Industrial Instrumentation
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Lecture - 5
Load Cell

Good afternoon! This is lesson 5 of the course Industrial Instrumentation. In this lesson, we will cover the load cell. Load cell is very important devices. It is basically a mass measuring or weight measuring instrument or sensor, whatever you say, using the principle of strain gauges. We have seen that in the lesson 4, we have covered strain gauge in details. So, using the strain gauges, now you will see that how we can make a load measuring devices.

Now, it is a very simple form of instrument. That are, the advantages of this instrument that it is simple, it can have a wide range, it is a linear instrument and it has, it can operate in a dusty and corrosive environment. These are the some advantages of this particular instrument. You can see in a, in a, if you move in a highway that there are load cells and weigh bridges basically you will find, where they used to take the weight of the truck or how much truck , how much load the truck is actually carrying, they can find in the load cell. If you know the tear weight or empty weight of the truck, so that you can find how much load it is carrying.

It is also used in the measurements of the load in the wagon online, I mean continuous measurement of the wagon, I mean how much weight they are in the wagon, all those things, I mean it is possible with this type of instrument. Basically we will cover, there are, there are two types of load cells. The first is the link type load cell and secondly we will cover the beam type load cell.

Now, link type load cell, usually we will find it is used for measurements of the large load, whereas beam type load cell is used for, for the measurement of the small load.
Now, there are other type of load cell like ring type load cells, all those things, but due to the restrictions of the, because same, principle is basically same that is the reason we taken, we have taken two different load cells and cover it in the, in this particular lesson.

Now, so far the disadvantages are concerned there are only, there is only one disadvantage, which is the phenomena called the creep. Now, creep is basically that the, it actually is a permanent deformation of the load cell. If a load is applied to a particular cell for a quite long time, that does not happen in the case of, I mean in the case of weigh bridges and all those ……. truck will move and after sometime the truck will go away. So, but if by chance if you apply a load permanently there are the chance of deformations, which will lead to the drift of the instrument, zero drift of the instruments and all those things. So, you have to be careful, very careful about that. The careful selection of the, also the material of the load cell also can prevent that type of problem.

Now, there are two basic type of load cell. One is so far the ranges are concerned, one is for the small load. Suppose from 500 gram to you can measure up to 5 kg and others you can measure suppose 10 kg to even 1000 tons, that type of load cells are also possible.

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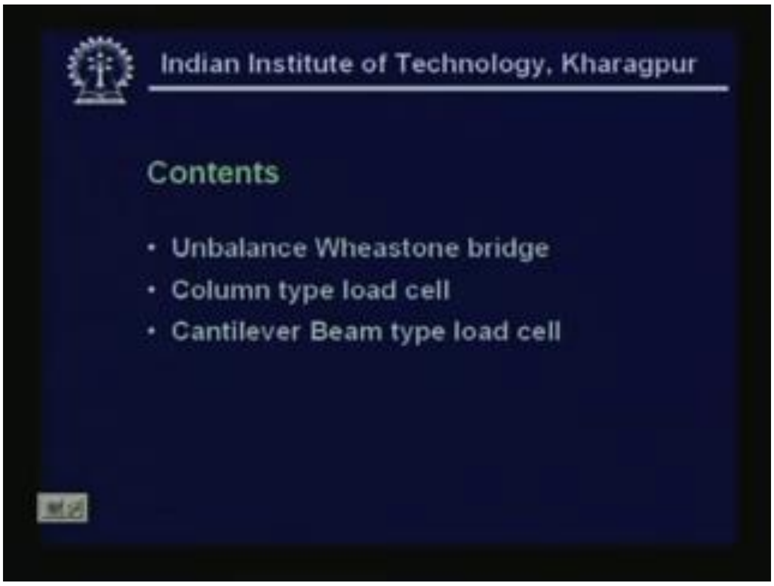

Now, contents are, we will first cover the unbalance Wheatstone bridge because we will use here the unbalanced Wheatstone bridge. That is the reason we have discussed the unbalanced Wheatstone bridge here. Then, we will cover the column type load cell. Instead of link type load cell, I mention it is a column type load cell. Sometimes people, some people call it even the axial link type load cell, some people call column type load cells. It looks like a column that is the reason it is more appropriate if I call it as a column type load cell. Then we will cover the cantilever beam type load cell, because it is basically a cantilever on which the sensor are used. That is the reason it is called cantilever beam type load cell.

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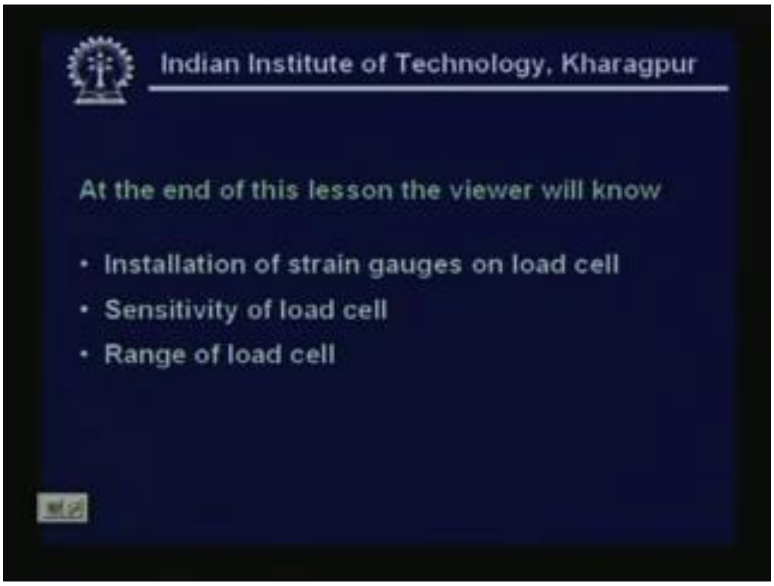

At the end of this lesson, the viewer will know installation of strain gauges on load cell, how the load cells will be, I mean installed and this is very important to make the sensitivity high, also to get proper output. You will see that if the orientation is something different, whatever we have prescribed here in the case of column type load cell, you will find there is no output. So, orientation is very important for making a load cell, because strain gauges are basic sensor there and it will make the complete instrument of load cell.

Sensitivity of the load cell, every time I mean in both the cases, both the, in the case of column type load cell as well as in the beam, I mean in the cantilever beam type load cells, we will compute the sensitivity of the load cell. Sensitivity means the load cell as well as the Wheatstone bridge combination, because ultimately we will measure this unbalanced voltage by a means of Wheatstone bridge and that unbalanced voltage will be calibrated in terms of load.

Range of a load cell, all that we will find that there are different load, I mean different range of the load cell that also and fatigue strength, all these things is very important to find the range of the load cell and you will see that in the case of column type load cells, the range is much more than the beam type load cell.

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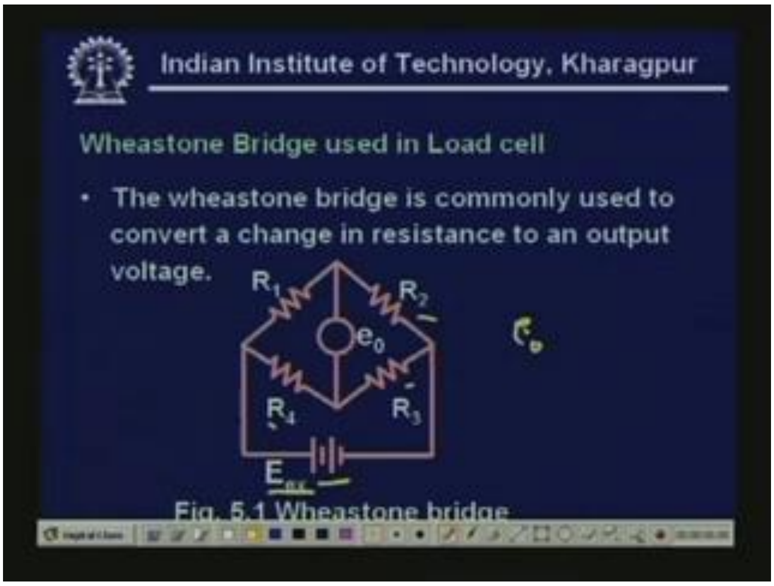

Now, as I told you that, you will use basically Wheatstone bridge in the load cell. Now, Wheatstone bridge is commonly used to convert a change in resistance to an output voltage; that we have seen in the case of simple, I mean balanced Wheatstone bridge. So, here I will use unbalanced Wheatstone bridge. You see, this is our basic Wheatstone bridge circuits and we can see here that that we have used 4 resistance. It is R 1, one resistance, then we have R 2, then we have R 3 and R 4 and we have used an excitation E ex. So, we have written E ex that is excitation voltage.

We can use DC voltage as well as AC voltage, it does not matter, because ultimately you will get a resistance. It is, so far it is a pure resistance then it hardly matters whether, whether you are using a DC or AC voltages. Here, we have used DC voltages and this is unbalanced voltage of the, of the bridge. So, this voltage e naught will be calibrated in terms of the load which actually we are going to measure by this instrument.

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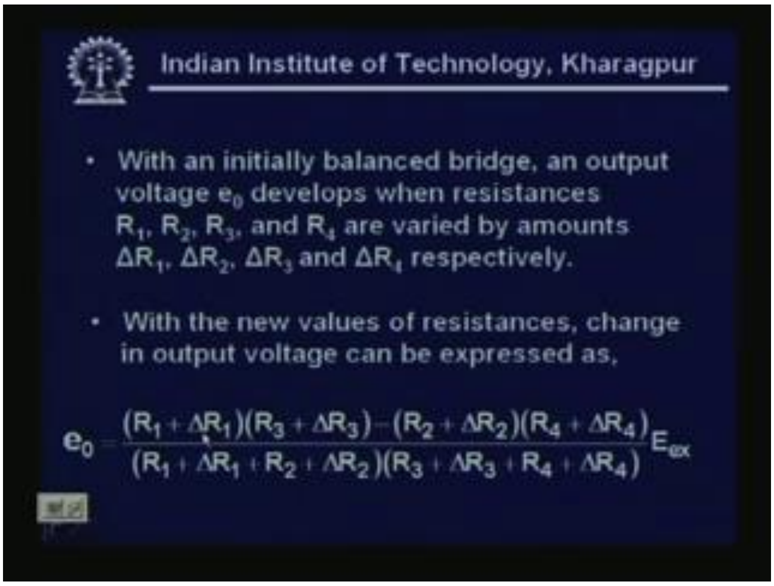

Now, with an initially balanced bridge, we can say that output voltage e naught develops when the resistance R 1, R 2, R 3 and R 4 are varied by the amount delta R 1, delta R 2, delta R 3 and delta R 4 respectively, we will get. With the new values of the resistances, change in the output voltage can be expressed as e naught equal to R 1 plus delta R 1, R 3 plus delta R 3 minus R 2 plus delta R 2 multiplied by R 4 plus delta R 4 upon R 1 plus delta R 1 R 2 plus delta R 2 whole in the parenthesis multiplied by R 3 plus delta R 3 plus delta R R 4 plus delta R 4 whole multiplied by the excitation voltage E subscript ex.

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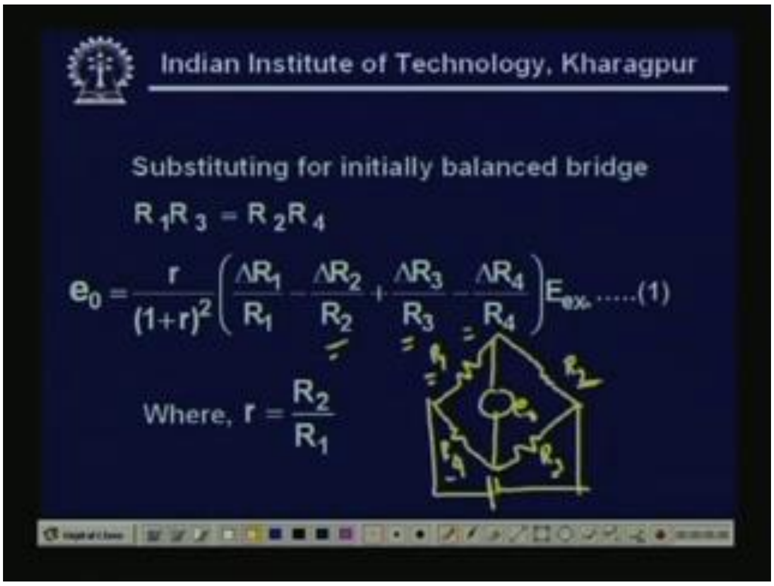

Substituting for initially balanced bridge, we can assume that if the bridge is initially balanced, usually in the standard load cells we will find that we will take all the four resistance equal; it is not necessary you have to, I mean you have to make it equal, because as you know the basic principle Wheatstone bridges are the bridge will be more sensitive, when it is, all the resistances were almost equal. Otherwise, you can say that when R 1 into R 3 equal to R 2 into R 4 this is also the initial, the balanced condition of the bridge.

Now, E naught output voltage or unbalanced voltage can be given by small r divided by 1 plus r whole square, whole multiplied delta R 1 plus R 1 minus delta R 2 by R 2 plus delta R 3 by R 3 and delta R 4 by R 4 into E ex, E subscript ex. This is equation number 1. This equation is very important, because you see that by looking at this negative term we can tell that, actually where I will put this R 2 and R 4, because that will make our bridge output much higher, because we always want in any instrumentation system that the output should be higher and higher, so that our sensitivity will be high and high, sorry, where small r equal to R 2 by R 1. So, if all the resistances are initially equal that means R 1 equal to R 2 equal to R 3 equal to R 4, so in that type of situation, this will be simply 1, right?

Now, if I say that if I use, I mean we, we have used three bridges, I mean four bridges, four resistances, I can use one resistance also in the case of Wheatstone bridge. However, suppose I have a, I mean I can simply use a, so instead of using four gauges, I can use only one gauge also. Suppose this is R 1, this is R 2, this is R 3, this is R 4, so if these are the, if R 1 is the basic, I mean our strain gauges, suppose R 2, R 3, R 4 are the fixed resistance, in that situation you will find that all these terms that means delta 2 by R 2, delta 3 by R 3, delta R 4 by R 4 all will be zero, right? So, our output will be e naught equal to delta R 1 by R 1 multiplied by 1 by 4 into E ex, E subscript ex. So, you can see that if I use 4 bridges, so I can make the sensitivity almost four times. You will find that this is very much true.

Now, let us derive this equation that means the equation number 1. How we got it, actually these equations, that is very important equations of unbalanced Wheatstone bridge, so let us derive that.

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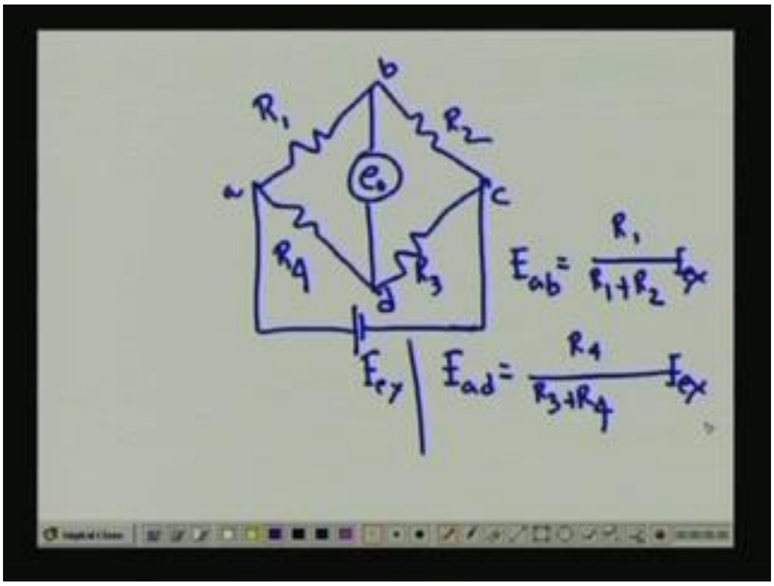

Suppose these equations I am writing, I am first drawing the Wheatstone bridge. This is R 1, so it looks like, so this is our output voltage e naught. I can use any simple multimeter to measure that voltage and I gave the, this name to E ex and this terminal node is a, this node is b, this node is c and this node is d. See, if you have this type of equations, quite obviously I can write that E ab that is voltage between this resistance R 1 is equal to R 1 by R 1 plus R 2 into multiplied by E ex. So, it does not matter whether it is balanced or unbalanced. It is, so always this is true.

Similarly, the potential across the resistance R 4, which can be derived as E ad equal to, this is separate, E ad equal to R 4 upon R 3 plus R 4 that means current flowing through this path multiplied by it is the E subscript ex.

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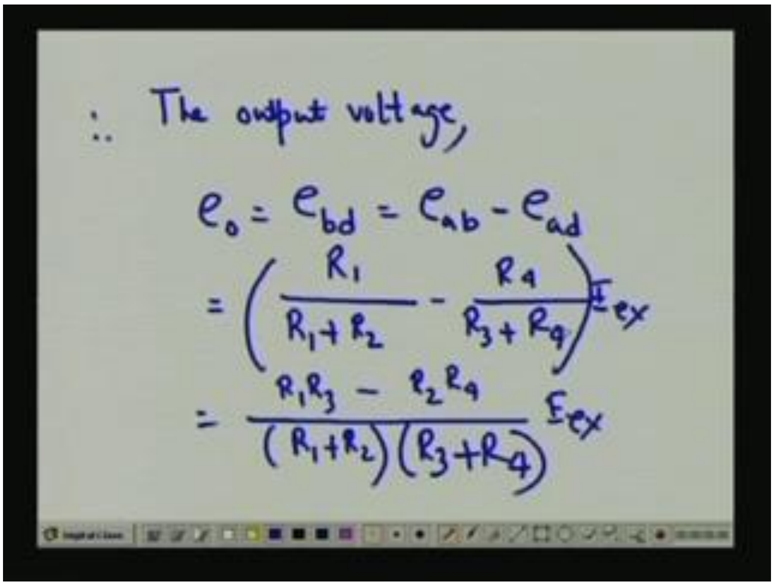

Now, the output voltage, I can take a new page, the output voltage, therefore the output voltage, output voltage e bd equal to e ab minus e ad, which I can write simply R 1 minus upon sorry R 1 plus R 2 minus R 4 upon R 3 plus R 4 E ex equal to R 1 into R 3 minus R 2 into R 4 upon R 1 plus R 2 R 3 plus R 4 multiplied with the excitation voltage E ex, right? So, these two terms, I mean we will see that R1, R 4 and R 4 and R 1 are cancelled out.

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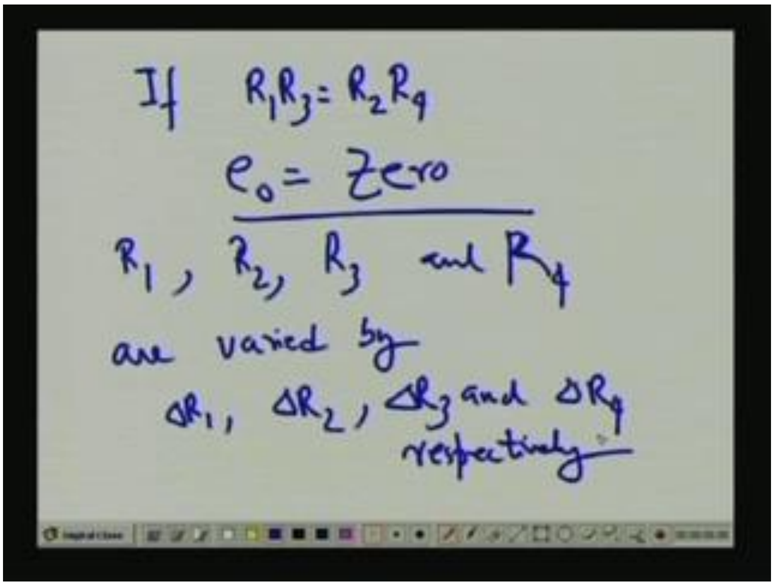

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So, if initially the bridge is balanced, if I say that the R 1, R 3, R 2 equal to R 4, as I told you earlier not necessarily the, all the resistance will be, I mean necessarily it will be equal, I mean if this condition is fulfilled at all, then also the bridge is balanced. So, the output e naught will be zero, right. Now, suppose all the resistance are getting varied, as it happens in the case of load cell, both the, in the case of column type load cell and the link type cell, all the four resistances are getting varied. If it is, we assume that the resistance R 1, R 2, R 3 and R 4 are varied by delta R 1, delta R 2, delta R 3 and delta R 4 respectively, so my output voltage will look like …

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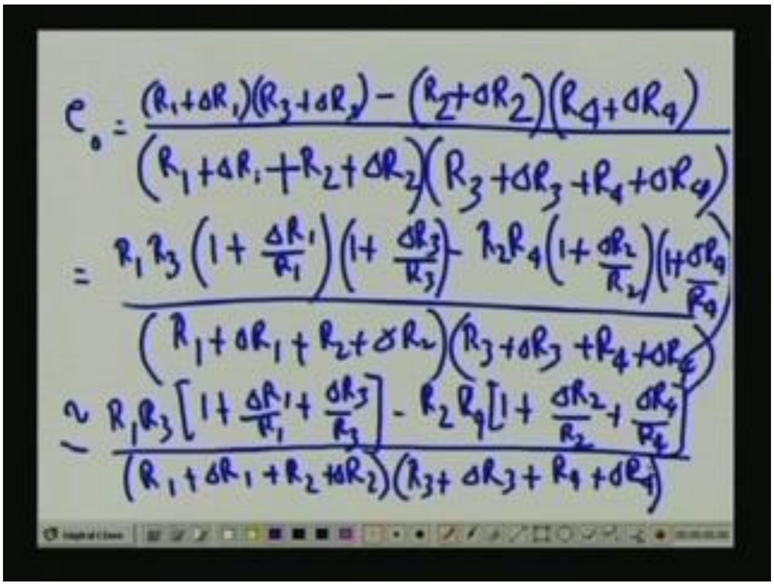

You see, e naught will be equal to R 1 plus delta R 1 multiplied by R 3 plus delta R 3 minus R 2 plus delta R 2 R 4 plus delta R 4 upon R1 plus delta R 1, sorry, this is, I am sorry again, so there should be actually a plus sign, yes plus R 2 plus delta R 2, R 3 plus delta R 3, R 4 plus delta R 4. See, if I take R 1 into R 3 common in the, from the numerator R 1, R 3 1 plus delta R 1 by R 1 1 plus R 3 minus R 2 R 4 1 plus R 2 by R 2 1 plus delta R 4 by R 4 bracket closed upon, all same R 1 plus delta R 1 plus R 2 plus delta R 2 R 3 plus delta R 3 R 4 plus delta R 4, right.

So, this almost we can write, because delta R 1 and delta R 3 will be very small. So, the multiplication of these two terms we neglect. So, this equation almost will be equal to R 1 R 3 1 plus delta R 1 by R 1 plus delta R 3 by R 3 minus R 2 R 4 1 plus delta R 2 by R 2 plus delta R 4 by R 4, right? Here also we neglect the term, multiplication term that is R 2 product of delta R 2 and delta R 4. We have seen this will be quite small, upon same denominator R 1 plus delta R 1 R 2 plus delta R 2 R 3 plus delta R 3 plus R 4 plus delta R 4, clear? So, R 1 R 3 1 plus, okay, yes take a new page again.

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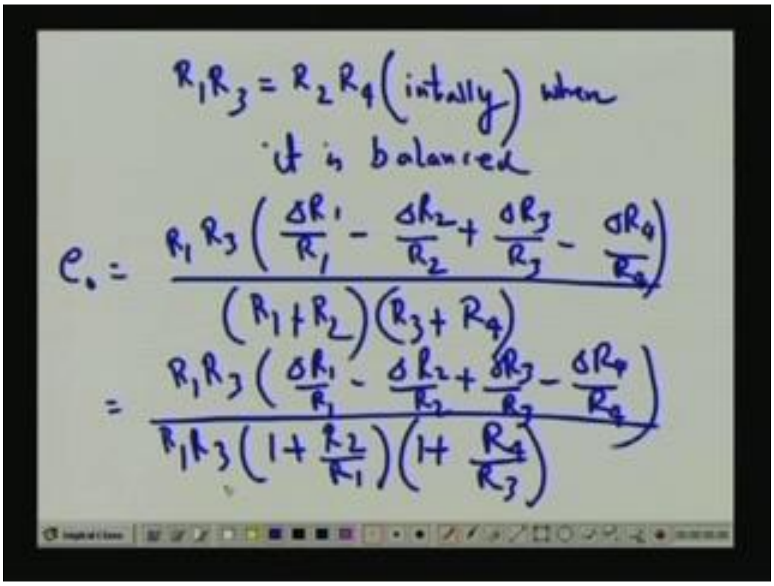

So, since the bridge is balanced, we can write R 1 or the initially the bridge is balanced R 2 R 4 initially when bridge is balanced, I can write the expression output e naught will be equal to R 1 R 3 delta R 1 by R 1 minus delta R 2 by R 2 delta R 3 by R 3 minus delta R 4 by R 4 upon R 1 plus R 2 multiplied by R 3 plus R 4. So, if I take from the delta R 1 by R 1 minus delta R 2 by R 2 plus delta R 3 by R 3 delta R 4 by R 4 if I take R 1 R 3 common from the denominator 1 plus R 2 by R 1 multiplied by 1 plus R 4 by R 3, like this one, we assume that the ratio …

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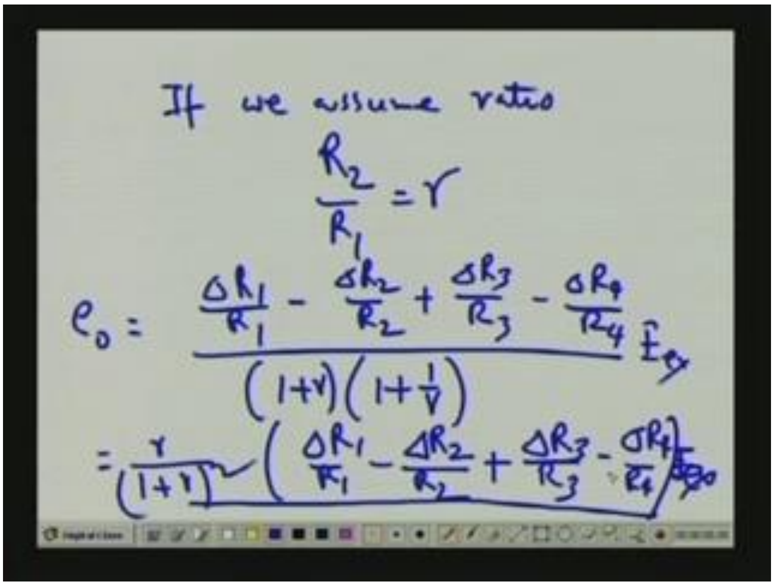

If we assume ratio R 2 by R 1 equal to small r, then output voltage will be equal to delta R 1 by R 1 delta R 2 by R 2 plus delta R 3 by R 3 minus delta R 4 by R 4 upon 1 plus r 1 plus 1 by r E ex. So, this will give us the equation r 1 plus r whole square delta R 1 by R 1 minus delta R 2, I can erase this part again, so it will be delta R 2 by R 2 plus delta R 3 by R 3 minus delta R 4 by R 4 into E ex. These expressions we have, the first we have shown in a basic. These equations will be utilized for all unbalanced Wheatstone bridge, right?

So, in both the case of the column type load cell as well as in the beam type load cell, we will use this unbalanced Wheatstone bridge equation and it depends, as you know that if you make only two gauges, in that case delta R 3 and delta R 4 by R 4 can be cancelled out, I mean you can use a fixed resistance. In that case, our output will be obviously less. But, if you use four gauges, you will get temperature compensation as well as the output will be more. As you know, for in the Wheatstone bridge to make the, because strain gauge is basically very temperature sensitive, since it is a resistance, resistance changes with temperature, but we want that the resistance will change only when the we will apply the load to the, that load cell. So, the temperature effect should be nullified. For that reasons, we have used that ambient temperature compensation scheme.

So, for the ambient temperature compensation, at least I need two gauges; one gauge can be active, other gauge can be passive also. That means it can be dummy. Even though it is made of strain gauges but you can, that may not be subjected to load.
In that case I will get temperature compensation, whereas in the case if I use two active gauges, then you will get temperature compensation as well as my output will be doubled. But if you use four gauges, I will get temperature compensation and my output also will be four times. In the case of, you will see that in the case of mean, I mean in the case of mean type load cell only that I will get the output almost four times.

Now, let us go back to our, so this was our final expressions we have seen, right? So, I can choose some other pen, yes.

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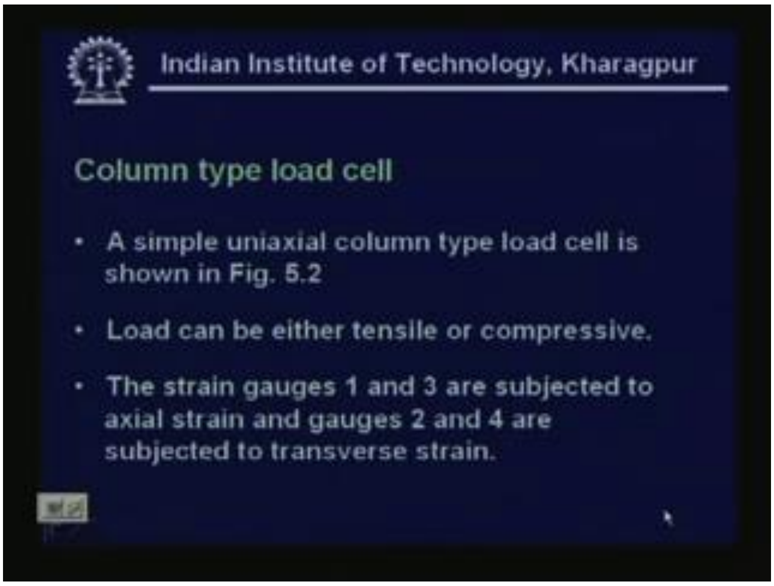

Now, column type load cell - a simple uniaxial column type load cell is shown in Figure 5.2. Load can be either tensile or compressive, because it depends on the where you will apply the load. If you apply the load on the top of the load cell, it is, it obviously the bottom of the load cell should be fixed. So, in that case it is a compressive load, whereas if you suspend the load from the bottom of the load cell that means our column type load cell, it will be a, it will be a load of elongation.

So, in that case, it is not … a compressive load. It is a, it is a load of elongation. So, that is the reason we are calling it either tensile. It does not matter, our expression, in a final expression of the Wheatstone bridge will remain same. The strain gauges 1 and 3 will show the, are subjected to the axial strain and gauges 2 and 4 subjected to the transverse strain.

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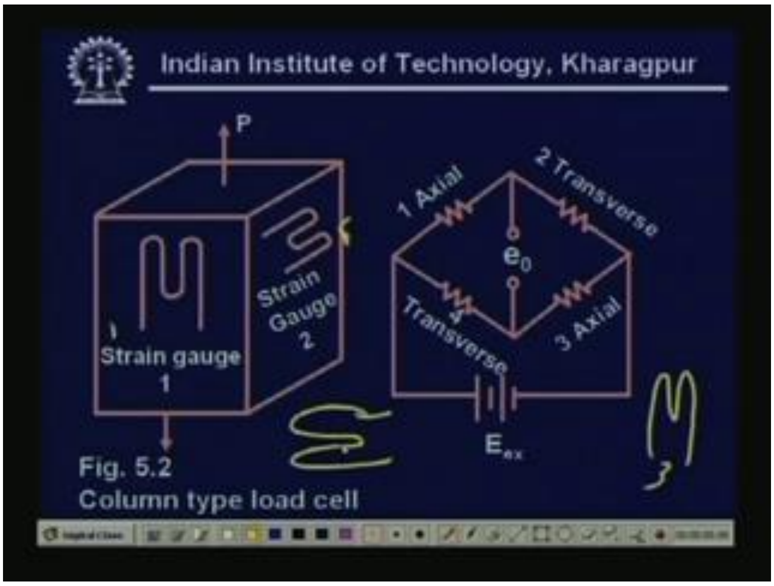

You see that this is a column type load cell, which is figure 2. Now, you see here that, let me take a pen; yes, you see here this strain gauge, here this strain gauge, it is shown like this one, whereas this is shown like, so these strain gauges and there is, similarly there is another, because if you take there are four phases of a load cell and this load cell, it appears that it is subjected to the tensile load or elongations. Now, what will happen? You see that, in this case this load cell will be subjected to axial strain.

Now there are, similarly there are, you will find the other side, because if there are four phases and you cannot see the phases three and four of this strain, of this load cell, see in the phases three also, that is the backside of this one also, there is another strain gauges which is subjected to axial strain, whereas gauge number four will be subjected to the transverse strain, right and this is axial. This is, that is the reason we call it axial strain. These are the resistance R 1, R 2, R 3 and R 4. This is subjected to axial strain, this is subjected to transverse strain. Gauge number 3 again is subjected to axial strain and gauge number 4 will be subjected to transverse strain.

Now, orientation of the gauges, this is like this, this will be like this. So, other side this is on the phase three. So, it will be axial. So, it will be again up. That means it will look like this, whereas in the case of gauge, this is three. In the case of gauge 4, so it will again, it will look like this, right? So, this will be subjected to transverse strain, whereas this will be subjected to, I mean tensile strain, because these are all, since as it is shown in the figure, so it is subjected to tension, so it will be tensile strain, right and now we have put in a Wheatstone bridge, it looks like this one.

Now see, what is very interesting factor that if I put all the strain gauges in the axial direction, then what will happen? If I put all the strain gauges that means this gauge number 2, gauge number, gauge number 1, gauge number 2, gauge number 3, suppose all are subjected to axial, then what will happen? Interestingly we will find the output will be identically zero, is not it? You can apply in our, our Wheatstone, unbalanced Wheatstone bridge equations, equation number 1, probably. So, we will find that output will be zero; that we do not want. That is the reason we have changed the orientation of the gauges, whereas in the case of beam type, cantilever beam type load cell you will find the, all the, I mean gauges are in the same directions. All are subjected to axial. Obviously, two will be compressive and two will be under tensile load.

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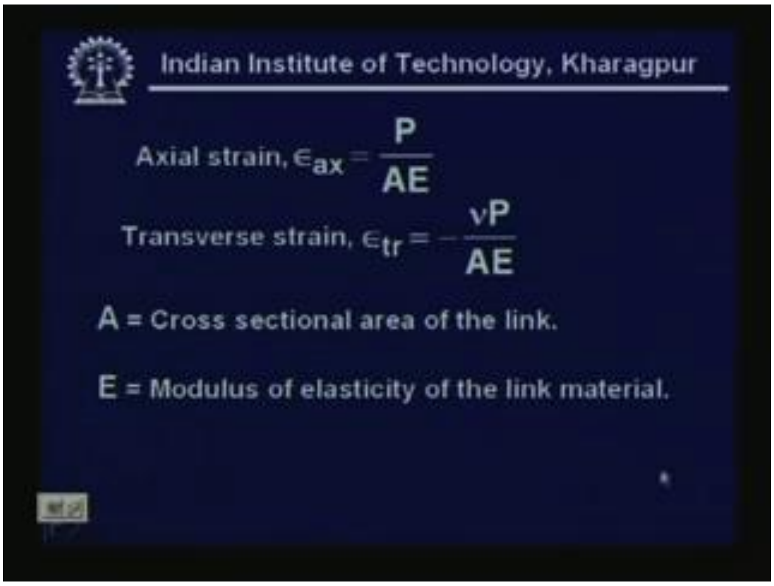

If it is there, so I can say that, now axial strain, you see it is given by epsilon ax. We write P upon A into E, right? Now, see we have written like this, E ax, so that it can easily divide, the E ax means axial. Now, transverse strain is given by nu P upon AE. Now, what are those, I mean legends let us look at, where A is the cross sectional area of the link. We have seen the link.

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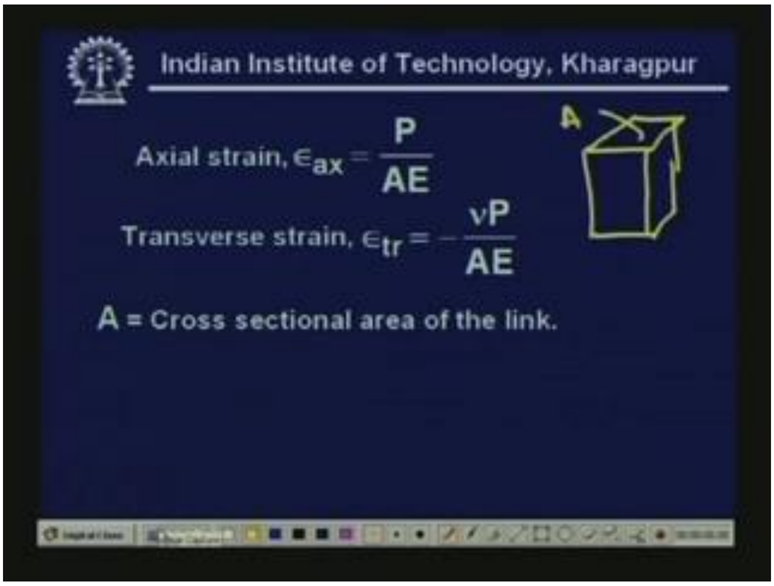

So, the link is, looks like this, is not it? So, this area, this is, the cross sectional area is A, right?

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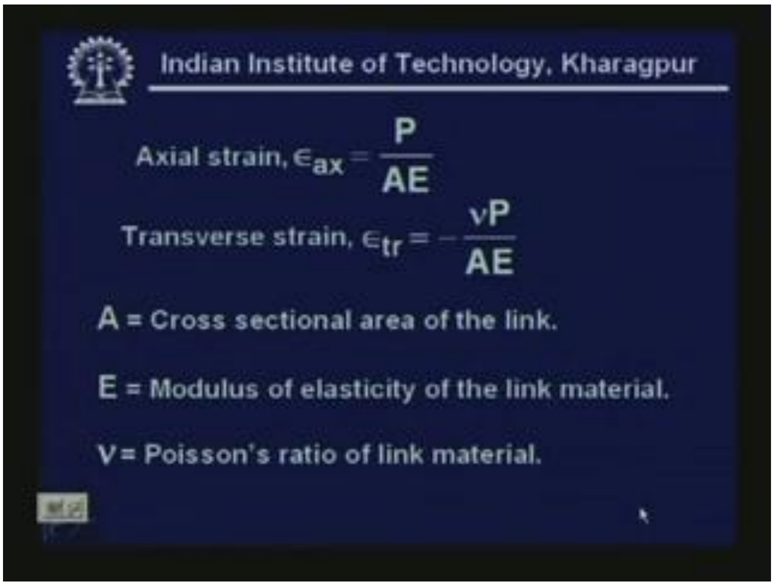

E is the modulus of elasticity of the link material, right? Then, we have Poisson's ratio nu of the link material and P as you know is the load, basically. It is a load and the ….

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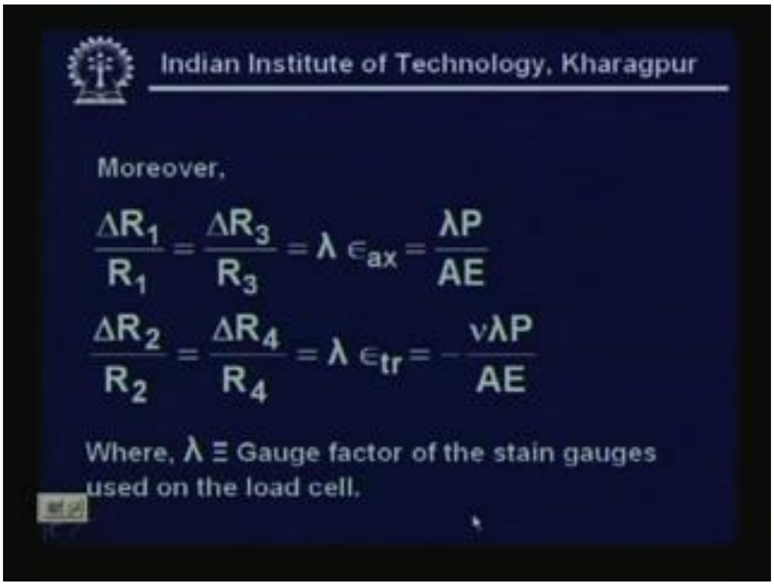

So, I can write delta R 1 by R 1 equal to delta R 3 by R 3 equal to lambda into epsilon ax equal to lambda P by AE. This is coming from the, I mean simple our strain gauge formula. Since delta R 1, R 1 and R 3 are initially same, we can assume that delta R 1 by R 1, because you see it very carefully, both R 1 and R 3 are under axial load, right?

So, whatever the value of R, delta R 1 by R 1 is, it will be similar to delta R 3 by R 3, right? So, it is multiplied by the lambda which is, lambda is the gauge factor of the strain gauge materials, multiplied by the strain will be equal to lambda P by AE and delta R 2 by R 2 will be equal to delta R 4 by R 4 equal to lambda into epsilon transverse that means transverse strain equal to minus, I mean nu lambda P by AE. This is coming from the basic formula which we have discussed, when we, in the lesson 4 actually when we discussed the load cell and when we discussed the strain gauges, where lambda is the gauge factor of the strain gauges used in the load cell, right?

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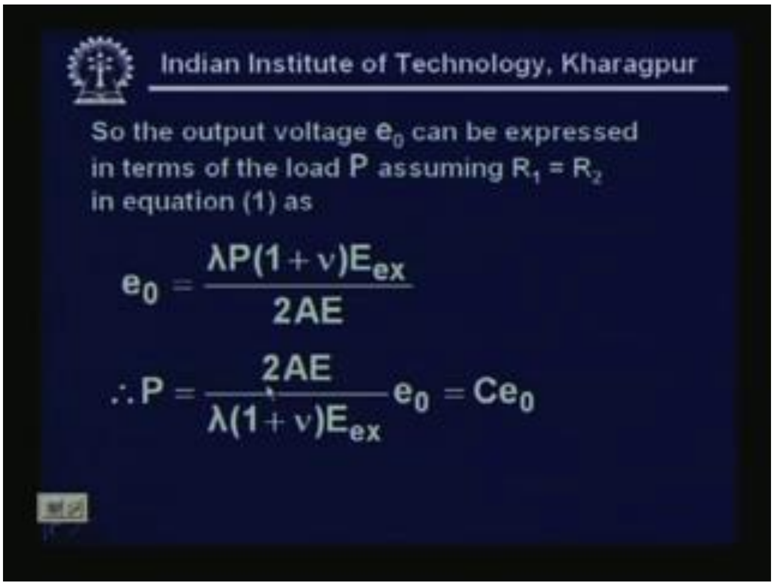

So, the output voltage e can be expressed in terms of the load P, assuming R 1 equal to R 2 in equation 1. So, you put all these values of delta R 1 by R 1, delta R 2 by R 2, delta R 3 by R 3 and delta R 4 by R 4 in equation 1. We will get output voltage e naught equal to lambda P multiplied by 1 plus nu E subscript ex, excitation voltage upon 2 AE, right? So, you see, it is a very, basically very linear instrument. If you look at very carefully, the P is load actually, lambda is the strain gauge, depends on the strain gauge usually if you use advance it is lambda equal to 2. It is a Poisson’s ratio, this is also constant. Supply voltage, DC supply voltage, this is also constant, area of cross section of the link this is also constant, Young's modulus of the material is basically …

So, you can, interestingly you see nu and e will depend on the link material, where lambda will depend on the strain gauges type of, so these are all constants. So, you will find that the output voltage ex also, if the supply voltage remains constant, if you use a battery, so obviously it will remain constant. Output voltage is directly proportional to P, right? This is very important, because it will make us very simplified signal processing. It will be our, it is basically coming under the category of the linear instrument or I can little manipulate, so I can write P equal 2AE upon lambda 1 plus nu multiplied by E ex into e naught, Ce naught, where C is called the calibration constant of the, of the load cell.

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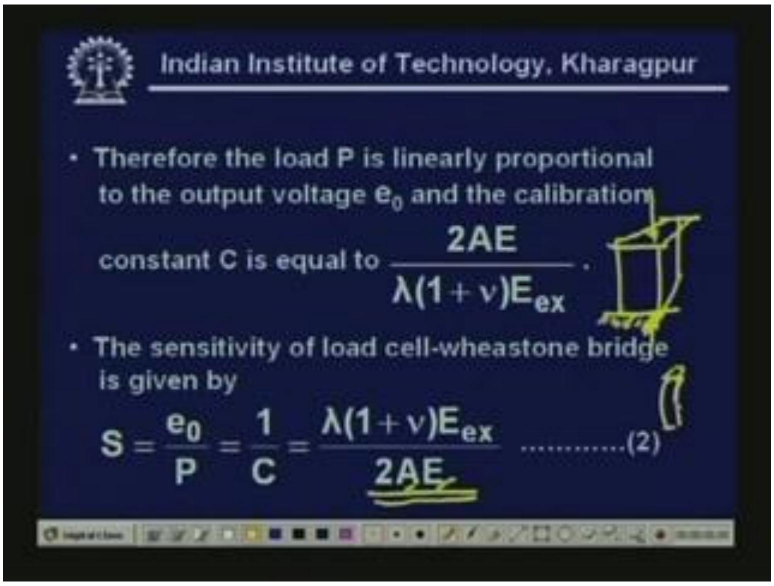

Therefore, load P is linearly proportional to the output voltage e naught and the calibration constant C is equal to 2AE lambda 1 plus nu into ex. So, obviously you can see that the sensitivity of the load cell Wheatstone bridge combination, there is no use of having only load cell. So, if you combine these two until its sensitivity is given by S equal to e naught by P is load, 1 by C lambda 1 plus nu ex by 2 AE; very important equations if I look at, so you see this is our equation.

Now, you see that one thing is very important that sensitivity can be increased by increasing the lambda. Poisson’s ratio, it is hardly, it does not matter much because it is around very small. It is .3 in the case of steel. Supply voltage we can increase, because if you increase the supply voltage, obviously our output voltage will also increase or we can decrease the value of A and E, right? A can, we can decrease that is area of cross section of the load cell we can decrease. I mean in ….. our column type load cell. Also, we can decrease the Young's modulus of elasticity of the material. So, we can choose material in such a way the Young's’s modulus of elasticity is also lower. So, in that case our sensitivity will increase. But, one thing is very important. You see that in the case of, I cannot E, increase the supply voltage or excitation to my bridge indefinitely. Because what will happen you see, each strain gauge has the resistance. It is basically, it is a resistance, so it has a current limitation, how much current I mean will pass through?

So, if I increase ex, so please note that since it is two resistances are in series, obviously what will happen that the current through the, each of the gauges will increase. So, you have to look at that this current should lie within the limit or the, if I square r if you take, so that it should remain within the range of the dissipation of the strain gauges. So, I cannot increase it indefinitely as some prescribe. Usually what we do? Usually if you find that the, if there, we know the resistance of the strain gauges and if you know the current, allowable current through the strain gauges accordingly we will choose the power supply, so that under no condition the, it will cross the current limit, right?

Now, interestingly you cannot decrease 2 and E. You will see that if you decrease 2 and A, A and E you will decrease the range of your load cell and one important thing you see that, you see that load cell looks like this. If it is on the compressive load, one thing we should mention, because we have already discussed the tensile load. If it is under the compressive load, so it should not buckle. Usually what we will fix this point and give a force on this side. So, if the load cell should not, I mean get a shape like this one, right. So, that will create problem, so that it should not buckle. So, so if you decrease that A and E, you will find there is a chance of that type of formations which will damage all our equations or whatever the equations which we have derived are no more valid in that type of situations.

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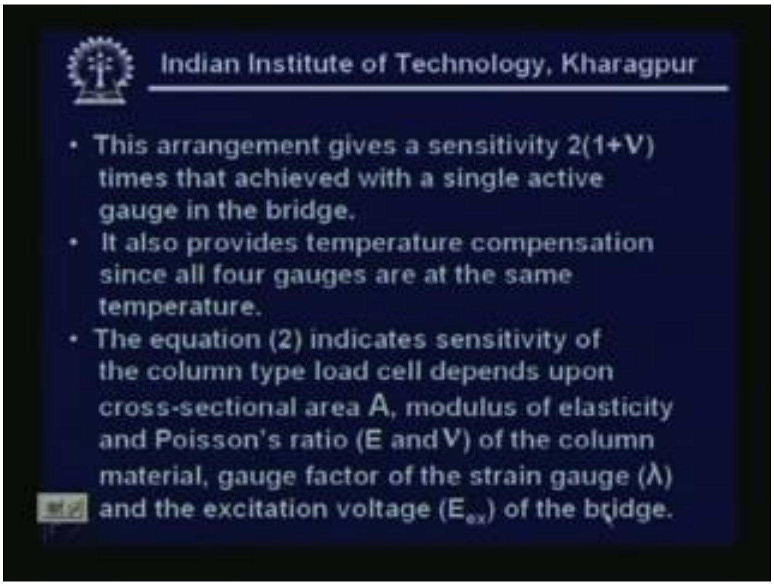

This arrangement gives a sensitivity 2 into 1 plus nu times that achieved with a single active gauge in the bridge. We have seen that if you use a single bridge, because you see here, if I go to the previous slide we will find that or you can see that this one that this 2 nu 1, 2 into 1 plus nu times that achieved with a single active gauges it is true, because in the case of single gauges, so you will find the sensitivity will be much lower, right. It also provides temperature compensation, as I told you earlier, since all the four gauges are at the same temperature.

The equation 2 indicate sensitivity of the column type load cell depends upon cross sectional area A, modulus of elasticity and Poisson's ratio of the column, gauge factor of the strain gauges that is lambda and excitation voltage of the bridges.

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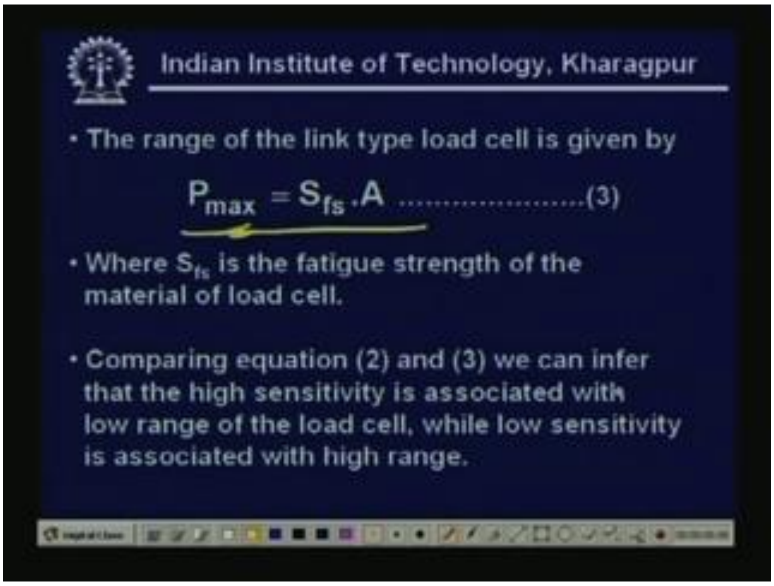

Now, range of the link type load cell or column, I mean, type load cell, both way we can say. Either we can tell column type load cell or we can tell link type load cell, is given by P max equal to S subscript fs into A, where S fs, S fs, is called the fatigue strength of material of the load cell, right? So, if you compare this equation with the previous equation that means sensitivity as well as the range, if I compare side by side sensitivity and range, because this will increase the range, P max is the range of your load cell, you will find that either sensitivity is high or range will be low and vice versa, right. That means low range of the load cell that means infer that the high sensitivity are associated with the low range of the load cell, while low sensitivity is associated with the high range of the load cell.

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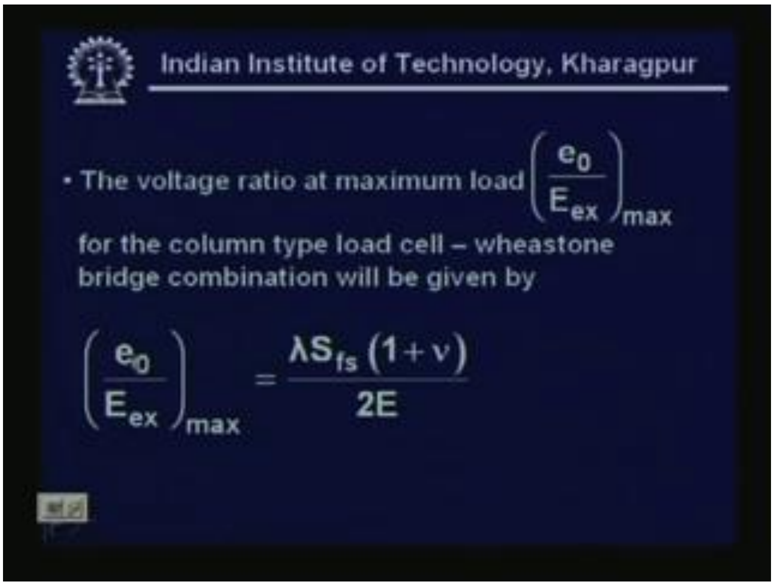

The voltage ratio at maximum load e naught upon E subscript ex maximum for the column type load cell Wheatstone bridge combinations will be given by e naught by ex maximum lambda S fs, I mean fatigue strength 1 plus nu by 2E.

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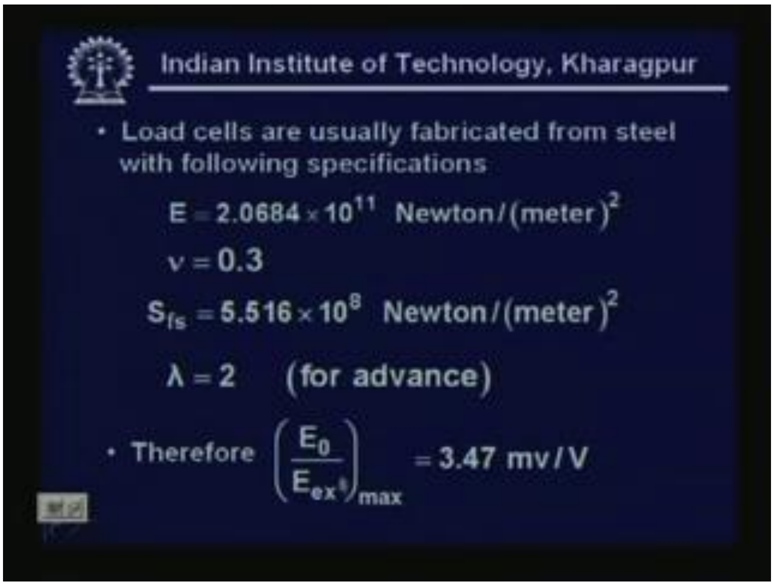

Now, load cells are usually fabricated from steel with following specifications. So, E Young's modulus is 2.6, 2.0684 into 10 to the power 11 Newton per meter square, nu equal to.3, Poisson's ratio and fatigue strength equal to 5.516 into 10 to the power 8 newton per metre square. Lambda equal to 2 for the advance; if the, if the strain gauge is made of advance, so the gauge factor will be 2. So, we have taken lambda equal to 2. In that situations we will find that e naught by ex maximum is equal to 3.47 millivolt per volt, right? So, this is our expressions.

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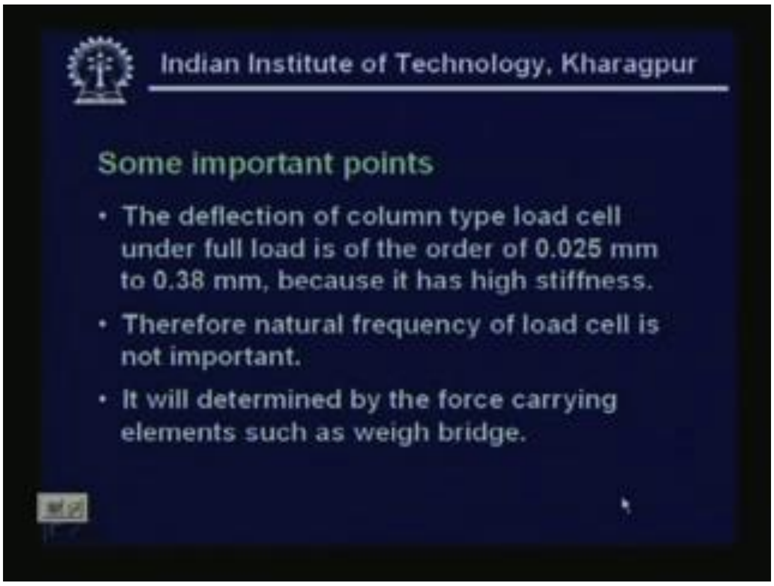

Now, some important points; now, see under the deflections of the column type load cell, under the full load is of the order of 0.025 millimeter to 0.38 millimeter, extremely small, because it has high stiffness and therefore, natural frequency of the load cell is not very important. It will be determined by the force carrying elements such as weigh bridges, because that itself carries, I mean a lot of its mass is much more higher than the load cell itself. So, frequency all this things will be covered, I mean determined by that platform itself.

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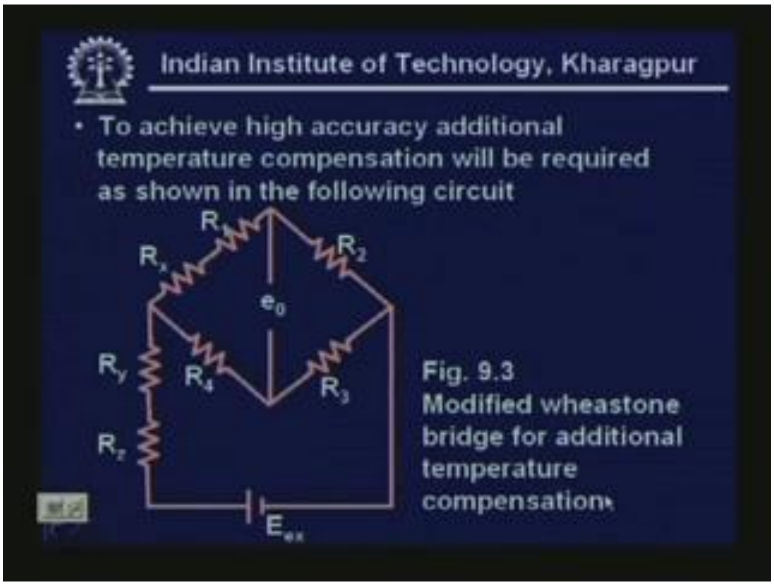

Now, some important features; you see that to achieve the high accuracy, additional temperature compensations will be required as shown in the following figure. Some additional circuits use modified Wheatstone bridge for additional temperature compensation is necessary, because you will find it may happen that the, all the resistance may not have the same temperature coefficient of resistance. So, in that type of situations, we have added, actually you will find very carefully only two, three resistance R x, R y and R R z, probably all will be the, I mean varying sort of resistance.

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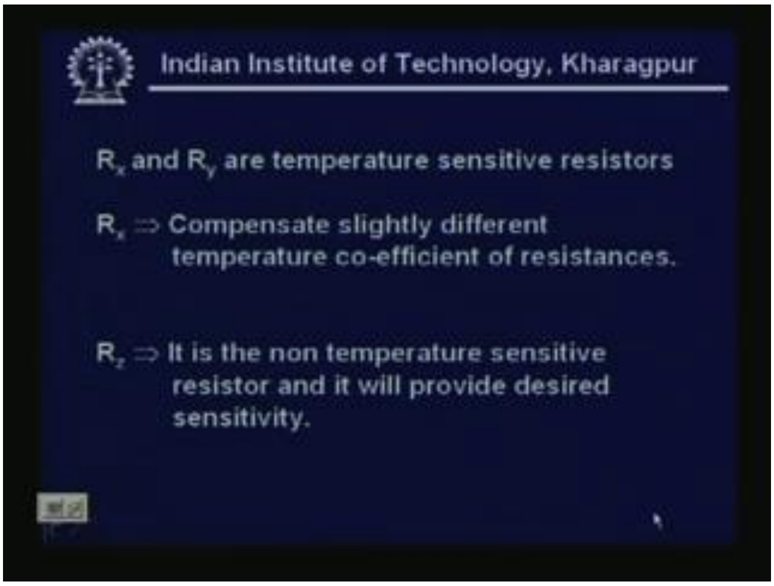

R x and R y are the temperature sensitivity, temperature sensitivity resistors and R x is the compensation, compensates slightly different temperature coefficient of resistances. R y, it is a non temperature sensitive resistors and it will provide desired sensitivity. I can control the sensitivity by that.

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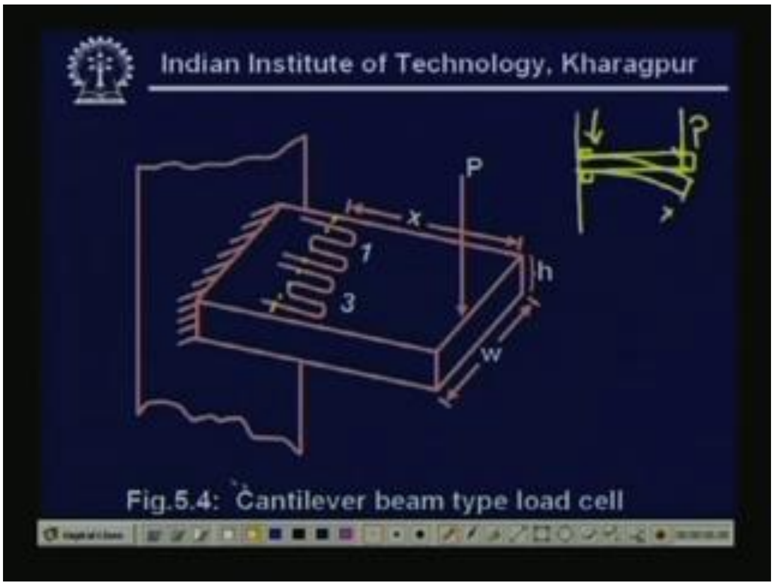

This is our cantilever beam type load cell. That ends the, previously ends the, now cantilever beam type load cell, you see that this is actually cantilever, you can see here. This is a cantilever and we have installed, we applied a force P, right, so that it looks like that the, I mean you will find it previously like this, now it will bend like this, is not it? It appears, you see, if I apply the load P here, this side is bending more that free end, this is the fixed end. But, you see very carefully that the strain gauges were installed very close to the hinge point. That means strain gauges are installed here, it is here.

Also, in the bottom also, there are two strain gauges. The reason is stress is maximum at this point, not at this point. The stress is not maximum at this point or stress gradient is also maximum at this point, but not at this point. So, that is the reason we install the strain gauges in this directions. Now, you see that here also we have used four strain gauges, 1 and 3 on the top and 2 and 4 at the bottom of the strain gauges. It cannot see from the top, so 2 and 4 at the bottom of the strain gauges, bottom of this cantilever beam type load cell, right.

So, you see that if I apply a force here at this point, at the extreme end, the load, the strain gauges 1 and 3 will be subjected to tensile load, whereas strain gauges 2 and 4 are subjected to compressive load, right and we have taken a dimensions that means this is, width is w of the strain gauge of the, of the, this cantilever, height is h and I am applying a force, which is almost from the midpoint if I take at a distance of X from the point, midpoint of the strain gauges. So, this is called the cantilever beam type load cell. Let us do the analysis.

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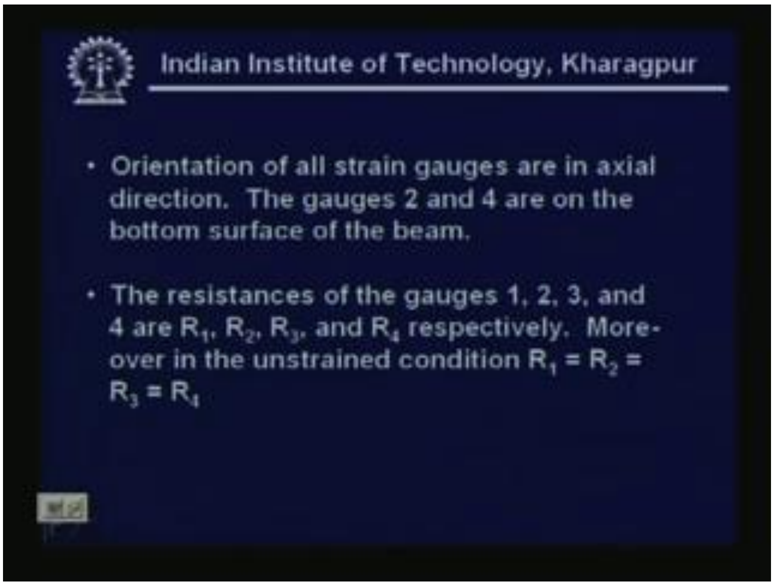

So, orientations of all strain gauges are in axial direction; this is more important. In the case of column type or link type load cell, we have seen that the gauge 1 and 3 are in axial directions, whereas gauge 2 and 4 are in the transverse directions, orientations, whereas here all in axial directions. The gauges 2 and 4 are on the bottom surface of the beam. The resistance of the gauges 1, 2, 3 and 4 are assumed that the R 1, R 2, R 3 and R 4 respectively.

Moreover in the, in the unstrained conditions R 1 equal to R 2 equal to R 3 equal to R 4. There is, there is no force applied on this gauge. So, R 1 equal to R 2, R 3 equal to R 4 and gauge, interestingly gauge 1 and 3 will be, I mean, I mean subjected to elongation, whereas gauge 1, 2 and 4 will be subjected to compression. Because it is on the bottom, so it will be subjected to compression.

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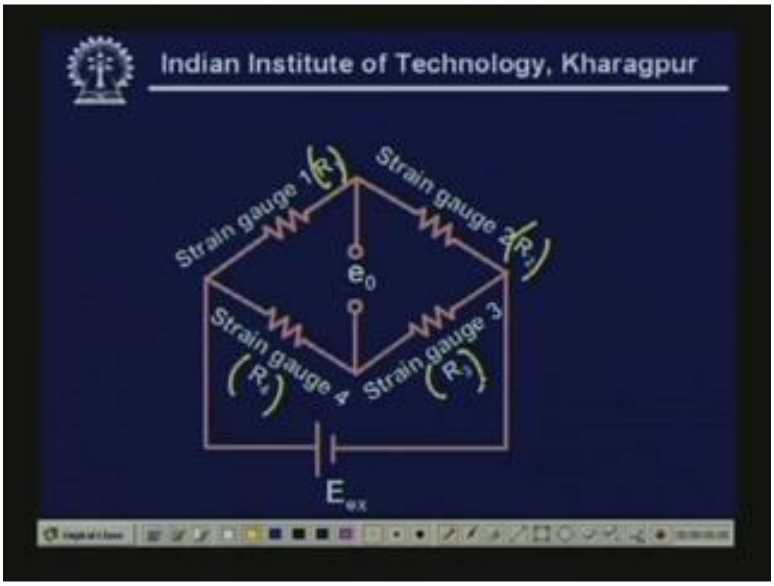

This is our strain gauge circuits. We can see E ex, you see here. So, strain gauge R 1, strain gauge 1, actually it should be, so …. parenthesis, so parenthesis and this will be like this one. Same excitation voltage we have given and I am getting output voltage e naught, right? Now, you see that, we have already seen that gauge, gauge 1 and 3 will be at the top. It will be subjected to the tensile load, whereas gauge 2 and 4, while the bottom surface of the cantilever beam, it is subjected to compressive load.

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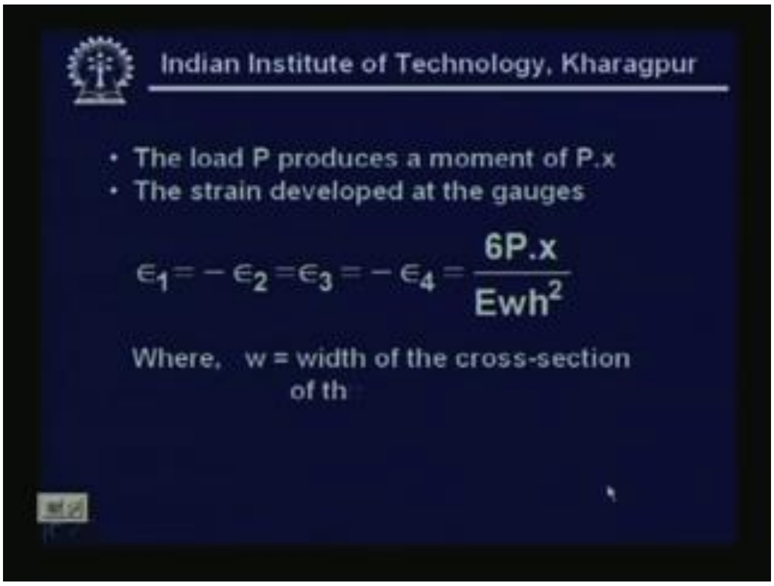

If that is the situation so I can see that I will get, the load P produces a moment of P into x. The strain developed at the gauges are given by epsilon 1 equal to minus epsilon 2, since it is, I mean under elongation, this is under compression, so these are same in magnitudes if the initial value is same, but opposite in sign, equal to E 3 equal to minus E 4 6Px divided by Ewh square, where w is the width of the cross section of the beam, h is the height of the cross section of the beam.

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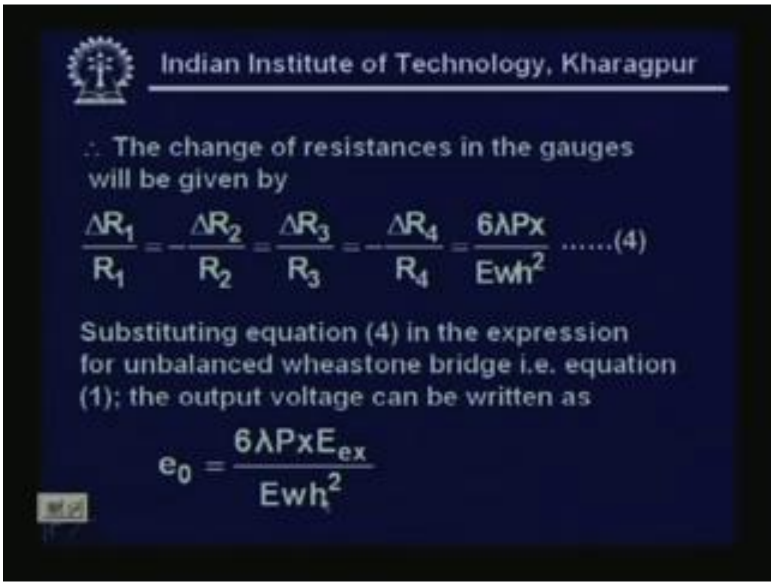

The change of resistance in the gauges will be given by, you see change of resistance of the gauges will be given by delta R 1 by R 1 equal to minus delta R 2 by R 2 equal to delta 3 by R 3 equal to minus delta R 4 by R 4 equal to 6 lambda Px by Ewh square which is equation number 4. Substituting equation 4 in the expression for unbalanced Wheatstone bridge, which you have derived sometime later, the output voltage can be written as simply e naught equal to 6 lambda Px. Because already that is negative sign in front of the delta R 2 by R 2, so it will, all will become positive 6 lambda Px by E subscript ex by Ewh square that is the Young's modulus.

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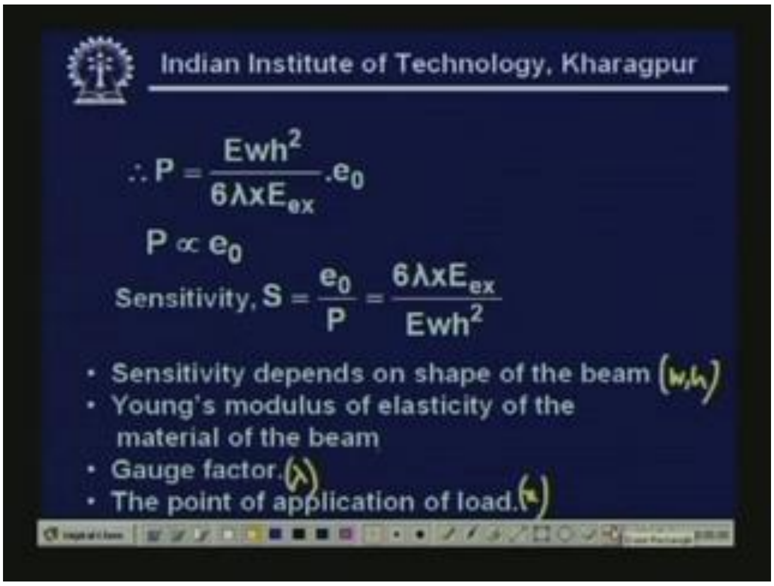

So, P equal to Ewh square equal upon 6 lambda x into E ex into e naught. So, the P is proportional to e naught. Again, it tells that it is a linear sensor. You see here it is a linear sensor. P is proportional to e naught, obviously it is a linear. Again, let us find the sensitivity. Sensitivity of the cantilever beam type load cell and Wheatstone bridge combinations will be e naught by P equal to 6 lambda x E ex Ewh square. So, as it happens as before that if you reduce E, w and h, so obviously our sensitivity will increase. But, if you decrease w and h, there is a little chance of reducing E, because we will use some, I mean steel, so we can only manipulate w by h square, w and h square. If I reduce wh, our range of the instrument will also reduce, right? Similarly, I cannot increase ex, excitation indefinitely, because this will create the problem of that, it, it may cross the limit of the, current limit of the strain gauges.

Sensitivity depends on the shape of the beam. Shape means wh that is the shape of the beam and the point of applications of the Young's modulus of the elasticity of the material of the beam and the gauge factor and the point of application of the load, because it is, x is the point of the application of the load. So, it looks like this. You see, this is our x, this is lambda, this is wh, sorry, this is wh and we can take, I do not know, yes, Young's modulus elasticity. So, it actually, basically we will …., so it will depend on, sorry, anyway it depends on the Young's modulus of the material.

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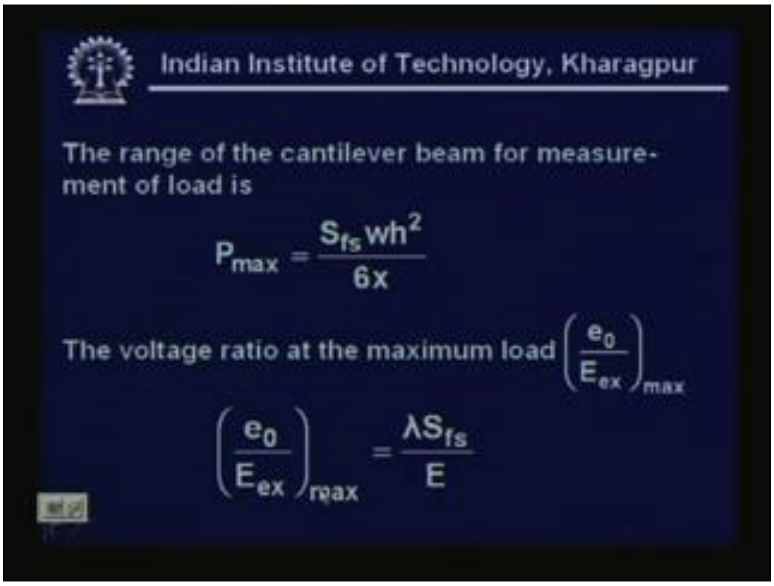

The range of the cantilever beam for measurement of load is Pmax equal to S fs wh square by 6x and this is the range. Obviously, it depends on the fatigue factor. The voltage ratio at the maximum, so you can see that it depends on the, so many other points like fatigue factors and all these things. So, you can see here and this will depend on all this wh and 6x. So, voltage ratio at the maximum load is given by, I am sorry, so voltage ratio at maximum load is e, e naught upon E ex max equal to lambda S fs by E.

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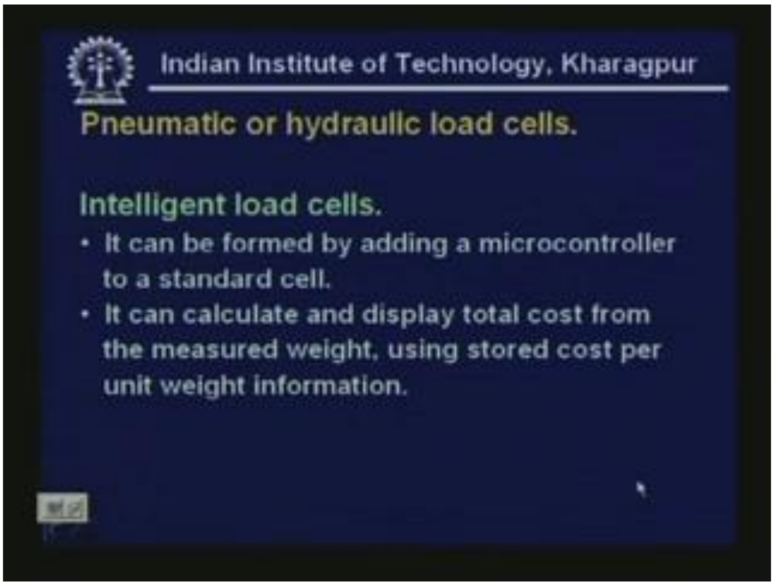

Now, there are, even though we discussed about the, all the, I mean electrical load cells, there are, pneumatic and hydraulic load cells are also there. Even though not much in popular, I mean there are intelligent load cells; we call it intelligent load cells. If you have, add some factors on this one, it looks like that it can be formed by adding a microcontroller to a standard cell. You know that microcontroller is basically, there are two types of microcontroller available. In many a cases in instrumentations we will find we use microcontrollers.

Now, microcontroller is nothing but a microprocessor, but with some additional peripheral chips built in. It is a some sort of embedded systems also, because those peripheral chips are there. Now, one of the popular microcontrollers, as you know, is 8051, which is basically an 8 bit microprocessor along with the, along with the certain amount of RAM. It has a very small RAM, 128 byte RAM. Then, two counters, so all those peripheral chips are inside these machines. So, we can use it for measurements of, for many controlled mechanisms.

Now, this is very important, because if you need little bit of computations, suppose in the case of, in the case we are no more use, nobody uses microprocessors, we use a microcontroller. There are two types of microcontroller available; the 8 bit microcontrollers and 16 bit microcontrollers. 8051 or 8091, is basically almost same, but it has the features which is basically 8 bit machines, 8 bit microcontrollers and because there is no use of using 8 bit microprocessor and you will find incidentally that 8 bit microcontroller can function so much, that it can do so much computations, we do not need 16 bit microcontrollers.

So, if it can be added as it say the ..…. load cells, I can make it. It can be formed by adding a microcontroller to a standard cell, right. It can calculate, display total cost from the measured weight using stored cost per unit weight information, because ultimately those who will take the reading of their truck, so they have to, must pay, so that it depends on how much load you are carrying, so depends on them, usually they pay. So it can be, we can all the scale factors different things, if there is certain amount of …. also can be solved with the use of microcontrollers, right?

So, this is called the intelligent load cell. This is not, not new for the load cell. I mean you all intelligent sensors or intelligent, I mean machines are, it has some inbuilt computations facilities. So, if you use a microcontroller, then we will call it intelligent machines.

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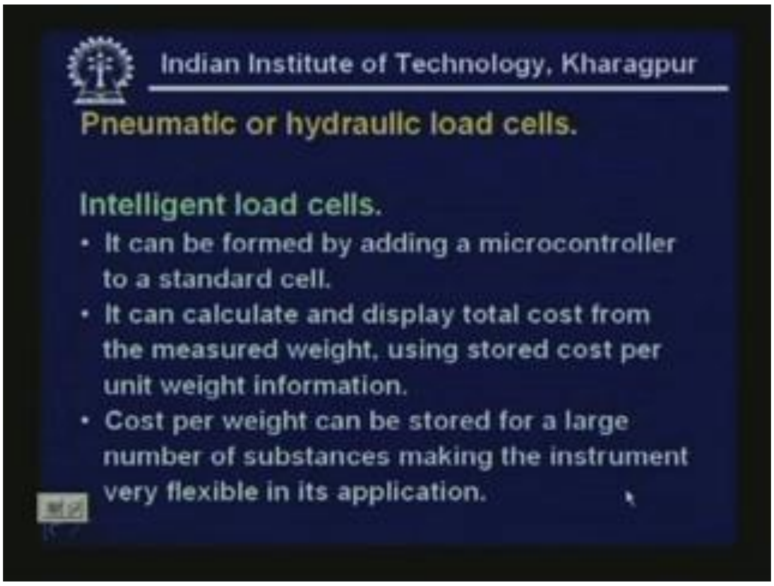

Now, cost per weight can be stored for a large number of substances making the instrument very flexible in its applications. This is also a, it is not true for, only for, I mean this type of load cells. You will find in many applications, you will, you can do it that means, that means suppose if you, I mean you can make a machines that means all the weights are, I mean selected all the weights of, I mean they are all, you, all the cost of the per unit volume ….. per kg of the different materials are there, especially in the grocery store and all these things, in abroad you will find these type of things are there that you can choose the particular cost and can calculate and make the total value of the, your material whatever you have bought.

So, this is all about our intelligent I mean load cells and it is very extensively used. So, we basically discussed two basic load cells that means the, a link type as well as your cantilever beam type load cell. As I told you earlier, the link type load cell, sometimes people call link type load cell, sometimes people call it column type load cell and other is a cantilever beam type load cell. You will, usually you will find that the cantilever beam type load cell used for the less load, slightly lesser load, whereas the column type load cells are usually used for the larger loads, right?

This ends the lesson 5 of Industrial Instrumentation.