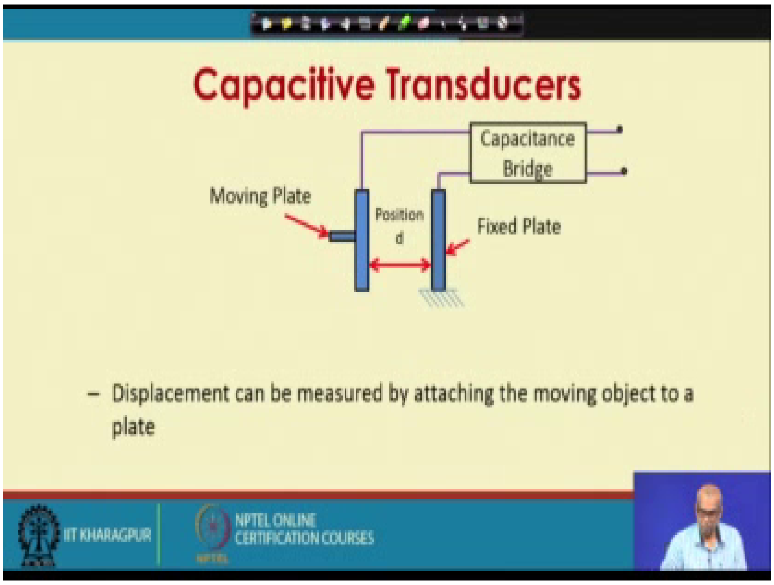

So, the displacement can be measured by attaching the moving object to a plate.

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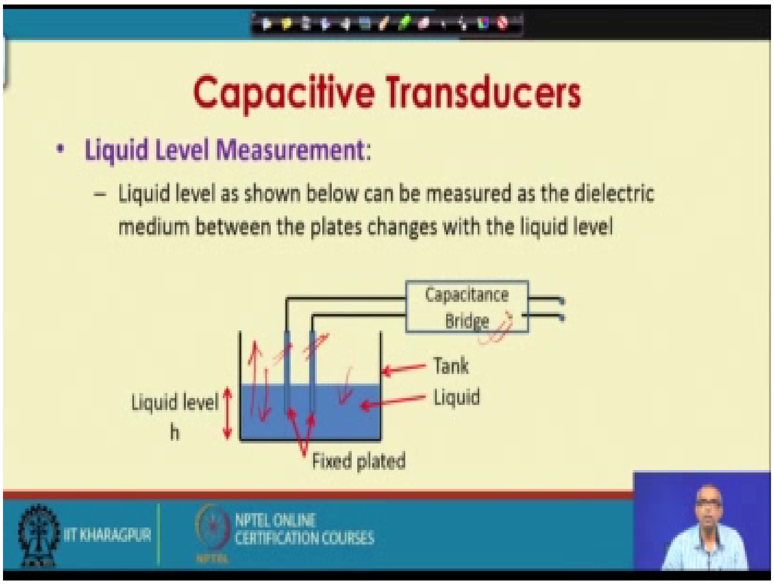

Capacitive transducers can also be used to measure liquid level. Liquid level as shown below can be measured as the dielectric medium between the plates change with change in liquid level. So, we have 2 plates that form capacitive transducer. Here, both the plates are kept fixed. Suppose, we wish to measure the liquid level in a tank, so, we put these 2 plates into the tank and these 2 plates are kept fixed. So, the distance between these 2 plates are fixed. Now, this liquid in the tank will change its level depending on the amount of the liquid in the tank.

So, as the liquid level goes up or comes down the dielectric medium between these 2 plates will increase or decrease. So, the dielectric medium between 2 fixed plates will change with change in liquid level. So, that will cause a change in the capacitance. We have seen the capacitance depends on area of the plates, it depends on the distance between these 2 plates and it also depends on the dielectric medium. By keeping one plate fixed and attaching the other plate with the moving object, we can measure the displacement. That is what we have seen in last few slides.

There the change of capacitance with changing distance was used. In case of liquid level measurement we make use of the relationship between the change in capacitance with change in dielectric medium because here the distance between the 2 plates are fixed. So, it is the dielectric medium that changes between the plates as the liquid level changes. So, capacitive transducers can become a very good liquid level measurements and it is a very common liquid level measuring instrument.

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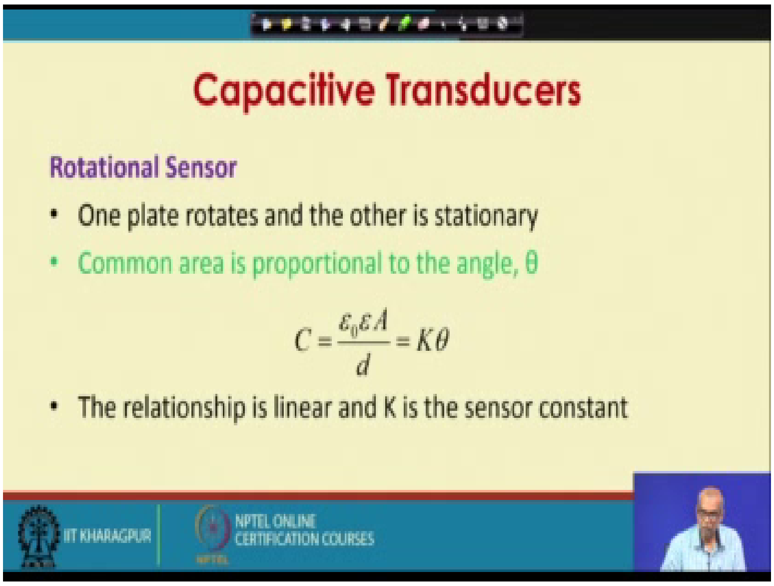

Rotational sensor; one plate rotates and the other is stationary. Common area is proportional to the angle theta. So, capacitance is proportional to angle theta. The relationship is linear and K is the sensor constant and K is the combination of these other parameters.

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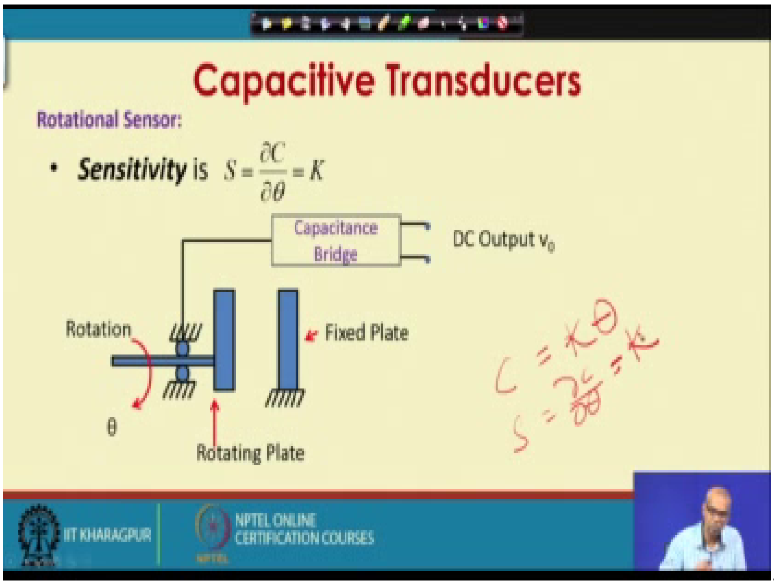

So, this is the schematic of the rotational sensor. So, these capacitive transducers can be used to measure the angular rotation. So, we keep one plate fixed and the other plate is connected to the rotating object. So, this plate is rotating. As this plate rotates, the common area changes and the capacitance also changes. By using a suitable bridge, I can relate the output voltage with the rotation. Since, the capacitance here is expressed as K into theta the sensitivity change in capacitance with change in angular motion, del C del theta becomes simply K. So, it is a constant. Relationship is linear.

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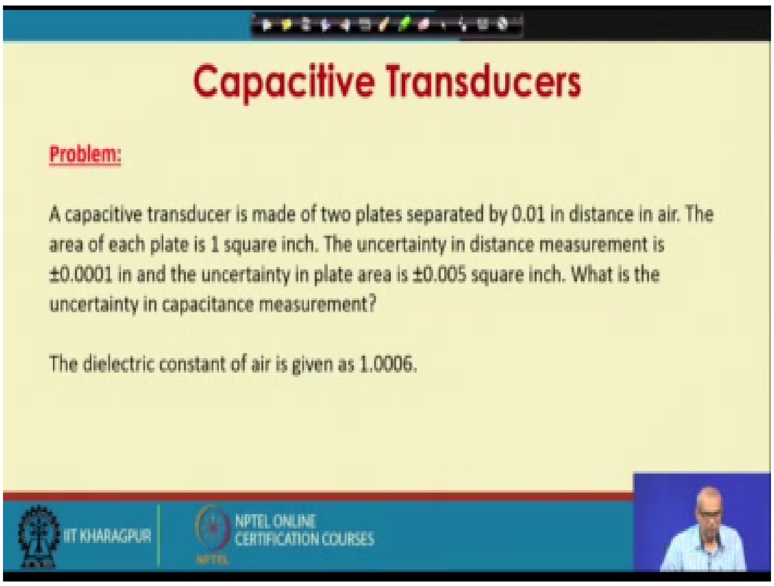

Now, let us take a problem as follows. A capacitive transducer is made of 2 plates separated by 0.01 inch distance in air. The area of each plate is 1 square inch. The uncertainty in distance measurement is plus minus 0.0001 inch and the uncertainty in plate area is 0.005 square inch. What is the uncertainty in capacitance measurement? It is given; the dielectric constant of air is given as 1.0006. So, the dielectric constant is known accurately let us say.

So, there is an uncertainty associated with the measurement of distance between the 2 plates and also there is an uncertainty associated with the measurement of area of the plates. So, we know those 2 uncertainties. Now, we have to calculate, what is the uncertainty in the measurement of the capacitance? So, you have to now apply the computation of overall accuracy, if the component inaccuracies are or uncertainties are known. This is what we have discussed few lectures back.

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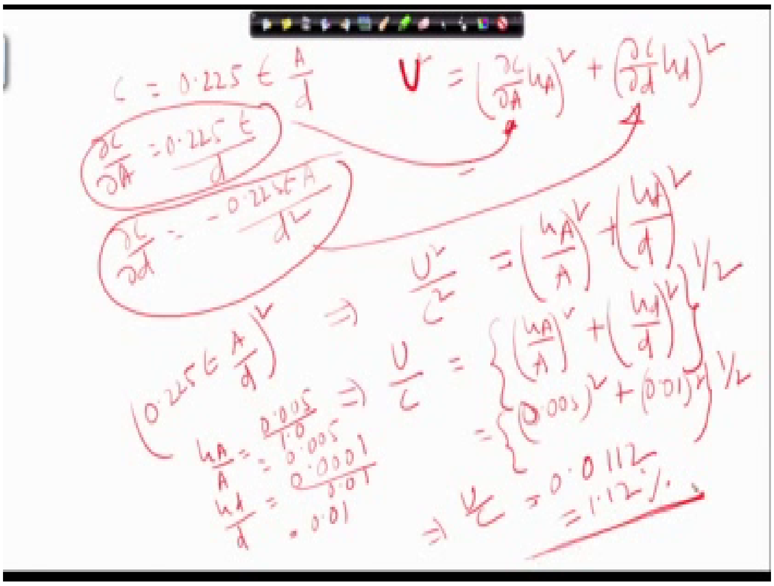

So, how do I solve this problem? What you need to know is, the capacitance can be expressed as 0.225 epsilon A by d. So, 0.225 becomes the magnitude of the constant when we use inch to express d and square inch to express area. So, capacitance is this. Now, you remember that uncertainty U can be written as del C del A U A square plus del C del d U d square, where U A and U d represent the uncertainty in the measurement of area and the uncertainty in the measurement of d or distance.

So, you now calculate del C del A. What is del C del A? It is 0.225 del C del A is nothing, but 0.225 epsilon by d. Similarly, what is del C del d? del C del d is nothing, but minus 0.225 epsilon A by d square. So, you put these quantities here. After you do that, you divide this equation by C square; that means, you divide both sides of this equation by 0.225 epsilon A by d square.

If you do that you will see that you are getting U A by A square plus U d by d square or U by C is U A by A square plus U d by d square whole to the power half. Now, what is U A by A? U A by A is the uncertainty in area is 0.005 and the nominal area was 1. So, this is point 0.005. So, this becomes 0.005 square, this is plus U d by d is 0.0001 divided by 0.01. So, this becomes 0.01; 0.01 square half. So, this becomes 0.0112. U by C becomes 0.0112 which means 1.12 percent.

So, uncertainty in the measurement of capacitance is 1.12 percent. So, this is how we can compute the uncertainty in the measurement of capacitance, if we know the uncertainty in the distance measurement and the uncertainty in the area measurement.

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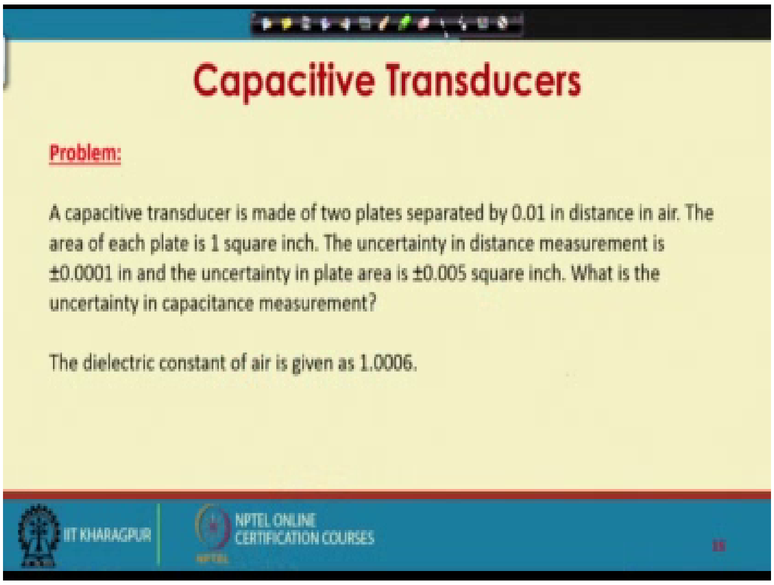

So, that brings us to the end of lecture 19.