Industrial Instrumentation
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Lecture - 18
Pressure Sensors

Welcome to the lesson 18 of Industrial Instrumentation. In this lesson, we will basically cover the pressure sensors. As you know in the, in the process actually, there are three important process parameters. In fact we call that is a pressure, temperature and flow. We already discussed temperature and flow in details. Now, in this particular lesson, we will discuss pressure sensors. Even though pressure has a different range, we have a low pressure range, we have a medium pressure range and for high pressure range, but in this particular lesson we will basically cover this high and medium pressure. For the low pressures or the vacuum pressures we will have, that will be covered in the lesson number 19.

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Now the contents of this lesson is: U tube manometer, then we have bourdon gauge, which is basically used for high pressure measurement, excuse me. Then we have bellow gauges and now we will find, mostly this U tube manometer, bourdon gauge and bellow gauge, these are basically the monitoring instruments and it is not transmitting though in the U tube manometer people tried to make a monitoring instrument. Then, we will discuss the diaphragm gauge. It is very important instrument; it has a direct electrical output, so it is widely used for the pressure measurements. We will discuss the diaphragm gauge also. Then, we will discuss the semiconductor diaphragm gauge to some extent.

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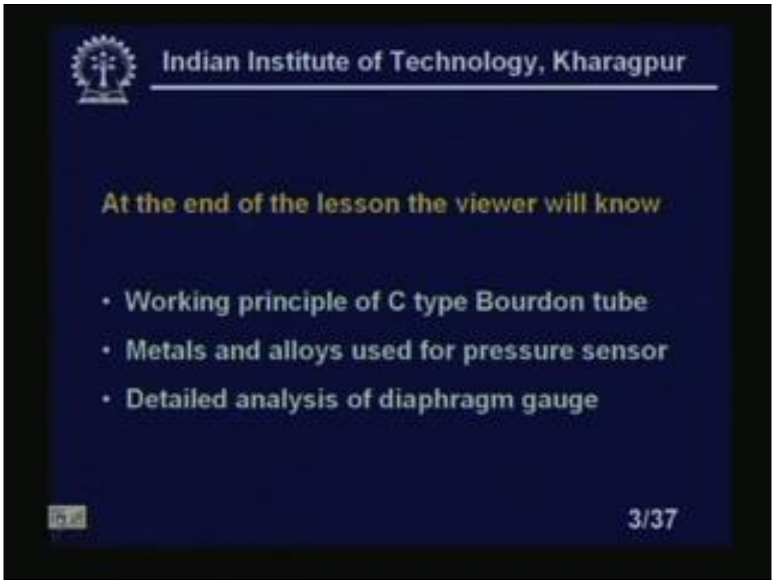

Now, at the end of the lesson the viewer will know the working principles of C type bourdon tube, metals and alloys used for pressure sensors, detailed analysis of the diaphragm gauge. These are basic things we will discuss, right? Now, before going to the, let us first discuss a U tube manometer, what is the basic principle of the U tube manometer? For this let me take a white page.

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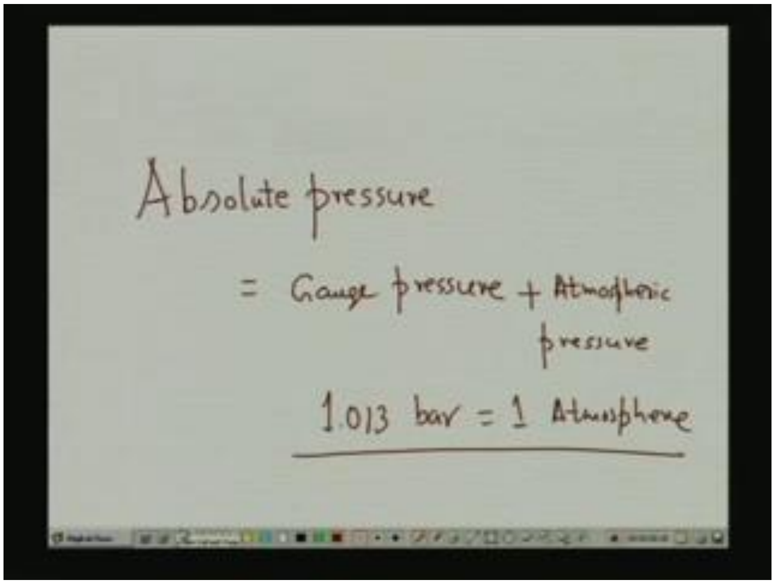

You will see the, in the pressure measurements we make the absolute pressure, absolute pressure equal to gauge pressure plus atmospheric pressure, right? Now, typically this, these U tube manometer it looks like a English letter U. That is the name, we have coined it U tube manometer and I should say it is one of the oldest pressure measuring, measuring devices so far the mankind developed. Still it is used for the monitoring instruments in many process industries or the estimation of the pressures in many, starting from your, I mean your, in the bioreactors or in the, in the, in the laminar hood or in the actual process this actually, I mean is and it has a wide range also.

Now, typical range for this U tube manometers it range from, starting from the actually 1.013 bar, as you know. Now, 1.013 bar is equal to 1 atmosphere, as you know, right? It starts from that range. Now, what is the basic principle? That let us look at. The basic principle, it is like this.

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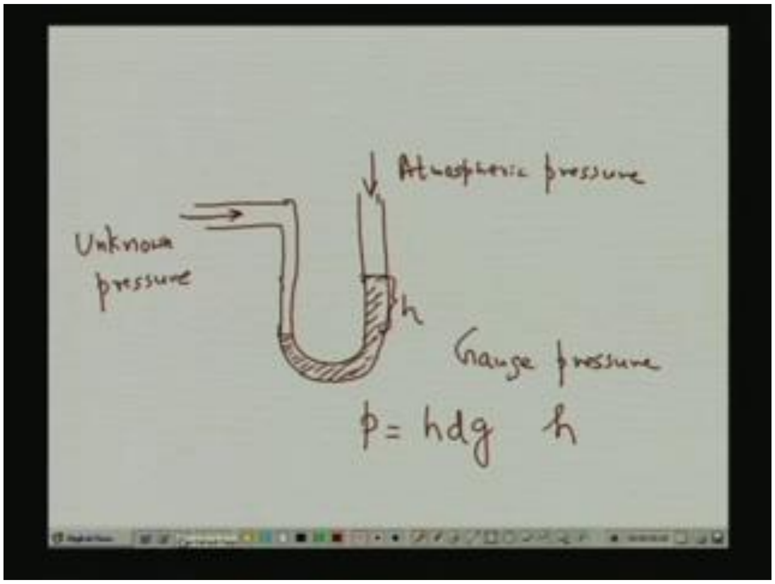

You see that we have a U tube. Now, this relates to the atmospheric pressure. This is unknown pressure which is coming in here and if the pressure is higher than this atmospheric pressure, obviously what will happen? The liquid, we have a liquid, previously we have a liquid like this, it is the same. Now, once the pressure increases, so what will happen? This liquid column, so now it is both same. You see, what will happen that so, liquid column will come down here, so it will come down here and liquid column will go up. It will go like this, right? This is a simple principle. These particular configurations will measure the gauge pressure; these particular configurations will gauge pressure.

Now, suppose the difference of height in the two, two arms of the U tube is h, so the pressure p 1, the gauge pressure p I should say, will be equal to hdg, where h is the height or the difference of the columns of the U tube, d is the, that is in the kg per meter cube, sorry h is in meter, d is density of the liquid of the manometer or manometric liquid sometimes we call it that is in kg per meter cube and g is the acceleration due to gravity which is in meter per second square, right? So, if we use all these units it will come Newton per meter square, the pressure, right?

Now, same we, at the same time we can measure the differential pressure also with this manometer. It looks like if I measure the differential pressure it will look like this.

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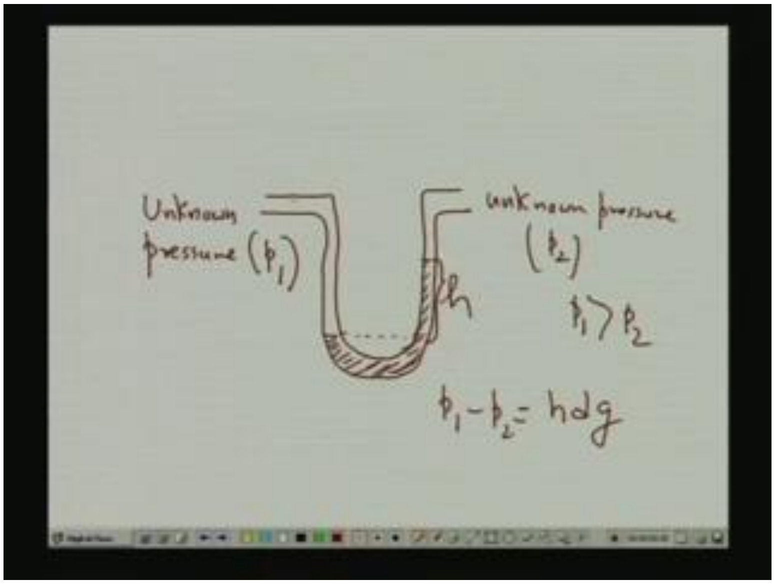

So the, what will happen you see that we have a U tube as before. So, this is unknown pressure, this is p 1; this is unknown pressure also, pressure p 2 I should say, this is p 1. So the, actually the liquid, if the p 1 is higher than p 2, so what will happen? Liquid, there is a height of difference, so it will be like this one, it will come like this, right? So, so this height that means starting from this point is h. So, again this p 1 minus p 2, the pressure is equal to hdg. As before, h is the height or the difference of the columns in the manometer, d is the density of the manometric liquid and g is the acceleration due to gravity.

Now, typical manometric liquid or cheap manometric liquid I should say is water; is easily available and clean water is, you can use distilled water which is, it will be clean. Now, there are two problems of using the water. Even though it is cheap and it is used in industries, so the typical problem is that the water will be evaporated very quickly. So you have, always the re should be toping that means you have to, whenever it is evaporations you have to, I mean fill it to the point and secondly that there is a problem, since it is transparent, water is also transparent, even if it is in the glass tube, if the U tube is made of glass, so it is difficult of viewing. These two difficulties with the water, I mean simple, I mean water, very difficult to use in the process actually.

Now, what will happen? You can make it colour. So, if you use colour water, so if you put some, add some colour, so you can also use this particular, I mean you can use manometric liquid as water. Now, there are two problem that the actual liquid which is coming or the fluid which is coming if it get contact with the water, if it, it reacts with the water that creates a problem In that type of situations, because you see the, in the, in the p 1 which we are measuring and the p 2, it will be connected to some liquid or some gas. So, in that case that gas or liquid should not react with water. So, you have to prevent that portions, otherwise that will create problem.

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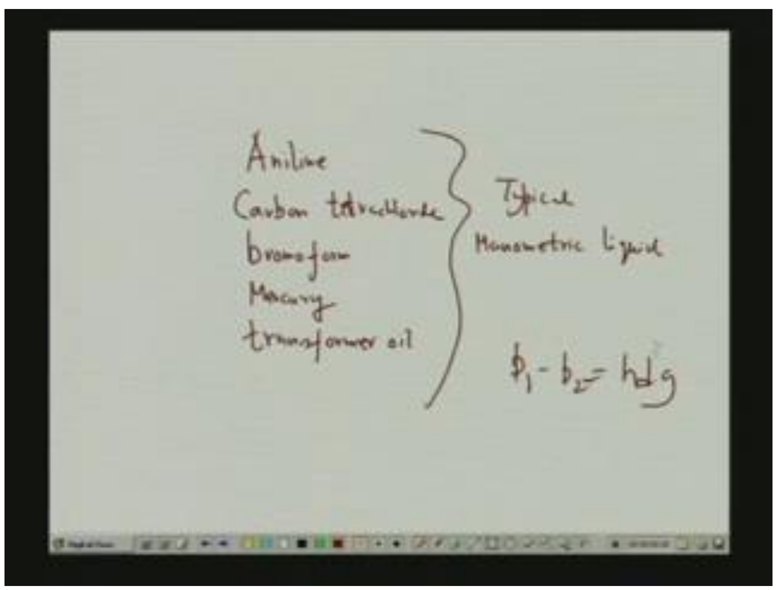

Now, typical other industrial manometric liquids are, are typically, these are aniline, then we have carbon tetrachloride, then we have bromoform, then we have mercury, transformer oil. These are all typical manometric liquid, right, typical manometric liquid. Now, another problem with the water as you know that means it, because the density of water is, it is, I mean less compared to the mercury and other liquid, so as you, with the, as p 1 minus p 2 equal to hdg we have seen that thing, right, so the density of water is less compared to mercury. Mercury is 13.6 times the density of water, so that if I use mercury, obviously my pressure range will also be high compared to the water. So, that is the reason people, I mean use different for that, as the case applies with, as a we have to measure the different pressure range, obviously the manometric liquid also you have to modify, right?

Now this is, we have used about the, we talked about the simple U tube manometer.

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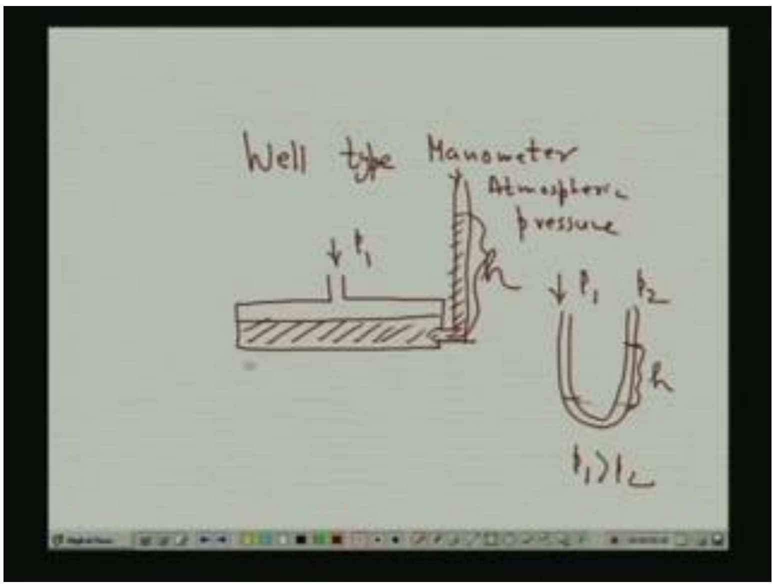

Now, there are other U tube monometers also which looks like this. You see we have well type manometer or it is called the system manometers. So, well type manometer looks like this. Instead of U tube what they do actually? So, there is a well. We have manometric liquid here, right and liquid is here and if the pressure p 1 is, this is released to the atmospheric pressure. So the liquid, manometric liquid is here. It is going up, suppose this is the height.

Now, advantages of this well type manometer or the system manometer is that you see, I have to measure the height only in this column, not here. The reason is this area is so large, so change of height, because you see in the, all U tube manometers we have seen that U tube manometer what will happen? If p 1, if p 1 is greater than p 2, so liquid, this column will go down and this will go up, is not it? So, both the columns I must, have to measure. This, sometimes it is very difficult. You have to measure this point, also this point from some reference level; only that times I will get the height.

Now, here what will happen, you see the, if the pressure p 1 is higher than the atmospheric pressure, this liquid will come down by infinitesimally small length. So, what will happen? I can, I have to measure only in this one, h. I do not have to bother, I should not bother for that, I mean difference of height of the liquid which is in the well, right? So, whenever this pressure will be released, the liquid will come down and again it will come to the, suppose this will be our previous position of the liquid, so this small difference of height you should, should not bother. So, that is the advantage of the well type manometer, right or it is called the system manometer.

Now, we have another manometer which is called inclined tube manometers or draft gauge. It looks like this.

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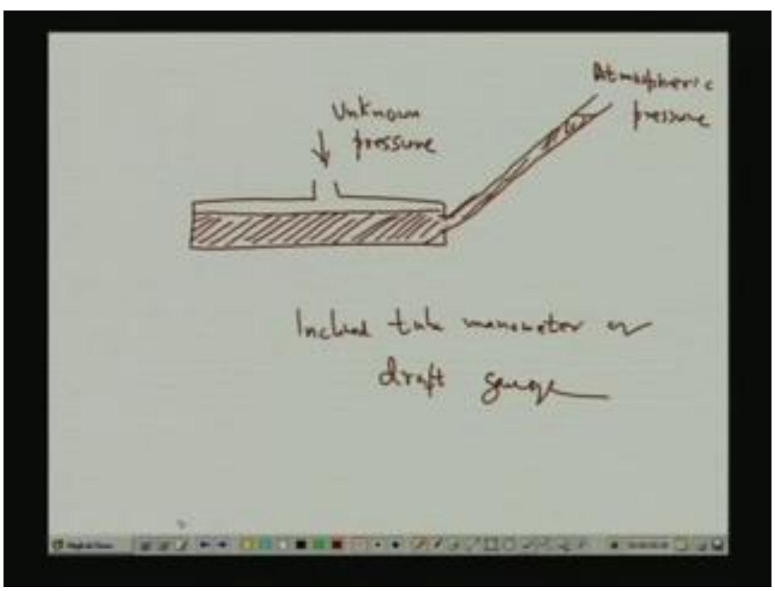

So we have here, I am sorry, so there should be, see here, now instead of, so they need inclined tube, right? Now what will happen? This is the unknown pressure and this is our atmospheric pressure. So, what will happen you see? The liquid will come down here.
Now, what is the difference between this and the inclined tube manometer and the well type manometer? You see in the well type manometer this, this column is straight. Now, here what will happen? The liquid, since the height is same, the liquid has to travel a more distance here. So, ultimately what will happen? I am getting the advantage of the well type manometer, but the sensitivity here in this case will be higher. So, I can measure a smaller pressure difference, resolution will also be better, right? So, this is the advantage of this type of manometer. This is called the inclined tube manometer or we called it draft gauge.

Now, all these manometers as you know is basically indicating sort of instruments as I told you earlier. So it is a, I won't get any, I mean electrical output digital. So, this is basically a monitoring instrument, neither transmitting instruments nor recording instruments. Though people tried with, mercury in glass manometer with some electrical output. How, let us look at. People tried with this, like this one. You see what they, what they did?

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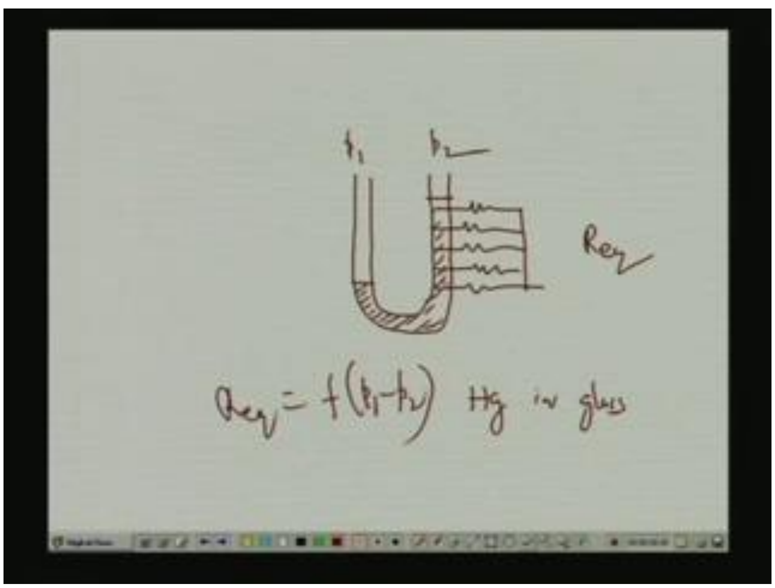

Suppose there is a U tube like this one. Liquid is coming in, so it is mercury in glass, Hg in glass. Now what they did? They put a resistance like this one and these are shorted. Now, what will happen? You know that when the, this liquid column grows in height, so one by one this resistance will come in parallel, right, otherwise it is not. So, there will be change of resistance whenever there is a change of pressure. Suppose this is p 1, p 2. So, this change of resistance, this R, equivalent resistance I should say, R equivalent, R equivalent will be a function of p 1 minus p 2. So, that can be utilized to get unbalanced voltage, if I put in a bridge circuit. So, that can be utilized to get unbalanced voltage of the, unbalanced voltage as a output. So, that can be calibrated in terms of pressure.

But as you know this is a discrete form. So in between, suppose in between the two resistance if there is a liquid column comes in, so that it won't get any change until and unless this liquid, manometric liquid touches this resistance and getting the change in resistance, right? So, these are the, all about manometer. Let us go back to the other type of gauges.

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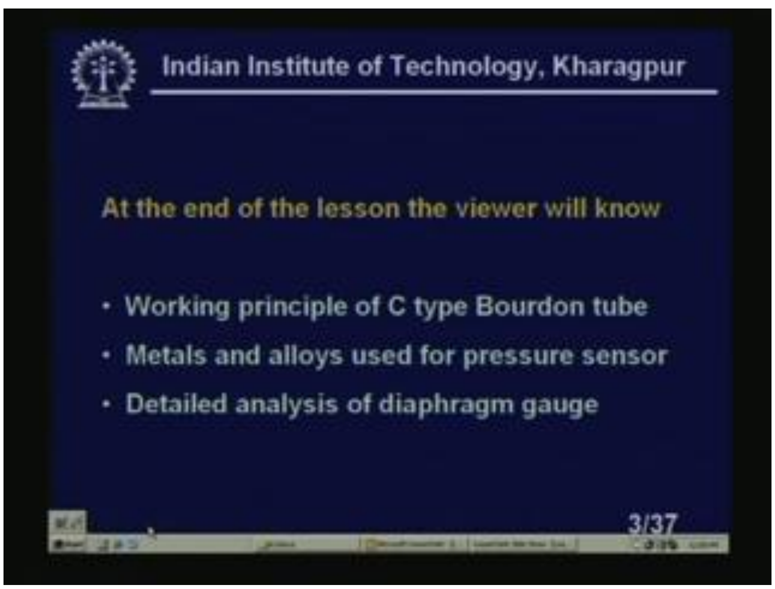

Now, as I told we will discuss a bourdon tube in more details.

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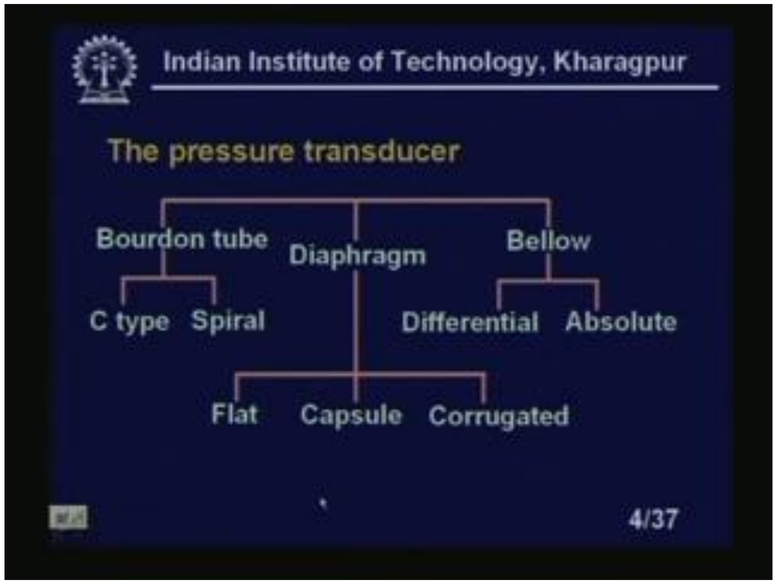

The pressure transducer, you see that this as I told you, this we have, even though there is, you won’t find the U tube manometer there. So, this is a entire gamut of the, our pressure transducer. We have the bourdon tube. We have two types: we have a C type, we have a spiral tube, we have a diaphragm. The diaphragms are flat, capsule or corrugated and we have bellow. These are differential and absolute. So, these are the entire gamut of the … Now, let us look at the bourdon tube in details, right?

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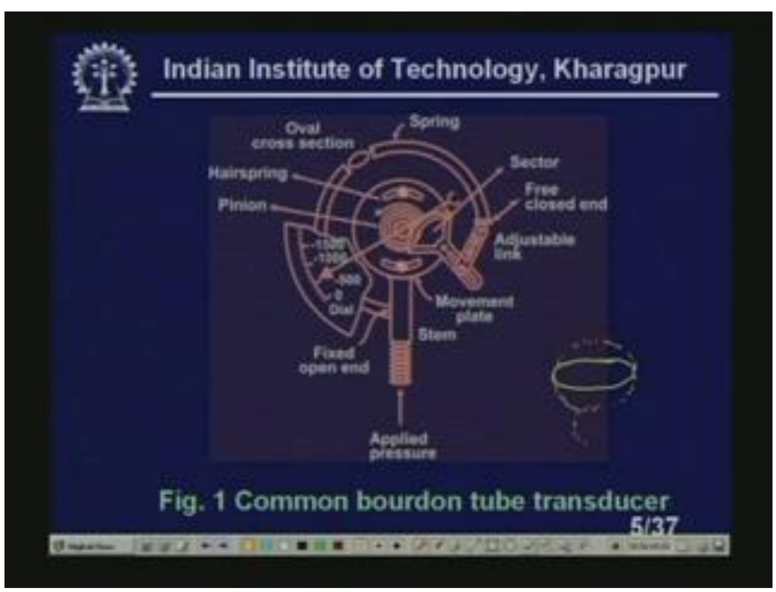

You see, this is our common bourdon tube transducers and you can see here, so we have a, we will see this one after sometime. We have a, now the cross section of this bourdon tube transmitter is like this one, transducer is like this one. Cross section is, looks like, sorry, its cross section looks like this. Now if the pressure increases, then what will happen? You know this will make, try to make circular. That means it will have a, it will try to make it circular. Due to this, I mean see, it is electrical initially, now it tries to makes circular. This tip of this bourdon tube, you see this is a closed end, this is a free closed end; this is free and this is closed. So, the pressure is coming here, it is going through this and hitting this portion. This is oval cross section or elliptic cross section. So, they hit cross sections.

Then what will happen? This will move up. It, it, it moves down. This tip moves out. Then what will happen? So, the sector, we have a sector here, it moves in this direction. If this moves in this direction, there is a gear in which this, you see this is a gear, you can see this gear, right, this is a gear, so what will happen? There is a hairspring, because to bring back this, our, this point up to the same position, what will happen? This needle will go up, go in this direction. How? It is, again I am telling this is a, if I apply the pressure, if the pressure is higher than the atmospheric pressure, this tip will go outside. If it goes outside, then what will happen? This sector will move in this direction. You see, this sector move in this direction. If it moves in this direction, this gear in which this needle is, is connected, your pointer is connected, so it will go in this direction, right? So, I will get a change of pressure.

It is a very widely used transducer I should say for industries, I mean it is thoroughly, I mean everywhere, from a cycle store to any process industry you will find it is a very wide range. It can measure the corrosive liquid, pressures of the corrosive liquids also, gas also. So making this, starting from the liquid, gas, air, everything we can measure with this and it is over the years people are using, even though this is basically a monitoring instruments, not a transmitting instrument. So, since it is a C, you see this, this tube is C, we call it C type bourdon tube and this, either it is written in PSI, pounds per square inch or in the kilo Pascal. Again I am telling, you see the fixed open end so liquids are and there is a threaded, so that it can put on a, actually the vessel in which I am interested to measure the, measure the pressure and it is covered you cannot see from outside. It is, the dial will be on this one so you cannot see anything from outside, right?

Now, let us look at the typical bourdon gauge of the, you see this is the dial of the bourdon gauge.

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You can see the dial of the bourdon gauge, right? You can see the dial here, fine; this is the dial of the bourdon gauge. Now, I remove the glass cover. You see here, now let us look at the back side.

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See here, right? See, it is the back side. This is the C type bourdon tube; you see, this is the C type bourdon tube. Pressure, unknown pressure is coming through this region; this region unknown pressure is coming and it is coming and it is, this side is closed. You see, this side is closed, right and you see with linkage it is connected to a sector; sector is here. Now, what will happen you see that when I will move this one, sorry, if I move this one, because this tip will move outside, is not it? So, what will happen? When the pressure increases, it will move this way. You see, the sector will move. There is, air in the sector will move and if I move what will happen you see here? With the sector the pressure will increase, right? Again it is coming back to the original position.

Now we will see here, again I am telling, see we are increasing this position, because now the, there is, it is in the atmospheric pressure. So, it is, can …., but if I increase the pressure you can see here, you see this is the closed end. It is sealed here. This is a, this is a typical bourdon, I mean your C type material we have seen. You see here, this C, this is sealed end, right and here, you see here now you can see the sectors. Again I will show you, you see here; here you see the sector is moving. You see the sector, you can see the sector; the sector is moving. C tube is coming down and we have, so we have air spring also here, here we have air spring which will bring back the needle and there is a gear also inside. You cannot see, so I will show from the backside you can see there is a gear also which is on the, the, actually the needle is connect, fixed on the gear itself, right? So, I am getting the output. So, this is about the C type bourdon tube.

Now, what will happen? You know that in many situations we have a spiral. That instead of one C I can make it a spiral, several spiral and at the tip that will be connected to the sector. Now, advantage of that type of thing is the, you see, I am getting the more deflections, because usually this is for the quite high pressure, right? But, if I have a longer length of the C tube, because if I make a only single C, I won't get much deflections. So, instead of that single C if I make a spiral, but it does not end here. It comes along this, we will have several turns and it ends here and that closed end now again connected to the, to the lever. You see there is a lever here, you see there is a lever. There is a sector here, sector on the backside; you can see here sectors. Again I am moving it. You see here, you can see the sector is moving, right, sector is moving. So, this way that measurements are taken, right? So, this is all about the and we have a different shape of bourdon tube. We will see the twisted bourdon tube. So, this is all about, of the bourdon tube.

Let us go back to the class again, digital class.

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Now, see that this is the bourdon tube arranged for the absolute pressure measurements. You see, what will happen here, we have a case open to atmospheric pressures. We have a sensing bourdon tube here. This is the applied pressure here. So, there are two C tube actually connected back to back. If I connect two C tubes back to back, now reference bourdon tubes sealed at zero absolute pressure. This is sealed at the zero absolute pressure. This is sealed, I mean totally evacuated and sealed it. There is no free end that means there is no question of giving any input to this, right, whereas here I am giving the input. So, this is, there is a free end and this is a closed end, right?

Now we, I mean liquid is going or feed is going inside. Now in this particular, what will happen? I will get a absolute pressure, because this is, this pressure will be already deducted. So, it is not a gauge pressure, so it is measuring the absolute pressure. But this case is, there should be, there should be little opening, because with reference to the atmospheric, atmospheric pressure. I am, this C tube will change its position, right? So, this is another form of absolute measure, measurement of bourdon tube. Let us go back to the next.

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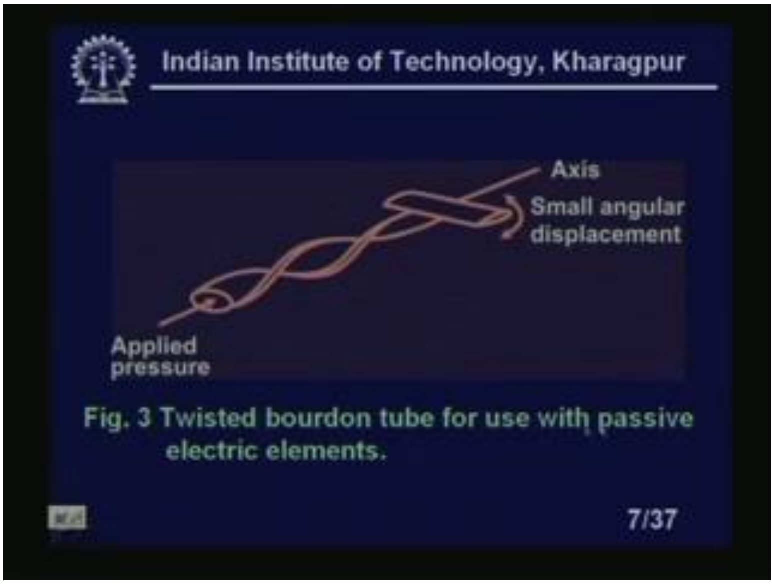

This is another one. You see, this is basically an axis or small angular displacement. This is a twisted bourdon tube. Instead of, I mean C type bourdon tube we have a twisted bourdon tube. What will happen if I applied pressure? So this, I mean side will try to move. Again the same principle, this is a electric or oval shape. It will try to make it circular. So, this will be rotated. So, this way also I am getting the, the small angular displacement that can be amplified mechanically and get the output, right? This is another form of bourdon tube. This is called twisted bourdon tube, right?

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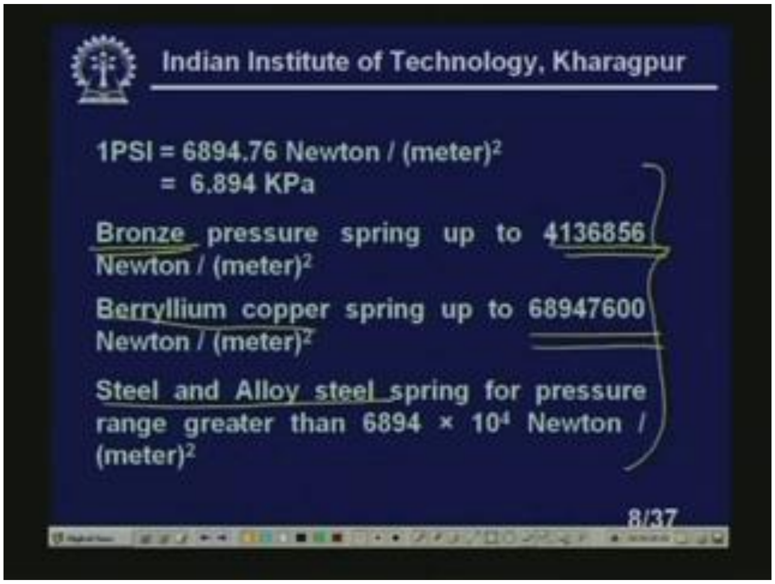

Now typically the, even though as I told you that in the academics we are using SI, in industry still people are using this, I mean PSI. They, still they call it 1 PSI, 3 PSI. So, you have two side, two things should be side by side. That means both the SI unit as well as say PSI unit, right, because you know the pounds per square inch is basically PSI unit. So, 1 PSI is equal to 6894.76 Newton per meter square, which is equal to 6.894 kilo Pascal. Bronze pressure springs up to, now I talked about the pressure spring that means what is the material of the C type bourdon tube? We have seen sometimes we are using brass, sometimes we are using a phosphor bronze.

Now, depending on the particular range the different pressure transducer is used. Now, bronze pressure springs up to 4136856 Newton per meter square. Berryllium copper spring up to 68947600 Newton per meter square. Then we have a steel and alloy steel spring for pressure range greater than 6894 into 10 to the power 4 Newton per meter square. Sometimes you know that the, this range of this particular instrument depends not only, not only we should consider the range, but also the, what the environments.

Suppose I am measuring the, I mean liquids, pressures of the corrosive liquids, in that type of situations we do not have any use or we do not have any choice rather than using the, your stainless steel C tube, right? So these are the different materials of the C type bourdon tubes. These are the different materials. These are the different material of the C type bourdon tube. It is typically used and the, the C type bourdon tube which I have shown in the, I mean in the, just few minutes back is basically, the material they are using is the bronze, right, easily available. The beryllium copper, these are not very, is expensive also, much expensive than the, I mean the Bronze pressure gauge.

Obviously, you can see the range. The range of the Bronze is much less than the Beryllium copper and steel alloy and all these things is necessary, depending on what type of environments we are using, what type pressures, I mean in what situations or what conditions you are measuring the pressure. In that type of the situations we use, I mean different types of C tube. But basically, these three are the, the three basic C type materials and among that bronze is the most widely used pressure C tube material.

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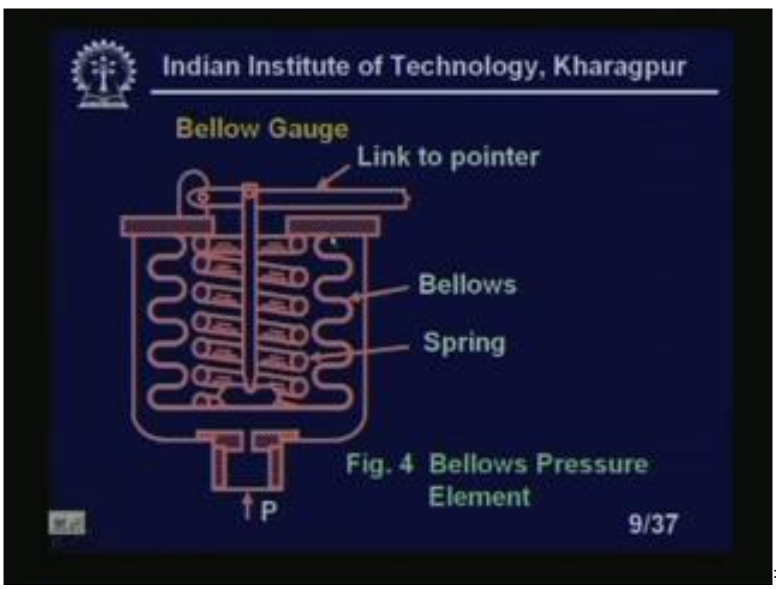

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Now let, next let us go to the bellow gauges. Bellow gauges is very widely used. You see, what will happen here, so that you see here we have a bellows, we have bellows. Now, what will happen? You see, this is a closed end, it is closed from outside. This is closed from outside, this is closed, sorry. You see here it is closed, right? What happened? Here you see, the bellows are, I will show you the bellows. Now if the, if the pressure increases from this side, if I, pressure goes inside these bellows will squeeze. If it squeezes, then what will happen? This pointer or link will go up, right? So, it will move like this one. You see, it will move like this one. If it moves like this one, then what will happen? So, I will get an indication. So, this can be calibrated in terms of the pressure, right? So, this is all about the bellows. So, we can show in next slides something, you see here.

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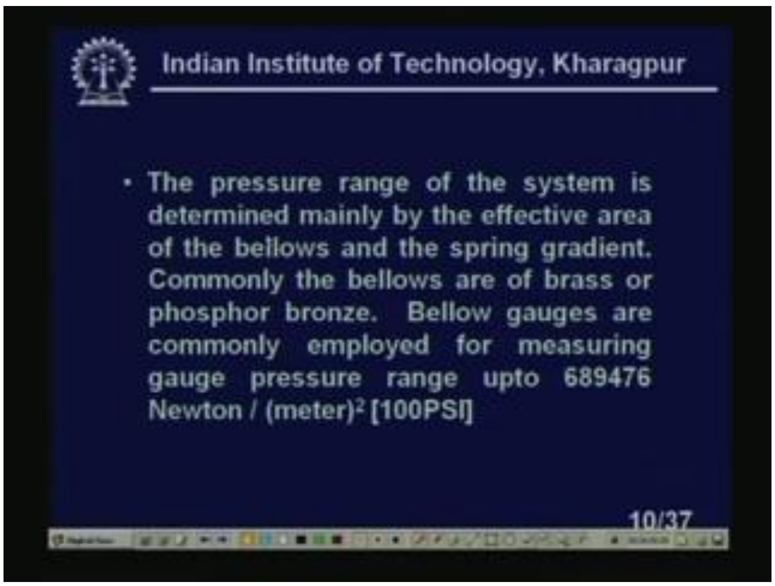

The pressure range of the system is determined mainly by the effective area of the bellows and the spring gradient. Commonly the bellows are of brass or phosphor bronze. These are basic material used for the bellows and bellow, these are basically annular ring and welded at two different ends. I will show you. This is basically annular ring welded at the alternative points and bellow gauges are commonly employed for measuring gauge pressures range up to 689476 that is in Newton per meter square that is 100 PSI typically and bellow materials are brass or phosphor bronze. Brass is most widely used bellow materials and we can show, show some elaborate arrangement of these bellows, let us look at.

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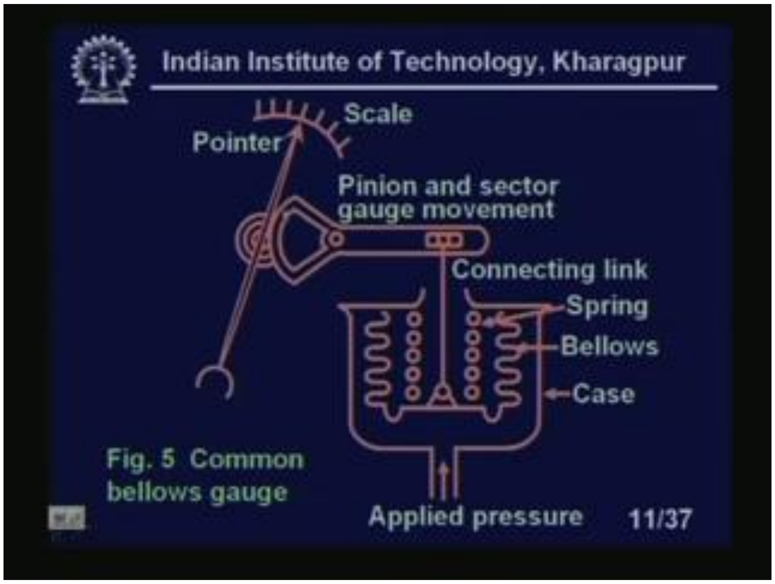

You see this is a bellow. This applied pressure is coming down here, so we have a pointer here. Again there is a sector and this needle or pointer is connected on a, on a, on a, on a gear. So, in this actually there is a teeth of this sector. So, we have not shown, we have not shown this thing. Now, what will happen? You see, the pressure increases this bellow will squeeze. This bellow will go up. If this goes up, then what will happen? The sector will move in this direction. If the sector moves in this direction, then what will happen? You see that this pointer will move in this direction, right?

So, this scale can be calibrated in terms of, in terms of the pressure, right? So, this is a pinion and sector gauge movement, this is a connecting link. This is a spring, because they …… because once you remove the pressure this, this bellow should come to the original position. That is the reason the spring should be inside and this is a case and case should be hermetically sealed. That means it should be sealed from all end that means from this side there should not be any leak, this side there should not be any leak. As you know, the bellows are also used for the, I mean pressure switch that will be discussed later on. Let us go and see one bellows.

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You see this is the, you see this is the bellow. See, I am squeezing, you see the pressure, if the pressure increase, goes inside through this one, so it will be squeezed. It will be, it will, if the pressure increases, then what will happen? You see, if that side it will be squeezed like this one, right, it will be like this one, right?

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You see, now you look at very carefully these are welded actually and join. This is made of brass. You see, this side is welded. Again the inner side is also welded, right? This side is welded; the inner side is also welded. So, we will get the movement like this one, right and as you know, the bellows are extensively used for measuring the, for using as pressure switch also. How? You see what will happen if this is hermitically sealed? In the refrigerators and this is typically used for your temperature control, because I can use this particular contact point for the temperature control. Then what will happen? You see, if the pressure increases, I mean suppose this is sealed unit, the pressure decreases then what will happen? It will squeeze like this one. If it squeezes, you have an electrical output that will be disconnected, right?

So, you see here how the pressure like this one it is doing like this, right? If the pressure, outside pressure with, the inside pressure is less than the outside pressures it will go like this. If the inside pressure is less than the outside pressure, it will squeeze like this. If the inside pressure, the pressure given, which is more than the atmospheric pressure it will expand like this. You see, we cannot expand it. So, it will expand like this, clear? That means in inside pressures which are pressure giving is more than the atmospheric pressure, I will show you again it will expand like this, right? So and this particular bellows is made of brass. This is used for some force balance system. We are taking that thing to show you. Let us go to the digital class again.

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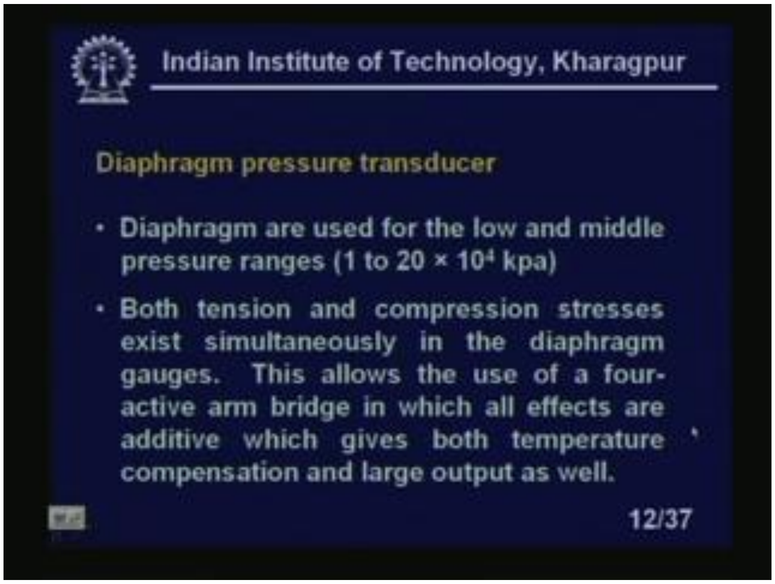

Now, the diaphragm pressure transducers, now the diaphragm pressure transducers is very widely used, I mean pressure transducers actually we will discuss this particular pressure transducers in detail. Diaphragms are used for low and middle pressure ranges. So. it is 1 to 20 into 10 to the power 4 kilo Pascal, right? Both tension and compression stresses exist simultaneously in the diaphragm gauges and this allows the use of a four active arm bridge in which all effects are additive which gives both the temperature compensation and large output as well.

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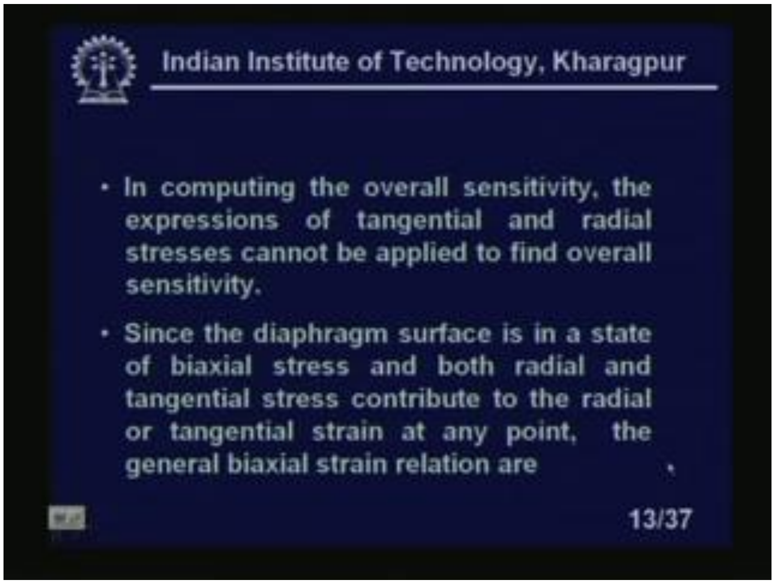

In computing the overall sensitivity, the expression of tangential and radial stresses cannot be applied to find overall sensitivity of this. Since the diaphragm surface is in a state of biaxial stress and both the radial and tangential stress contribute to the radial or tangential strain at any point, the general biaxial strain relations are …

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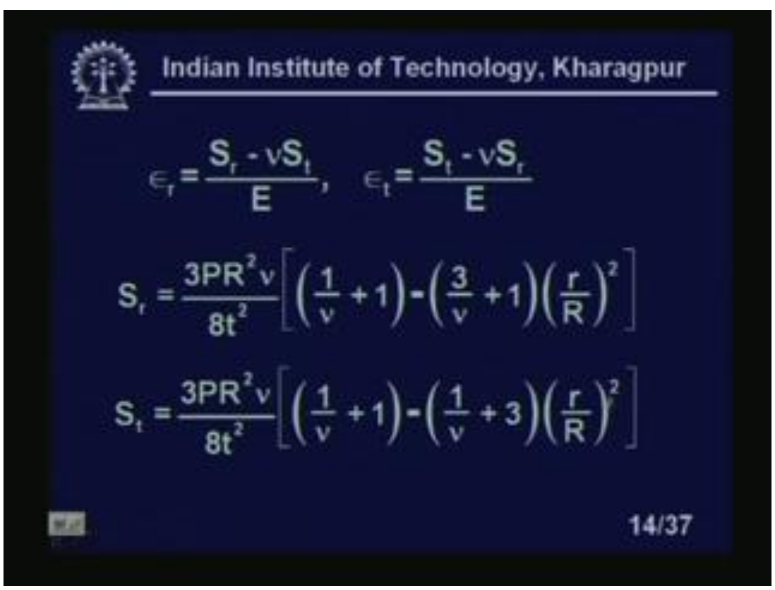

Epsilon r which is radial strain equal to S r which is radial stress minus nu S t upon E. Similarly the epsilon t which is a tangential strain equal to S t minus nu S r upon E, where S t is the tangential stress and nu S, S r is the tangential radial stress and nu is the Poisson's ratio and E is the Young's modulus of elasticity. Now, S r can be given by, this S r can be written as 3 PR square nu by 8 t square whole bracket 1 by upon nu plus 1 minus 3 upon nu plus 1 small r capital R whole square. S t that means the tangential stress 3 PR square nu by 8 t square 1 by nu plus 1 minus 1 by nu plus 3 small r by capital R whole square, right?

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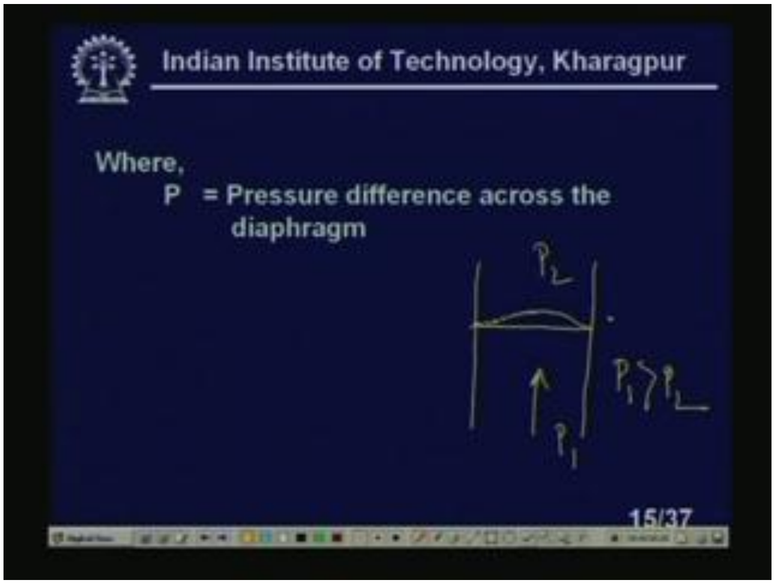

The P is a pressure difference across the diaphragm. Now, diaphragm is, looks like this actually. If I see that looks like this. They have a stretched diaphragm, right? Suppose this is P 1 and pressure on this side is P 2 P 1 greater than P 2, so this diaphragm will be stretched like this, right? So, this centre point deflections either you can use LVDT or we can use some force strain gauges to sense this particular, I mean deflections. So, that is calibrated in terms of pressure, right?

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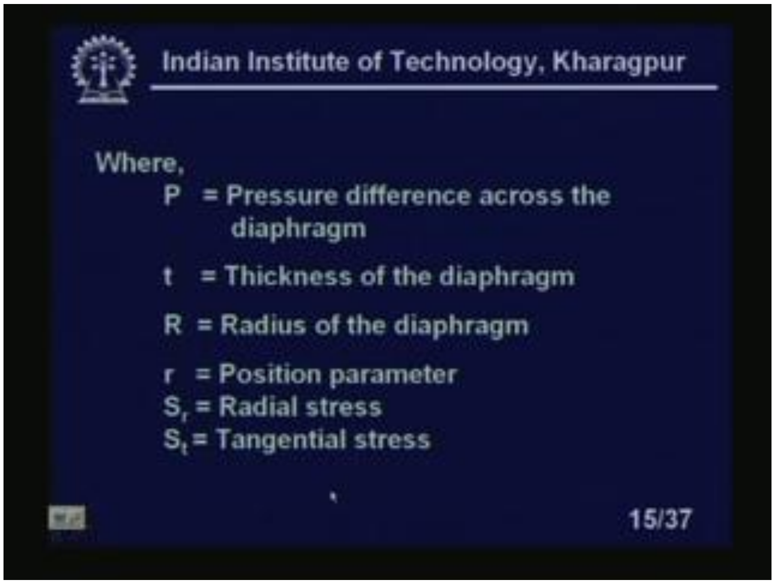

Let us look at the legends. What are the legends? We have t is the thickness of the diaphragm. This is very important. It relates to the linearity of the sensor, then radius of the diaphragm, outside radius of the diaphragm, then we have Poisson's ratio, position parameter, I am sorry this is the position parameters, I will tell you what is that actually? Then we have, S r is the radial stress, S t is the tangential stress.

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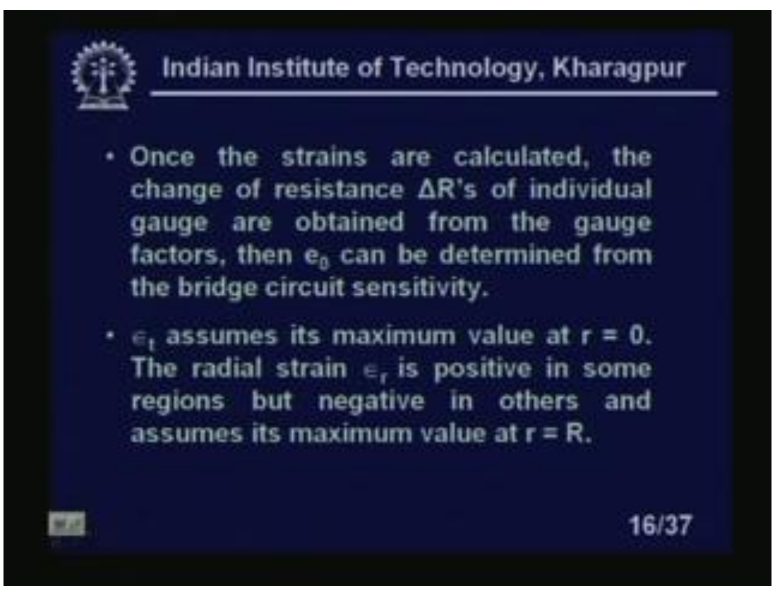

Once the strains are calculated, the change of resistance delta R's of the individual gauge are obtained from the gauge factors. Then e naught can be determined from a bridge circuit sensitivity. Now, epsilon t assumes the maximum value at r equal to zero and the radial strain epsilon r is positive in some regions, but negative in others and assumes its maximum value at small r equal to capital R.

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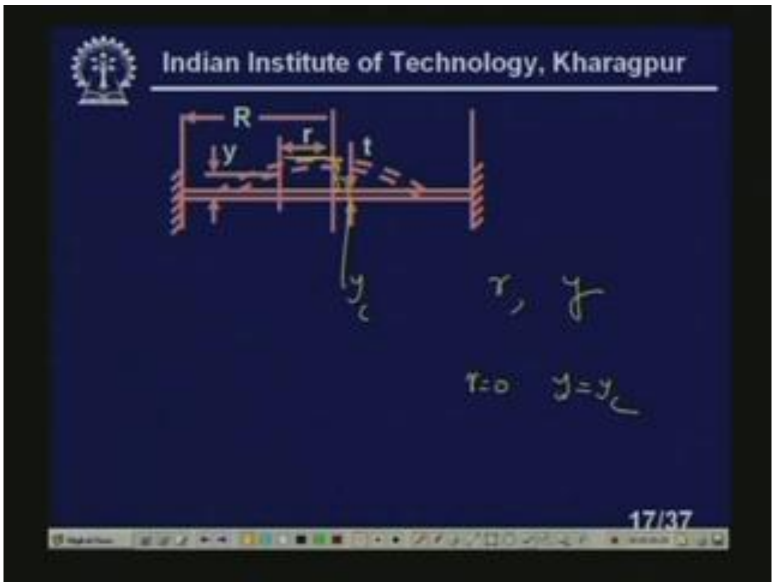

You see here the diaphragm, how it looks? You see, this is the position parameter small r, right? You see here if I take a, this is the position parameter, right? At any point what is the deflection, right and height at this point, particular point is y and t is the thickness of the diaphragm and R is the radius of, of the, the I mean total diaphragm or the inside radius of the pipe. Almost it is equal to the inside radius of the pipe and at any point from the center, center volt deflection will be the maximum. These deflections we are calling it y c. These deflections we are calling it y c. So, at any point deflection we are calling it y. From the center at a distance r the deflections we are calling it y. When r equal to zero at the center we are calling y equal to y c, right?

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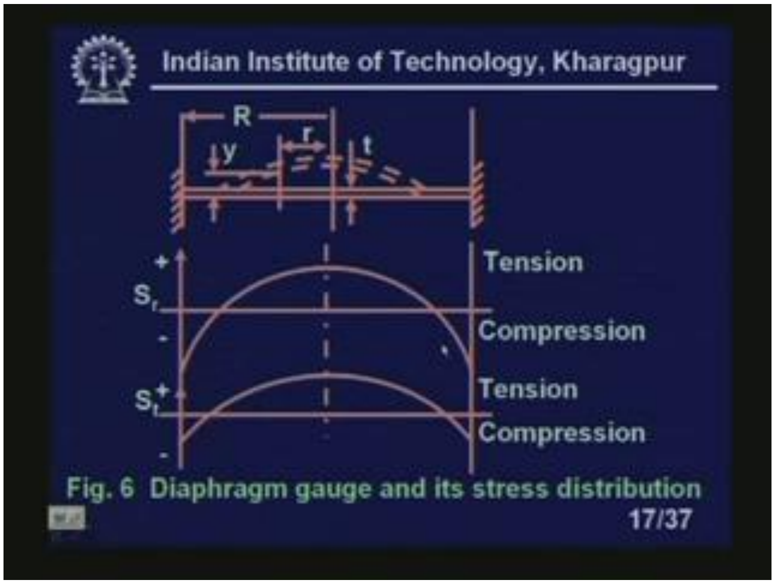

Now see, this is the strain distribution. So, diaphragm gauge and its stress distribution looks like this. In both the cases we have both tensile and compressive stress. Here you see the S r or the radial stress is given like this one and radial stress if we look at very carefully, radial stress is maximum at the circumference which is compressive. This radial stress is compressive and it is maximum at the circumference, whereas this tangential stress is maximum at the center point. Why I am telling that is very much important. You see, again I am telling you see, this radial stress is maximum at the circumference.

So, we will put two sensors at the circumference which will sense the radial strain and we will put two sensors at the center which will sense the tangential stress, right and there is some particular, I mean strain gauge available for that which is called strain gauge ….. We will come to the details of that. So, this is our diaphragm gauge and stress distributions.

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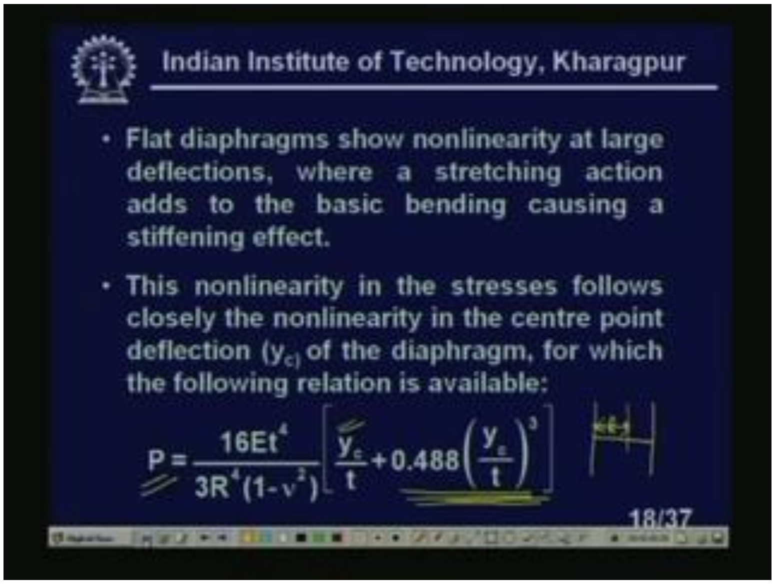

Now, flat diaphragms show nonlinearity at large deflections, whereas stretching action adds to the basic bending causing a stiffening effect. So, this should be the, the deflection of the center point which we have to keep minimum. Otherwise there will be distortions, right? This nonlinearity in the stresses follows closely the nonlinearity in the center point deflection y c of the diaphragm, for which the following relation is available. This is the relation between the, this is the relation between the pressure P and y c, because you see all other things are constant.

Young's modulus of the elasticity of the material of the diaphragm is constant, thickness of the diaphragm is also constant, t is constant. Now, nu is Poisson's ratio that is also constant, R is the radius of the diaphragm that is also constant. Radius of the diaphragm is a constant that means if I have a diaphragm here, so this, this is radius R, right? This is our diaphragm relation between P and y c and see, very interestingly this is our nonlinear term, we have to avoid this thing. That means this part should be very, very small compared to this part.

So, you can see very easily if the y c is very, very small compared to t, if the y c is smaller than compared to, we can neglect this part. So, nonlinearity will be less. If the y c is higher, then the nonlinearity will be higher, then we cannot neglect this term, whereas say this term is much, much less than this term, so we can easily neglect that part, right? So, you will solve some problem; how much nonlinearity will be introduced by this? Obviously, but always you see the deflection of the, deflection of the center point or center point of the diaphragm should be much less compared to the thickness of the diaphragm. So, these two are the quite related, y c and t to have, to eliminate the nonlinearity in the system. Let us go back again.

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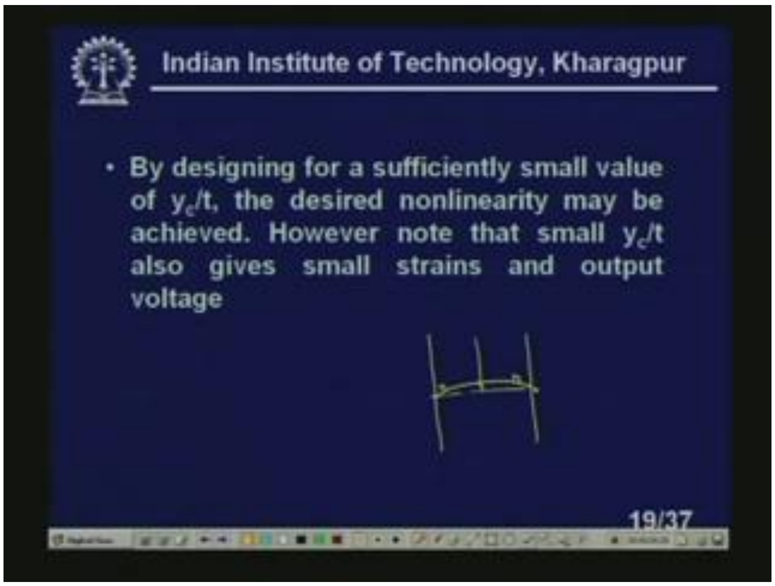

By designing for a sufficiently small value of y c by t, the desired nonlinearity may be achieved. However note that small y c by t, please note, also gives smaller strains and output voltage, right? Why? It is very clear. You see, what will happen if I have a diaphragm like this one? So, I have a deflection like this one, right? So, either I have to sense this center point deflection by some LVDT or there is some strain gauges will be there. See, if the deflection is less, then what will happen? This strain developed also will be less. So, I will get the less output, right? So, those things you must keep in mind.

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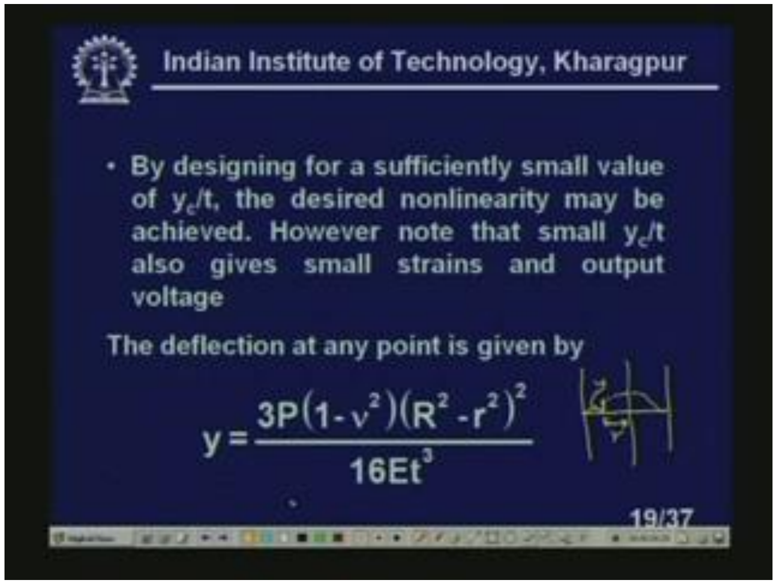

Now, deflection at any point, any other point than the center point as I told you at the distance r, y is equal to, is given by this expression y equal to 3P 1 minus nu square R square minus r, small r square 16 E t cube. What is that, let us look at. Basically that means on the central point suppose I have, at any point, I have a diaphragm, now it is deflected like this one. This is our centre point. Suppose this I am taking about y, so this distance is y, this deflection of the central point and this distance from the center is r, so that deflections or height is here y at this point, which is at a distance r from the center. For that reason our expression of the deflections y can be given by this particular expressions.

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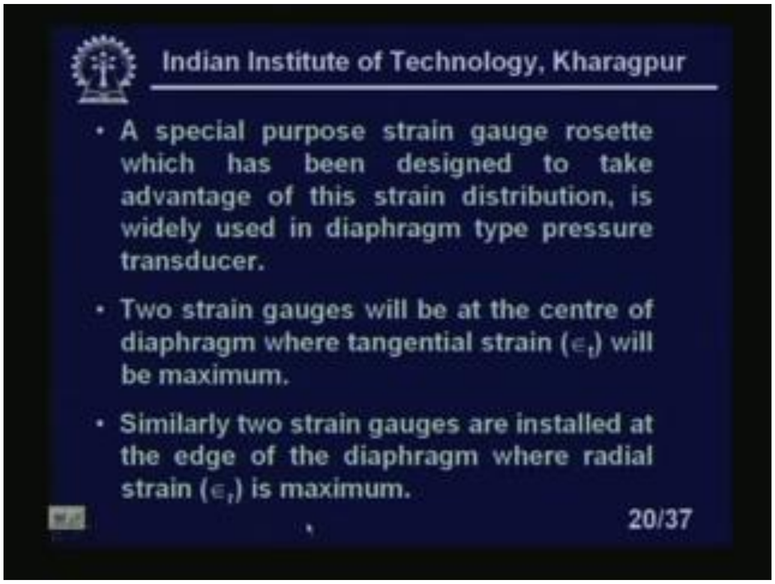

A special purpose strain gauge rosette, which has been designed to take advantage of this strain distribution and is widely used in diaphragm type pressure transducers. Two strain gauges will be at the center of the diaphragm where tangential strain will be maximum and two strains, similarly two strain gauges are installed at the edge of the diaphragm where radial strain is maximum. We will show you.

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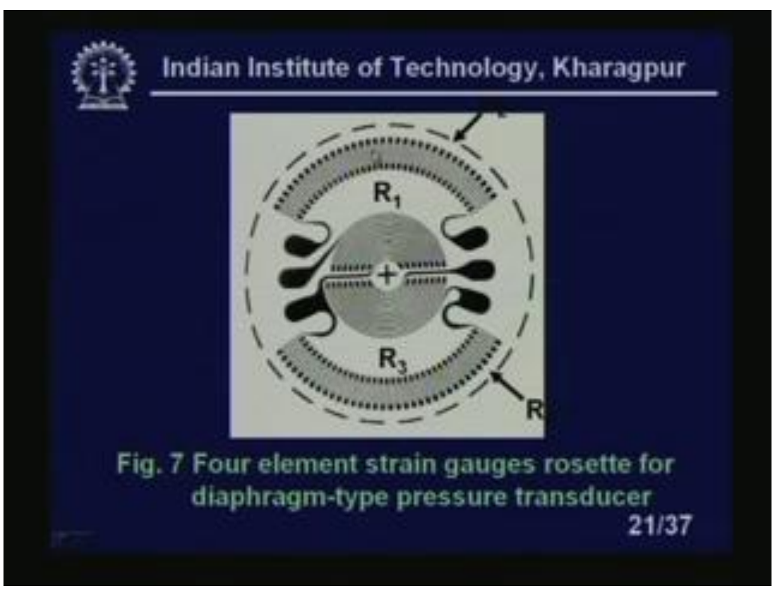

You see, this is a bit typical. Now you see here what will happen? You see here, this is at the circumference. You see here, this is R 2, it is not coming anyway, so I can draw it here, I am sorry. What will happen you see here, this is the, this sensor, this strain gauges and this strain gauges will sense, this R 2 and R 4, it is not coming; this is R 2 and this is R 4. This will sense the radial strain, right, which is maximum at the circumference. So, that is the reason it is, you see this is a total diaphragm.

This is the diaphragm, size of the diaphragm or I should say this is a, from this this is the, distance is radius R. The two strain gauges are at the center. You see here this R 1 and R 3 will sense the tangential stretch, stress which is maximum at the center point which is positive. Whereas, the radial stress which is at the two extreme positions is, is basically compressive and it is negative, right? Because we have seen the strain, the stress distribution curve, in some case it is positive, in some case it is negative.

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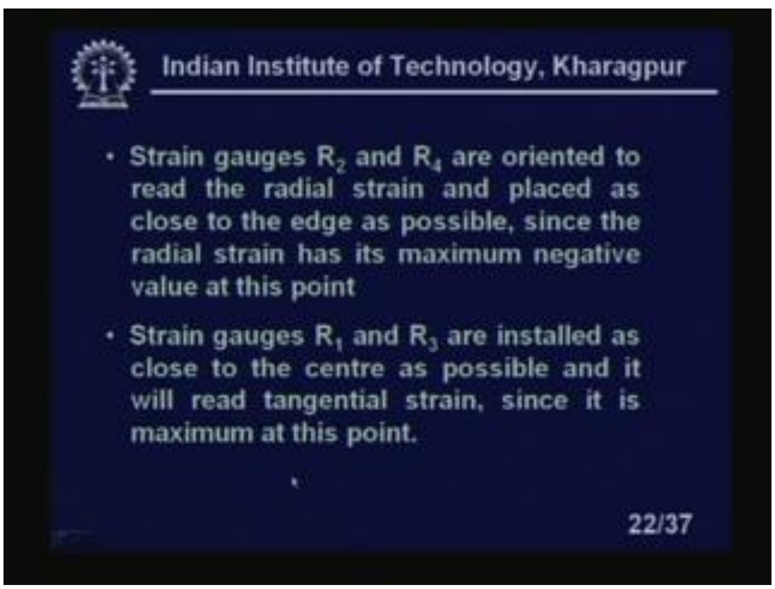

Strain gauges R 2 and R 4 are oriented to read the radial strain and placed as close to the edge as possible, since the radial strain has maximum negative value at this point, as I told you earlier. Strain, strain gauges R 1 and R 3 are installed as close to the center as possible and it will read tangential strain, since it is maximum at this point.

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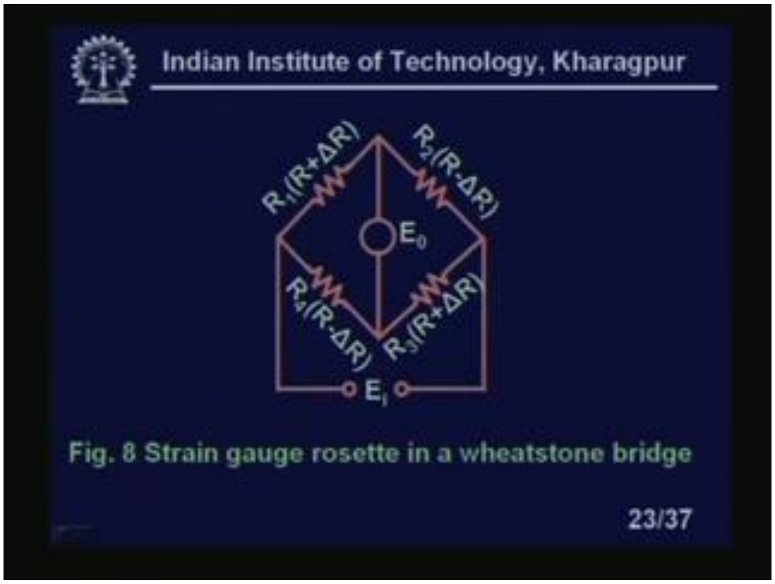

You see this is our strain gauge. R 1, R 3 which will basically sense the tangential stress, R 2 and R 4 which will sense the radial stress and it is compressive. So, it will be negative. So, resistance values are decreasing, here this is increasing. All are active gauges. So, strain gauge rosette in a Wheatstone bridge, so our output will be quite obviously ….

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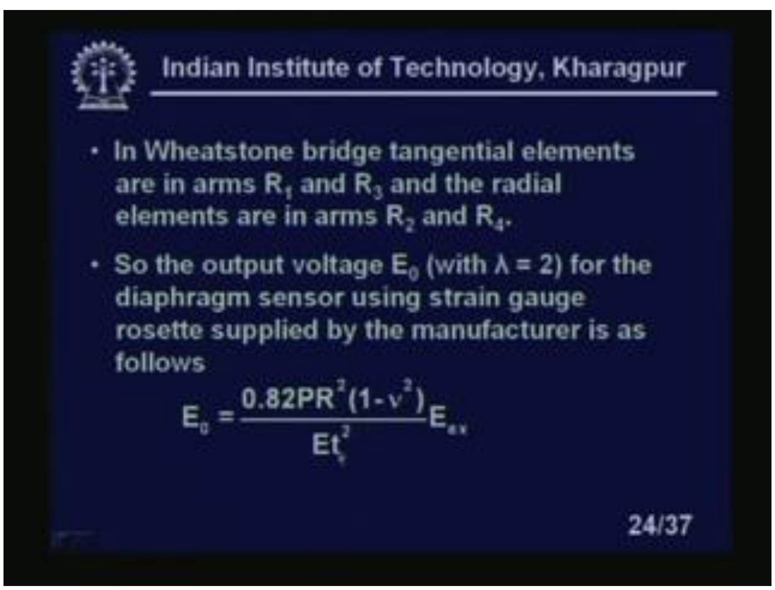

In Wheatstone bridge tangential elements are in arms R 1 and R 3 and radial elements are in R 2 and R 4, right? Radial elements are R 2 and R 4 and tangential elements are R 1 and R 3. R 1 and R 3 is positive, right? So, the output voltage E naught with lambda equal 2 for the diaphragm sensor using strain gauge rosette supplied by the manufacturer is as follows: so, you are using advance. Since lambda equal to 2, obviously you can see it is advance, so E, E naught equal to 0.82 PR square 1 minus nu square upon Et squared ex.

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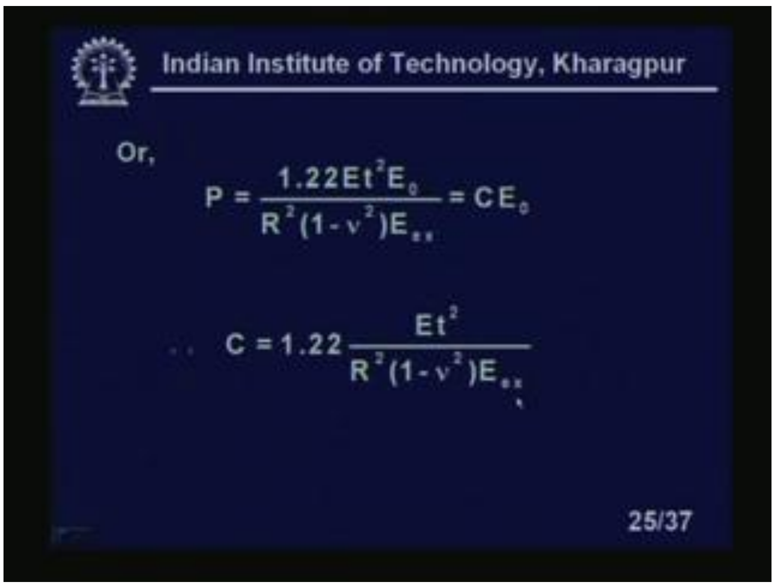

Or I can say that P equal to 1.22 Et square E naught upon R square 1 minus nu square here E ex, where C into E naught, where C is a calibration constant which is equal to 1.22 Et square, R square 1 minus nu square by excitation voltage of the Wheatstone bridge.

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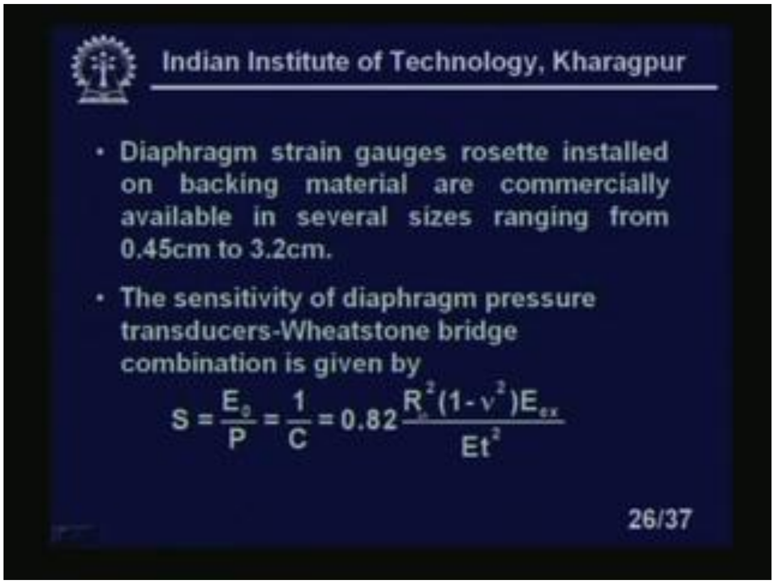

Diaphragm strain gauges rosette installed on backing materials are commercially available in several sizes ranging from 0.45 centimeter to 3.2 centimeter and the sensitivity of the diaphragm pressure transducers Wheatstone bridge combinations will be given by S equal to E naught by P upon, equal to 1 by C equal to 0.82 R square 1 minus nu square E ex square Et square. You know that we can measure this deflection by the LVDT also, but we are not discussing. We are discussing the strain gauges, so this is the sensitivity.

Sensitivity, you can see that it depends on the power supply, on the excitations, on the radius, diaphragm, thickness of the diaphragm, Young’s modulus. Poisson’s ratio is hardly, in India, in our country is mostly 0.3 for steel.

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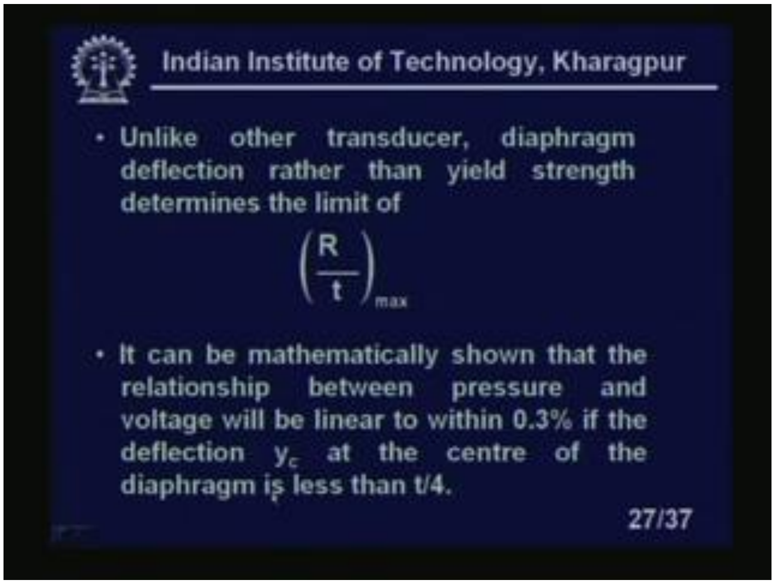

Unlike other transducers, diaphragm deflection rather than the yield strength determines the limit capital R by t max. It can be mathematically shown that the relationship between the pressure and the voltage will be linear to within 0.3% if the deflection y c at the center of the diaphragm is less than t by 4.

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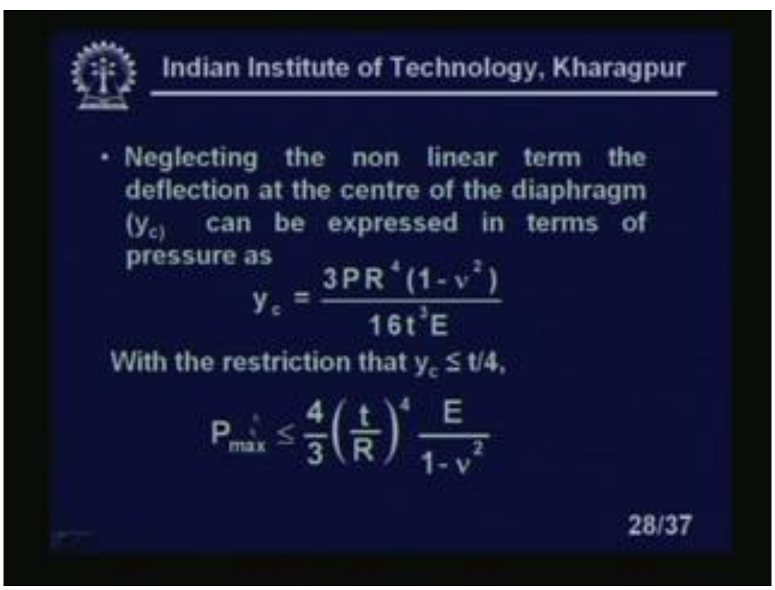

Now, neglecting the non linear term, obviously deflection at the center of the diaphragm y c can be expressed in terms of the pressure as this relation, right? This already we have given in terms of P. Now we are neglecting the, that cubed term that the third I mean that, so if we neglect that terms, so I will get a expression. So, over all I can, I should say it is almost, y c is almost center point deflections equal to 3PR to the power 4 1 minus nu square 16 t cube into E.

With the restriction that y c should be less than t by 4, because this is the restrictions we have to follow, otherwise that nonlinearity term we have to introduce here, so that with this restriction, the maximum pressure which I can measure should be less than 4 by 3 t upon R to the power 4 multiplied by E upon 1 minus nu square. We can see this ratio is very important. That means thickness to, thickness to the radius of the diaphragm is very important to control the maximum pressure, right?

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Pressure transducers that use a diaphragm sensors are well suited for either static or dynamic pressure measurement, quite obviously. The diaphragm sensor has a very high natural frequency with a small damping ratio, because of its low mass and relative stiffness.

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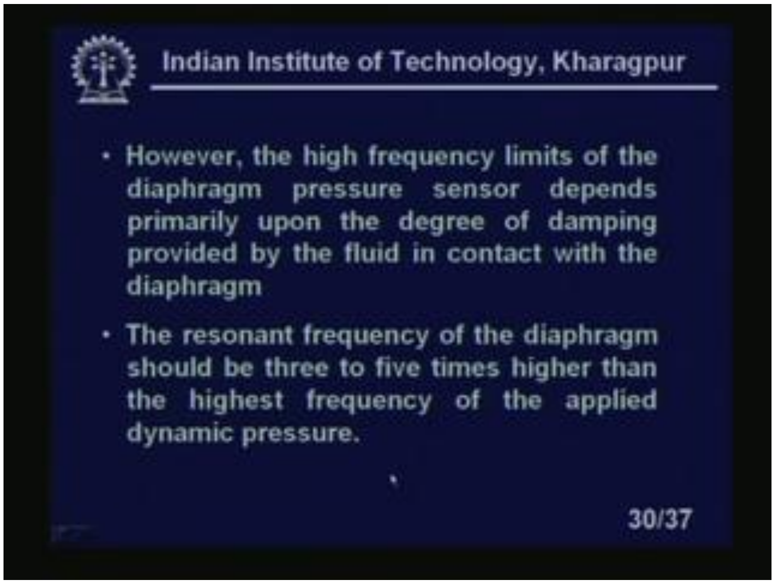

However, the high frequency limits of the diaphragm pressure sensor depends primarily on the degree of damping provided by the fluid in contact with the diaphragm, because not necessarily we measure the gas pressure, we can measure the fluid pressures or gas pressures also. In that case also that damping will be basically controlled by that particular liquid. The resonant frequency of the diaphragm should be 3 or 5 times higher than the highest frequency of the applied dynamic pressure.

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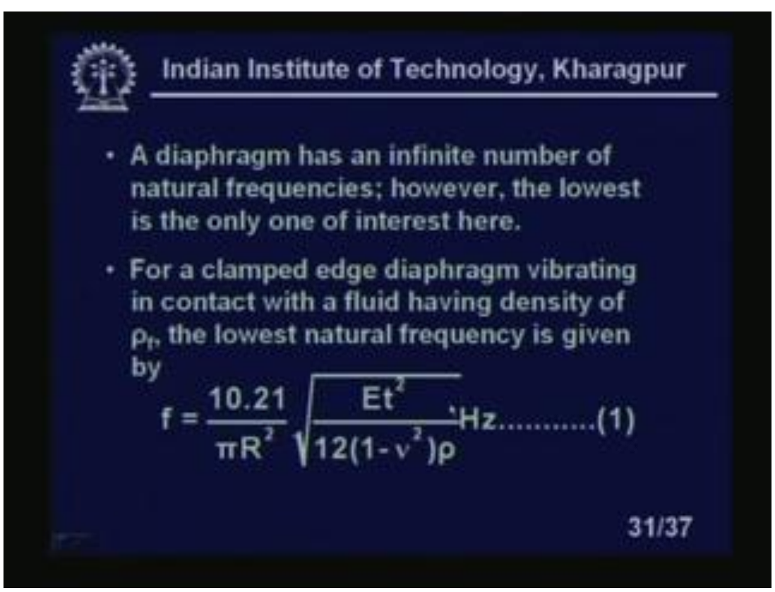

A diaphragm has an infinite number of natural frequencies. However, the lowest is the only one of our interest, we have, we should be. For clamped edge diaphragm vibrating in contact with a fluid having density of rho f that is the fluid density in which it is in contact, the lowest natural frequency of the fundamental is given by f equal to 10.21 upon pi R square under the square root Et square by upon 12 1 minus nu square rho into and that is in Hertz. This rho is basically the density of the, density of the diaphragm material.

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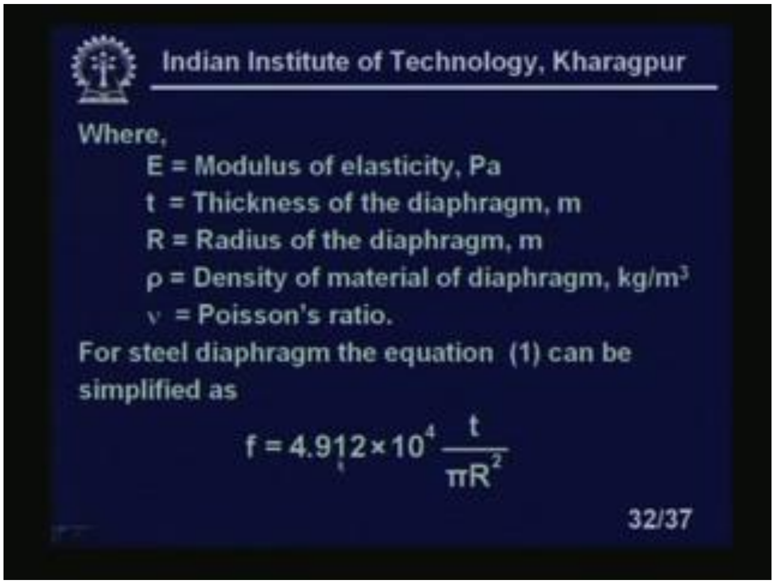

E is a modulus of elasticity in Pascal, t is the thickness of the diaphragm in meter, R radius of the diaphragm in meter, rho is the density of material of diaphragm in kg per by meter cube, rho is a Poisson's ratio and for steel diaphragm, the equation 1 can be simplified as f equal to 4.912, this is, I mean in Hertz we are telling, equal into 10 to the power 4 into t upon pi R square.

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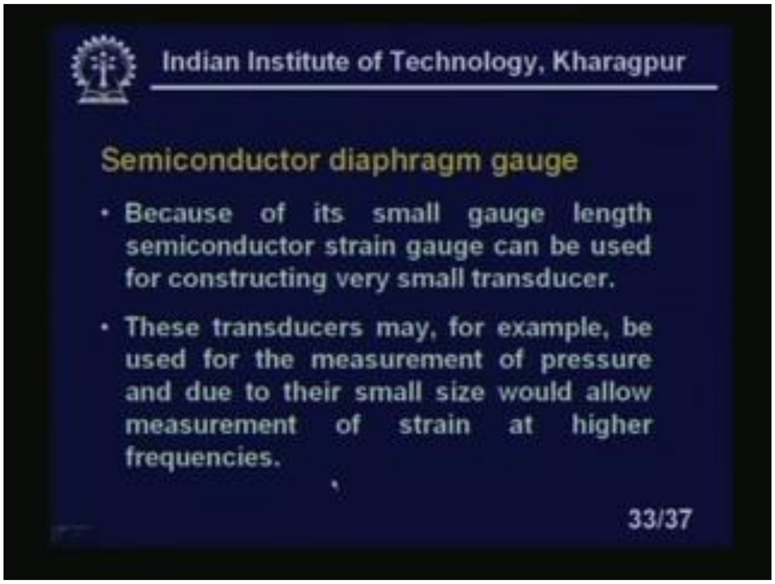

Now, another type of, I mean diaphragm gauge is avilable, is called the semiconductor diaphragm gauge, because as you know the semiconductor is very widely used. So, it is, we are using the diaphragm as a semiconductor. Here actually, this, the entire diaphragm is not made of semiconductor material and what will happen you know that where you want to get, because there also the rosette, rosette concept is there, right? So, rosette concept is there also. What they will do that , actually that, in that, in particluar what will happen you know that where you want to make the gauge in that paricluar point they dope it, right?

So they, that way they are making the semiconductor. Now semicondtor, the advatage you know the sensitivity, because the, one thing you have noticed that in a diaphragm gauge the less the deflections of the central point or the less the deflection of the pressure, so it is better. Now the problem is if I want to make very low pressure, if the deflections are very small, then I won't get any output, because strain and because lambda is equal to 2 and what about the output unbalanced voltage in Wheatstone's bridge I will get, that is …… may not be sufficient to measure or calibrate in terms of pressure. Whereas, assuming in the case of semiconductor strain gauges, thus the gauge factor is very high.

Now, if it is advanced it is 2, lambda equal to 2. In the case of semiconductor strain gauge, the lambda is 130 or 140. With this high, such a high, I mean the value of the gauge factor, advantage is that, advantage, what the advantages we will get that you know I can measure very small pressure, because the deflection at that point can be very small. But, I will get a larger unbalanced output of the bridge. So, helping us to measure the low pressure there also; not that low, but the medium pressure, right? So, that is what is the, inside the diaphragm I mean semiconductor diaphragm gauge let us look at. Because of its small gauge length, a semiconductor strain gauge can be used for constructing very small transducers. These transducers may for example be used for measurement of the pressures and due to their small size, would allow measurements of strain at higher frequencies.

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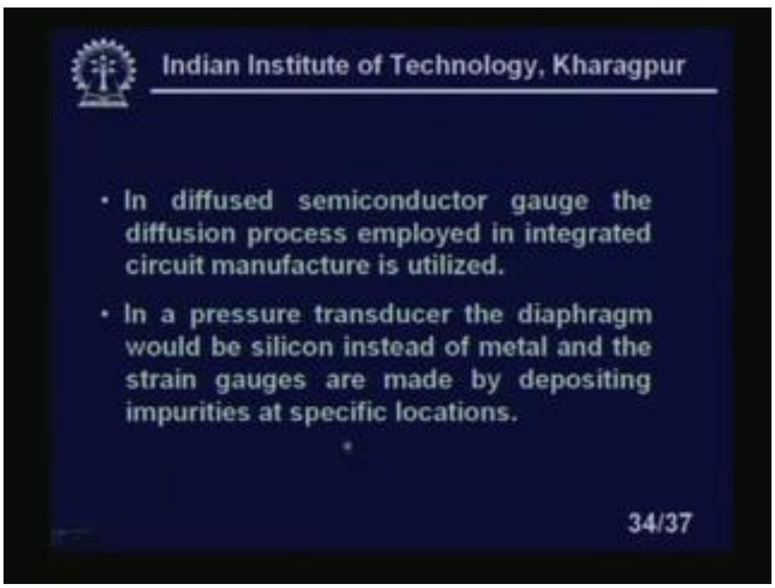

In diffused semiconductor gauge the diffusion process employed in integrated circuit manufacture is utilized. In a pressure transducer, the diaphragm would be silicon instead of metal and the strain gauges are made by depositing impurities at specific locations, as I told you. So, I will not use any metals, I am not using brass, steel or anything. I am using the semiconductor wafer itself as a diaphragm and where I want the particular strain gauge, particular that position will be doped, right? As I told that the pressure transducer diaphragm would be silicon instead of metal and the strain gauges are made by depositing impurities at the specific locations.

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The use of semiconductor technology in pressure transducer construction has led to the development of variety of very fast, very small, highly sensitive strain gauge diaphragm transducers. Silicon piezo resistance strain gauges can be diffused, because as you know that in the case of the, case of semiconductor strain gauges the piezo resistive effective is more, right? So, silicon piezo resistance strain gauges can be diffused in a single silicon wafer which forms the diaphragm, right?

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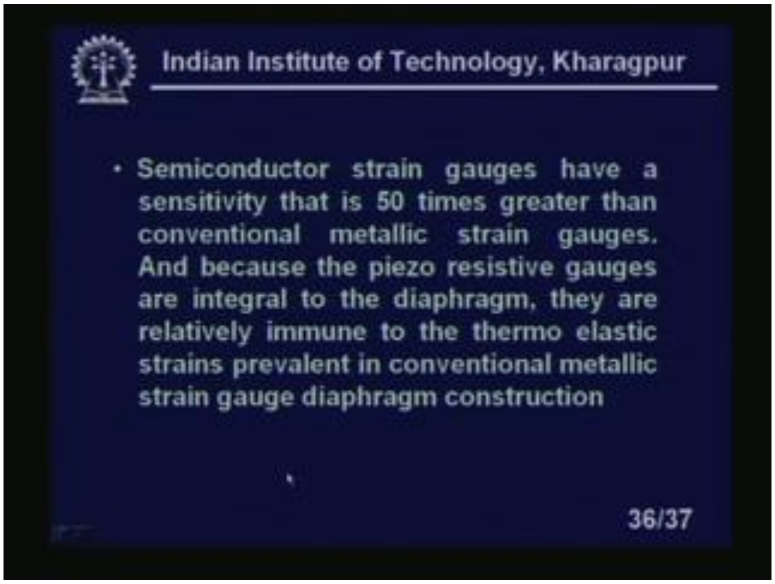

Now, semiconductor strain gauges have a sensitivity that is 50 times greater, almost 50 times; sometimes even more. Because in the case it is I have told you in case of advance it is 2, but if you use some other, suppose isoelastic which has around 3 to 3.5, in that case it is 50 times, 50 times greater than the conventional metallic strain gauges and because of piezo resistive gauges are integral part to the diaphragm, they are relatively immune to the thermo elastic strains prevalent in the conventional metallic strain gauge diaphragm constructions, right?

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Now, further more a silicon diaphragm will be, will not creep with age. That is the typical problem with the metal diaphragm, it is not creeping. But not always everything is good in the case of semiconductor strain gauges. It has been minimizing the calibration drift over time. However a gauge failure is catastrophic in the case of, which is in the case of metal strain gauge is hardly it fails, whereas our gauge failure is catastrophic in the case of silicon and its performance deteriorates with the presences of the moisture. That is I am telling that however the gauge failure is catastrophic and silicon is not well suited to wet environment, right?

So, that is, most times it is very difficult to control that the, what type of an environment that there might be a wet environment also. So, in the case of, I mean if I have a metal gauge that problem does not arise, but if we use a semiconductor, if it is the, measuring the pressures of dry air, so in that situation there is no problem, right? But other cases it will be a problem, right and since, but since it is, developments of the, it is not that popular I should say, because after the development of the strain gauge rosettes force strain gauge rosettes which is used for the diaphragm gauge, it is, I mean people are more using that sensor than the diaphragm.

But diaphragm, the semiconductor diaphragm is the integral part. You do not need any strain gauge rosettes there, which is to be installed on the metal diaphragm. Because you have to wait for sometime, because you are drying, because strain gauge rosette will be available separately on a backing material that is to be installed normally, installed on a metal gauge, on the metal diaphragm and you have to keep using all these adhesives. Here, we have to use that thing epoxy. Then you have to dry it, you give the time for drying as it happens in the case of other strain gauges. But that type of situations does not arise in the case of and since it is factory processed, this entire things, you are not using in the laboratory or in the, in the, in the actual process. So, the advantage is its accuracies is also being better.

This ends the lesson 18 of Industrial Instrumentation. In the lesson 19, we will start to make the low pressure measurement.