Industrial Instrumentation
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Lecture - 4
Strain Gauge

Welcome to the lesson 4 of industrial instrumentation. In this lesson, I will cover strain gauge - one of the very, I mean important sensor in instrumentation. However, before, before I start the, this lesson I must solve because as I promised that at the end of the lesson 3 that I have given the lesson 3, I mean problem 3.4 to 3.6, which I will solve in this class.

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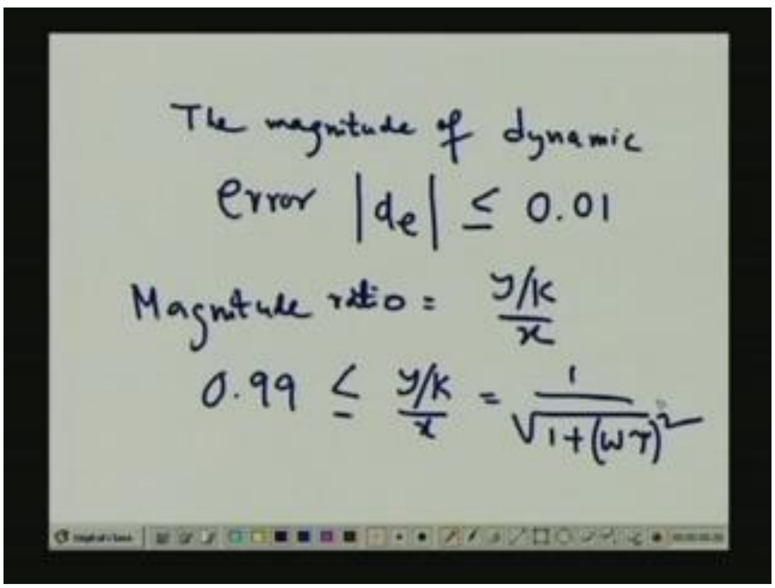

Now, problem number 3.4 as you know is the magnitude of the dynamic error. Dynamic error is or I should write d e, mod of d e should be less than equal to 0.01, because you know that it is a first order instrument, even though I told that the error can be plus minus 1%, but in the case of first order instruments we have seen that there is no over shoot, so error should be always less than, can only have, it should be less than that means it should be always .99 instead of 1.01. So, if it is there, so the magnitude ratio we know equal to y by K by x. So, it should be 0.99, because .01%, 1%, so it is 0.01 should be less than equal to y by K by x, right and as you know this is equal to 1 upon under square root 1 plus omega tau square.

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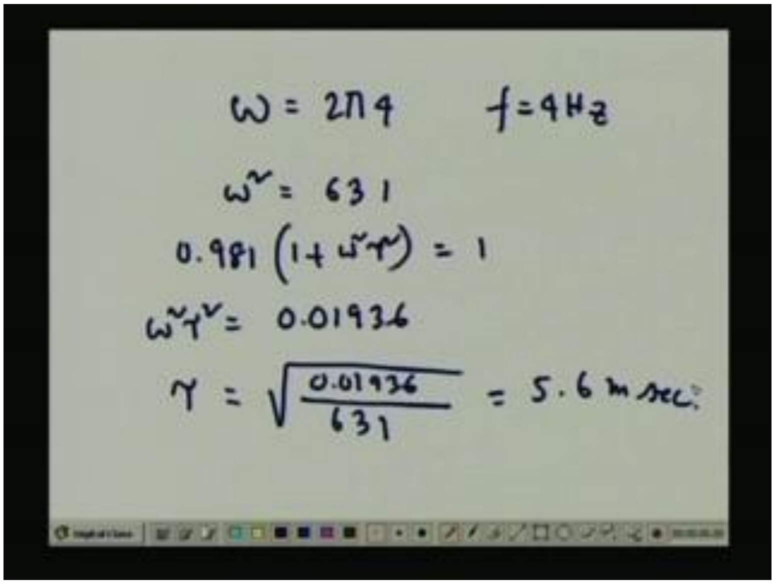

Now, omega is given, let us calculate for omega equal to 4. So, if I calculate for omega, I mean frequency of 4 Hertz, so it will be 2 pi into 4, because f equal to 4 Hertz, as it is given. So, it will be, omega square will be equal to 631. So, it will be 0.981 into 1 plus omega square tau square equal to 1. So, it will give you omega square tau square equal to 0.01936. So, tau will be equal to under the square root 0.01936 divided by omega square is 631, so it will give you tau equal to 5.6 milli second.

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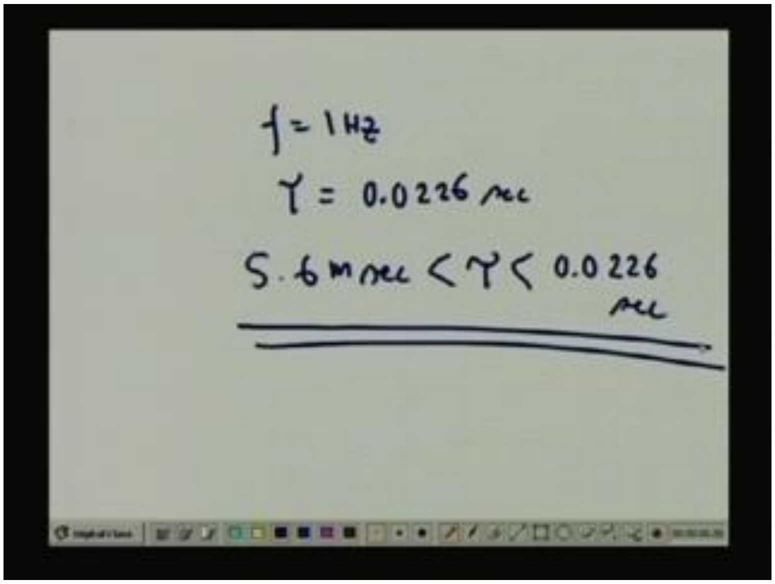

Similarly, if we take f equal to 1 Hertz, because we say that the frequency will lie between 1 hertz and 4 hertz, so we will get tau equal to 0.0226 second. So, I should say that the tau should lie between 5.6 milli seconds and 0.0226 second that means 5.6 milli second, tau 0.026 seconds. If the tau lies between this, the time constant lies between these values, so I can handle the signal for the first order instrument of 4 Hertz to, 1 Hertz to 4 Hertz.

Now, let us solve the problem number 3.5.

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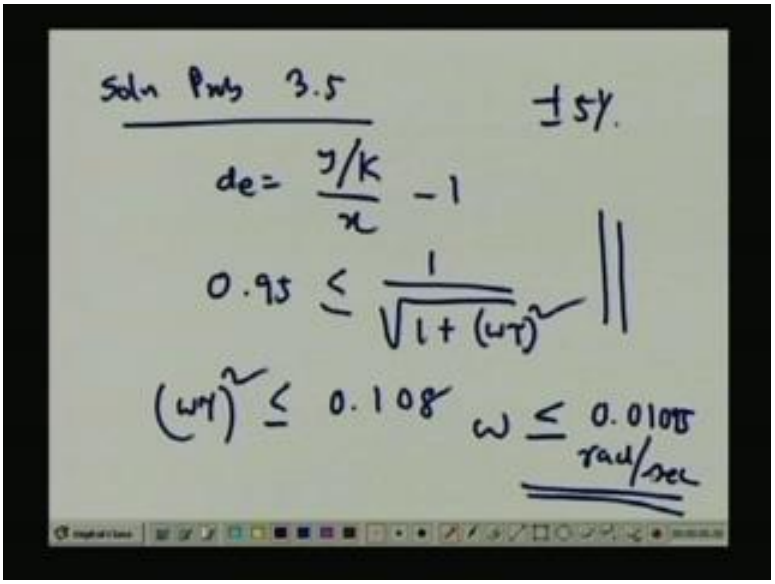

3.5, you see we have to find the, the highest frequency, right? That was the problem. It is also a first order instrument. So, problem number 5, solution to problem 3.5, so it will look like, d e equal y by K by x minus 1. It is here, the error is plus minus 5%. So obviously, so it will be .95 less than equal to 1 upon root over 1 omega tau square, sorry that was the given. So, I can write that, from this omega tau square will be less than equal to 0.108. So, I can write omega will be less than equal to 0.01095 radian per second. So, I have not solved the intermediate step; that you can do. But, this is our principle, how we can find the value? This is our answer. So, if omega is less than that, I mean that means it can handle the frequency which has a circular frequency value of 0.01, .01095 radians per second.

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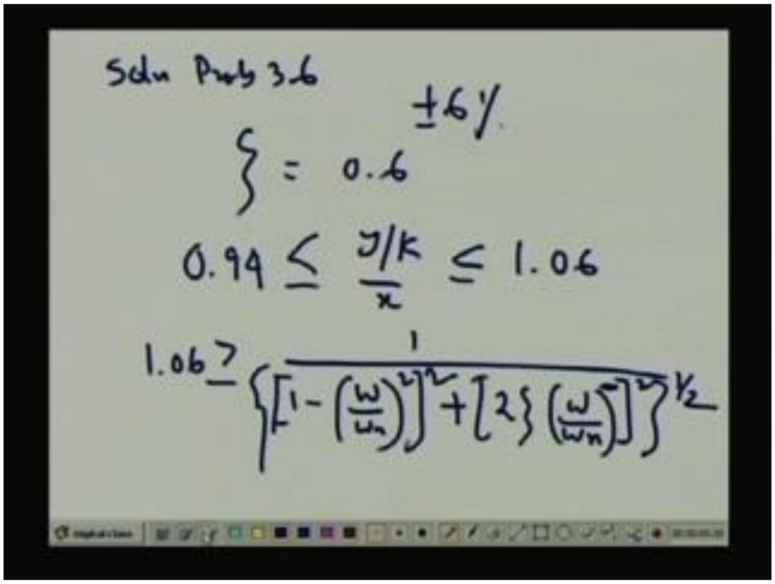

Now, problem number 6, 3.6 rather, so the solution to problem 3.6, it looks we have a dynamic error of plus minus 6%, right? We are given, error constant zi you are given .6 and since it is a first order instrument, so it will lie between, sorry it is a second order instrument, so it will lie between .94, so it can over shoot. So, the plus minus, both plus minus 6% will be valid here. So, y by K by x equal to 1.06, right. So, we have two equation for this that means 1.06.

We know in this case 1.06 greater than equal to 1 upon, if I take 1 minus omega by omega n whole square square plus 2 zi omega by omega n whole square square half. No, I am sorry; I think there will be no square here. So, this will be, so it will get, this is 1.

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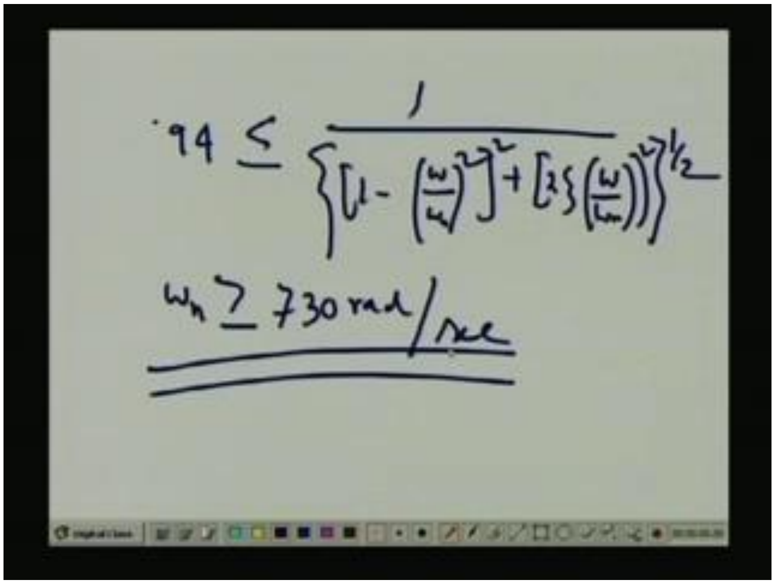

And another one will be .94. It is .94 greater less than equal to 1 minus omega by omega n whole square square plus 2 zeta two zi omega by omega n whole square to the power half. See, if you solve these two, so I will get omega n greater than equal to 730 radians per second. This is our answer, right? Now, let me go back to the, our today's lecture. It is strain gauge.

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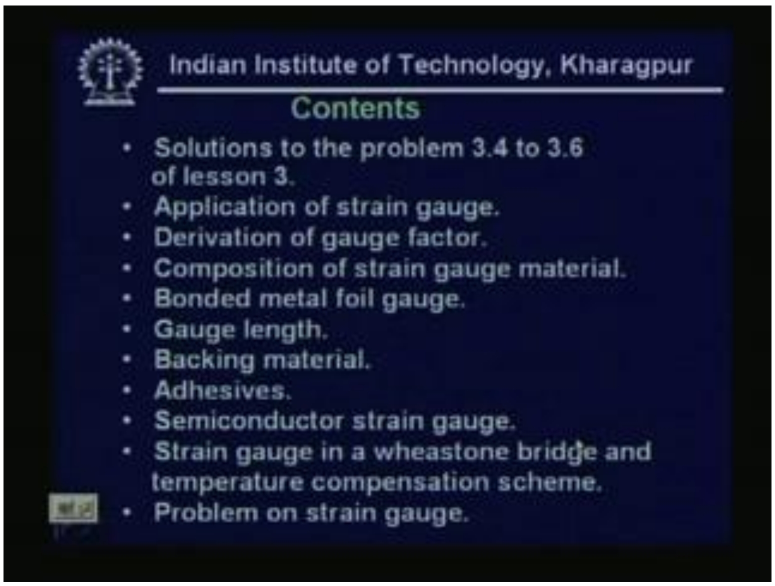

Now contents, as I told solution to the problems of 3.4 to 3.6 of lesson 3, application of strain gauge, derivations of gauge factor, composition of the strain gauge material, bonded metal foil gauge, gauge length, backing material, adhesives, semiconductor strain gauge, strain gauge in a Wheatstone bridge and temperature compensation scheme and problem on strain gauge. We will solve some problem later on also.

Now, you see that strain gauge is basically a device, is a, when it is subjected to some, subjected to some force that means if there is a stress there will be a change of strain. That means what will happen that if there is a change of resistance? So, that change of resistance can be calibrated, that or measured and can be, in future can be calibrated in terms of, in terms of either load or displacement.

Now, directly this strain gauge is used for the measurement of load; indirectly it is used for measurement of displacement, small displacement as well as for measurement of pressure. We will see later on that it is used for the measurement of the pressure, when it is used in conjunction with the diaphragm gauge, right? Now, let us look at the, so that is the basic application of strain gauge. Now, let us look at the derivations of the gauge factor of the strain gauge.

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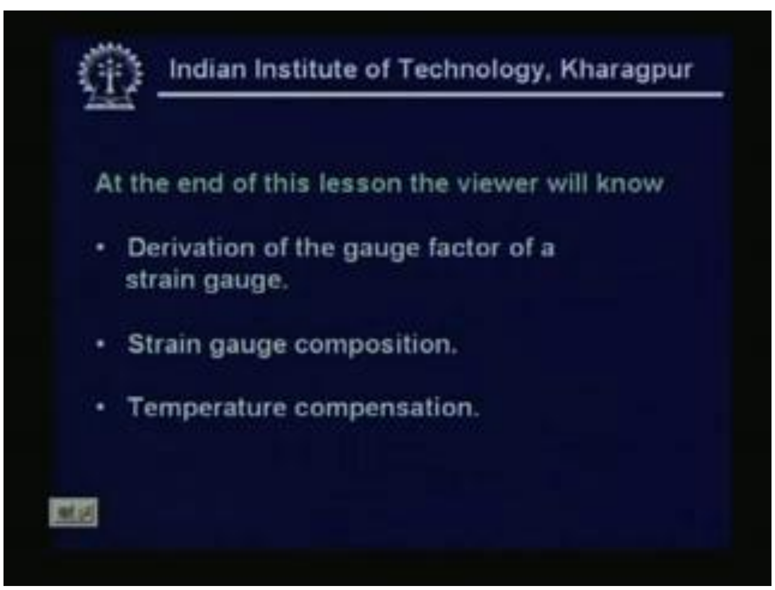

Now, I mean, it is the, at the end of the lesson the viewer will know the derivation of the gauge factor of the strain gauge, strain gauge composition and temperature compensation.

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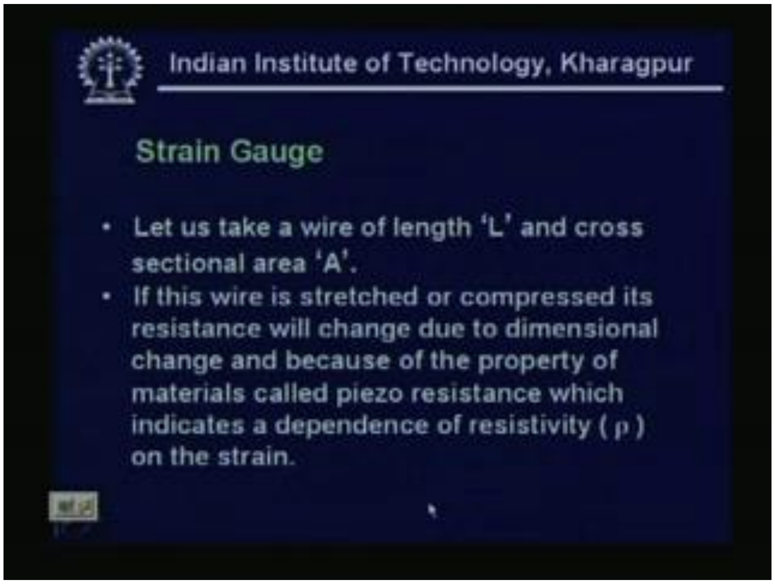

Let us take a wire of length L and cross sectional area A and if this wire is stretched or compressed, its resistance will change due to dimensional change and because of the property of the materials called Piezo resistance which indicates a dependence of resistivity on the strain.

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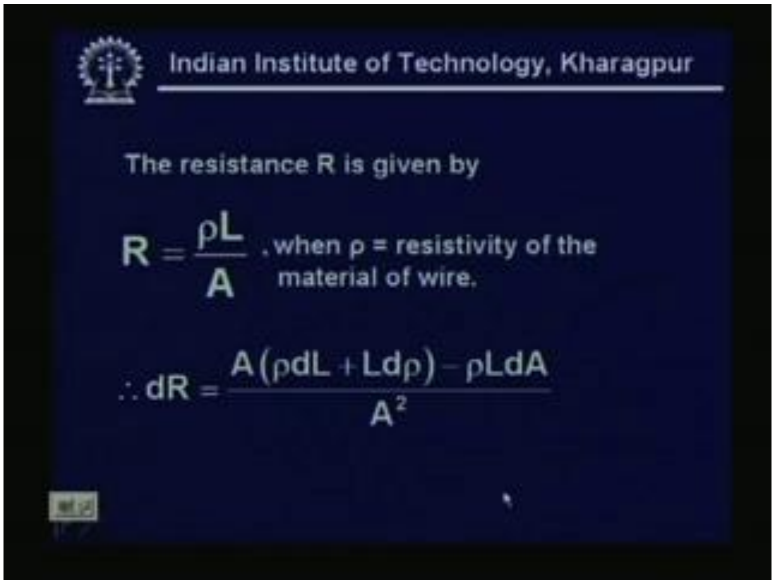

Now, resistance R is given by, as you know this is very common equations, rho L by R equal to rho L by A, where rho is the resistivity of the material of the wire, L is the length of the wire and A is the area of cross section of the wire, right and if I take differentiation of this, so dR equal to A rho dL plus L drho minus rho L dA upon A square; all are variable, so in this case we will get equation like this.

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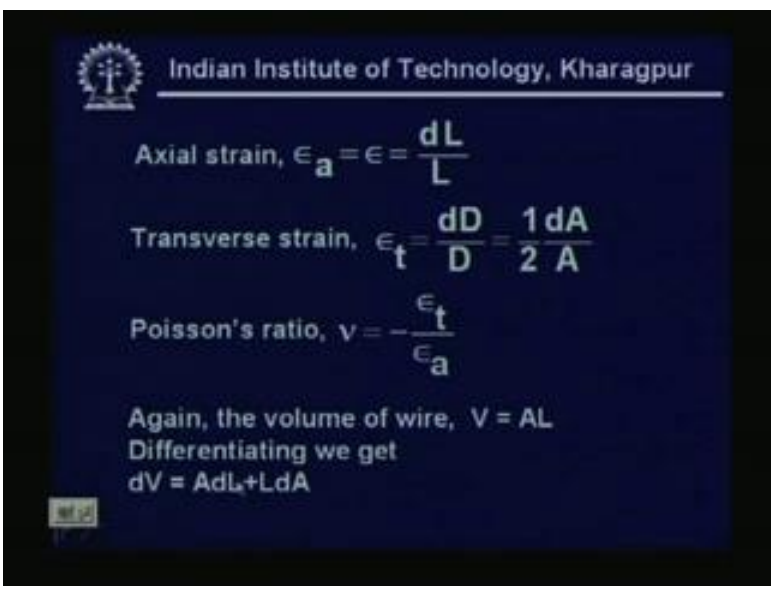

Now, see the axial strain we defined as this one that means axial strain we have defined epsilon a equal to epsilon into dL by L. The transverse strain we have defined as epsilon t equal to dD by D, which if you take derivative it will be 1 by 2 or half equal to dA by A, where A is the area of the, area of the cross section of the strain gauge. Now, Poisson's ratio is defined by, you see, nu equal to minus epsilon t by epsilon, you know or epsilon t by epsilon, simple epsilon. Again the volume of the wire V equal to AL. As you know V is the volume, so it is A multiplied by the length of the wire. If you differentiate we will get dV A dL plus L dA.

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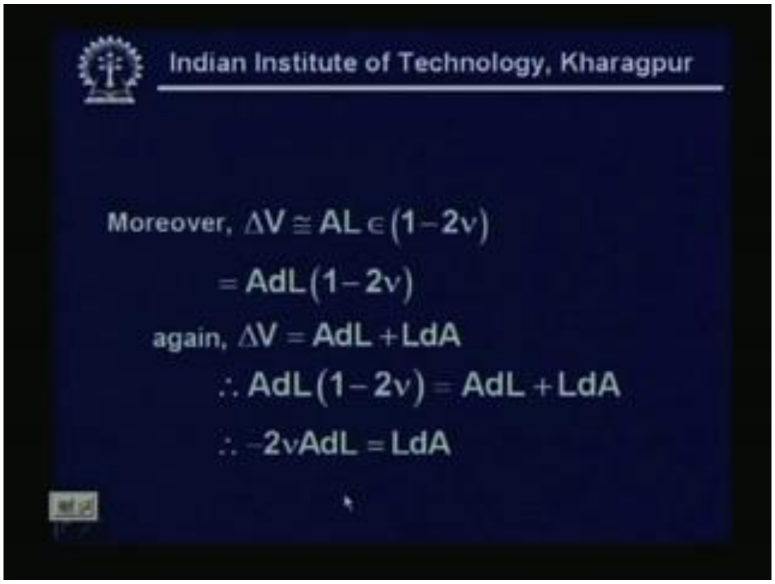

Moreover, we can prove that del V equal to, almost equal to AL epsilon 1 minus 2 nu.
Now, I will combine these two, I mean, so I will get after combining AL and epsilon, after combining AL and epsilon we got dL, so 1 minus 2 nu. So, this can be further simplified. Again we know that del V equal to A dL plus L dA, so A dL 1 minus 2 nu equal to A dL plus L dA, so minus 2 nu A dL equal to L dA.

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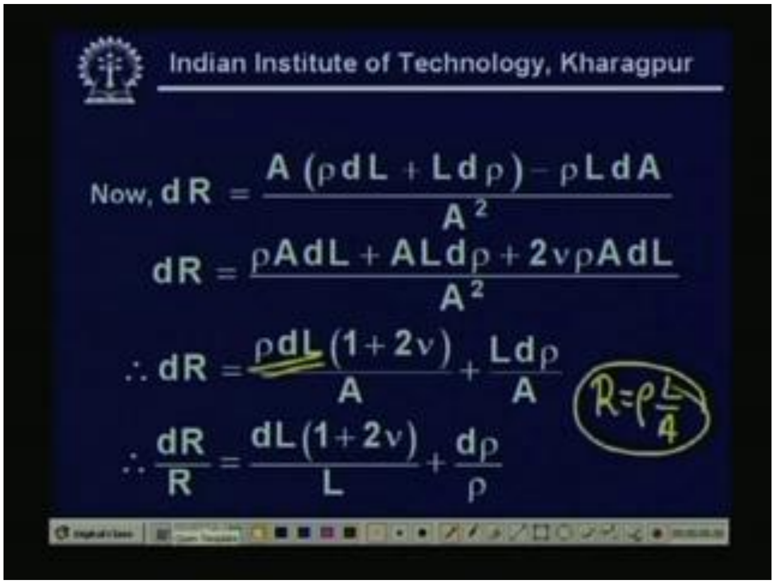

Now, dR equal A rho dL plus L drho minus rho L into dA upon A square. So, it will further be simplified like this, right, because we are using the Poisson's ratio, so we make it positive. So, I will get the equation, the change of resistance equal to dR rho dL; rho is the resistivity of the material of the strain gauge, multiplied by dL 1 plus 2 nu, where nu is the Poisson's ratio divided by AL drho by A. It can be further simplified, if I write like this, dL equal to, because as you know that R equal to, because you know that, we know that R equal to rho L by A, so we have applied this here. So, it will be dR into R, sorry rho dL equal to, then R if you replace rho then it will be R into A. A, A will cancel out, so we take the L in the denominator and R on the left hand side. So, change of resistance per unit value of the resistance that we have actually done.

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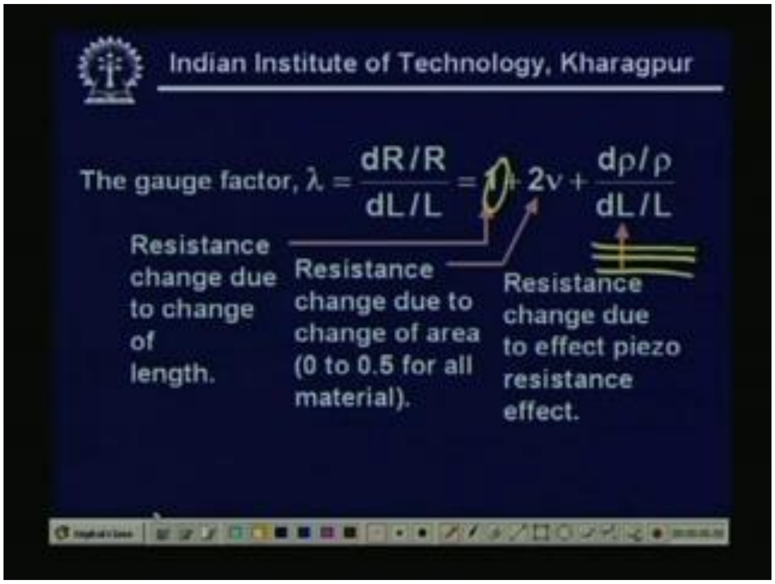

So, the gauge factor is given by, it is usually defined as lambda, is very standard notation for the gauge factor, into dR by R upon dL by L equal to 1 plus 2 nu plus drho by rho upon dL by L. Now, you see this, this one is actually resistance change due to change of length. This is the resistance change due to change of area. Typically its value lies between zero to .5 for all materials and finally the, that is the resistance change due to, due to the effect which is called Piezo resistance effect, right?

Now, in the case of semiconductor this will be very high, whereas in the case of metal, I mean this is predominant. In the case of metal you will find 1, whereas in the case of semiconductor, it is, this will be predominant. You can almost neglect these two parts, because it is so high, right?

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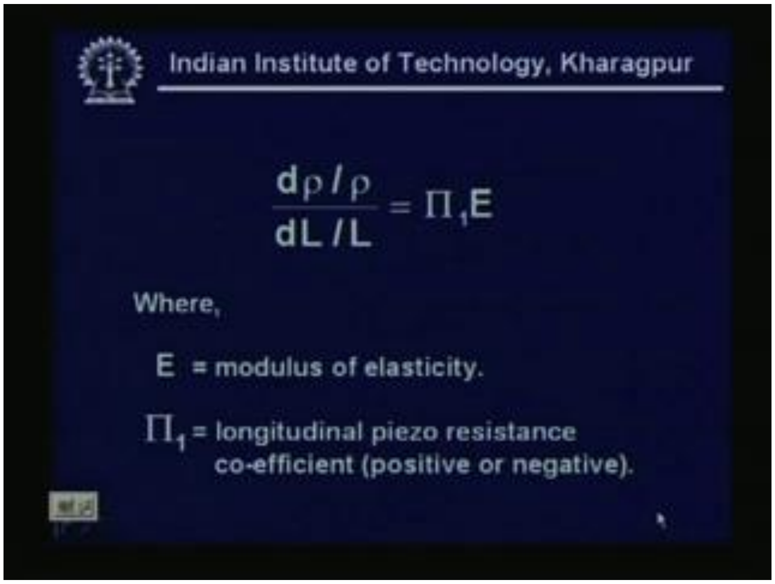

Now, further we simplified. We have introduced drho by rho upon dL by L equal to pi 1 into E, where pi 1, where E is the modulus of elasticity and pi 1 is the, capital pi 1 is the longitudinal Piezo resistance coefficients, which can be positive or negative, right. So, with this that gauge factor, expression of gauge factors we have seen. Now, we always want, for in the instrumentation systems or for the strain gauge that the gauge factor should be as high as possible, because if the gauge factor of high, then for unit strain I will get more change of resistance, my signal conditioning circuit will be simplified. That is requirement for all sensors, right.

Now, let us go to the instrumentation lab and see one practical strain gauge, how it looks like and which is used as a displacement sensor to make a small, I mean displacement sensor that means for the small measurement of small displacement. We will come back after sometime.

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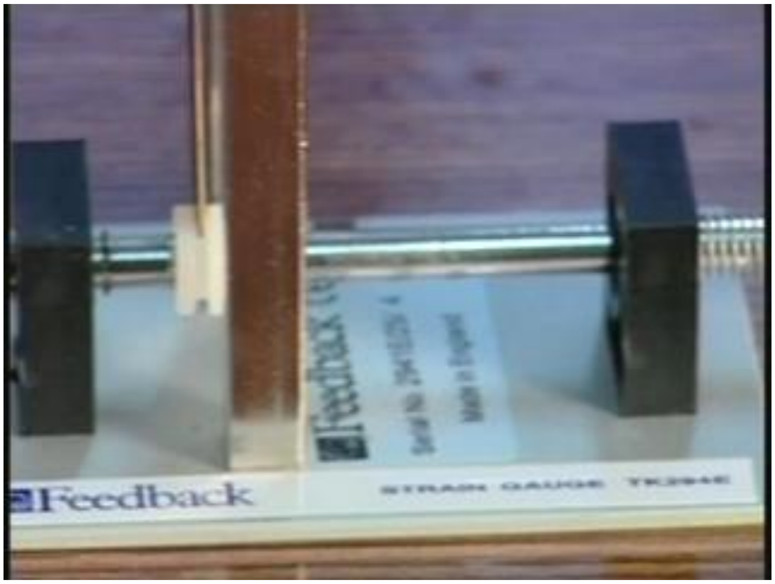

It is a displacement sensor based on strain gauges. We have already seen that in all strain gauge measurements we usually, we use a bridge, Wheatstone bridge with four arms and for temperature compensation as well as for the larger output, we usually use at least two strain gauges and sometimes you will find there are four strain gauges. In this displacement sensor, we have two strain gauges and one will be on axial elongation, other will be on axial compression.

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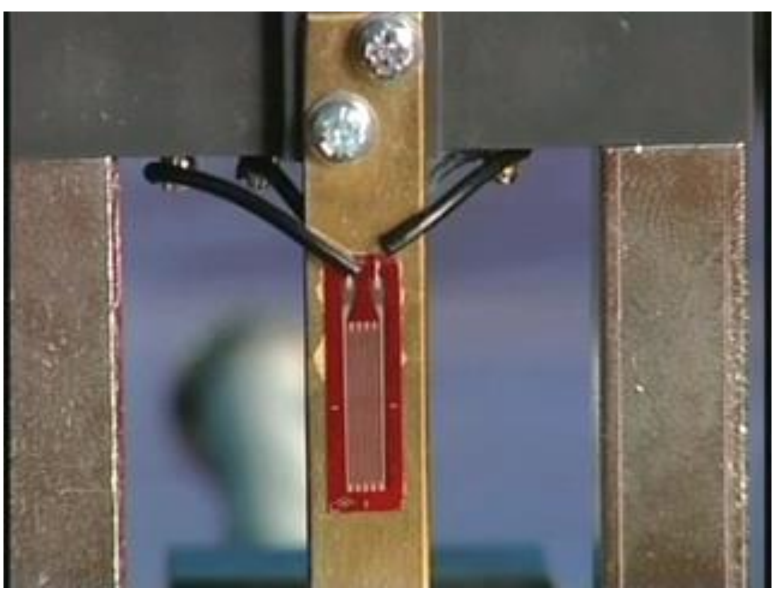

And if we put this two strain gauges on the opposite arm of the bridge I will get larger output.

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You see here that there is a strain gauge on this side; you can see here, so and there is another strain gauge on the backside of this brass plate and how it works, you see, when I give the displacement like this, you see here, the displacements I am giving here. So, this strain gauge will be under axial elongation and the strain gauge on the back side that means on this side will be under compression. So, if I put on the opposite arm of the Wheatstone bridge, obviously I will get double the output as well as you will find that I will receive the, I will get the temperature compensation in this particular circuit and this particular displacement sensor is used for the displacement of, small displacement like less than 1 centimeter and that type.

Welcome back to the class room. You know the strain gauge is implemented in several different ways.

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Number 1 is unbonded metal wire gauge, number 2 is a bonded metal wire gauge and number 3 is a bonded metal foil gauge and bonded, number 4 is bonded semiconductor gauge and 5 is diffused semiconductor gauge. Now, in the case of bonded metal wire gauge, I can have any unbonded metal wire.

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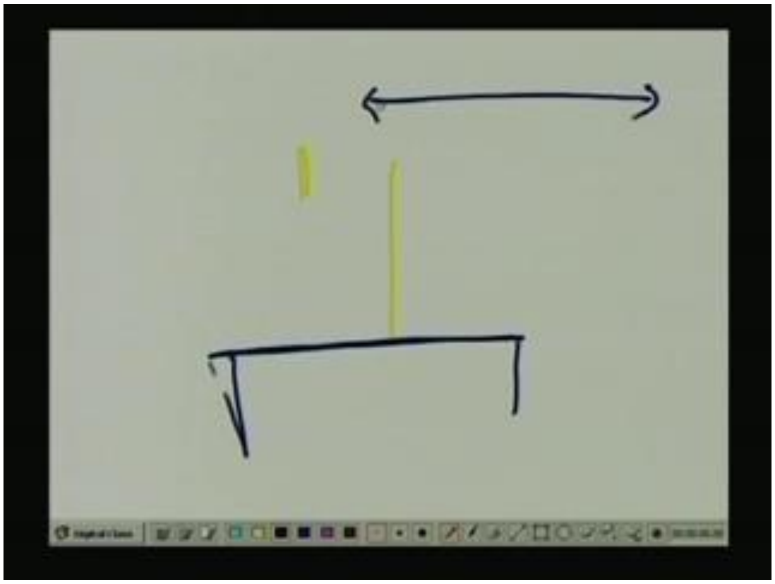

Suppose I have a two pillars, sorry suppose I have a two pillar that means two pillars here. So, I have put a wire, so if there is, if this, if this pillar is tilted like this one, so some stress will be developed, because this wire will be under tension. In that case, so the stress will be developed. So, it is the unbonded strain, because any wire, a simple wire if it is under, if you pull on both side, so it will have certain amount of stress and strain, right? So, this type of ….. measurement was, I mean people used sometime back, so we can call, I mean it is some sort of academic interest, because unbonded wire strain gauge is very uncommon nowadays.

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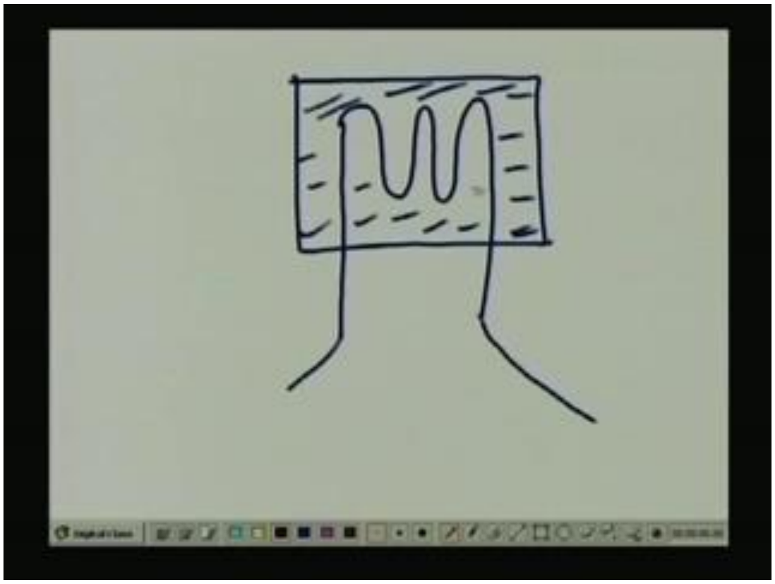

Now, next we will find the most widely used gauges, bonded metal wire gauge, right and here in this case that the strain gauge will be bonded on a backing material. It looks like that means it looks like I have a backing material, so over which this strain gauge is put like this one, right. So, I have a backing material there. So, we have electrical connections we have taken out. So this is a, backing materials are various types which will be discussed after sometime. So, this is the strain gauge which is called bonded strain gauge. So, it is actually with the adhesives, so it is to be, this is our vacuum material and it is to be placed on a body on which we are interested to measure the stress or strain, right?

Third comes the bonded metal wire gauge which is most widely used metal wire gauge nowadays. Because we will concentrate on this lot, because it has some advantage. We will see that the transfer strain will be very less in this case, because the same technology, whatever they are using for making the PCB is also used for making the bonded metal wire, metal foil gauge and interestingly you will find, you will find the shape is something like that that this end resistance effect will be very much less in the case of bonded metal wire gauge.

Now, bonded semiconductor gauge is also there. You will find the semiconductor itself is used to bond on a material. So, it is a, instead of I mean simple wire type of gauge I am using the semiconductor strain, whereas the diffused semiconductor is something different. You will find that in the, one of the example of the diffused semiconductor gauge is the, is a pressure gauge, diaphragm pressure gauge, where the diaphragm material is of, made of semiconductor. It looks like this.

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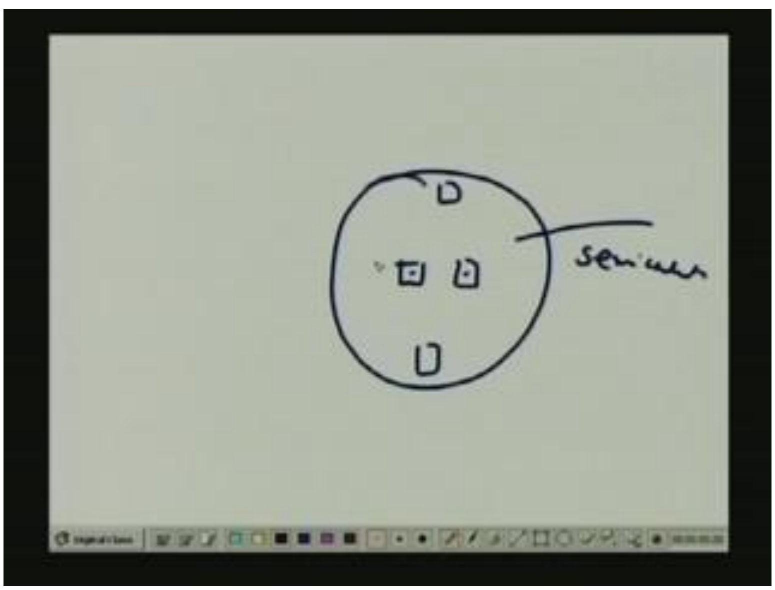

Suppose I have a diaphragm, circular diaphragm, you can see here. So, I have 4 strain gauges here, suppose two on the, so this material is semiconductor and where I want to make the strain gauges that portions will be doped. So, if I dupe, I mean dope like this that portions, so I will get some gauge there and this type of strain gauges is called, is called the diffused semiconductor gauge. It is used for, it is a very, because of the advantage of a semiconductor strain gauge, as I told you earlier, is a high gauge factor whereas in this, almost you can say some 60 to 70 times the gauge factor is more than that of the wire type of gauge or gauge made of metal, right?

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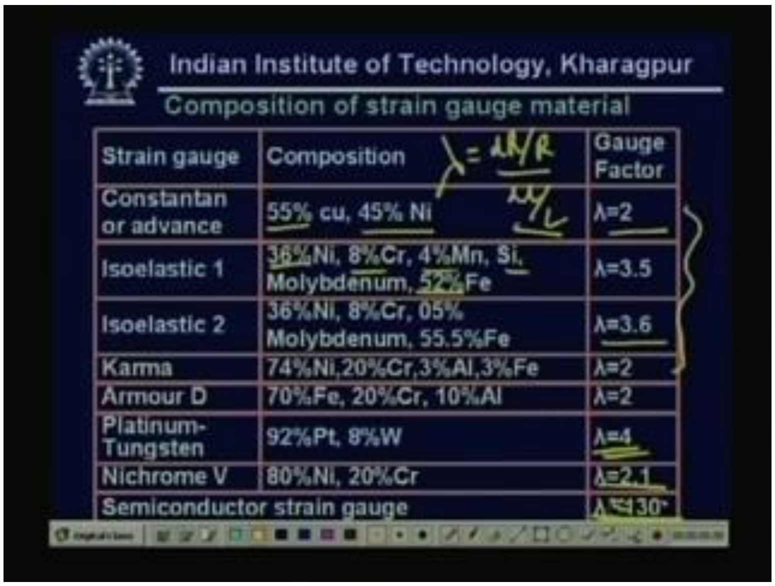

So, composition of strain gauge material that is very important. You will find that there are many strain gauge are available in the markets and you will find here the different gauge factors we are given. Lambda equal to 2 is a very common type. It will be cheap, low cost strain gauge is called constantan or advance. Here, the composition is 55% copper and 45% nickel. Then you have isoelastic, which is 36% nickel, 8% chromium, 4% manganese, silicon and 52% iron.

Then, you have isoelastic 2. These are all trade name, because you see the strain gauge was first developed, I mean commercial strain gauges which are developed mostly in the industry, so they have given some trade names. Later on they gave, gave the composition, but that is the reason the funny name, they have given constantan, isoelastic, like that.

Then, we have molybdenum, isoelastic 2, which is 36% nickel, 8% chromium, .5% molybdenum and 55.5% iron or steel. So, lambda is 3.6, not very high.

Karma, which is lambda equal to 2, because you see, what is the use of this 2? You will find the applications will be different if you have that 74% nickel or 20%, because strain gauges are used for various environments. Somewhere you will find the reducing atmosphere, somewhere it is oxidizing atmosphere, somewhere it is very corrosive atmosphere. So, in all these, I mean, features you will find that, in all these different applications you will find that you have to use different type of strain gauges.

Then, we have a armour D, which is 70% iron, 20% chromium, 10% aluminum; lambda is same. Platinum - tungsten rather I should say it is a very good gauge factor. It is 92% platinum, obviously quite costly, 8% tungsten and lambda equal to 4. Gauge factor is 4, because of the gauge is higher, gauge factor is higher, obviously I will get the better and better output. Because, as you know that lambda means dR by R by dl by L, so whenever the lambda is high, so I will get more change of resistance, right? For the same amount of strain, I will get more change of resistance. So, that is very much necessary, okay, to have a, simplify our signal conditions.

Then, we have a Nichrome V 80% nickel, 20% chromium, lambda equal to 2.1. Semiconductor strain gauge i s lambda equal to 130, right? This should be equal, I do not know why it did not come, so lambda equal to 130, exceptionally high. You see that compared to all these this is almost 60 to 70 times more, at least 60 times more; 62, 16, I mean 5 times more than the conventional wire or please you note one thing that whether it is a wire type of gauge or a, I mean bonded wire gauge or bonded metal foil gauge, the value of lambda does not change. It is a physical property; it depends on the compositions of the materials.

People for the, over the years they have tested this; you have, they have seen, they made some funny composition to get the value of lambda higher and higher. Whether you are using in a bonded metal gauge or unbonded gauge, bonded gauge or bonded metal foil gauge, it does not matter, because ultimately the value of lambda depends on the composition of the material which is used to make the strain gauge.

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So, bonded metal foil gauge as I told you earlier, it is the most widely used transducer for stress analysis. It consists of a metallic foil pattern similar to the process used to produce printed circuit board. So, the as you know, the printed circuit board, because it is printed circuit board what happens that as you know that it is a bakelite type of material is taken and it is covered with copper. Then, a mask is put on this one and it is a, it is ultraviolet light falls on that and whenever the, that falls whenever it is obstacle, so that portions when you put later on in the liquid, some special liquid you will find that that will go out. The same principle is also used for making the strain gauges, the reason I will tell you after sometime. So, photo etched metal foil pattern is installed on a backing material.

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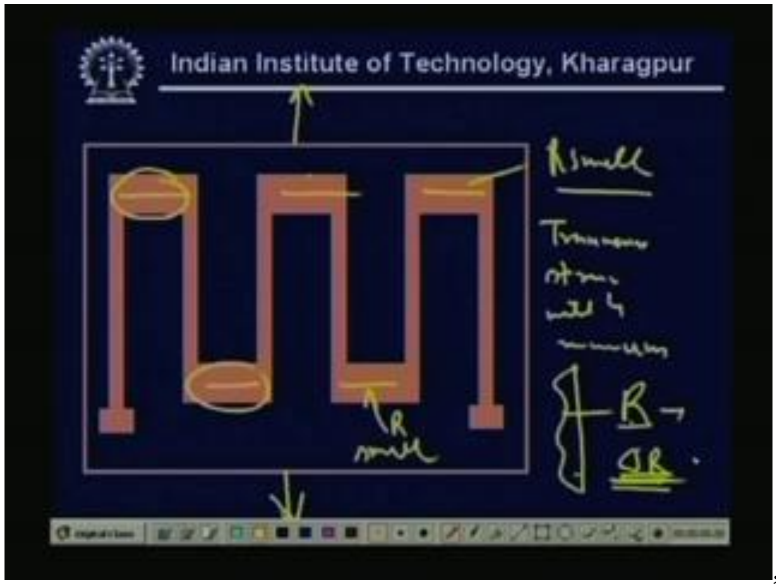

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You see, here it is a typical metal foil gauge where in the case of wire gauge this two thickness will be same, whereas you see here all the end resistance or end portions of the strain gauges are made very thick. The reason is, you see, when I am subjected to some stress, so I am supposed to, that suppose in this case suppose I am giving it some tension here. So, all these supposed to have an axial tension, is not it? Whereas, what will happen you see here on these portions? These will have a transverse, right? But, while I am making the calculations I have not included this part. So, what I have to do?

I have to do in such a way if I make it thick, so the contributions, so the value of R in these portions will be very, very small, is not it, compared to this portion. So, the contribution to the transverse strain or the transverses strain error in this case will be very, very low. That is the reason metal foil gauge purpose, because in the case of wire gauge I cannot change the dimension of the wire in between, but in the case of metal foil gauge we can do it, because it is the principles of the, principle of the printed circuit board is utilized to make this type of gauges. So, this end portions are very thick. So, the resistance small, r small, here r small, so the error, transverse error will be minimum, transverse strain error will be minimum.

You may immediately say, sir, what is the harm if I take a simple stretch of wire like this one. This is not possible. You see that I have to make a sufficient length of the wire, so that the value of r is sufficient. If the r is large delta R will also be large, please note.
So, that will ease our, simplify our measurement. If the r is small, r is small if I take suppose a small length of wire, if I take a full length of wire, this one, so my delta R also will be small, R will be large delta R also will be large. So, that is the reason all the funny shape and this type of shape you have to make in the case of strain gauges. This is very simplified.

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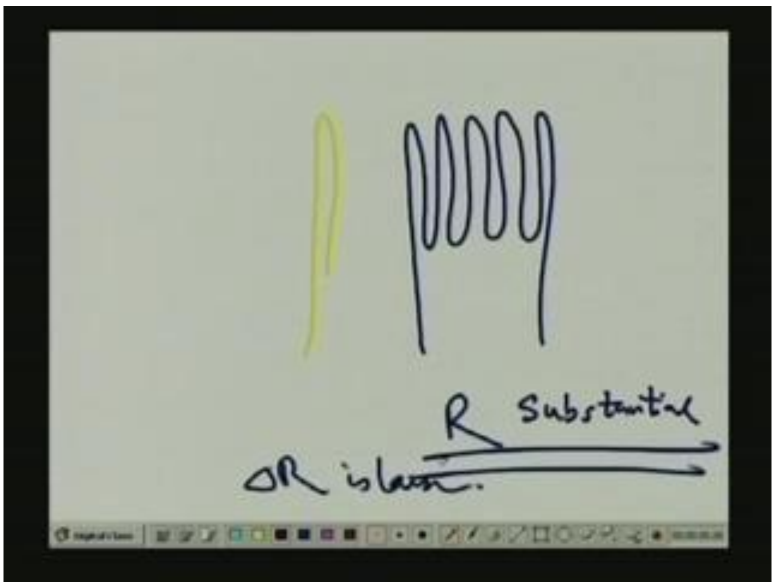

Actually, you will find there are various ….. It looks like, I have several, you will find that there are several that means, so that the value R should be that means substantial. So, this value should be very substantial, so that the delta R also will be large, right? So, that is very much necessary.

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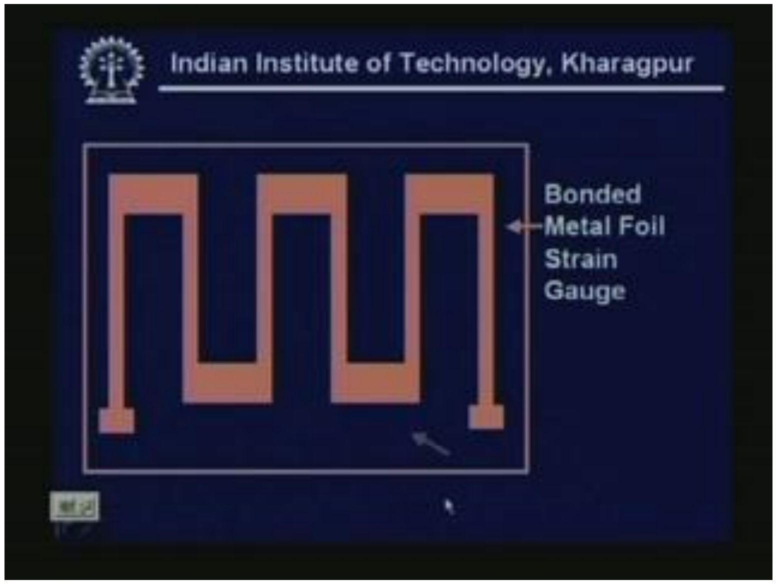

So, is a bonded metal strain gauge. You see this here, this is a backing material on which we have put, right?

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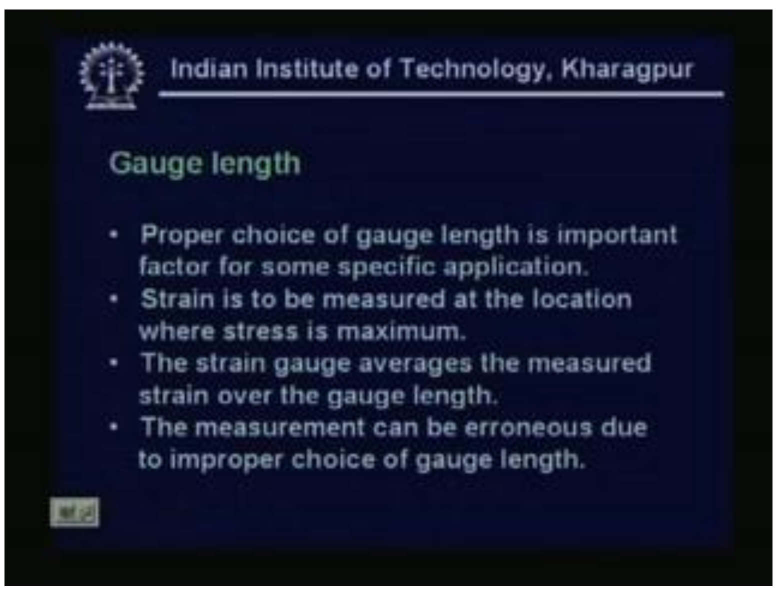

Now, gauge length, the proper choice of the gauge length is important factor for some specific applications. Strain is to be measured at the location where stress is maximum and the strain gauge averages this measured strain over the gauge length and the measurement can be erroneous due to improper choice of the gauge length, right. So, gauge length is very important.

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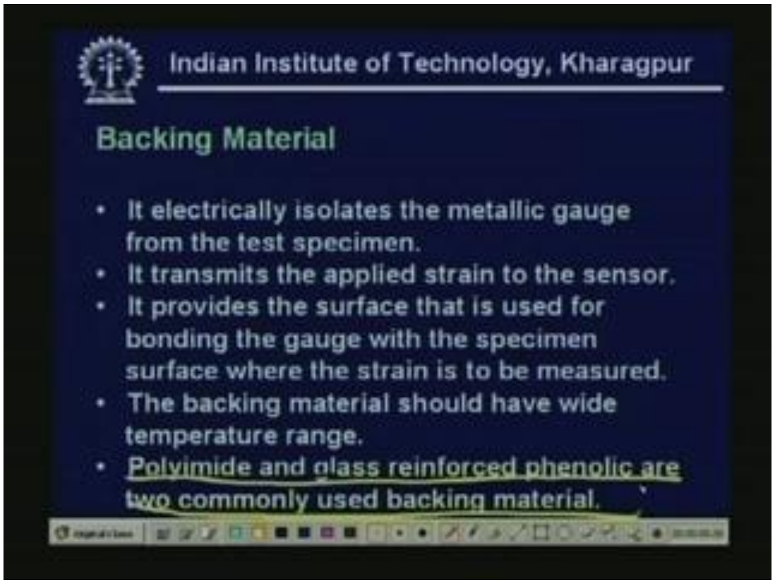

Backing material, it electrically isolates the metallic gauge from the test specimen, right, because you see in all the cases you will find strain gauge we will put on a Wheatstone bridge. So it is a electrical circuit, so that electrical suppose I am interested to measure the, measure the strain or a load on a beam, steel beam. So, in that type of situations, so I cannot connect directly on the steel beam itself. I have to insulate, because we are interested only on the strain we have.

I do not want to make electrical connection with the, I mean, steel beam itself, right. So, that is it will isolate, first of all it properties, electrically isolates the metallic gauge from the test specimen Then, it transmits the, and applied strain to the sensor. It provides the surface that is used for bonding the gauge with the specimen surface where the strain is to be measured. The backing material should have a wide temperature range. Polyimide and the glass reinforced phenolic are two commonly used backing material. These are the most commonly used backing material.

You see, these are polyimide. So, these are polyimide and glass reinforced phenolic and two commonly used backing material. Now adhesives, because you know that this bonded metal gauge, I mean wire gauge or foil gauge it does not matter, it cannot, I mean you cannot, you have to use some adhesives. So, usually you have to put some adhesives on which and there is, at least there should be a some time of one 24 hours you have to keep for the curing or drying up process, right?

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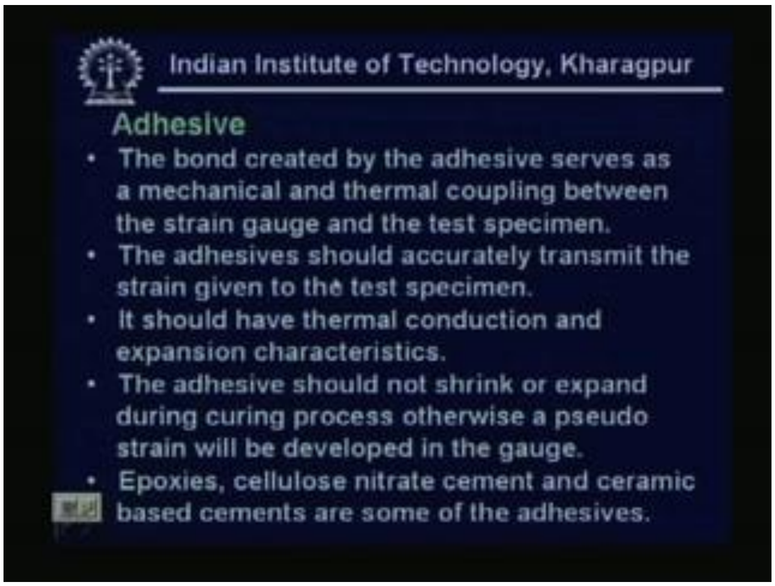

So, there should be some features, as you know, in the case that while you are installing on a, suppose a pipe, suppose I have pipe like this one, so I put on a strain gauge over this one. So, I will put a strain gauge. I want to ….. suppose there is a bending of pipe, how much strain will be developed in that pipe? So, in that case, so I have to put the strain gauge and I have to, whatever the strain developed on this pipe, after the, one, once it is under tension or compression same should be transmitted to the gauge itself, right?

So, there should be a very strong bonding of the, first of all the, gauge with the backing material, then backing material with the, this test specimen, right? If there is a some gap that means between the test specimens and the, and the gauge, so the actual load which is I have given to this, this pipe or test specimen cannot be ….., will not be fully transmitted to the gauge. So, there will be some error which I do not want, right? So, the bond created by the adhesive serves as a mechanical and thermal coupling of the strain gauges and the test specimen.

This is very important, because you know the, all the strain gauges since it is a resistance, it is temperature sensitive. So, I have to make all sorts of temperature compensation and whatever the temperature compensation is there, so I have to incorporate that, because you see the, if the, I am not interested in the resistance change due to the change of temperature. I am interested into the resistance change due to the change of the strain there, because if it is, there is a resistance change due to the temperature that will be erroneous reading, because I am interested, I am measuring in the test specimen how much stress is developed, how much load is developed there. So, in that case, if there is a some strain developed due to the change of resistance, so that will give us erroneous reading.

Adhesives should accurately transmit the strain given to the test specimen. It should have a thermal conduction and the expansion characteristics same as the metal itself or test specimen. The adhesives should not shrink or expand during curing process otherwise the pseudo strain will be developed in the gauge. This is also very important, because while in the curing process means you have to leave for at least 24 days hours to dry up or curing process. Once you put the, suppose in my pipes I put a strain gauge here, so I put an adhesive. So, I have to leave it for 24 hours before drying.

Now, during drying up, so during drying, during curing process or dry up process there should not be any pseudo strain developed. If it is developed, then what will happen? You know that the, that resistance, strain gauge will be under tension. So, it will give you some false reading. Even though you can compensate for that you can use some other resistance to balance the bridge and all those things, but that is not very desirable, right? The epoxies and cellulose nitrate cement and ceramic based cements are the, some of the adhesives used for making the adhesives, I mean for adhesives.

Now, semiconductor strain gauge is most widely used, as I told you, because of its high gauge factor. Only problem with the semiconductor strain gauge is that the, it is very sensitive to temperature. That means it is, temperature coefficients are very high, so that immediately it changes the value of those temperature, I mean resistance changes as the temperature changes and also the, its performance deteriorates in the presence of the moisture. That is main problem in the case of semiconductor strain gauge.

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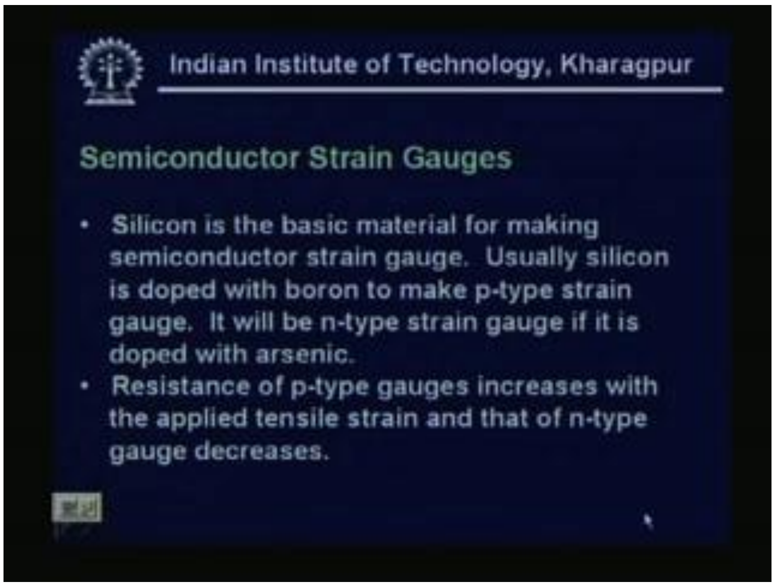

Silicon is a basic material for making the semiconductor strain gauge. Usually silicon is doped with boron to make p-type strain gauge. It will be n-type strain gauge if it is doped with arsenic and the resistance of p-type gauges increases with the applied tensile strength and that of n-type gauges decreases, right? Now, only problem with the strain gauge you see that, you will see later on, I have to use some dummy gauges for temperature compensation. We will see later on this thing.

Now, getting two strain gauges, two semiconductor strain gauges of exactly same value of the lambda is a very difficult, because see, see in the case of I mean metal gauges, the value of the lambda depends on the composition. If the composition is correct it does not matter whether you make it wire, I mean metal foil. So, you will get always the same value of lambda, whereas in the case of, if the slight doping changes in the case of semiconductor strain gauges its value of lambda changes. So, the two, exactly two gauges having the same value of lambda is very difficult to get, like beta of a transistor. Two beta is always, we say that there is some, it lies between some value, two values. I cannot have a two transistor exactly same beta. I can measure it and make, make it. Suppose in the complementary symmetry amplifier and push amplifier we always, we try to make beta of the two transistor same. We pick up and measure. If two are equal we say these are pair.

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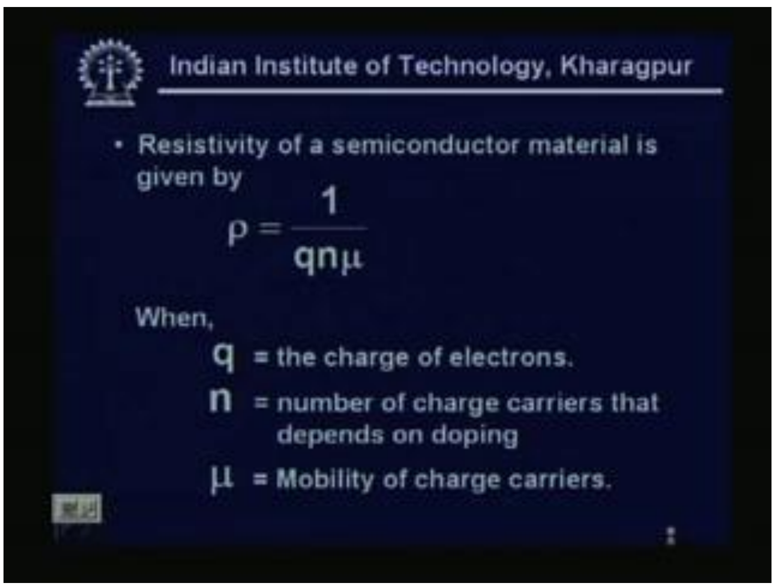

Now, resistivity of a semiconductor material is given by rho equal to 1 upon q n mu, where, I am sorry, this will be where, so this will be where q equal to charge of electrons, number of charge carriers that depends on the doping and mu is the mobility of charge carriers, right?

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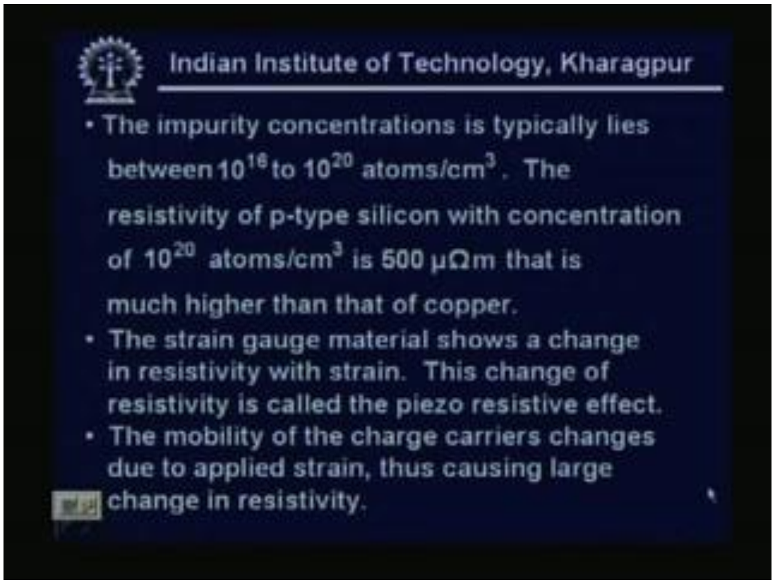

The impurity concentration typically lies between two values which will come at the end. The resistivity of the p-type silicon with concentration, let it come first, then you will, you see here the impurity concentration typically lies between 10 to the power 16 to 10 to the power 20 atoms. The resistivity of the p-type silicon with concentration of 10 to the power 20 atoms per centimeter cube is 500 micro mho meter. That is much higher than that of the copper. The strain gauge material shows a change.

Now, interestingly you will see that if you increase this beyond 10 to the power 20, you won't get any, much change of, much change of the resistivity in the case of, if you apply some strain there, whereas if it lies between these two values, you will get sufficient change of resistance in the case of semiconductors, I mean that you, actually we want. The strain gauge material shows a change in resistivity with strain and this change of resistivity is called the piezo resistive effect and the mobility of the charge carriers changes due to applied strain thus causing the large change in resistivity. This is the most important, you see, in the case of semiconductor strain gauge this change of resistivity is very high that is the reason I am getting the large value.

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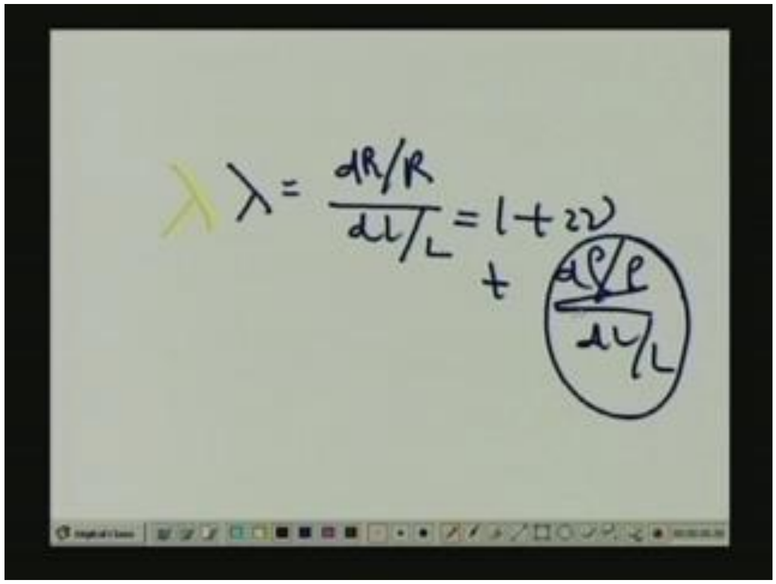

If you remember our main expressions, so it, our expression was lambda, sorry lambda equal to dR by R, excuse me, dL by L equal to 1 plus 2 nu plus d rho by rho dL by L. So, this term for the semiconductor strain gauges will be very high because of this factor. This term is not predominant in the case of metal wire gauges, right? So, that is I am saying in the mobility of the charge carriers changes due to the applied strain, because the mobility, it depends on the mobility, we have seen, right, so thus causing the large change in resistivity.

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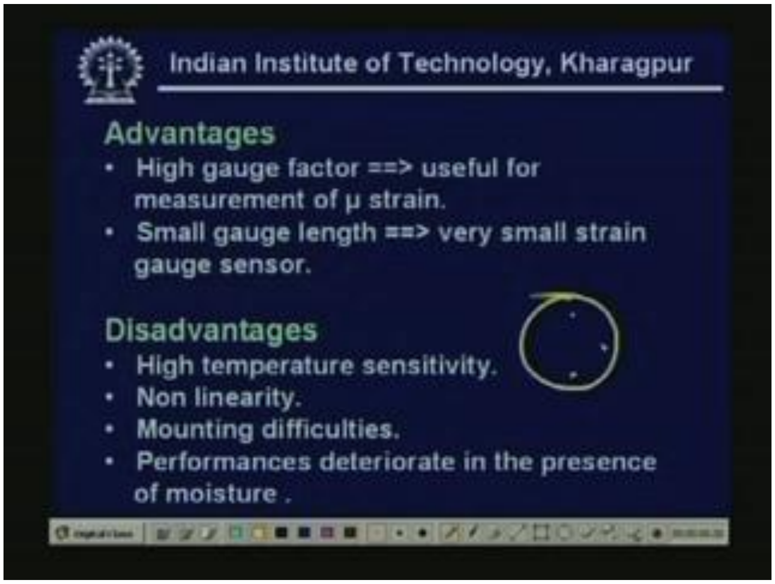

The advantage you see, the high gauge, gauge factor useful for measurement of micro strain, very small strain I can measure. It is not possible with the case of wire type of gauges whether foil type or it does not matter, foil or wire type. In the case of metal gauge it is not possible. Small gauge length, so very small strain gauge sensor we can measure. So, the dimension of the gauge I can make very small. As I told you earlier, that you see that in the case of pressure sensors we have seen that the, that small size I can make which is not possible in the case of, in the case of wire type of gauges.

Now, disadvantage is high temperature sensitivity. Temperature sensitivity we can compensate. It is very easy to say that is why we can compensate by using the dummy gauges or using four strain gauges, but having four semiconductor strain gauges, having the exact value of lambda is very difficulty. Nonlinearity, so nonlinearity is another factor in this case of semiconductor gauge. Mounting difficulty is also there, because semiconductor is very, I mean if it is diffused that is advantage, but if it is not diffused bonded semiconductor strain gauge, bonded difficulties will be there and performance deteriorates in the presence of the moisture and instrumentation, not necessarily you will measure, I mean without moisture, I mean sometimes you will have to measure in some moist where super heated steam is there. Sometimes you have to use corrosive liquids, sometimes you have gas which is very hostile in nature, so in that type of situations semiconductor strain gauge is not very suitable.

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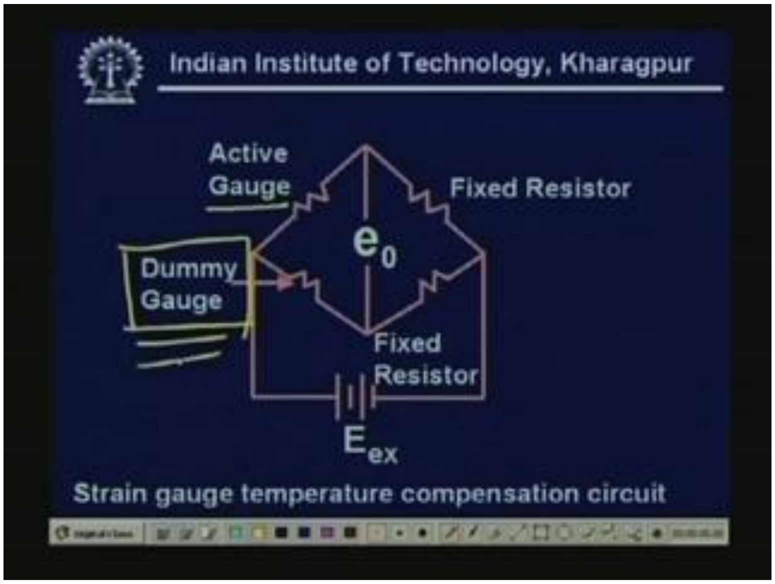

Now, see that I will make a temperature compensation. Strain gauge temperature compensation is there, so it is necessary. I will do the temperature compensation; it looks like this. I have an active gauge, one dummy gauge and fixed resistors. You see here, I have an active gauge. You see that in the case of strain gauge, I can measure with a single strain gauge also. I, whatever the change of resistance I will put on a Wheatstone bridge. Suppose there is all the gauges resistance, simple resistance, I put one active gauge, in that situation there is no problem.

I can measure that change of resistance values when it is subjected to strain, but the problem is that you see it won't, there, there will not be any temperature compensation. That means due to temperature change some change of resistance will come, so my circuit will not take care of that, whereas in the case of dummy gauge, dummy gauge the meaning is that this gauge will not be subjected to stress or strain. That means suppose I am interested to measure a, I mean, I mean measure the stress developed on this pipe, so I will put the actual gauge or active gauge on this one and dummy gauge I will not put over this one. It is also a strain gauge. These are not strain gauge.

These two are fixed resistors, simple carbon or any other type of resistor, but these are basically the strain gauge. These two are strain gauge, whereas this gauge will be subjected to strain and this will not be, I mean this will not be subjected to strain. So, whereas this is subjected to strain, this will not be subjected to strain. So, what will happen to this? This will be very close to the pipe, but it is not subjected to any strain. So whatever, the reason is why I am saying that this should be very close to the pipe, whatever the active gauge have the temperature this dummy gauge should have the same temperature that I want to mean. If I can do that, so there is no problem. So, always we will measure this, I mean this, this change of resistance by a Wheatstone bridge.

Now, there are two types of measurement. One case I will use a balance bridge, in another case we will use an unbalanced bridge. Now, we will first consider the unbalance bridge, let us look at.

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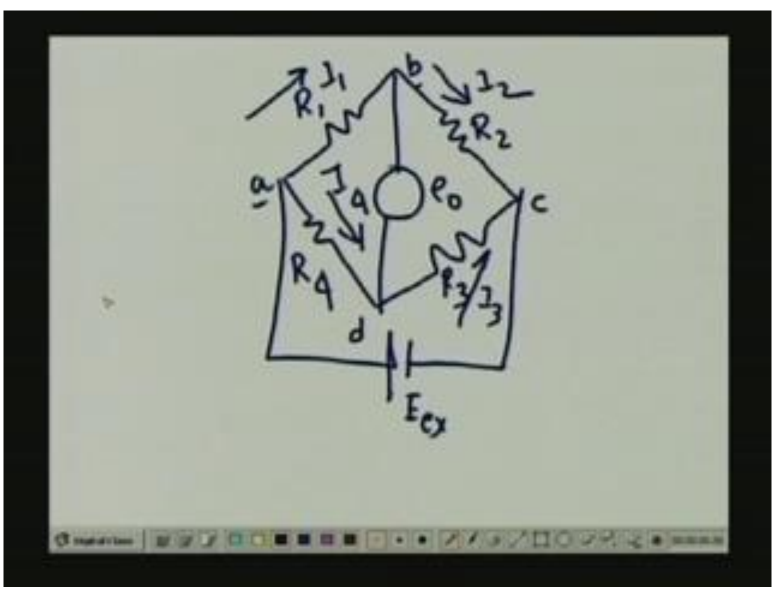

So, in the unbalanced bridge we will find that, sorry it is a balanced bridge, so I have four, so this is my output voltage. This is, let us take a Wheatstone bridge. So, otherwise I cannot write. Suppose this is I 2, all current different, R 2, this is I 4, this is R 4, this is R 3. Current is going in this direction I 3 and this is my excitation, E ex, right and I gave some nodal point a b. This is a, this is b, this is c and this is d.

Now, let us, let us analyze and let us analyze this circuit.

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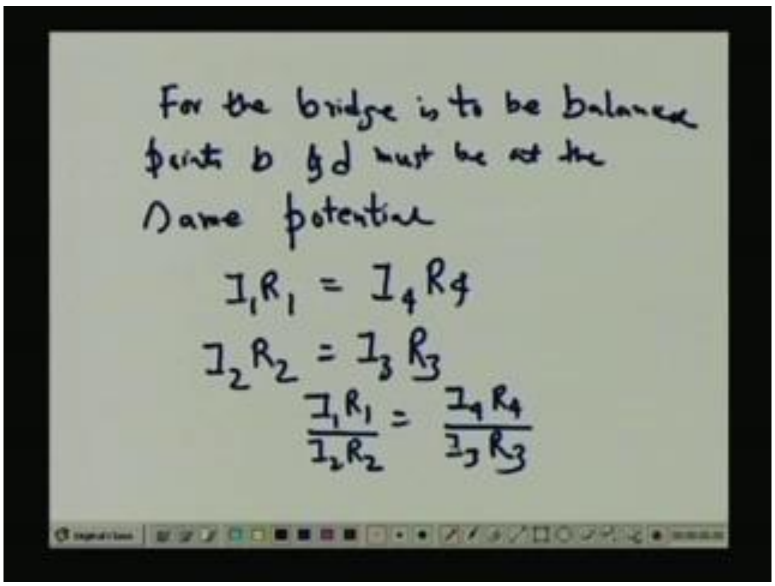

For the bridge to be balanced, is to be balanced, points b and d must be at the same potential, at the same potential. So, I can write I 1 R 1, is not it, equal to I 4 R 4 and I 2 R 2 equal to I 3 R 3. So, simply I can divide. If I divide these two equations, I will get I 1 by R 1 I 2 by R 2 equal to I 4 R 4 I 3 into R 3.

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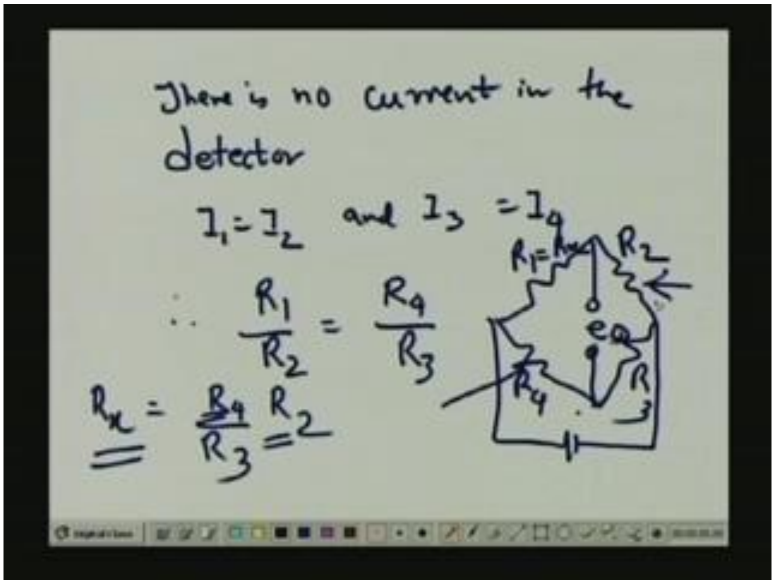

Now, if there is no current, there is no current in the detector, so I 1 equal to I 2 and I 3 equal to I 4. So, R 1 by R 2 equal to R 4 by R 3, right, sorry, right? Now, what will happen? Suppose R 1 is an unknown resistance or our, that means our circuit looks like this. If I redraw the circuit, so R 1, R 2, R 3, R 4, so this is our output voltage. So, suppose now R 1 equal to R x, so R x unknown resistance or strain, strain gauge, I can write R 4 by R 3 into R 2, is not it?

Now you see, I can use either R 4 or R 2 to make the temperature compensation, is not it? I can choose either of this one, because in that case whatever the changes occur in the R x due to the temperature, the same change will occur also in the R 4 and R 2. Then, either R 4 can be dummy gauge, this can be dummy gauge or R 2 can be dummy gauge. In that case any of the resistance, if you check R 4 suppose for balancing the, I mean for, as dummy gauge, so in that case R 2 be used to balance the bridge. So, this is the case when there is a no current flowing through the detector.

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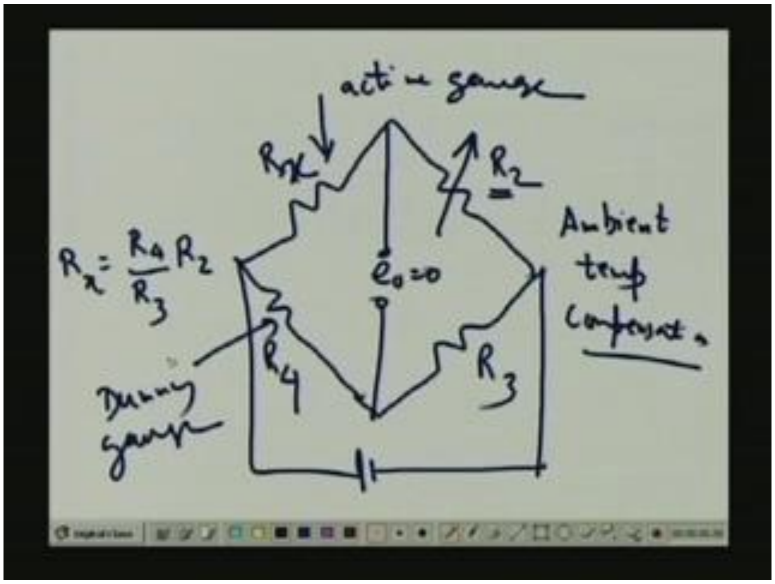

That means I am assuming in that case that is I will vary R 2 that means if I take a new page that means, so this is R 1, R 2 R, 3, R 4, so this is our strain gauge suppose and the R x, so as I told you before R x equal to R 4 by R 3 into R 2. So, this is our active gauge, this is our dummy gauge, right? That is this is used to for making the temperature compensation. So, ambient temperature, because if the ambient temperature changes, my, this gauge will take care. So it, sometimes is called ambient temperature compensation also, ambient temperature compensation and R 2 and R 3 should be of similar type. So, these are fixed resistors or it can be variable resistors, because this is variable resistor to balance the bridge, because of, suppose I have subjected to strain, again I will make e o equal to zero. So, this R 2 can be calibrated in terms of the load, right or displacement, whatever you like, because it can be used for making the displacement sensor also.

So, in that case R 2 will be calibrated in terms of the displacements or R 2 can be calibrated in terms of the, in terms of the load also. So, it will be …., so that we will see, look at and then, we will find how much is the load, whereas this will be our makeover temperature compensation, right? We will find that in, later that we will use 4 gauge simultaneously. All are active gauges to increase the value of the, value of the unbalanced voltage, because I, sometimes I need large unbalanced voltage, so I can do it.

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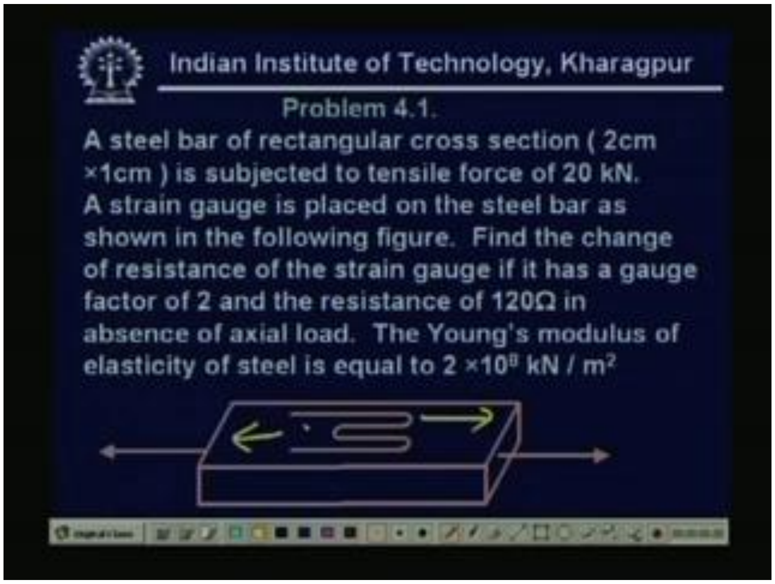

Now, let us go to the problem, problem 4.1, a steel bar of rectangular cross section 2 centimeter into 1 centimeter subjected to tensile force of 20 kilo Newton. A strain gauge is placed on the steel bar as shown in the following figure. Find the change of resistance of the strain gauge, if it has a gauge factor of 2 and the resistance of 120 ohm in the absence of axial load. The Young's modulus of elasticity of steel is equal to 2 into 10 to the power 8 kilo Newton per meter square, right?

There is no question of bridge or anything. Simple problem we have given, we have shown this that it is a, you see here that the installation it is, it is subjected to tensile, is not it? So, it is, tensile load here, so it will be axial, so there is no question of any transverse. So, there will be axial load and you have to find that the change of resistance in this strain gauge. It is a very simple problem, right? So, no question of bridge or anything, we have to, with that we will do later on, right?

Now, let us solve this problem.

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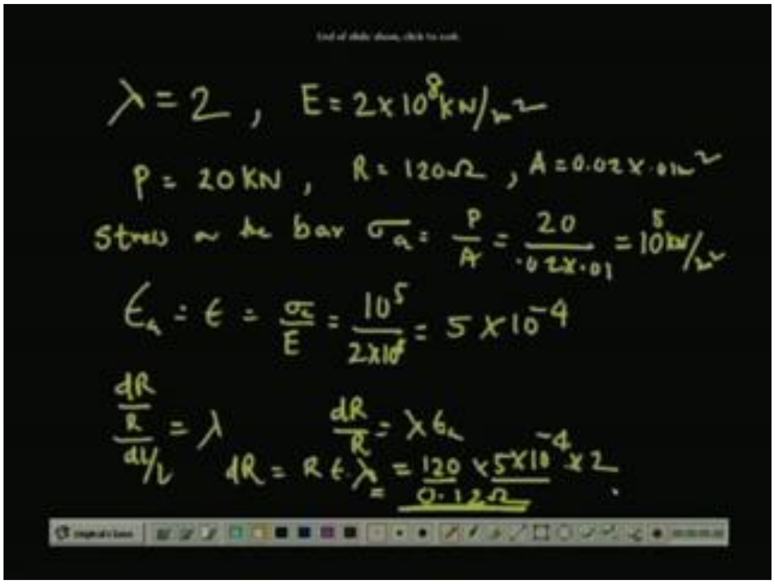

Let us take, I am sorry, I can take this one. Here you see, lambda is equal to 2, is not it and E equal into 2 into 10 to the power 8 kilo Newton per meter square, P equal to 20 kilo Newton and R equal to 120 ohm. Area of cross sections we have given A equal 0.02 into 10 to the power 01 meter square. So, stress on the bar, bar, is sigma a equal to P by A equal to 20 upon .02 into .01. So, this will give you 10 to the power 5 kilo Newton per meter square.

So, epsilon a or epsilon equal to sigma by E or sigma a by E. E is the Young's modulus 10 to the power 5 by 2 into 10 to the power 8. So, it will be 5 into 10 to the power minus 4. So, dR by R we know by dL by L equal to lambda, is not or I can write dR by R equal to lambda into epsilon a axial. So, delta R or dR will be equal to R epsilon into lambda. So, it is 120 into 5 into 10 to the power minus 4 into I want to take the resistance, 5 into 10 to the power 4 is strain, multiplied with the gauge factor, which is advance probably, yes this is advance strain gauge, obviously 2, so this will give you change of resistance .12 ohm, right? So, the answer is 0.12 ohm.

I have solved this problem to know that you see that how small this change of resistance. It is not very easy task to see this, measure this and as I told you that just using a one simple, you can use one resistance that means R 2 and calibrate R 2 in terms of stress or strain, it is very difficult and you look at this change of resistance. It is very small. So, mostly we will see that, we will use that unbalanced voltage and we will calibrate that unbalanced voltage in terms of displacements or force or pressure or load, whatever it and we will use, instead of one gauge we will use four gauge, try to get four gauge. In that case, there will be more unbalanced voltage.

Then the, we have seen that in the case of, in the case of our displacement sensor, one gauge will be under compression, another gauge will be elongation. I will get the temperature compensation as well as my bridge unbalance voltage will be also very high, so that this will help us to make the circuit, signal conditioning circuit simpler, because if the small, higher the voltage, the more and more or less will be the error in the measurement also. So, those things are to be, to be considered. So, strain gauges we have covered. We will see later on in the future lesson that it will be extensively used for the measurement of load, right?

So, this is a basic sensor which is used, but a strain gauge alone cannot be used. It is used either in some pressure gauge or some load cell and all those things and this ends the lesson 4.