Industrial Automation and Control
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Lecture No - 5
Pressure, Force and Torque Sensors

Welcome to lesson number 5 of the course on industrial automation and control. Today we are going to talk about pressure, force and torque sensors. These sensors are used in a variety of contexts, both for the process industry as well as the manufacturing industry. So, let us look at the instructional objectives as is the practice first.

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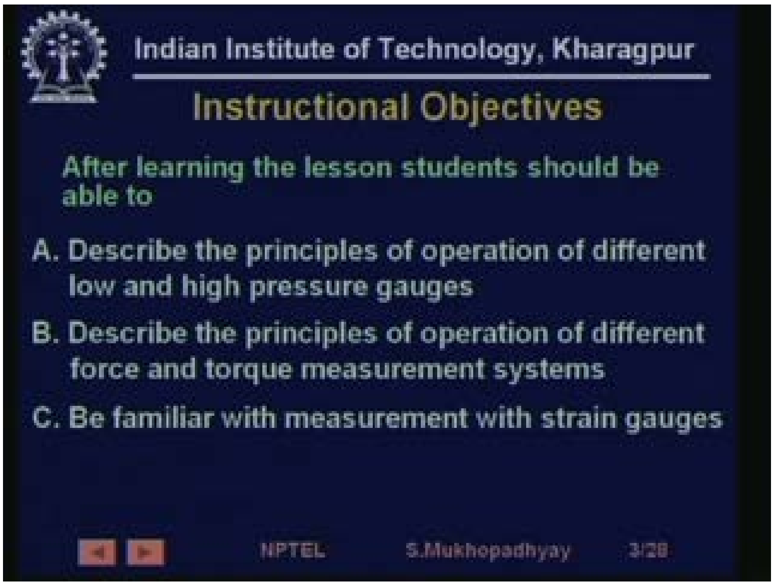

So, the instructional objectives are the following. Number one, to understand the basic principles of operation of various pressure gauges, which work in various pressure ranges. To describe the principles of operation of different force and torque measurement systems. And most of them use, many of them use the so called strain gauges so, to understand the basic principle of measurement with strain gauges.

So, it turns out as we have learnt earlier that, when we want to get the value of a physical variable from one form to an electrical form which is convenient to sense, to process, to display this transformation from the variable that we want to actually measure and its electrical form actually goes to a number of stages as we have learnt. So, it gets transformed to some intermediate forms and these transformations, each of them in turn are sometimes achieved through sensors.

So, in an, in an, in an overall measurement system, you often find that there are a number of sensors. The sensor which actually senses the physical variable that we finally want to measure, is often called a primary sensor. And it may not deliver the measurement of that variable in an electrical form. So, we have to use other sensors and sometimes and after that we have to get it into a more convenient electrical form in the, in the form that we need is a voltage value, frequency.

We need further electronic circuits, generally electronic or electrical circuits which are called signal conditioning and processing circuits. So, we have learnt about this in our basic instrumentation, basic measurement systems lesson before. So, this architecture is very much relevant in the case of pressure, force and torque measurement. Therefore, we will review it. So, we will understand.

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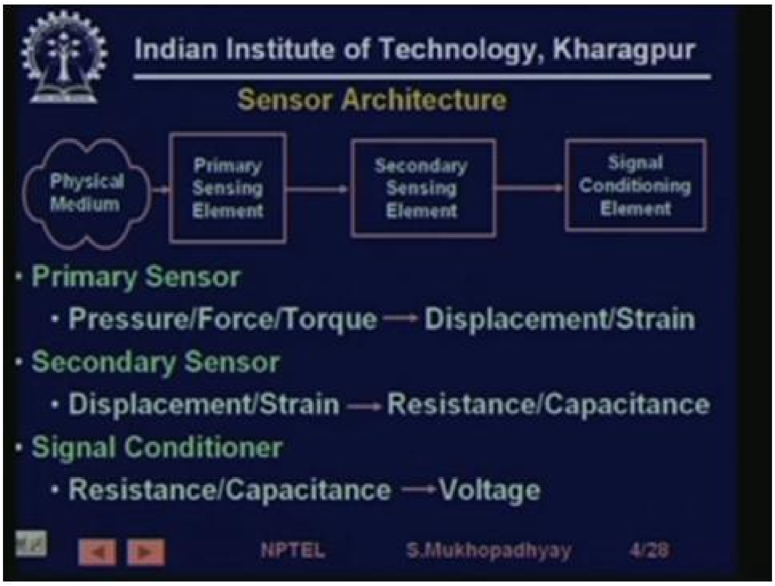

So, therefore, look at this picture, basically a blog diagram where we have the physical medium. It is, it is in the physical medium that we want to, this is the medium where the variable of interest exists, variable of interest. It may be temperature, it may be pressure whatever in this case we are, we are interested in pressure, force etcetera. That pressure will be transformed, first it will be sensed by a primary sensing element. Something that will, that will produce another variable, which will be roughly or accurately proportional to the pressure. So, that variable may be, it may be a displacement, it may be that now.

Suppose, it is a displacement or it may be a strain. So, whatever it is that displacement or strain is not in electrical form.

So, therefore, we have to use some other sensor along with this. So, first we have an element which will, which transforms let us say pressure into displacement or strain. Then, we put another sensor which we are calling the so, this element which say converts pressure to something else is the primary sensing element. Then, we have the secondary sensing element which will sense this variable, which is produced by the primary sensing element and will convert it to some other form closer to an electronic form may be resistance, may be capacitance whatever.

And then finally, we will have a signal conditioning circuit which will transform this resistance capacitance change into a, into a corresponding voltage let us say. So, you see that essentially for these sensors the transformation or the measurement will be achieved using a number of sensors. This is the point that I wanted to make. So, coming back so, as a typically as a, as a primary sensor we use displacement or strain. Sometimes, all the time we need not have a primary, I mean we can, we can sometimes have only a primary sensor. It is not that at every time we will need a secondary sensor also.

Sometimes, pressure value can be I mean directly we can we will be able to produce an electrical form that also is possible. But generally there will be a primary sensor and generally this primary sensor converts the pressure, force and torque into an equivalent displacement or strain. Then we have a secondary sensor, which will take this displacement or strain and will produce, generally produce a resistance or a capacitance change.

And finally, we will have the signal conditioning circuit which will, where this element where the resistance or the capacitance change takes place will be a part of a circuit. And therefore, there will be a, there will be a voltage produced sometimes voltage, sometimes change in frequency also may be produced, which will be proportional to this change in resistance. So, this is the basic architecture which will be evident in most of the sensing systems that we are going to see here.

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So, we will first talk about pressure measurements which are you know low pressure in 10s of 10, 20s of P S I, may be lower. So, we will, we will, we will typically review these three measurements systems. One is the pirani gauge, the second is a thermocouple gauge and the fourth is an ionization gauge. Now, here I must mention that one of the, one of the, one of the simplest methods and one of the oldest methods and perhaps one of the most accurate methods of pressure measurement is well known as the, as the so called U tube nanometer.

So, that principle just we are mentioning because we are not, we are not going to mention it in detail because generally this principle is not so much used for industrial online measurements, they are more used in laboratories. So, therefore, we will not treat this in detail. But, we all know this that the, that the basic principle is that you have.

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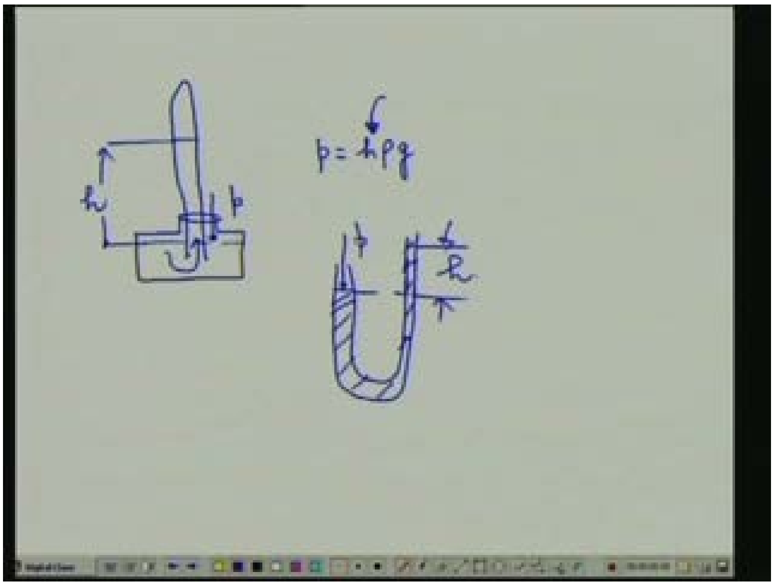

Let me change my pen. So, the basic principle is that you have one vessel and where there is some liquid and suppose you have you have another vessel. So, if you have a pressure on this as p, then this liquid will be forced into this and it will rise above a certain level. So, this pressure basically force balance so, this pressure will be equal to the standard formula. That is, if this is the height h and if the density of liquid is rho. And if the force of gravitation is g then, p is equal to h rho g. So, we measure h and we sense the pressure p. This is, this is the famous barometric principle. Sometimes, you can have, you can have, you can have various variants of this principle. You can have a, you can have a manometer which is a, which is an U tube.

So, if you put pressure on one side and then, you will create a, you will actually create a level difference that is the liquid column on this will be higher. So, you can measure the pressure by sensing the difference in the liquid columns again. So, if this is h and if this is p then you can again sense the difference. So, these are very standard one of the, one of the, one of the earliest methods of pressure measurement. But we are not going to speak much about them because they are generally not so much used in an industrial context, but used more in a laboratory context. So, coming back we will we look at the pirani gauge, the thermocouple gauge and the ionization gauge. So, let us look at them one by one.

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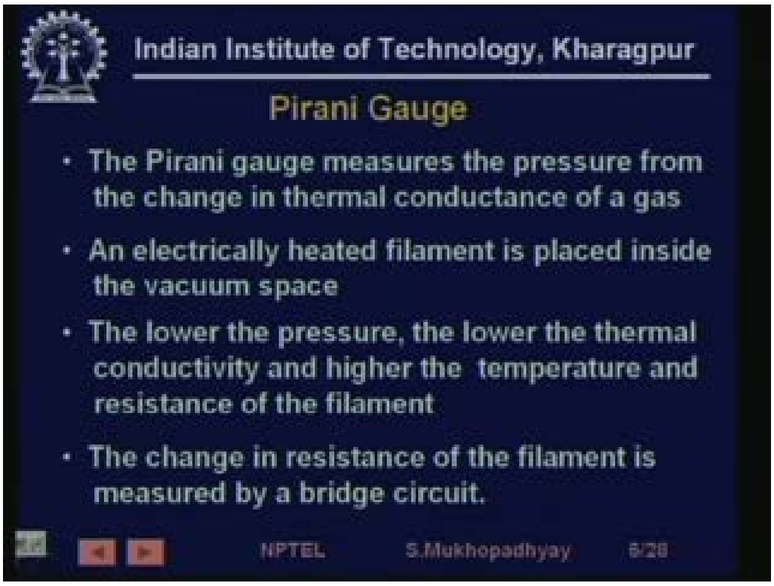

In the pirani gauge, incidentally in the in the pirani gauge you can say that there is no secondary sensor. So, the effect of the pressure basically the pirani gauge says that if in a it is used for measuring pressure of gases. So, if you have and it is, and it is used for measuring low very low pressure.

So, if the pressure is very low then the number of molecules, which exists in the gas or going to be low. Now, if you have a heated object inside that gas then heat will be conducted through the gas. So the, so the, heated object will lose heat by thermal conduction through the gas. And the amount of the heat that will be carried away from the, from the heated object by the gas, obviously depends on the number of molecules present in the per unit volume in the gas which is proportional to the pressure. So, if the pressure is high then the then more heat will be taken away, if the pressure is low then less heat will be taken away.

So therefore, an electrical heated filament is placed inside a vacuum space, vacuum space means very low pressure space. Then the lower the pressure then the, then the lower the thermal conductivity of the medium and higher the temperature of the resistance because less heat is being taken away. So, the temperature of the, of the filament will increase. Therefore, its resistance will increase. So, if we put that filament into a circuit we can directly sense a resistance change. So, it is measured by a bridge circuit. So, you see that here the what is the principle used? The principle used is that the thermal conductivity of low pressure gas depends on its pressure.

So the, so the pressure is directly through the same element which is a filament. The pressure affects the thermal conductivity, which affects the temperature, which affects the resistance. All this serial effect is within the same sensor. So, in this case we can say that there is no explicit secondary sensor. And this filament is directly put into a signal conditioning circuit which is the bridge and the resistance change will give us a measure of the pressure. So obviously, it is also possible to measure it online. So, you simply put it in a bridge circuit.

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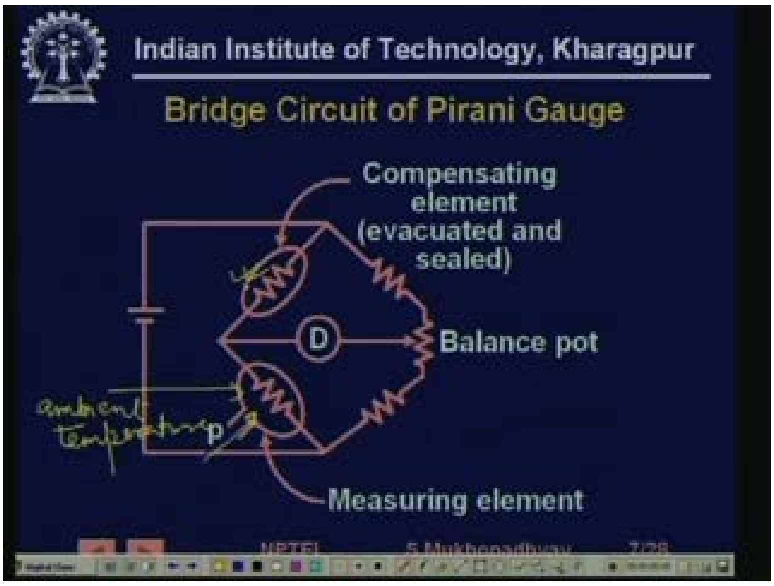

So, you have this is the, this is the measuring element in which you want to measure the pressure. So, you are subjecting the pressure is actually applied here. So, the pressure is actually applied here. This element is actually a compensating element, which takes care of see the, see the temperature of the filament will actually depend on many things.

It will depend on the pressure certainly. It will also depend on the ambient temperature because the heat flowing out depends not only on the thermal conductivity, but also on the temperature difference between the filament and its environment. So, if the ambient temperature changes then this is, this is actually a you can say an interfering or a it is actually an interfering input. So, this can be compensated by this compensating element. And then you have a normal Whetstone’s bridge which will give you an output which is which will show you the pressure. So, this is a case where only a primary sensor is used.

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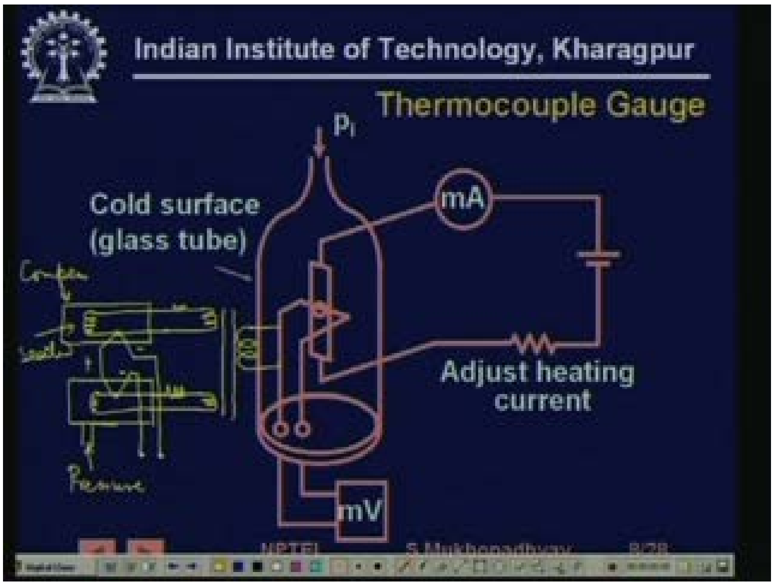

Similarly, exactly similar principle is used in the thermocouple gauge. In the thermocouple gauge, we are doing exactly the same thing. We again have a filament, we again heat it up using a current and we again try to measure its temperature, which will depend on the pressure in the, in the same way only thing is that, in this case we do not depend on, we do not sense its resistance change. But rather we directly put a thermocouple on that, on that heated object which will give a voltage which is proportional to the, to the, to the, to the temperature of that object.

In fact, in fact, one can use here also one can use a compensating element. For example, here also one can use a compensating element. So, you can have two such sensors. So, you can have one coil here and another coil here. Both of them can be driven say by some voltage source which may be a, which may be a normal A C source like a transformer.

So, you have the transformer primary and you have two secondary's wound on the same core. So, if the primary voltage varies. So, you have the transformer. And you connect one thermocouple here and another thermocouple here. So, these two positive wires of the thermocouple are connected and the negative wires are taken out as output. So, this is one output and this is the other output. So, these two are the plus wires and these are the minus wires.

So, this so, in this case this is the basically extension of this. So, you are using this is a compensating element and here you can input the pressure, this is sealed in vacuum. So, you first create very low vacuum 10 to the power minus 5 kind of P S I kind of pressure and then, you seal it. So, this can be. So, so, so, now the, now the this voltage, this voltage will be a measure of the pressure. In this case, we are using a secondary sensor, which is a thermocouple which senses temperature. So, in this case the secondary we had made said that the generally the primary sensors transforms into the displacement or strain, but in this case it is being transformed to a temperature.

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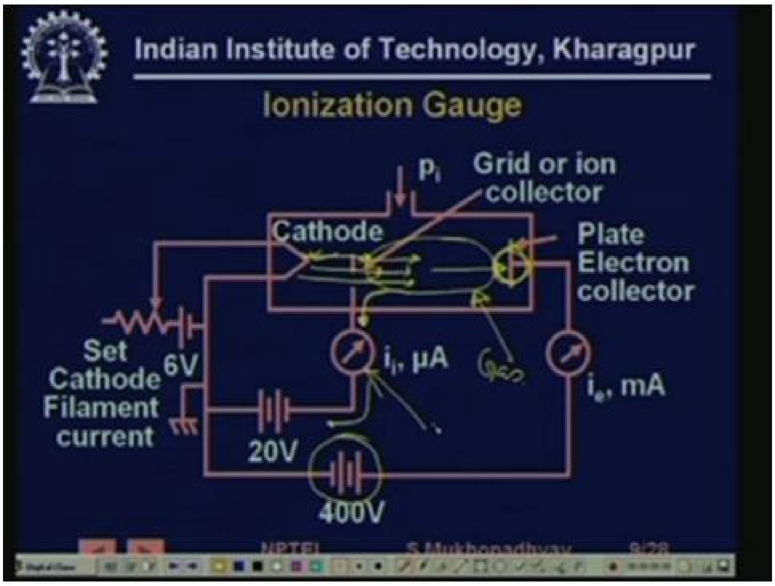

Then we have an ionization gauge, which is also used for sensing very low pressure. So, what we are doing here is here also we do not have an explicit secondary sensor. This principle is different, this principle is that in from this cathode you have a stream of electrons are produced right. And you see that between these cathode and this plate there is a there is a large voltage applied.

So, what happens is that during this in this zone, in this zone there are there these speeding electrons which come out from the cathode bombard the molecules of the gas. So, the gas is here and they displace some electrons from the those molecules. And therefore, the gas molecules generate an ion pair. One is the heavy positively charged ion and the other is a negatively charged, other is basically an electron. So, what happens is that this, these positively charged ions actually come and get collected in this so called grid.

And the electrons as usual travel along with the, along with the electrons which is created by the cathode to the plate and gets collected in the electron collector. So, you see that the, that the electron current is basically the sum of this cathode electrons which are, which is much larger in number and the electrons created here which are, which are smaller in number. So, therefore, this electronic current remains more or less constant. While this ion current which is produced which is entirely due to the, due to, due to those positive ions which have been produced by electron bombardment.

They are the one's which get collected. So, it is this current which is the measure of the pressure, because the current will be higher, if the number of positive ions produced will be higher. And the number of positive ions produced will be higher if two things, if the number of basically, if the number of molecules per unit volume is higher because we are, we are keeping the number of electrons coming from the cathode to be constant.

So, we are so, we are so, the cathode current is more or less kept constant. So, the ion current will depend on the pressure. So, in this case you see by directly these, this pressure is can be sensed in terms of the current. So, even you can say that even a signal conditioning circuit is also included here. So, you, so, you just measure the current. So, this, these are the three gauges that we, that are and we use to measure lower pressures. So, now we will move on to other measurement schemes which sense higher pressures of the order of 1000s of P S I.

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Of course the diaphragm, of course the diaphragm gauge can measure pressure at a, at lower values also.

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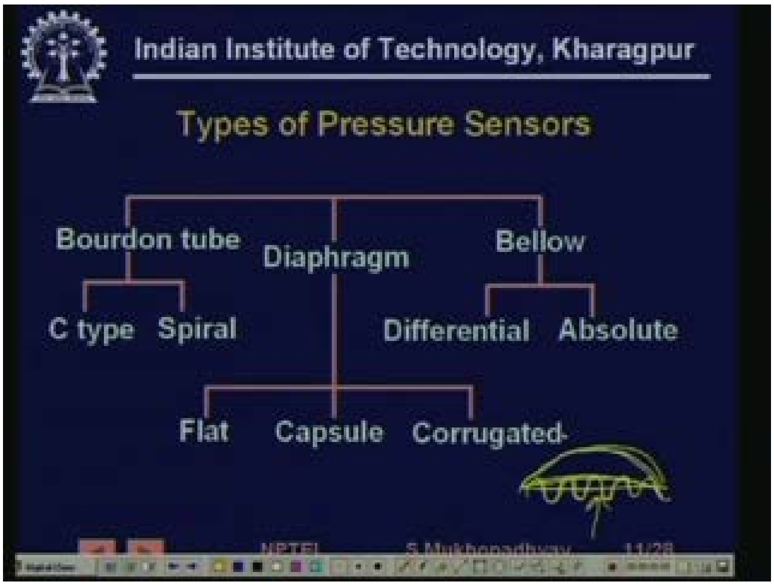

So, coming to the first the bourdon gauge the basic principle. So, right. So, before that let us show all these sensors both the, both the bourdon gauge, the diaphragm gauge and the bellows have come in you know various flavors. So, for example, a bourdon gauge can be the well known C type gauges we will see one of them. And if you extend the tube you can make it into a spiral which will give better sensitivity, in the sense that it will give the bourdon gauge actually converts pressure into a displacement. So, if you use a spiral you will get a higher displacement.

Similarly, if you have I mean you can have a diaphragm where you, where it can be a flat diaphragm. Sometimes, it can be a, it can be a stretched diaphragm in the sense that to keep the diaphragm taught you need to apply a pressure. Sometimes, they are thin plate diaphragms where which can which are anyway taught, because their thickness is more. Sometimes, you can have capsules where you can apply pressure from both ends. And sometimes when you want to have higher displacement for these diaphragms then you make the diaphragm corrugated.

So, you actually you can if you have if you actually make the diaphragm corrugated so that for a given pressure application the displacement because there are, there is, there is a lot of play here. So, this diaphragm can actually stretch much higher. You may have magistrate probably it would have stretched only this much. But because it is corrugated so now the corrugations can expand and it can give you a higher displacement although that comes sometimes with an amount of nonlinearity. Similarly, bellows can be either absolute or differential, in the sense that if your bellow is again you know something like a, something like a diaphragm which whose ends are not fixed.

So, therefore, the rather than the diaphragm moving due to, moving it can, it can actually physically move because the, because the whole diaphragm is actually put on a moveable element, we will we see that. So, coming to the C type bourdon tube this is the usual bourdon tube. So, you can see the different parts.

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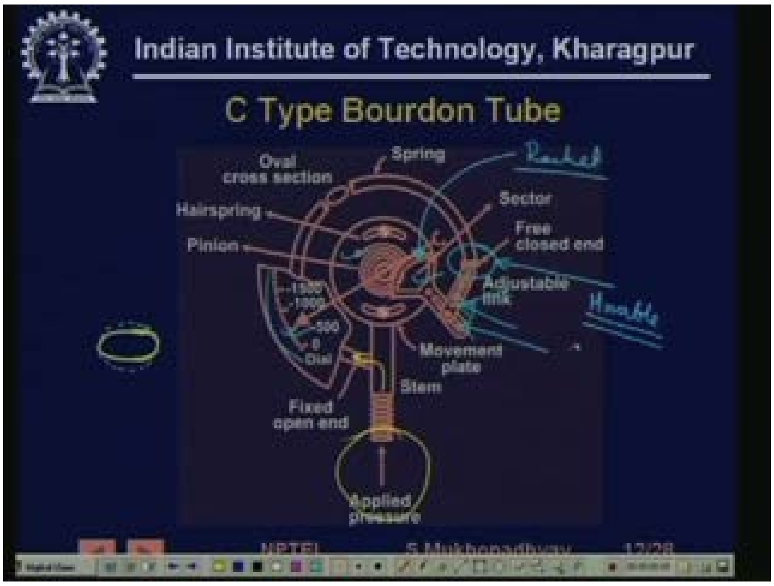

For example, this is the place where the pressure is actually applied. So, it is a, it is a, it is a tube which is connected to the region where you want to measure the pressure and this pressure is comes into this pipe. Now, the most interesting thing is that this pipe actually has a oval cross section. This is the crucial point about the bourdon gauges. So, whenever you apply pressure this cross section tends to become because of the pressure it will tend to become roundish. So, the tube, the tube is like this when it will have pressure it will have a tendency of stretching out into a, into a square circular cross section, right. So, it will have a tendency of stretching out into a circular cross section.

And this stretching out actually creates, this stretching out actually creates forces such that this end, this end this is the moveable end, this is the moveable end. So, because this is stretching out this moveable end will move and that is now connected to some you know mechanisms links and other things.

And so, here you have a, you know a ratchet kind of mechanism and so the ratchet moves this moves a pointer there is the spring. So, this all these are actually just simple motion translating mechanisms such that you get a movement of the pointer on the scale. So, the basic idea is that you have a tube which is of oval cross section which will stretch as the pressure is applied and because of the stretching this end will move. Now, because this end moves and it is connected to a mechanism so, therefore, the pointer will move.

Now, it is not necessary that you have to connect it to a mechanism like this. This is, this particular diagram happens to be an indicating instrument. So, therefore, it is connected like this. You can, you can, you can also connect it to any position sensing equipment something like an L V D T whatever or a, or a, or a magnetic position sensor anything and then that position can be transformed again to an electrical form. So, this is the in this case this mechanism actually is the secondary sensor.

So, the primary sensor produces using pressure it actually first produces strain, but that strain is actually produced strain and the, and, but the strain in turn produces a displacement of the C tube end which is sensed by a secondary sensor. Very simple as such it can measure pressures up to very high ranges 100, 1000 P S I kind of, no 100, 1000 may be 20000 P S I type of values.

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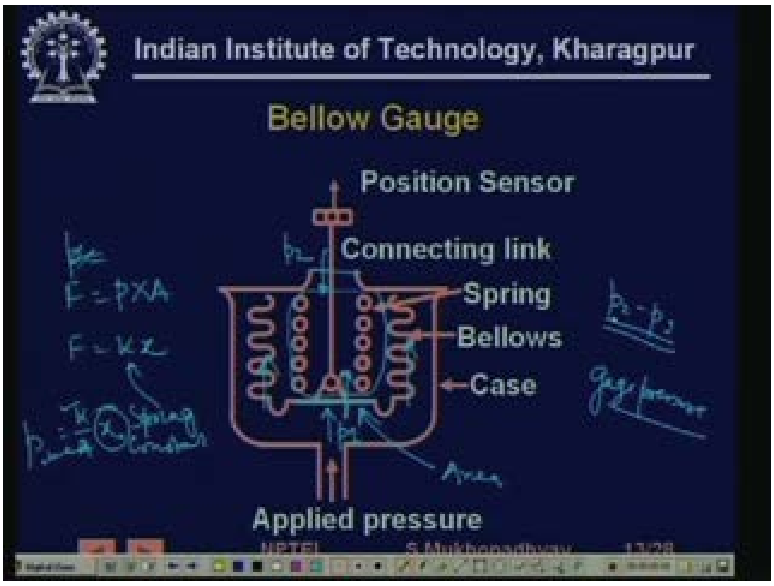

Then, you have bellow gauges. So, bellow gauges are used for lower pressures, they give higher displacements. And so, the so, the basic idea is here is again that as I was telling that you apply the pressure here. This is an element, which senses the pressure actually the pressure is sensed as the force. Now, rather than in the case of, now here in this case what happens is that this force will push these up.

So, there will be a it is like a, it is like a spring. There is, there are, there are springs inside and there are bellows. You know bellows are mechanical elements which are which are organized like a, in the side it is actually is a cylindrical thing. It is actually cylindrical thing which has, which has corrugations it is a, it is a, it is a closed surface. And obviously, if there is pressure this thing will move. So, the so, the gaps will close and this up this will move up. It is generally used to move up at a particular, against a particular spring.

So, that it comes to rest and this position now because a spring has a certain spring constant. So, this pressure is equal to p is equal to basically the force created F is equal to p into A where A is this area. And this will, this F will be again equal to K into x where K is the spring constant. So, therefore, the pressure will be equal to K by A into x. So, if you sense x, K and A are fixed constants. So, you can sense pressure. And as I was telling that if in this case, if this end is vacuum sealed or if this end is open to the atmosphere, then, you will if it, if it is open to the atmosphere then you will sense what is known as gauge pressure. That is the displacement will be proportional to the, to the amount by which this applied pressure exceeds the atmospheric pressure.

On the other hand, you can sometimes other than having an absolute pressure measurement you can also have differential pressure measurement. So, if you apply a pressure p 1 here and a pressure p 2 here, then this displacement will be, will be a measure of the differential pressure which means p 2 by p 1, p 2 minus p 1 actually.

So, as we said that the same principle can be very well used to measure either absolute pressure or the absolute pressure means if this end is sealed with a vacuum or gauge pressure or differential pressure. So finally, again we have a here we have a. So, this is our, this is this position. So, here also pressure is transduced to a position and it goes to a secondary sensor.

Next, we come to the diaphragm gauges. Diaphragm gauges are very well used because of a number of factors that they take small areas, they can be constructed in for wide ranges of pressure, they are very amenable to, they are very amenable to online measurement, etcetera.

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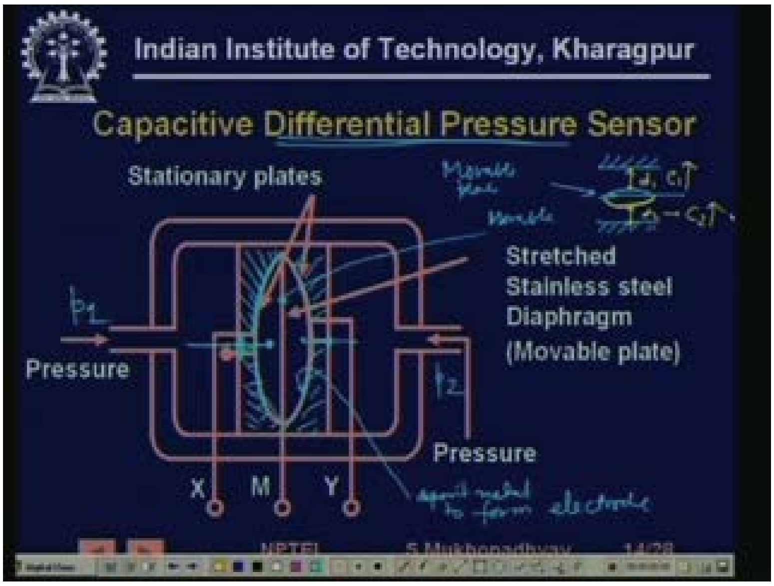

So, coming to that so, here we have a first, we are using the principle of a diaphragm, which is in this case it is actually a stretched. You know you can, it depends on the range if you have a if you use a very small range then you sometimes in the place of the diaphragm you use membrane. Actually what you want is that you should get a certain amount of displacement which can be accurately sensed for that range of pressure. So, if you have lower range of pressure, now obviously for a, for a given range of pressure how much of displacement will be that will depend on the thickness of the membrane.

So, if you have lower range of pressure you sometimes create take a, take you know things like membranes which are stretched something like you know when we, when we seal you know tins. Then we have, we have we are often sealed them by aluminum membranes. So, membranes are different from plates, in the sense that membranes deflect under their own weights.

And have you seen those tins where the, where the, where the top membrane is you know kind of loose because it cannot support its own weight. It is, it is so thin. On the other hand, plates are used for higher pressure ranges they can support their own weights. So, depending on the range you can use either a plate or the membrane. Membranes have to be kept stretched because unless they are stretched they do not have a neutral position. So, in this case we have. So, look at this here we are trying to you see, these are two pressure ports, we are trying to sense differential pressure. So, we want to sense the pressure difference between two ports. So, one here we have one port which is p 1, here we have another port which is p 2.

Now, these ports and this pressure actually comes through into here. So, you have you know there are, there are holes here and there are holes here through which the pressure comes into the here. Now, these are the fixed parts this surface, this the sometimes made of glass. So, this is a fixed surface this is, this is full glass fixed surface on which you can make on this surface you can deposit metal and form an electrode, to form electrode.

So, you see that here is one electrode this surface is one electrode, this surface is another electrode and this is the moveable plate. So, actually you have formed two parallel plate capacitors. These are the two fixed plates and there is one plate, which moves. This is the, this is the membrane or plate, moveable plate.

So, as it goes this way or as it goes this way epsilon naught A by D is, epsilon naught A by D is capacitance. So therefore, if this D 1 decreases then this capacitance C 1 will go up. Similarly, when it comes bends this way then, this one D 2 decreases. And therefore, C 2 goes up. So, you have formed two differential capacitors and if the moving plate moves this side then these capacitors will increase, these capacitors will decrease. So, now, you can use these capacitances in a, in a, in a, in a normal bridge, right.

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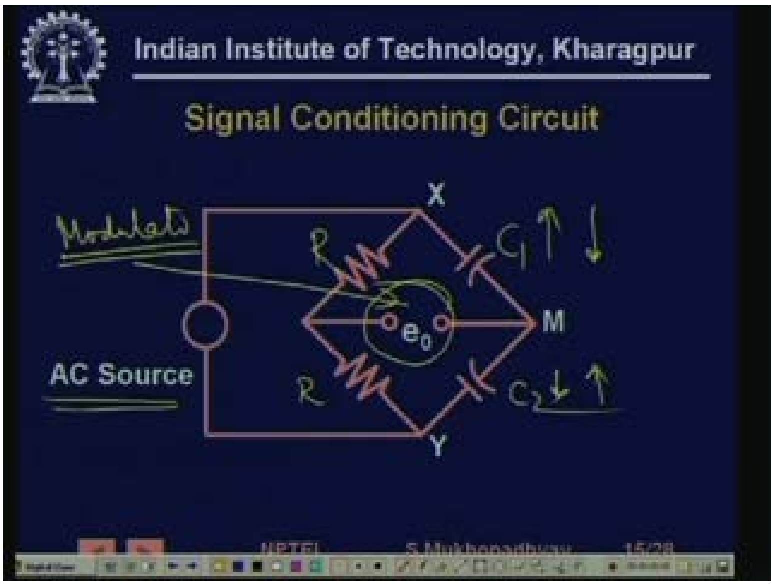

So, the signal conditioning circuit is a simple bridge like this where you have. Just a moment so, the signal condition. So, here you have C 1 and here you have C 2. So, as the membrane moves this can go up, this can go down or this can go up, this can go down. So, since these resistances are fixed that will create an, that will create an E M F.

Now, we must note that this is if this is an A C source then, this motion or the pressure fluctuation if you have pressure fluctuations then this pressure fluctuations will actually cause, will create a modulated wave because this itself is A C. So, they will create a modulated output which has to be demodulated. So, we will learn about that when we learn about L V D Ts. That is how amplitude modulated A C waves can be demodulated, right. Now, we are not discussing that.

So, coming to the next one we have. So, now, that was one use of diaphragm where the diaphragm, where the movable diaphragm was used as a as the moveable plate of two capacitors which two of which had fixed plates and this moveable plate created a push pull capacitance sensor.

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Now, we will see another application of diaphragms, where we use mainly use strain gauges sometimes you can use also other position sensors, but mainly use strain gauges to measure pressure. So, as I said that diaphragms are used for low and middle pressure ranges. So, they can be used for measuring, yeah it will quite good pressure 10 to the power 4 kilo pascals. They can also be used for low pressure measurement. By low pressure I do not mean extreme low pressure, which are measured by things like you know ionization of pirani gauges, both. So, in the diaphragm I will we will just see the diaphragm. In the diaphragm both tension and compression stresses exist on the diaphragm. So, we have to use them in a push pull configuration and we can use a four active arm bridge which will give better sensitivity.

It all, it as we know that if you have more than one we have, we have four active arm bridges then we get some benefits like improved sensitivity, improved linearity, we get improved temperature compensation. So, all these things are possible if using things like strain gauges on this diaphragm so, we look at that.

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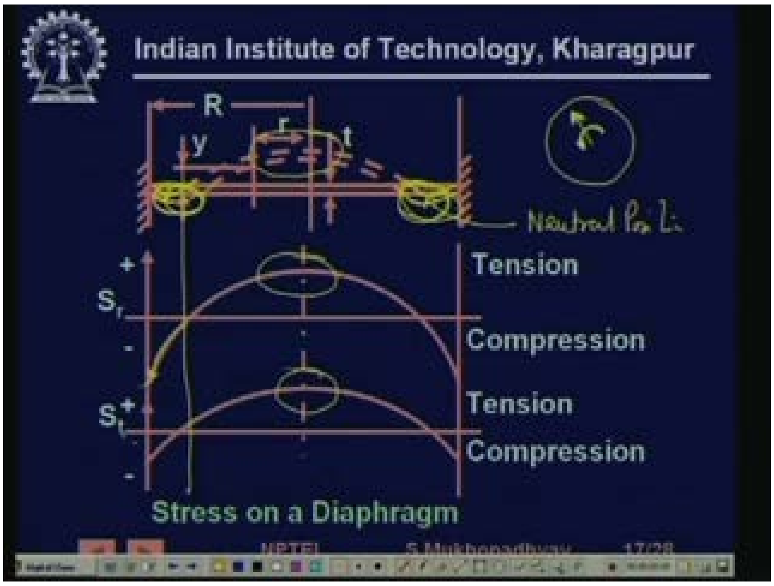

So, this is a diaphragm. So, this is a plate. So, you see that this is the unstressed, this is the sort of a neutral position and this is the position under pressure. So, you have actually it looks somewhat like this it bends an exaggerated picture. So, you see that here, obviously now you see that the diaphragm, this is a side view this is what you have been showed is a side view. So, similarly you have top views. So, in the diaphragm you can have as you press the diaphragm suppose you apply force from the top or if apply force from the bottom you are going to have two kinds of strains.

So, one you are going to have strains which are you know one you are going to have radial strains. So, you are going to have radial strains and you are going to have circumferential strains and it turns out that because in this part of the diaphragm actually gets stretched, this part of the diaphragm actually gets stretched. So, you have positive radial strain, positive radial strains. So, the thing wants to stretch along the thing wants to stretch both along the radius and you have positive circumferential strain, because the whole element tries to expand. So, on the circumferential, on the circumference also that is a tangential strain is also positive.

On the other hand, when you come to the, to near this point you know where this bend takes place there you have compressions. So, the so, you have. So, the radial strain also goes negative and the. So, there you have because it is clamped on one side and stretched on the other side. So, here in this zone you have compressive strains. So, this both the tensile, both the tangential and radial strains go negative. So, this gives a kind of, this gives an idea about the stretch distribution or the strain distribution which occurs in the diaphragm. Now, we have exploit this by using strain gauges. So, what we do is we put strain gauges on this diaphragm.

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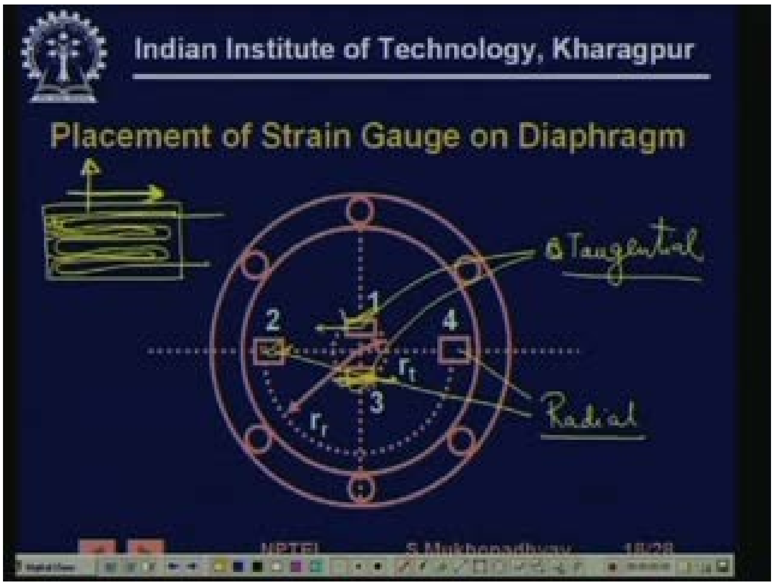

See, a strain gauge is actually something like this, a strain gauge if suppose we take a, take a foil gauge where you have thin metal deposition and a long you make a long wire on a foil. So, what happens is this also have some thickness and these parts the thickness is made large, this part of the thickness is made small like this.

So, because is a, if you make it like this then what happens is the, this is the resistance of this will change due to strain. Now, strain can be in this direction, strain can also be in this direction that is strain can be broken up into components. Now, turns out that because these parts are made thicker and this is longish, most of its length is along this direction. So, therefore, this is predominantly sensitive to strains along this direction and very less sensitive come to strains along the perpendicular direction.

So, that is why we. So, we have placed two strain gauges this 2 and 4. What kind of strain they sense? They sense radial strain, because they are oriented along the radius. While this 1 and 3, they sense strains along these directions. So, they are, they are tangential strains. So, now what will happen according to our stretch distribution these two will sense radial compressive strains while these two will sense circumferential tensile strains.

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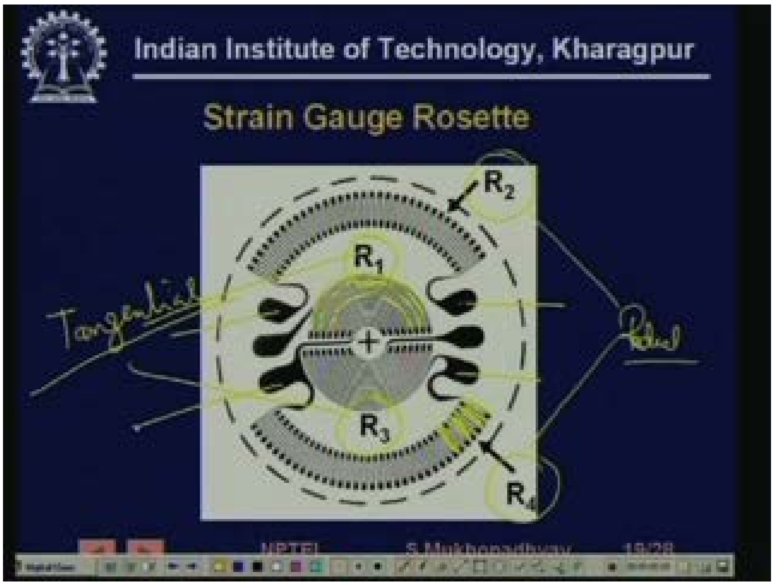

So, sometimes other than putting discrete foil gauges we can make one big rosette. See the same thing these sensed, these are, these two R 1, R 2 and R 4 these sense radial strain. See that they are, they are arranged along the radius their sensitive axis. While this R 1 and R 3 see their lengths are along this. So, these are sensing tangential strain, and these are the electrodes through which through which you take connection. So, now you have 4 resistances and you can put them in a bridge.

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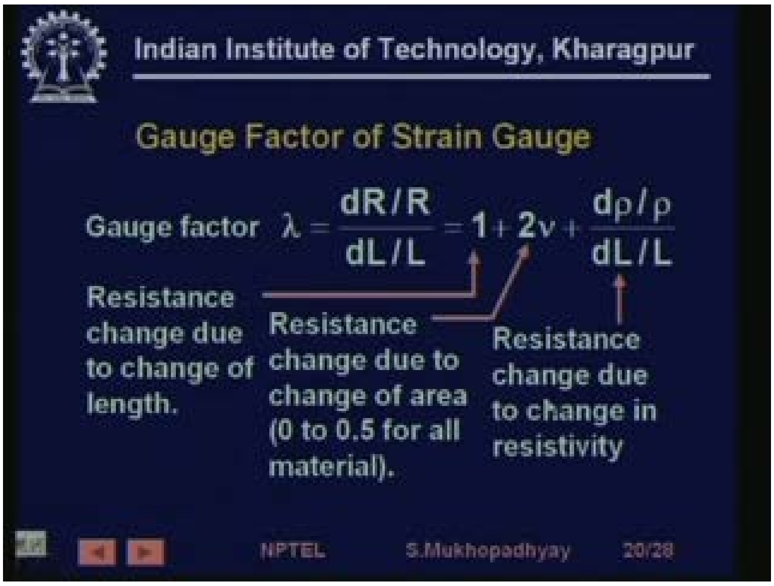

It turns out that the what a, what a, what a, how is the resistance changed related to the strain. So, if you have that is, that factor in the case of strain gauges is called a gauge factor. So, the gauge factor is the percent resistance change for per unit strains. See the strain in the direction is actually dL by L. dL by L is the along the orientation axis of the strain gauge how much there is length change.

So, dL by L is the strain and d R by R is the fractional resistance change. This resistance change can be actually attributed to three factors. One is the resistance change due to the change of length. So, the length of the wire itself will increase because the volume must remain same. So, therefore, it is there will be a change in area and that change in area is, this is the resistance change due to the change in area because resistance depends on length as well as area. This new is the poissons ratio. So, if you it says that if the length if you pull a wire and if you if its length increases by delta L then, area will also decrease by delta A because the overall volume must remain constant.

Similarly, due to force sometimes there is a resistivity change. This is very predominant in semi conductor strain gauges. So, in fact I mean, I mean semiconductor strain gauges are have much more sensitivity then metal strain gauges and this is basically due to the fact that you have large resistivity changes in semiconductor strain gauges. And although they have, they have great sensitivity they also very sensitivity to temperature. So, that is the disadvantage. So, in any case we are going to have depending on the gauge factor we are going to have resistance change which is proportional to the strain and the strain is proportional to the pressure.

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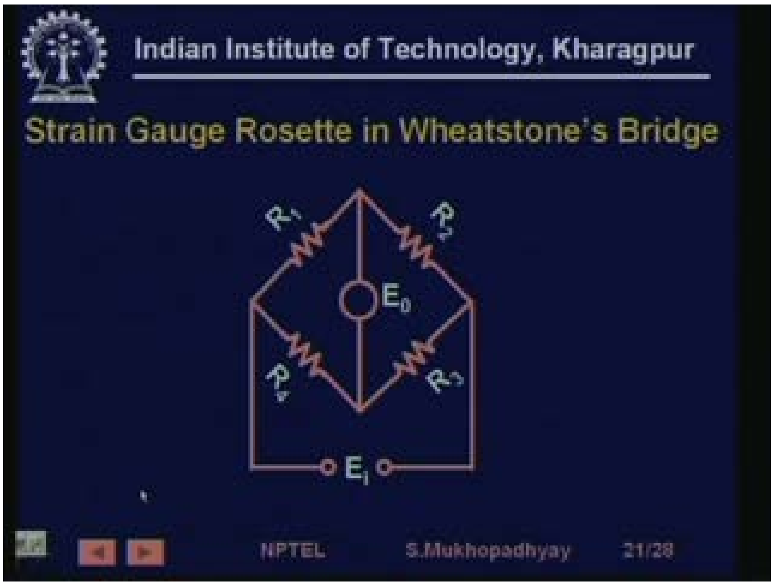

So, that is how we sense pressure. So, we put them in you know R 1 or R 3, R 2 and R 4 on these two sides again standard Whetstone's bridge principle and we can get a output.

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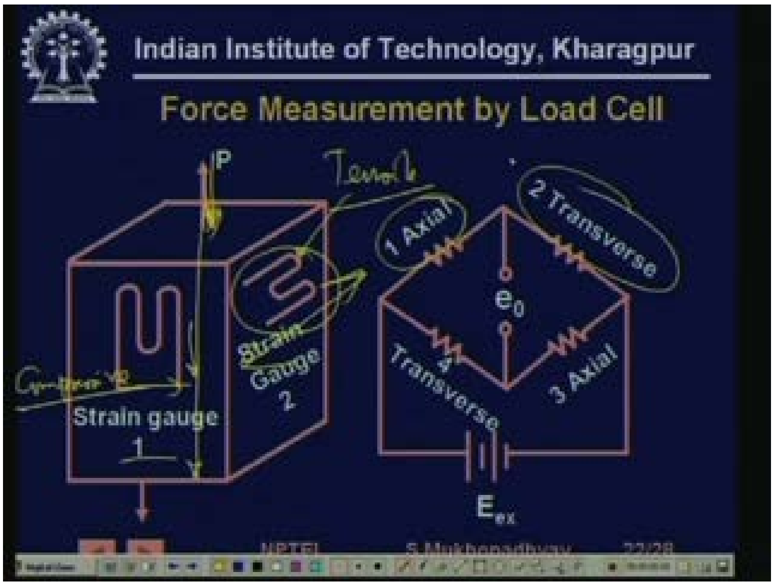

The same principle can be used in a, in a, in a variety of configurations. For example, when if you are, this is a standard weight measurement principle, which is used in the industry weighing cells. So, you have this is a, this is a cylindrical mechanical member, this is a cylindrical mechanical member. So, if you put pressure, if you put force on it either up or down say by, say the ((Refer Time: 47:16)). So, if you put a large object on it then on, then the there will be, there will be deformations on this member, there will be strain created and if you put strain gauges then you can put the strain gauges.

You see this one. Suppose you put a weight on it then this one will undergo compressive strain and because this will undergo compressive strain this will undergo tensile strain. So, now so, this is axial along the axis and this is transverse along the perpendicular to the axis. So, you can have 4 such gauges. This will both resistance will change, will be negative resistance will, resistance will be lower. Here, the resistance will increase. So, you put them in opposition, in the bridge and get a voltage.

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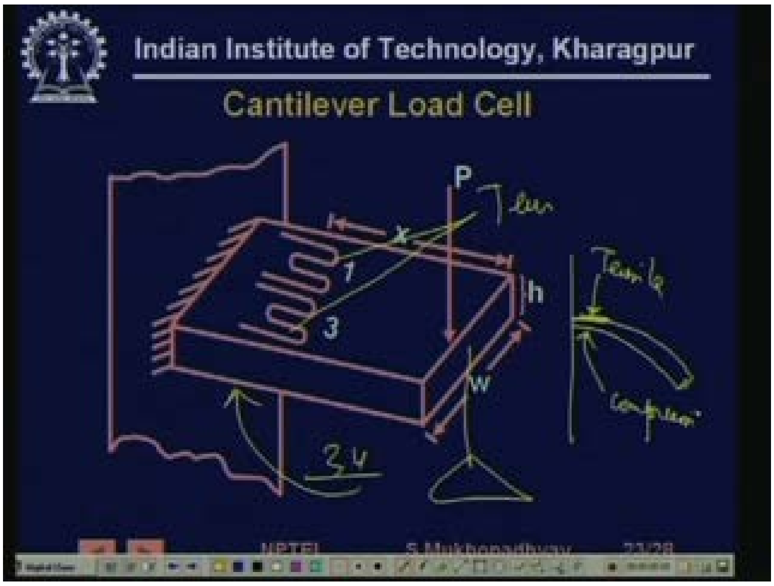

Similarly, you can have various other mechanical configurations. So, you can have a we have put a cylindrical, we have put a pillar type cell where we load vertically. We can have also a cantilevers of type cell where we can, where we are applying the force here. Suppose, we hang the weight from here and we are putting the load cells at the base, and we can put the loads cells 2 of them on the top surface, two of them on the, on the bottom surface. So, 2 and 4 are on the bottom surface. So, what happens is when you hang a weight these will undergo tensile. See the beam will bend, I am pressing this every time.

So, the beam will bend and therefore, this surface you will have tensile and this surface you will have compressive strain. So, you can put the gauges 2 and 4 on this surface in the exactly in the same manner and 1 and 3 as shown then again put them in a bridge.

And because they are the same place so, they can provide excellent temperature compensation. So, if the ambient temperature changes the resistance change in the temperature is going to be completely canceled. In the same now the same principle we can use with for torque sensing.

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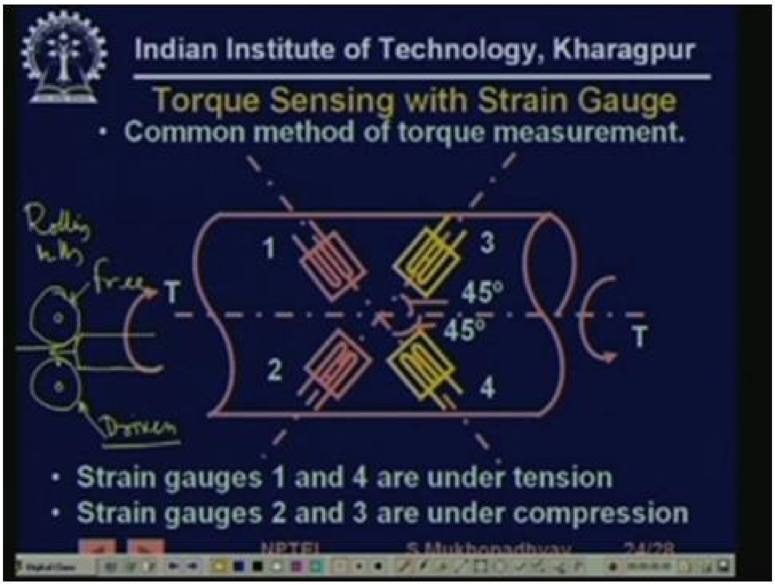

So, this is a very, this is a very common application we are, we are talking of again, we are taking of torque sensing as it a online torque sensing. We are not talking of you know dynamometer torque sensing where we actually stop the member which is rotating from rotating and then we measure the torque that is used for I mean calibration purposes. But here we are talking about torque sensing as the equipment is working or as the member is rotating typical application is rolling mills.

So, in a rolling mills have very large rolls. One of them this is the roll, this is one of them is generally free and other is driven by a motor and a bar metal bar which is which may be hot is passed through this. So, when it comes out it becomes rolled into a lesser width and there is tremendous torque generated on this. So, there is actually a. So, the motor this is a shaft, right. This is a shaft of the roll, which is being driven and on this side you have the motor. So, there is so much rolling force required that this shaft actually on one side the motor is trying to drive it and on the other side you have that big roll through which you are rolling the material.

So, there is a tremendous load here on this shaft and the, and the motor is trying to move that. So, on the shaft you have a torsion created. So, the force which the torque which is created by the motor is actually transferred to the roll through the torsion of this shaft. So, now on this shaft if you, if you, if you put 4 strain gauges like this as shown and along 45 degrees then, what happens is this.

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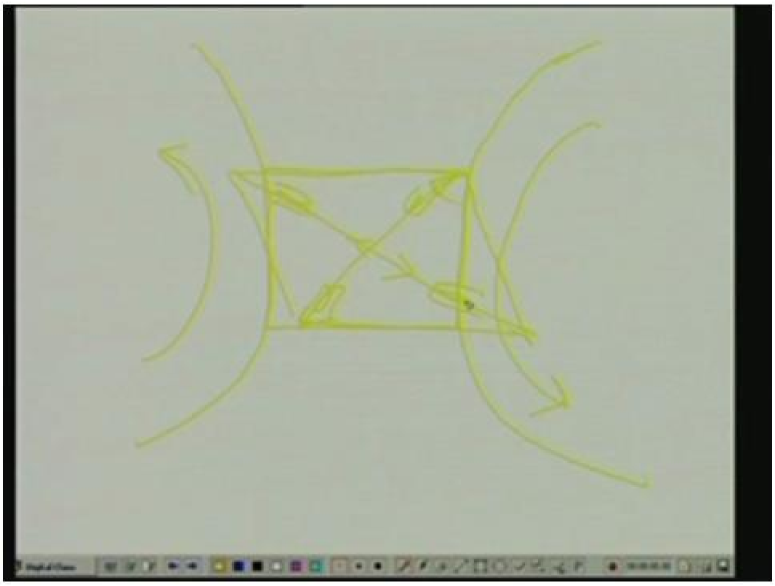

See, in the initial position take a consider a rectangle that is consider a rectangle on the shaft. So, this is the shaft. So now, and this is the other end of the shaft. So, now if you rotate it in this fashion, if you twist it in this fashion then what will happen is that this will tend, this will tend to get in the form of rhombus and this diagonal will expand and this diagonal will compress. So, if you put strain gauges along these then what will happen is that. Now, you see that this diagonal will, this diagonal will expand 1 and 4 under a tension and 2 and 3 will be under compression. So, now again they will sense opposing, they will sense opposing strains and you can put them in a bridge in the same way. So, this is the basic idea.

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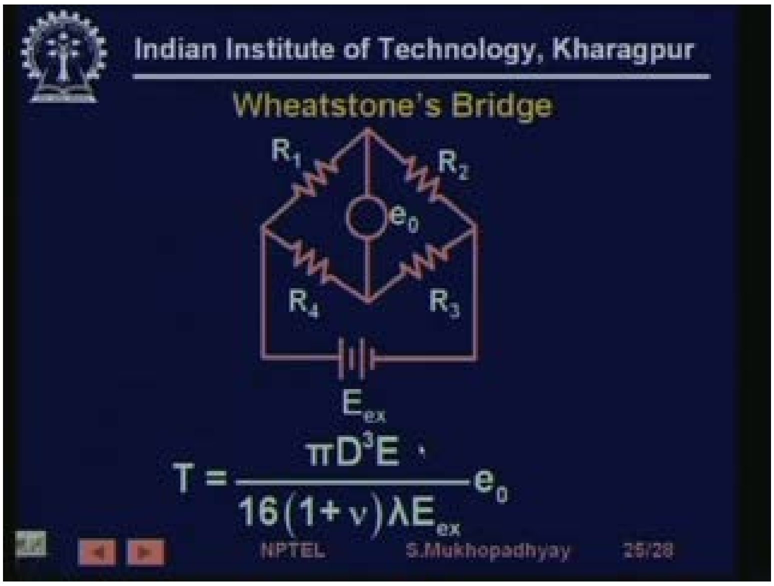

So, you can again put them in a Whetstone's bridge and the torque measured can be inferred. This is the formula, which is obtained using the mechanics of torsion as well as the bridge sensitivity equation.

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So, we have come to the end of the lesson. In this lesson, we have seen various principles that are used to measure lower pressures and some I mean which is sometimes effect to as vacuum. So, we have seen pressure affect of pressure on thermal conductivity, effect of pressure on the degree of ionization of gas which can be produced. And we have also seen so, basically these two.

And then, we have seen the other members for example, we have seen the bellows where the pressure as a force i is produces some sort of you know either strain or produces some sort of displacement and that displacement is sensed. That is the other common way of measuring pressure and it this can be, this can this can measures high pressure. And the same similar kind of principles can be used for measuring force using strain gauges, by using various configurations of mechanical members like you know sometimes you have rings which are called proving rings. Sometimes we have beams, sometimes we have pillar type load cells. So, we have various kinds of load cells which are used for measuring force and we have also seen a similar principle for measuring torque.

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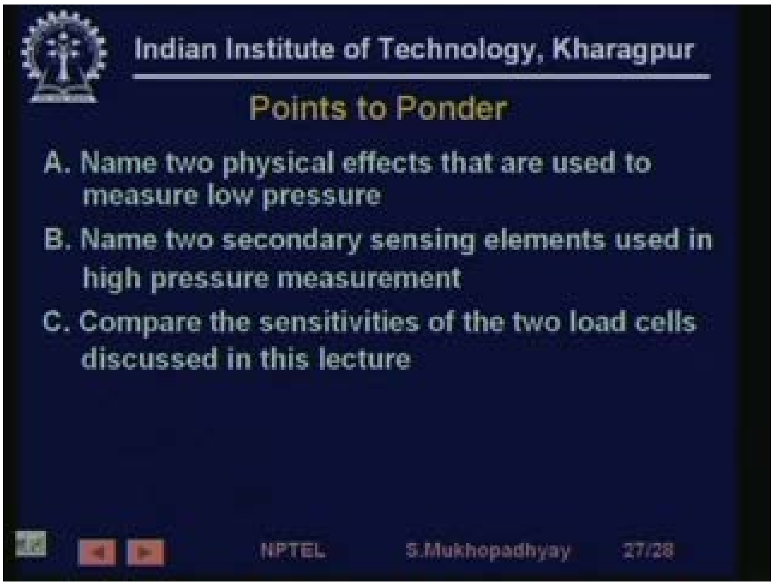

So, coming to some points to ponder, name two physical effects that are used to measure low pressure? These answers are there in the lecture you can try to recapitulate. Then, two secondary sensing elements used in high pressure measurement? Compare the sensitivities of 2 load cells discussed in this lecture? So, that will depend on the strength of material considerations how much of strain is produced for how much of force. And finally, mention one industrial application of shaft torque measurement, we have given one application. So, we end here today.

Thank you very much.

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Welcome to this lesson on motion sensing in the codes on industrial automation and control.

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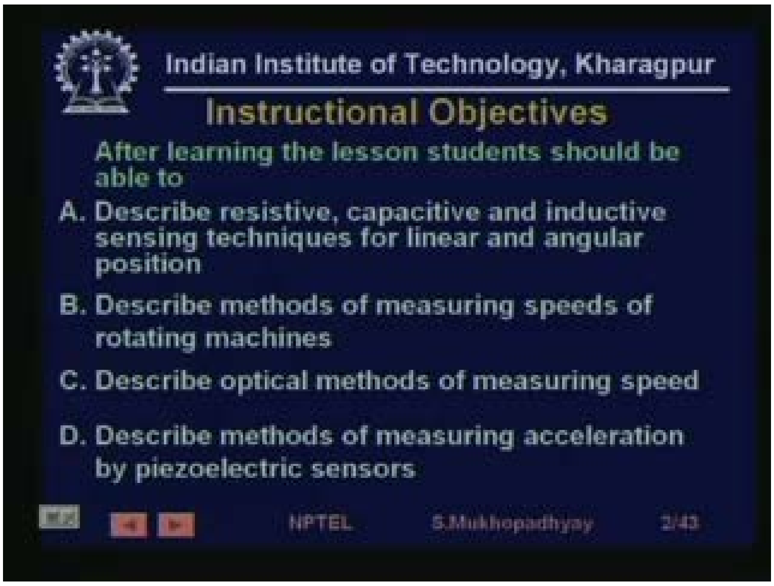

So, today our instructional objectives are that we will motion means position, velocity, acceleration. So, today we will. And there are various types of motion sensing instruments, but we will only look at those which are of relatively more importance in the context of industrial automation. There are other application areas like aerospace where some of the other kinds of sensors are very important. They are also motion sensors, but we will not look at them for same.

So, the first objective is that. There are some basic techniques by which we will see that how changes in position can be converted to changes in resistance, changes in capacitance or change in inductance. Sometimes you know changes in mutual inductance. So, and then once we so that is the first step where we are converting this mechanical motion into an electrical parameter change after that we can employ standard signal conditioning circuitry for which are, which are there for you know sensing these changes.

So, we will learn about the signal conditioning circuitry at another in another lesson. So, right now we will show how, predominantly we will show that how these how the motion actually translates into change of resistance capacitance or inductance. So, that is. The second one of the major applications is measuring speeds of rotating machines because rotating machines are a very important class of actuators in the industry and they have to be controlled. So, for the purpose of controlling it is very important that we measure their not only their position, but also because position measurement is basically angular position measurement.

So, we not only measure their position, but we also measure their speed. So, we will see look at some of the methods of measuring speeds of rotating machines. We will also look at some optical methods of measuring speeds. Optical methods are very good in some respects and not so good in some others, but they are, there are a distinct class of methods. So, we will have a look brief look at that. And we will also look at measurement of acceleration which is typically done in the industrial context by piezoelectric sensors.