**Principles of Mechanical Measurements**
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**Lecture No. # 13**

So far we have seen the fundamentals of measurements which is common for all types of measurements. From now onwards we are going to see the specific measurement that is what we actually do in practice. So first and foremost and a very important measurement is displacement measurement. It is important because many other measurements are based on the displacement measurement. For example force measurement if you want to make, force is allowed to act over a surface and that deformation is measured by using a displacement measurement transducer that transducer reading is converted in terms of the force units.

So you find the displacement measurement is appearing later on in other measurements also force measurement pressure measurements for example another good example where a diaphragm will deform when pressure acts. That deformation will be measured by a displacement transducer, we have seen as an example for a closed loop system, one of electronic pressure gauge. For pressure gauge there is also a displacement transducers. So a displacement measurement is one of the important measurements in mechanical measurement and now we are going to see first the standard for displacement or length.

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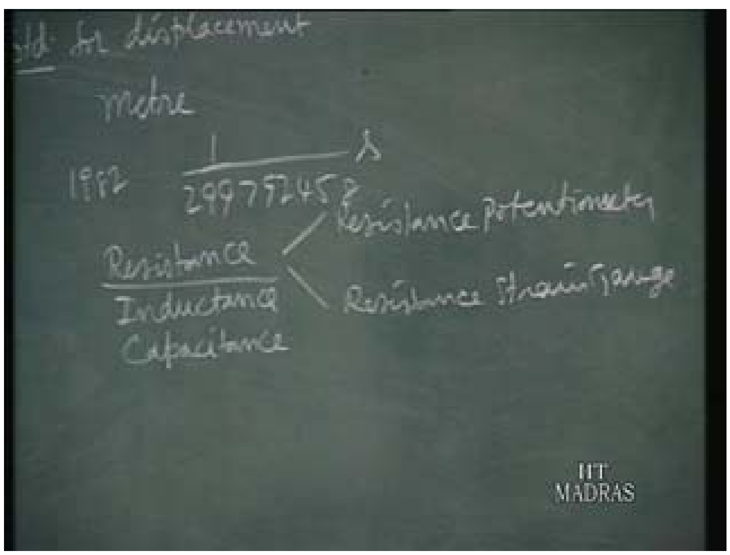


Length is one of the four fundamental quantities, length along with the other length, mass time and temperature. In the earlier case measurement means assigning a number to a parameter, here for a displacement or length we have to assign a number for any given length in terms of standard. So what is that basic unit that is what has been accepted by all the countries is meter. Meter is the basic unit which has been defined as a length between two marks in a some rod near Paris that is the standard. Later on we had in 1960 we had another standard in terms of krypton 86, so many wavelengths equal to one meter.

Now the latest standard is accepted in the year 1982 is the distance traveled by light in vacuum in a duration of 1 over 299792458, more or less 3 into 10 to the power of 10 that is the velocity of speed so many meters. One over this number in that second whatever the distance traveled by the light in vacuum that is taken as one meter this is latest standard which can be simulated in any laboratory. As in the case of first standard if you want to check you have to go to a place near Paris but here you can allow the light to travel in a vacuum chamber for this duration of second and whatever the light that has traveled in this duration is same as one meter length. So that is the unit based on which the measurement is made for length or displacement.

Now for the displacement measurement the standards are available in Clark's table also. For displacement measurement our main aim is in mechanical measurement to convert that displacement into immediately an electrical quantity that is actually the transducer. For that purpose we are using mostly we will find the passive elements resistance, inductance and capacitance. These are three elements or passive elements in electrical engineering they are used. The distance whatever we want to measure is used to make some variation resistance or used to make variation inductance or in capacitance and these elements will form part of an electrical circuit and there you will get a voltage output. This is the basis or concept of making displacement measurement by using these passive elements. First and foremost is say resistance, in this we have got two types one resistance potentiometer and other one is resistance strain gauge. So these are the two ways in which the resistance is made use of in measuring a displacement and first figure shows that is potentiometer transducer that is our resistance potentiometer or potentiometer transducer, it is made up of a resistance $R_p$ it is a total resistance $R_p$ and whatever displacement we want to convert in terms of voltage is given to the contact point.

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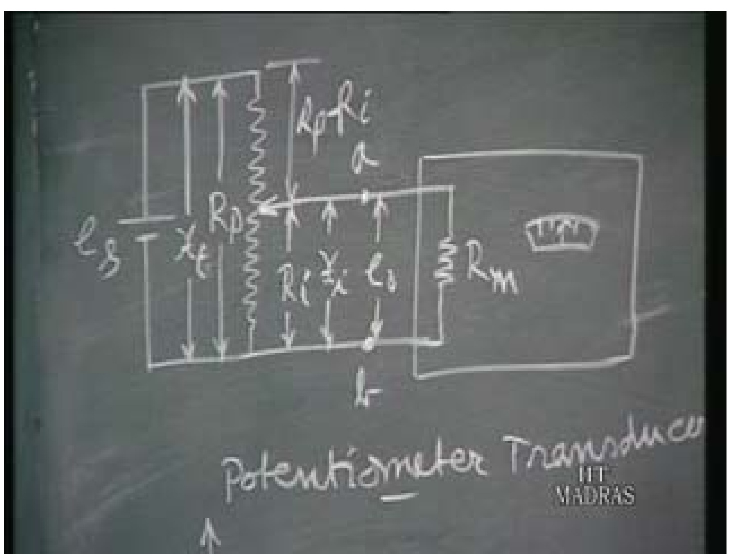


So the contact point will be moving up and down when we give the displacement of a machine number for example. So when the point is here, you will have zero, as the point moves up you will find the total voltage of $e_s$ is distributed over the full length of the resistor. So as per the travel you will have you will have a voltage output. So at any instant the displacement is $x_i$ and then accordingly you will have a voltage output.

Now to get an equation for the output voltage $e_o$ in terms of say $x_i$ and $e_s$, we will derive an equation. We are connecting an instrument $R_m$ in case if it is open circuit a and b are open, no meter is connected this is a meter it's a voltmeter. If you don't connect this voltmeter it's an open circuit voltage $e_o$ dash. That will be proportionate to $x_i$, if $x_i$ is zero you have zero voltage and half the travel then half the total voltage will appear here and so on proportionate but once we connect the voltmeter we will find the loading effect which we have learnt earlier that will come into picture. The output voltage is no more linear with the displacement, for that we will derive an equation. So before connecting the voltmeter whatever be the resistance output as seen from the points a and b in the circuit a and b.

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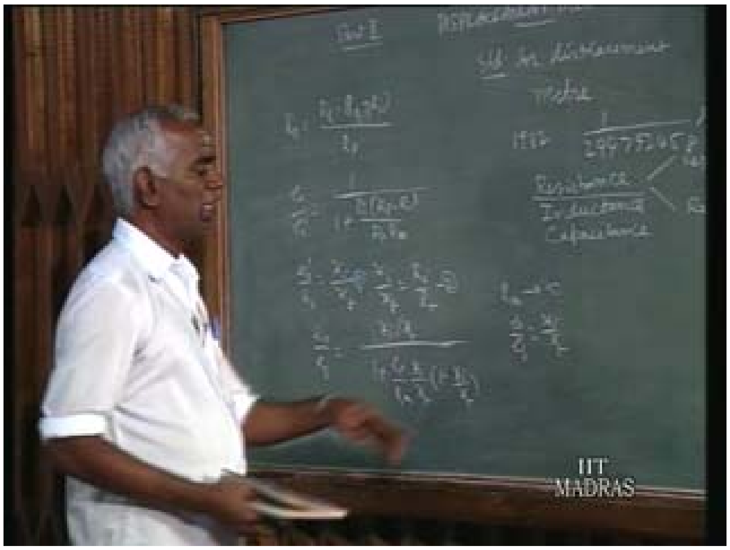


Then we will say $R_o$ the output resistance of the potentiometer circuit that is we have to go from a to b that is why we have to find out the equivalent circuits. From a to b one resistance $R_i$, $R_i$ corresponding to $x_i$ and other resistance is parallel path is $R_p$ minus $R_i$ and again you can come to point b and $e_s$ is short circuited for the purpose of equivalent resistance. So now $R_o$ is made up of two parallel resistance and then it is equal to $R_a$ $R_b$ that is $R_i$ into $R_p$ minus $R_i$ these are the two parallel resistances divided by the summation of these two things. So $R_i$ plus $R_p$ minus $R_i$ that you will have $R_p$ so this is the output resistance, input resistance is $R_m$. So $e_o$ by $e_o$ dash, $e_o$ dash is the open circuit voltage of the circuit at a, b so $e_o$ by $e_o$ dash equal to 1 over 1 plus $R_o$ by $R_i$.

So $R_o$ is equal to this one $R_i$ into $R_p$ minus $R_i$ divided by $R_p$ and the whole thing is divided by $R_m$ that is $R_m$ is our input resistance so this is our loading effect. Now this expression can be transformed in terms of $x_i$ and $x_t$ and also $e_s$ in place of $e_o$ dash by using the equation $e_o$ dash by $e_s$ is equal to $x_i$ by $x_t$. This is one relation that is open circuit voltage is always proportional to $x_i$ that is one equation and then $x_i$ by $x_t$ is equal to $R_i$ by $R_t$. So using these two equations the equation for loading effect can be rewritten in terms of $e_o$ by $e_s$. The $e_o$ by $e_s$ is equal to $x_i$ by $x_t$ divided by one plus $R_p$ by $R_m$ into $x_i$ by $x_t$ into one minus $x_i$ by $x_t$ so this is the equation in terms of $e_s$ and $x_i$ by $x_t$. Suppose $R_m$ that is meter resistance infinity, you will find when $R_m$ is infinity $R_m$ tending to infinity then $e_o$ by $e_s$ equal to $x_i$ by $x_t$.

That is $e_o$ is proportional to $x_i$ because then you bring $e_s$ this side so $e_s$ is constant $x_t$ is constant total travel so $e_o$ is proportional to $x_i$, that is what you have got in this characteristic equation, the plot the same equation $e_o$ by $e_s$ that equation is plotted here.

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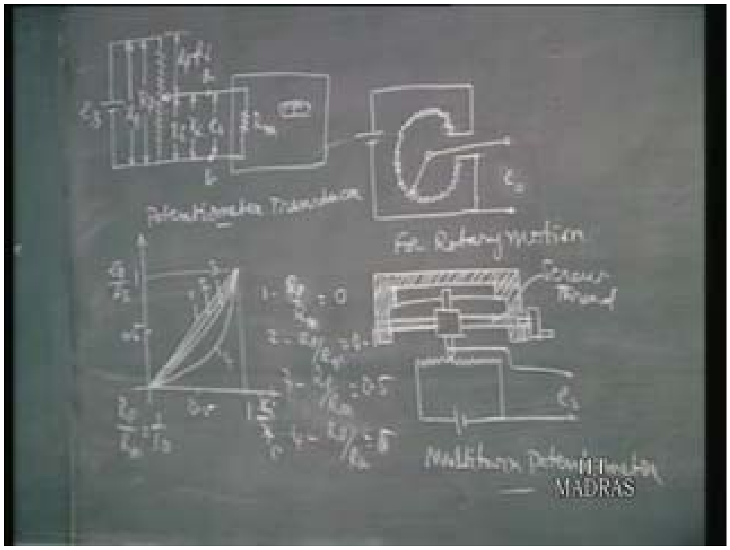


We find the curve one $R_p$ by $R_m$ is equal to zero that is $R_m$ is infinity then you find it is linear that is $e_o$ is proportional to $x_i$ by $x_t$ proportional to $x_i$, $x_t$ is constant, $e_s$ is constant. When $R_m$ is having its definite value then we find there is no more linear, the $e_o$ is not linear to $x_i$ then you will have non linearity comes into picture. So the curve 2 is for point one $R_p$ by $R_m$ is equal to point 1 and curve 3 is for point 5 the ratio and for 4, see when the ratio increases you will find non linearity also gets increased. So in order to keep the error within limit, loading effect within limit $R_p$ by $R_m$ normally selected as 1 over 10. So that meter resistance should be at least 10 times the total resistance of the potentiometer in order to have the error within a limit.

Now the potentiometer is also used for the rotary motions so this is for rotary motion that is the total resistance is arranged in a circular fashion and you have the supply voltage and contact here. Also we have the potentiometer it's called multi turn potentiometer so say it is a ten turn potentiometer that is here construction is we have here screw thread. So as you rotate the nut moves to and fro and the travel is restricted between these two limits and for making the full travel, probably you have to make ten turns. If you make ten turns then you will find the total travel is there so proportional to a number of turns we get the output voltage here.

These are the various constructions of the potentiometer but you find that in selecting $R_p$ value you have to be little bit careful because it has got certain opposite effects. See here we find $R_p$ should be small compared to $R_m$ in order to have loading effect smaller. So $R_p$ should be small to have smaller loading effect but when we consider the sensitivity, here sensitivity is equal to $de_o$ by $dx_i$, $x_i$ is the input motion, $e_o$ is the output. So $de_o$ by $dx_i$ is equal to $e_s$ by $x_t$ this is our sensitivity of this resistance potentiometer. Now sensitivity is proportional to $e_s$ that is supply voltage, higher the supply voltage higher will be the sensitivity for this transducer but you will find to have the higher $e_s$ then we find the power rating; power rating is equal to P is equal to $e_s$ squared by $R_p$.

This is the power rating of the resistance or the manufacturer will specify that much power only it can dissipate so when you want to have larger $e_s$ for larger sensitivity the power is always constant, when you increase $e_s$ you have to correspondingly increase $R_p$ also. That means to have a higher sensitivity you should have higher $R_p$ so $R_p$ should be high for higher sensitivity.

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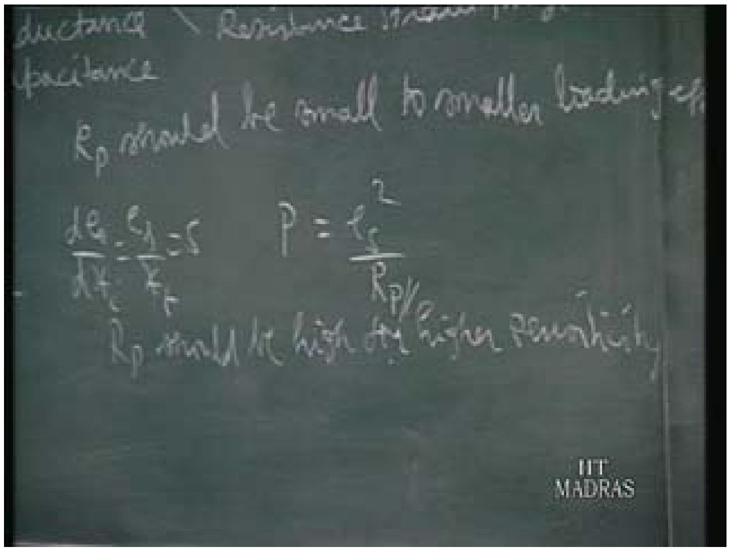


So now you find contradicting requirements for $R_p$, $R_p$ should be small for smaller loading effect but it should be large for higher sensitivity. Hence selecting $R_p$ we should be careful. If we increase too much then you will find that you have got loading effect, these are the considerations when selecting $R_p$ and now we have the potentiometer sometimes single wire potentiometer.

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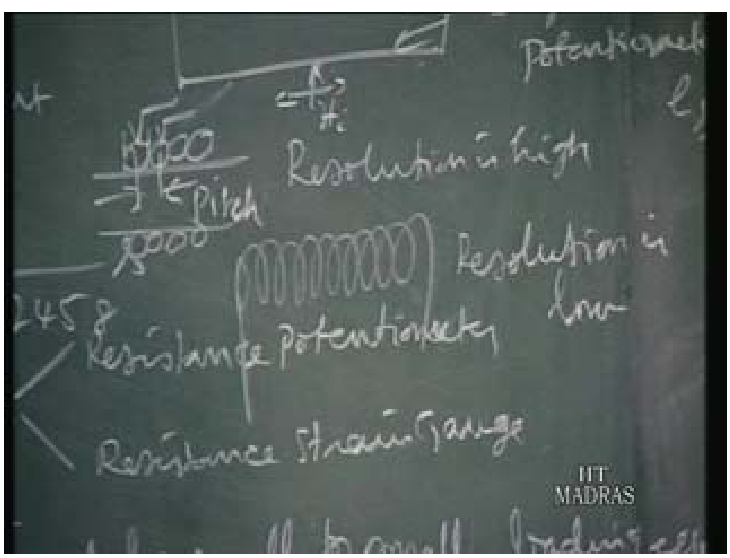

So this is a single wire potentiometer and this may be moving to and fro and here we have the voltage supply, this is a single wire single wire potentiometer. The advantage of the single wire potentiometer is resolution is high that means you can have a movement of the $x_i$ as small as possible. You will have the corresponding output but problem here is the voltage $e_s$ cannot be large because this resistance is small so $e_s$ cannot be a large value for having a larger sensitivity. So to increase the value of $e_s$ you should have the larger length for the resistance wire that is achieved by having a wire wound potentiometer. This is wire wound potentiometer as for a given length, the length of potentiometer you have larger wire wound over a spool but the problem here in the wire wound potentiometer is, the resolution is low.

The resolution is low because we have the wire windings, one winding is here another winding there. So this is a spool similarly this side also so when the contact is here you have one voltage and until it moves over to another wire the voltage output will be same. So the resolution here is equal to pitch of the winding, pitch of the winding is equal to resolution. Now if we consider say a single conductor, within the conductor the voltage doesn't change the voltage output that means from the middle point putting the error plus or minus, half the distance here half the distance the other side you don't get any output change that is the error. Even though motion is there over the conductor there is no corresponding change. That means error is equal to plus or minus half the resolution. So half the resolution because resolution is more or less equal to the pitch distance or equal to the pitch distance is equal to the diameter of the wire.

So that's why we say our error is equal to plus or minus half resolution half resolution so these are some of the characteristics of a potentiometer. A resistance potentiometer what we have seen is a very old device primitive but still it is used, nowadays also it is used. Next form of a usage of resistance is resistance strain gauge, very widely used in mechanical engineering as well as in civil engineering to find out the stress at different points very widely used one. This effect was found out by Lord Kelvin in the year 1856. When a metallic wire is strained, the resistance is changed that is the physical effect that is being made use of there.

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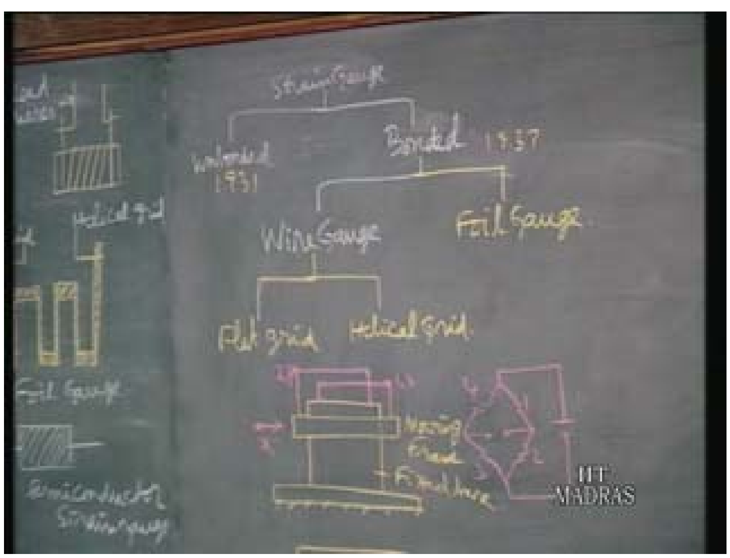

In the strain gauge there are two main types, one is unbounded strain gauge other one is the bounded strain gauge. Unbounded strain gauge came earlier that is first it was made in 1931; this came into picture in 1937. So such an unbounded strain gauge one such strain gauge usage is illustrated in this figure how this unbounded strain gauge is fabricated and made use of and the bounded strain gauge which came later, you will find again there are two types wire gauge and foil gauge. Wire gauge itself we have got flat grid and helical grid flat that is made up of wire, here it is foil.

So the wire is found in two different ways flat grid that is what is shown here flat grid. So the wire is taken in zigzag fashion and whole thing is fixed in paper or plastic packing,  two such packing’s and there will be cement to hold this in between the paper packing and you will find the whole thickness this wire is of the order of 25 microns diameter. With the thickness of the paper and cement and everything will work out to 70 micron, the whole thickness of the strain gauge will be 75 micron so to say. So this is a flat grid, instead of flat grid we have also got helical grid available in the market that is you have a core a paper core or whatever it is a flat piece. On this in helical fashion the wire is wound, same wire is wound in this and the whole thing is embedded, whole thing is the fixed in two paper packing’s or plastic made up of plastic packing of very thin and total thickness of the whole strain gauge will be of the same order of 75 microns.

They are also available because here it is helical grid it's easy to wind and make it, whereas the foil gauge is made up of electrochemical machining its electrochemical etching. Electrochemical etching process by that we make this foil gauge, here the thickness is of the order of 4 microns, the whole thing is again fixed in thin paper and with cement, it is held there. The main advantage of this foil gauge is for a given cross section you have got more surface area and also it is a rectangular cross section. The whole configuration so it gets better bounded than the wire gauge to any base material and since surface area is more we find its heat  conducting capacity also is more in case of foil gauge. Nowadays foil gauge are easily available in the market so these are the different types in bounded strain gauge, mainly three types in strain gauge and unbounded strain gauge the usage is illustrated here. For example we have a fixed base and it is surrounded by a moving frame supported by springs.

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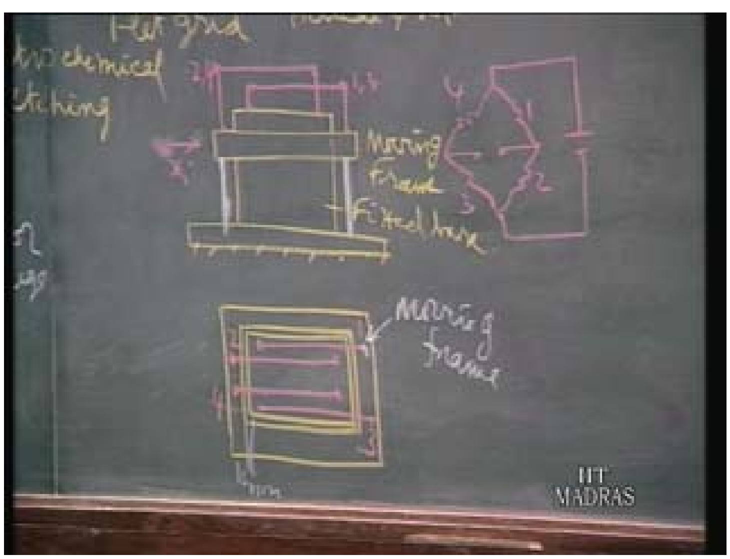

Say 4 springs leaf springs, it cannot stand just in space so from the base the moving frame is supported from bottom say two numbers, 2 or 4 numbers we can support this frame it's a moving frame. Moving frame means it is within the gap only it can move; later on it will hit this middle projections fixed base. So within this gap it can move, the spring support will deform, when we move this the spring support will move and this motion of the frame is measured by using the four wires that is wire 1, 2, 3 and 4. The wires are fixed in such a way that it is elongated; it is pulled a little bit and then fixed to the pin here. That is in the assembly condition you have to assemble, it allows assembling the wire under strain. Here we find the two wires are pulling the frame in this direction the other two wires will pull in the opposite direction.

So two wires pulling in one direction other two wires pulling in the opposite direction, net force on the frame will be zero and so it will take a neutral position when you assemble all the four wires. The wires are assembled in tension it is because the wires cannot take any compressive load it will buckle. So in order to use these instrumentation for both the direction of motion of the frame when we want to measure then the wire should be assembled under tension. That is the natural distance between the point in the frame and this will be smaller so you have to pull it and then assemble the wires. Suppose we give a motion in this direction left to right, we give a motion to the frame left to right of course motion is limited say within 1 mm only.

So if we assume the gap is one mm, within one mm only we can give the motion. Suppose it moves this direction what will happen, the tension in wire 1 and 3 will increase and tension in wire 2 and 4 will decrease for this motion. So that means 1 and 3 which are connected in a bridge like this where the tension is increased or opposite arms and where tension is decreased in the other pair. So we will find four times it is full bridge say in two wire tension is increased other two wires tension is decreased so you find a resistance increased in the opposite pair and the other opposite pair resistance is decreased. So we find a full bridge effect there that is how the four wires that's why it is called unbounded strain gauge. Strain gauge strain gauge is made up of the four wires. Now we have all the semiconductor strain gauge I mean semiconductor strain gauge also available there they have got very high gauge factor. Now what is the gauge factor we will derive an equation.
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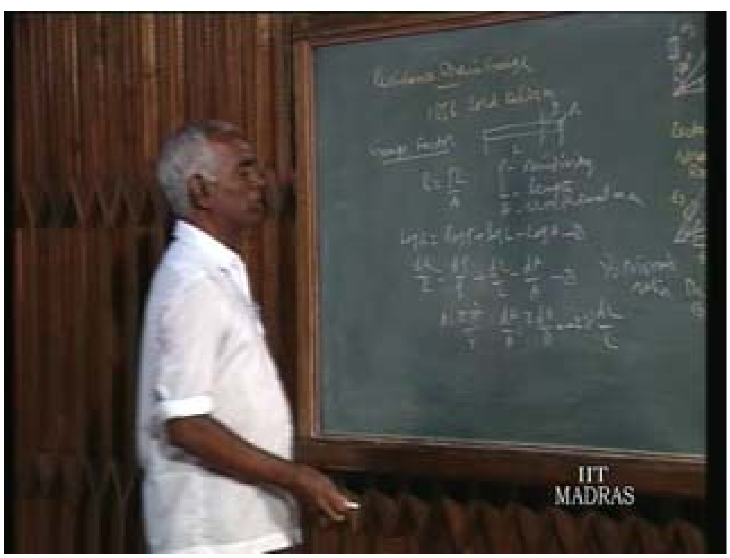

Gauge factor of strain gauges, say for any metallic wire R is equal to resistance of the wire is equal to rho L by A where rho is the resistivity and L is the length of the wire. Suppose this is the length of the wire, this is the area, A is the cross sectional area. So R of this conductor is given by this equation. Now take logarithm on both sides log R is equal to log rho plus log L minus log A and differentiate both sides dR by R is equal to d rho by rho plus dL by L minus dA by A that is differentiating this equation 1, we get equation 2.

Now dA by A, now A is equal to pi D squared over 4 that is, the D is the diameter of the wire, so if we find dA by A. From this you will get dA by A is equal to twice D by D that is twice dD by D and that is equal to in terms of Poisson’s ratio minus two nu dL by L because the contraction is proportional to the Poisson’s ratio in terms of linear strain. So nu being Poisson’s ratio now substituting this in the equation two we have got dR by R is equal to d rho by rho plus dL by L plus 2 nu dL by L. Now divide the whole equation by dL by L So dR by R divided by dL by L is equal to one plus d rho by rho divided by dL by L plus 2 nu. Now this dR by R by dL by L is called the gauge factor this is the gauge factor of the strain gauge.

What does it represent? The relative resistance change to the strain per unit strain that is the definition for gauge factor relative resistance change per unit strain that is the gauge factor which is equal to one plus 2 nu, nu is the Poisson’s ratio for steel it is around 0.3. So twice 0.3, 1.6 so 1.6 comes due to the strain and the other portion d rho by rho by dL by L is called piezoresistance effect. For a metallic wire generally the gauge factor is around 2 so we find here 1.6, 0.4 comes from this piezoresistance effect for metallic wires whereas for the semiconductors we have got, the gauge factor for semiconductor strain gauge is around say 100, 120 whatever it is very large number and that is mainly due to the piezoresistance effect d rho by rho by dL by L. That is the resistivity of the material itself is changed when there is a strain in the semiconductor material. Now we will see how the strain gauge is made use of in measuring a displacement; in potentiometer what was given is, the displacement is given to the pointer which moves over the resistance. Here how it is done?

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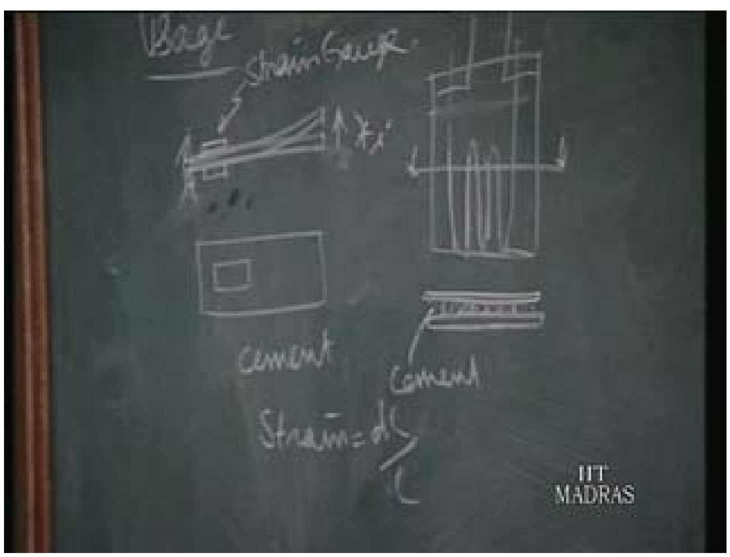


Say for example if you want to measure displacements give it at the end of a cantilever, this is cantilever beam fixed here and at the free end you give this motion.

When you give the motion, you find near the fixed end of the cantilever you have got stress and strain so this strain is picked up by the strain gauge. For this purpose what should be done? You have to fix the strain gauge, suppose the plane is like this you have to fix this strain gauge here. For this purpose you have got so called cement the manufacture who makes this strain gauge also supplies cement. So with the help of a cement suppose with a help of a cement you have to fix the strain gauge to the base metal and then you have to wait to put a small weight over it and wait for few hours say 6 hours or 12 hours then you will find the strain gauge will become part of the metal. That means whatever the strain that happens or occurs in the base metal or the cantilever; it will be transferred to the strain gauge. It is because as you have seen in the flat grid, see flat grid is somewhat like this embedded between the plastic or paper packing and if you have the cut section suppose you cut it here and see you find a paper is there and then another paper and in between you have got this cross sections of the wire and this space between the wire is filled up with cement.

Here also we have got cement, completely filled. There is no gap between the wires; there will not be any empty gap all the space is filled up with the cement because of this construction we find the wire can also take up any compressive strain. A free wire cannot take compressive stress or strain because it will buckle but here there is no space for buckling as it is manufactured. So the wire can take up both tensile as well as compressive strain. So such a strain gauge is pasted for example one at the top of the cantilever and the displacement is given here that is displacement suppose due to this displacement this will bend like this, to that extent it is strained that strain is picked by the wire and when there is a strain, what is strain? Strain is equal to dL by L that is our strain what we have seen in the equation dL by L is the strain. When there is strain then correspondingly we have got the gauge factor multiplied with the strain, you have got this resistance change in the strain gauge this is what is happening.

So you give the motion to the end of the cantilever and the motion is measured by using the strain gauge. So in this process we should know the direction of the strain. Here we know in the cantilever beam the top layer will be tension and top layer for this is here that is for this type of motion here will be tension there will be compression. We know that happens along the length of the cantilever. So we know the direction of the stress and strain. This is the axial length of the strain gauge that is along the axis of the cantilever you can fix it that is it will be same in the same direction of the strain it is fixed. Suppose in some pictures, some structures we will find the direction of the strain will not be known for example in rocket panel structures, rocket structures you will find due to acoustic stress or strain the panel is strained in all directions. So we find no fixed direction can be fixed, in such instances what is done is we go for the strain gauge rosettes this is strain gauge rosettes.

We have got 2 types of rosettes say delta strain gauge rosettes and the rectangular strain gauge rosettes where that is 3 strain gauges are fixed say in case of rectangular rosettes so 90 degree and middle is 45 degree it is fixed there on the structure similarly you can go for delta. So these 3 strain gauges $\text{epsilon}_1$, $\text{epsilon}_2$, $\text{epsilon}_3$ which is fixed on 60 degrees to each other and measure the each strain.

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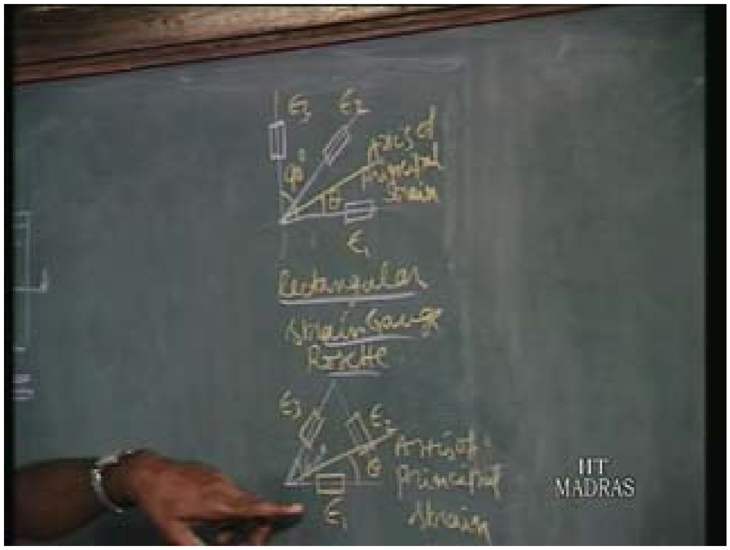


For each strain separate circuit you will have, measuring each strain then you can find out the principal strain, we have got formula that can be referred in standard textbooks. By measuring the three strains the principal strain axis of principal strain, as well as principal strain can be computed in terms of epsilon$_1$, epsilon$_2$, epsilon$_3$. That is in case you do not know the strain or stress direction you have to go for the 3 strain gauges fixed on the structures and from there we can find out the maximum strain produced in the structure where we have fixed the strain gauge. Now this strain gauge has got so called when the strain gauge is made up of like this, suppose the strain is in this direction unidirection, one direction we have got two segments one is along the axis say segment one and another segment two transverse that is 90 degree to this axial direction.

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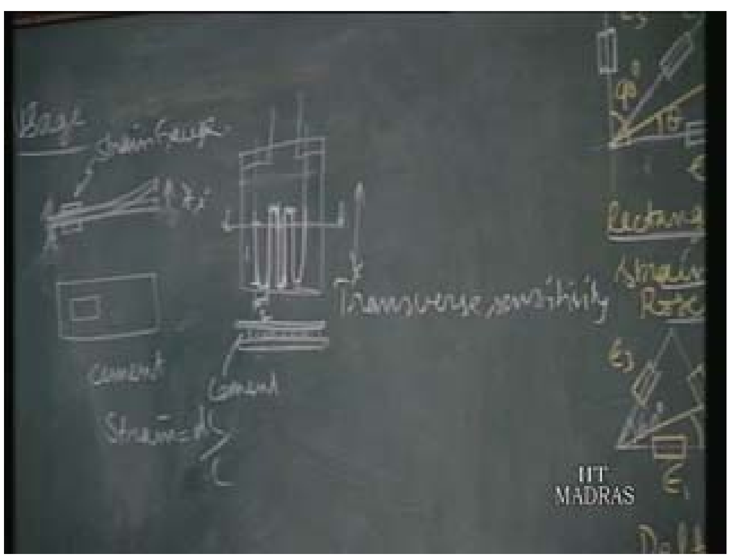

So each it's made up of loop, you have got here 1, 2, 3, 4, 5 loops are there. So for a given strain in one direction, axial direction the segments one similar segments one say 1, 2, 3, 4, 5, 6, 6 segments and axial directions and you will find 1, 2, 3, 4,5 segments in the transverse directions. So what happens for this tensile for example its tensile strain, the linear along the axis the wire will extend, due to tension it will increase so resistance will increase but for the same strain you will find the transverse directions the cross sections increase and you will find resistance is decreased, rho L by A so when A is increased R is reduced. So for axial strain you will find it, for some portion of strain gauge it is reduced resistance, for major portion is increased resistance and a smaller portion is decreased. So we will find net effect on the strain gauge for an axial strain is reduced that is called transverse sensitivity but in most of the strain gauges the perpendicular segment, portion of total wire is very small hence transverse sensitivity will be low. So this is one of the error sources so that is normally small, since the perpendicular segment is small. Second error source is temperature; temperature is main error source in a strain gauge measurement. Suppose we are using one strain gauge quarter bridge it is used in Quarter Bridge.

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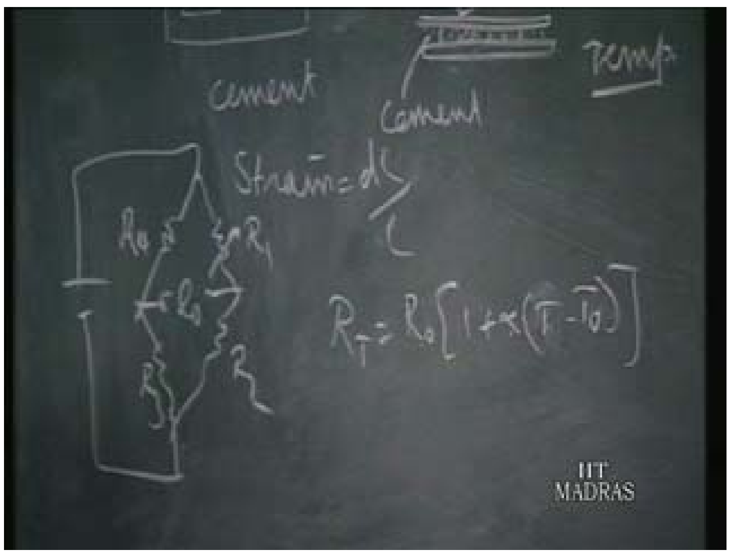


That is only one is active arm that is $R_1$ is active $R_2$, $R_3$, $R_4$ are constant resistances and we get output voltage here $e_o$ then we find due to temperature there are 3 effects, noted in the strain gauge. First one is the strain gauge wire itself expands when the temperature is increased that we know, the equation $R_t$ is equal to $R_o$ into one plus alpha T minus $T_0$ that is coefficient of a resistance alpha temperature coefficient of resistance. When $R_0$ is resistance at $T_0$ degree centigrade then $R_T$ at any other temperature T is given by this equation, when T is increased we will find $R_T$ is increased that is one effect.

Secondly you find that differential expansion, the wire material you will find there are two types of wire material. One is advance alloy, it is made up of nickel and copper and other one is isoelastic. These are the two types of material used for strain gauge but suppose we fix this strain gauge over a mild steel or some other material you will find the coefficient of linear expansions are different for the strain gauge wire and the base material. Then you will find there is a difference in expansion of the wire gauge material and the base material.

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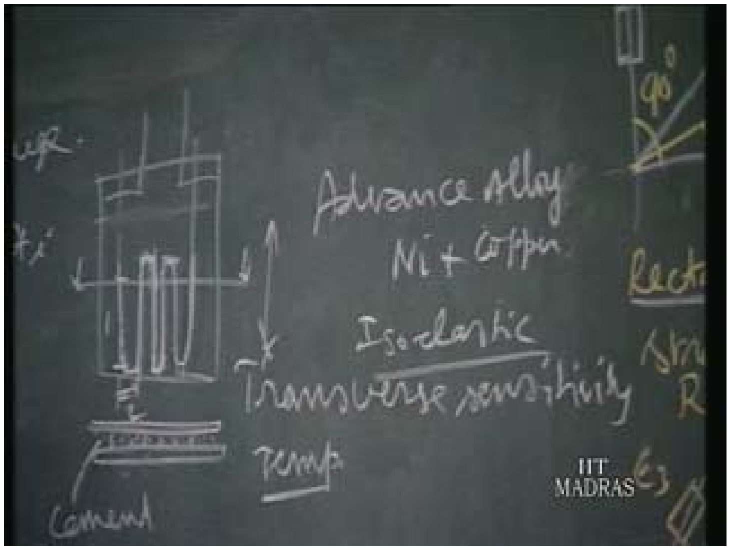


Due to the difference of this expansion suppose we will find the base material where it is fixed, expands more than the strain gauge wire. Then for any given temperature rise the wire will be pulled by the base material. That is all these things are happening without any input signal just because there is temperature increase you will find resistance has changed due to temperature rise as per the equation again it is being pulled by due to difference in coefficient of thermal expansion, it is being pulled again strain that is another source. The third you will find creep, when the operating temperature is more than 200 degree centigrade so called creep occurs. Creep is a phenomena, when the load is constant the deformation continues, the more and more deformation comes that is creep that also will be there when the operating temperature is more than 200 degrees. Otherwise we will find due to temperature alone we have two different effects and this gives output voltage even when there is no input signal there is no displacement we have given. So this is compensated what we have learnt already under bridge circuit by using a dummy gauge this we have seen under bridge network.

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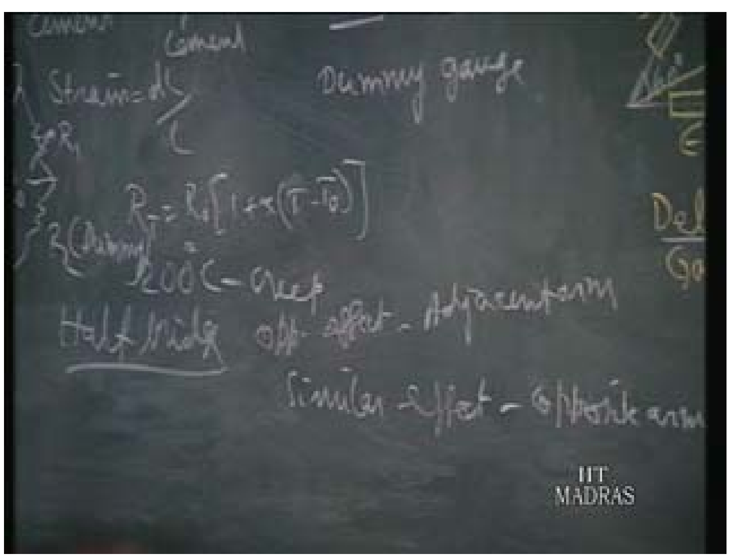

That is we put another strain gauge fixed to the same base and don't load it and keep it in the same atmospheric conditions and you will find whatever the temperature increase is there that will put similar effects on both of them and similar effect are put in adjacent arms, the $R_2$ will be more dummy gauge, similar effect is adjacent arms get nullified. So when the temperature is there that effect will be nullified, no $e_o$ will be appearing due to this temperature effect and this is one way by using a dummy gauge we can compensate that is for a quarter bridge. For a half bridge we know there are two types, you have two situations, you will be using half bridge that is when the stress and strain are apposite in polarity you are connecting in the adjacent arms. That is one is in tension or resistance increased other one is resistance decreased then we will be using in adjacent arms that is opposite effect we are putting in adjacent arms. When we have the similar effect that is similar effect that we have learnt under the bridge network, similar effect in opposite arms of the bridge but when it is opposite effect that is a cantilever for example opposite effect is very near a cantilever we have learnt.

So this is what is displacement is given, one is top one is bottom so here tensile strain and here you have got compressive strain that is opposite in polarity and these two strain gauges are connected as adjacent arms. In this case the temperature is similar effect gets canceled automatically whereas if we are using the similar effect that is putting the two strain gauges at the top of the cantilever itself then both the strain gauge will be picking up a similar strain, tensile strain then we are putting the opposite arms. Then if we put in opposite arms temperature effects also gets added up, in that case we should go for two dummy gauges and plus one dummy gauge we put one more dummy gauge same it will be the dummy gauge and here we have got two, one behind the other because all the four strain gauges will be simultaneously affected by these temperature and you will find net effect will be zero. So in case of the similar strain you have to use the other two arms as the dummy arms and connect them according in the bridge network. If it is a full bridge so that is in the cantilever so suppose this is the cantilever.

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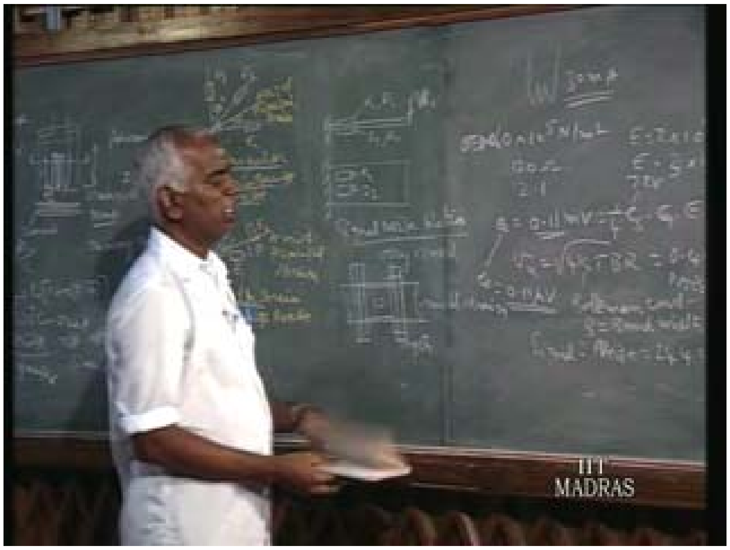

This is $x_i$ displacement so displacement is given there and suppose this is a broad sheet made up of and you have got two strain gauges $R_1$ and $R_3$ and that is $R_1$ and $R_3$ one behind the other and we placed another other two pair $R_2$ and $R_4$ at the bottom of the cantilever that means all the four are active and two in one direction other two in opposite directions, in such a case you find the temperature compensation is automatically there. So since all the four arms will be affected in similar way by temperature it gets canceled out whereas signal is opposite you will get proportional to the signal. So that is the temperature compensation for a different usage of the strain gauge either quarter bridge or half bridge or full bridge you have to adopt this temperature compensation.

Now one more point you have to see is signal noise ratio. In most of the applications we find the strain produced in the base member should be of sufficient magnitude, if it is very small we will find signal noise ratio will be very small. If the strain produced is small then a voltage output will be small and the noise in the instrument maybe more, noise is coming we have learnt under amplifier the Johnson's noise and so in terms of some microvolt will be there and our signal should be much more than that noise. This is what is meant by signal noise ratio. Otherwise if signal is small say if the signal is also of the order of few microvolts that will be lost in the noise. You can't find out which is signal and which is noise.

So signal noise ratio is of around 100 or 200 if we should ensure that is possible only if you deliberately make a bar. Suppose you want to fix a strain gauge over a bar suppose this is a bar if it is existing bar which has been designed for the strength. If it is has been designed for strength and pasting strain gauge on this, you will have only very small strain and in that case voltage produced from the bridge will be very small, signal noise will be small. So what you are supposed to do is weaken this cross section, make it smaller dimension and then put your strain gauge here. So this is little bit problem in the sense you will find a dimension will be small for a larger strain and you cannot paste it for that purpose what is done is instead of solid piece you go for a tubular constructions.

So from here to here you have a tubular construction and you can fix a flange with a bolt and middle portion alone is the tubular, the other portion outside it is solid piece. Now you can paste your strain gauge one here, one at the other side and so 2 or 4 means Poisson's configuration we have to fix. So you have to ensure a sufficient signal noise ratio that is possible only if we weaken the surface, sufficient noise ratio will be there. As an example it is worked out suppose there is a strain of or stress of 60 bar, 60 into 10 to the power of 5 Newton per meter square for so many Pascal's that much stress is there in a rod and we are using one strain gauge of 120 ohm. Gauge factor is 2.1 and in this case $e_o$ will be output of the quarter bridge will be 0.11 millivolt. So $e_o$ from the bridge will be 0.1 millivolt for a stress of this and Young's modulus is E is equal to 2 into 10 to the power 11 Newton per meter square.

So for this we have a strain of 3 into 10 to the power of minus 5, this is 0.3 micron and that is giving rise to $e_o$ which is equal to actually it is obtained 1/4 $e_s$ into EG epsilon. That is the output of a bridge and this supply voltage is assuming, for a strain gauge 30 milliamps because capacity of the strain gauge to dissipate the heat energy limits the current carrying capacity for 30 milliamp and 120 ohm as the resistance we have got 2 ohms will be there. Two ohms across this voltage supply so 240 ohm into 0.3 milliamp running will give rise to a voltage of 7.2 volts so 7.2 volts supply, $e_s$ and G is 2.1, epsilon we have found out. So we find a voltage output of 0.11 millivolt.

For this if we use an amplifier the noise voltage $v_n$ is obtained as root of 4 k TBR where T is the higher temperature and K is the Boltzmann constant, constant B is the bandwidth of the amplifier and R is the resistance of the strain gauge. Now we substitute here you will have around 0.45 microvolt. So this is the noise voltage, noise voltage is 0.45 microvolt, our signal is 0.11 millivolt, giving a signal to noise ratio that is noise equal to 244:1 this is a good signal noise ratio. When we are weakened you will have sufficient stress, suppose we paste the strain gauge in the existing rod and if the stress is only this much 0.060 into 10 to the power of 5 Newton per meter square then you will have $e_o$ as 0.11 microvolt. That is in this case if a noise is larger noise is 0.45, 4 times larger so we find signal is lost in this case. That is why we should not paste the strain gauges on any existing rod, any existing machine one.

Suppose we want to find out stress or strain in an automobile part which has been designed already for strength, there we should not paste the strain gauge. That part you have to remove it, put a weaker and paste it then you will have sufficient stress strain that is you are deliberately weakening the part but the weakening should be done below the yield stress. If we go to plastic region then it plastically deform it will spoil the whole thing so within the elastic limit you have to weaken the part and then paste the strain gauge. So that we can have sufficient signal to noise ratio of the order of 244:1.
Thank you.