Engineering Metrology
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Lecture – 31
Strain Measurement (Part 2 of 2)

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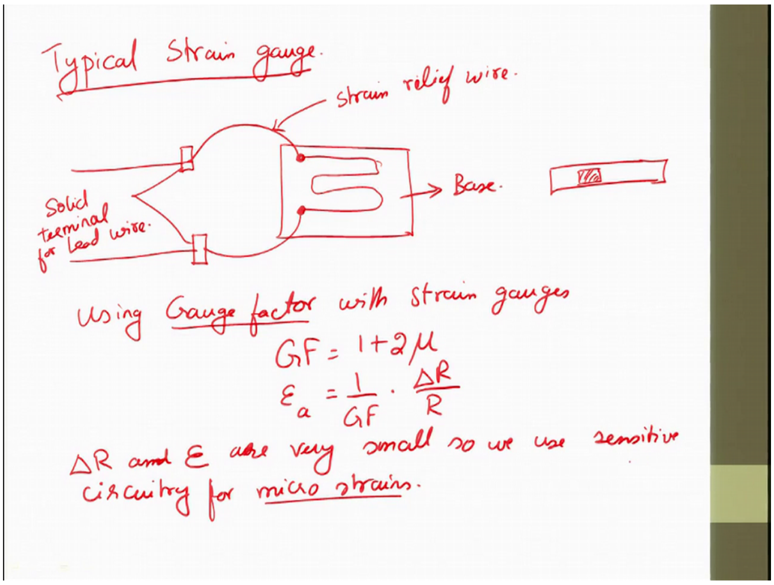

So, now let us see a typical strain gauge how does it look like. So, we will have a base ok. And then, we will have a wire this wire will be junctioned at 2 point. I am just giving a typical example and the output will be taken and this will be connected to other junction. So here, these are the wires which are taken as output. So, this one is called as the strain relief wire ok. These are the solid terminal for lead wire ok. This is a base where this base is used to stick on to the surface.

Suppose, you have a shaft, so, we stick strain gauges to the shaft. So, this portion is the base on which we have this gauge going and whatever we have seeing is the deflection of this wires, the diameter change in diameter and other things.

Now, let us look at the gauge factor. So, using gauge factor with strain gauges to the strain gauge looks like you can have 1 direction 2 direction and 3 directional measurements ok. So, gauge factor is nothing but 1 plus 2 times mu which we saw the earlier derivation or the axial strain is nothing but 1 by G F into delta R by R ok. So, the application of delta R and strain are very small. So, we use sensitive circuitry.

So, that means, to say you need to amplify, that is what we are trying to say circuitry for measuring micro strains ok. So, this is our strain gauge looks like and the gauge factor whatever we have used. So, this gets into the strain gauge measurements. So, that we find out the micro strains.

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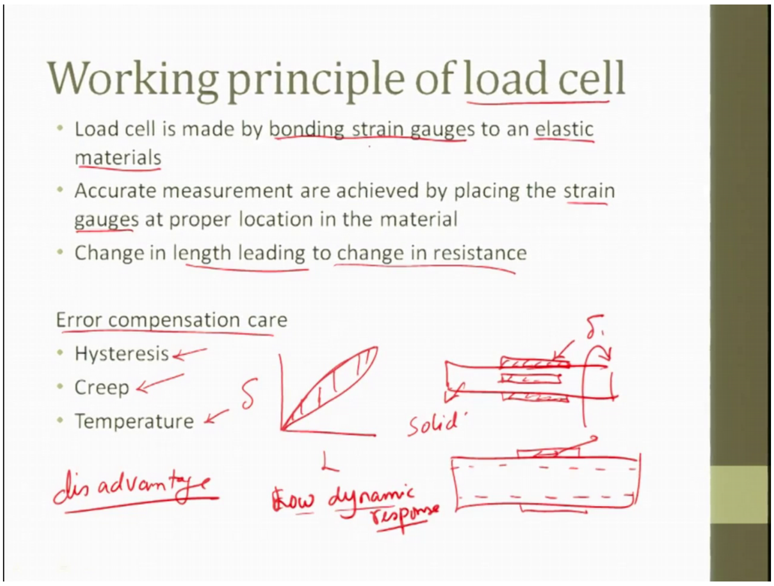

Let us now discuss about working principles of load cell. The load cell when we talk about load cell, is nothing but you take a member and in that member you stick a strain gauge right,. So, when you try the stick a strain gauge, you try to measure the deflection of the in the strain gauge. So, basically an increase in length. So, a load cell is made up of bonding of several strain gauges. It need not be only one, it can be multiple, it can be multiple. So, in the same membrane member, if you have a various loads for example, if you have a torsional load coming up, so then you want to measure 2 3 deflections.

So, you can try to place the strain gauge at the locations where there is maximum strain. You bond the strain gauge with the member and try to get the displacement here. So, this displacement can later the converted into strains right. So, a load cell means, you take a member and this number need not be only solid; it can be also hollow. You have no where is the location to be placed and at that location, maximum deflection should be there because, the strains whatever you get is very small micro strains.

So, when you try to amplify this, you will try to get more noise signals. So, that has to be nullified. So, we place it at the exact location. So, basically what is a load cell is you choose a member. This member can be a combination of several member or it can be a single member. And then, in a single member it can be a hollow, it can be solid, it can be hollow. You decide what the member is on, then you decide where the location to be placed such that these strains can be measured.

So, that is nothing but a load cell load cell is made up of bonding strain gauges to an elastic material ok. So, elastic material we talked about within the Hooks law. So, it has to be arrived. If you put it on a brittle material, you will not be able to do when if you put it on a completely ductile material. For example, polymer and then strain gauges. Here, the strains what the strain gauges can undergo is also limited. So, completely ductile material also will be a difficult task.

So, you have to choose a material where and which you have a proper balance of elastic modulus. Then, you choose accurate locations by calculations and find out what is a where is a maximum stress are coming out and then you try to measure the location for the strain. And then, you try to change the when you apply load, there is a change in length and then that leads to resistance you can measure.

By the way, where the heavy trucks when it moves on the road, you can see there are load cells available which are nothing but weighing bridges. So, in the weighing bridges, when the truck goes there are strain gauges placed at different locations on the load on the weighbridge. So, those deflections are measured and then that gives you what is a load of the truck ok. That is also a load cell. Sometime strain gauges are used; sometimes even mechanical livers are used for measurement.

So, there are generally, there are errors which happen in this strain gauges. When you use, they always have something called as hysteresis loop. For example, this is deflection, this is load. As the load increases, it might go like this and when it comes back, it traces another route. So, this area, this loop is called as hysteresis loop. So, this many a times you repeat it 100 1000 and 10000 times. So, then this loop the tracing path might change ok. Then, the other issue with strain gauges are creep. So, then the last one is going to be temperature.

So, you have to make sure you have a compensation for hysteresis creep and temperature and measure the when we use this for measurement and you make sure these error are compensated properly. Then, you try to get the signal out ok. And, the other most important, if you say this advantage the advantages are many.

If you want to have a load measuring device or a load cell at then in a load cell, if the operation, what do you do is slightly peculiar where in which you cannot fix the flat piezo crystals. Then, the strain gauges comes up in your help in big way the strain gauges. If you want to have a rough measurements, then we always go with strain gauge load cells. And once we have established the process very well, we will now then redefined changing the strain gauges with the piezo crystal.

The major disadvantage of the load cell which is using strain gauges, it has low dynamic response or I can say it has most probably no dynamic response. So, that means, to say if the event which is happen is very fast, then the strain gauge must expand and contract also very fast. So, many a times when you have an event which is happening at very small intervals of time dynamic load measurements cannot be done effectively by using load cells which is working on the principle of strain gauges.

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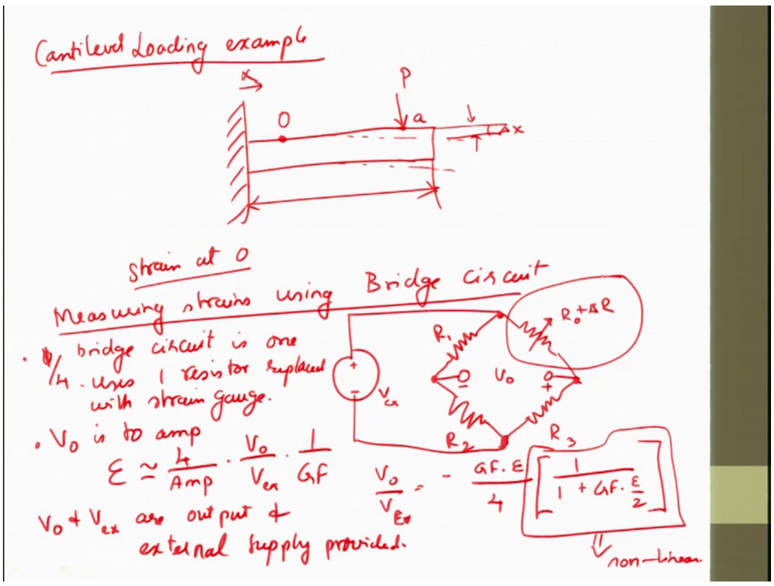

So, now let us see how do we stick it on top of a beam which is getting loaded or beam loading example, we can see or beam load or transverse load or axial load taking. So, the beam is attached to a, this is a fixed end, this is the cantilever ok. So, here the length of the beam or the cantilever, I would suggest it not beam, I would suggest it as cantilever, cantilever loading example. So, I here you have a load which is getting applied the and because of that there is your small displacement which is delta x ok.

So, if you want to measure the strains. So, this is x and this is a point which happens at a. So, this is strain at b point. So, this is the point, any point or let us take O strain at O we can try to measure the strain at O or we can try to apply the load and try to measure it.

So, after if you want we can put strain gauges here. So, if you want to measure strain at O, so, this strain whatever comes out of that small wire, it is now attached to a the bridge circuit. So now, measuring strains using bridge circuit that is what wheat stone bridge principle we see now that is what it is. So, here what we do is we have ok. So, here we have resistance 1, we have resistance 2 resistance 3 resistance 4 ok. So, this is R 1 this is R O plus delta R this is R 3 this is R 2 and this is varying. So now, I should try to attach it with the voltage.

So, this is plus this is minus. If this is the voltage, we apply and this is how a bridge circuit looks like of it this is V 0 if you want to find out from this bridge circuit, what we get is this is x V. So, this is external voltage is equal to minus G F gauge factor into strain divided by 4 1 by 1 plus G F into strain by 2.

And in which this entire term is a non-linear term ok. So, if we wanted to write it here a quarter of a bridge circuits is 1 which is very simple wheat stone bridges principle which uses 1 resistor replaced with the strain gauge ok. So, V naught is to be amplified. So, what we do a strain which is approximately 4 times amplification which is V naught by V externally force into gauge factor 1 by gauge factor ok.

So, V naught and V external are the output and external supply which is given to the principal. It is now supply provided and here what are we trying to do? We are trying to use only 1 quarter of the circuit.

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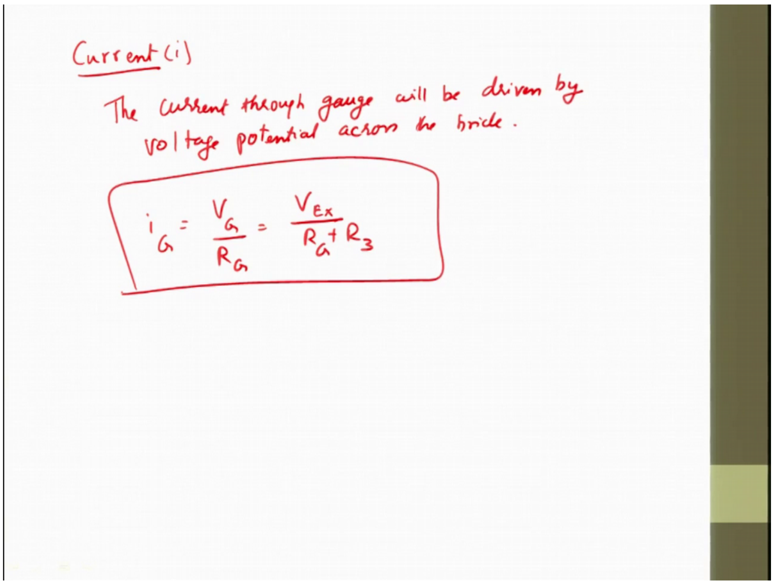

So, you we can also measure current, but the only problem is current, very high currents very high currents I cannot be measured because the strain gauge, the small thin foil or small thin wire will get burnt. So, we always try to use the current signal is given the current through the gauge; gauge will be driven by voltage potential across the bridge ok. So, i G can be written as V G by R G which is equal to Vex by R G plus R 3 ok. So, this is the typical i G which is can be measured.

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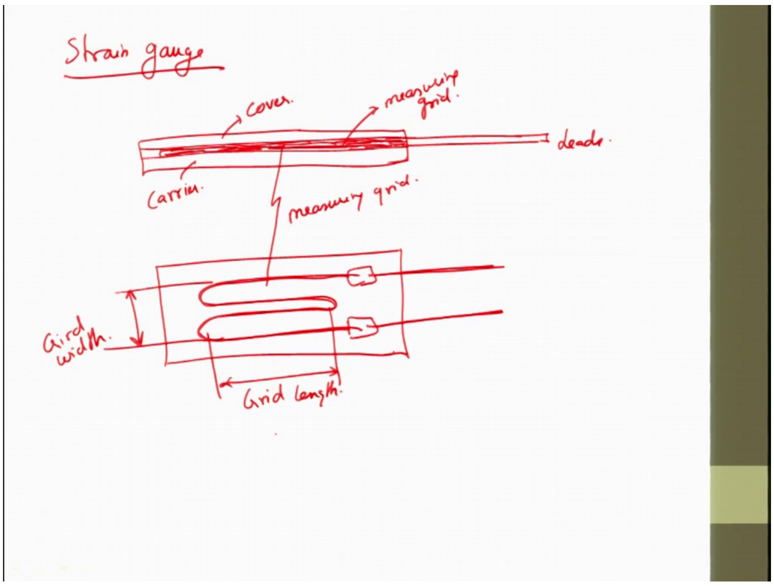

So now, let us try to look at a strain gauge much closer ok. So, if you see the side view of the strain gauge you will have a cover you will have a carrier, this is the cover ok. This is the carrier and here whatever you have is the measuring grid ok. So, and then this goes long. So, this is the measuring grid and these are the leads. So, this is side view if you look from the top view. So, this is how it looks like. So, you will have 2 junctions a lead goes and then you will have which is slightly thicker and.

So, this is called as a the this is called as the grid width and this is called as a grid length. Because all this things are very important because, the delta L and other things which you measure. So, and this is the measuring grid and you have this lead lengths whatever. So, this is how a typical strain gauge looks like from both the views and these are some of the factors which are very important to be addressed.

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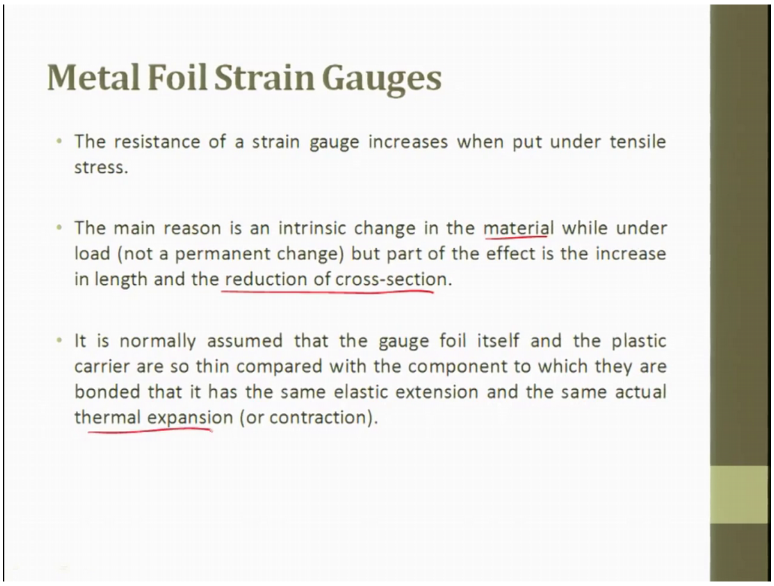

Next, let us see the metal foil strain gauge. Some more points we will see. The resistance of a strain gauge increases with when put under tensile stress can be tensile compression. The main reason is an intrinsic change in the material while under load, but part of the effect is in the increase in length and decrease in the reduction of cross section. It is normally assumed at the gauge foil itself the plastic carrier are so thin compared with the component to which they are a bonded that it has the same elastic extension and the same actual thermal expansion or contraction.

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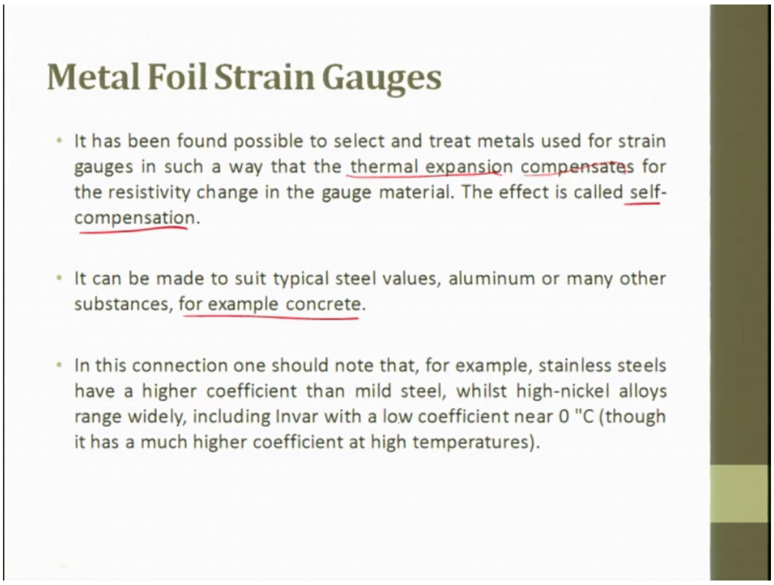

It has been found possible to select and treat metals used for strain gauge in such a way that the thermal expansion is compensates for the resistivity change in the gauge material. So, this effect is called as self-compensation. They compensate for the thermal change.

It can be made to suit typical steel walls aluminum or many other substances. For example, concrete where and which we can stick this metal, foil strain gauges for usage in this connection one should note that for example, stainless steel has the higher thermal coefficient than mild steel while high nickel alloy range widely including invar with a low coefficient of thermal expansion of 0 degree Celsius. So, you can choose metals to the requirement.

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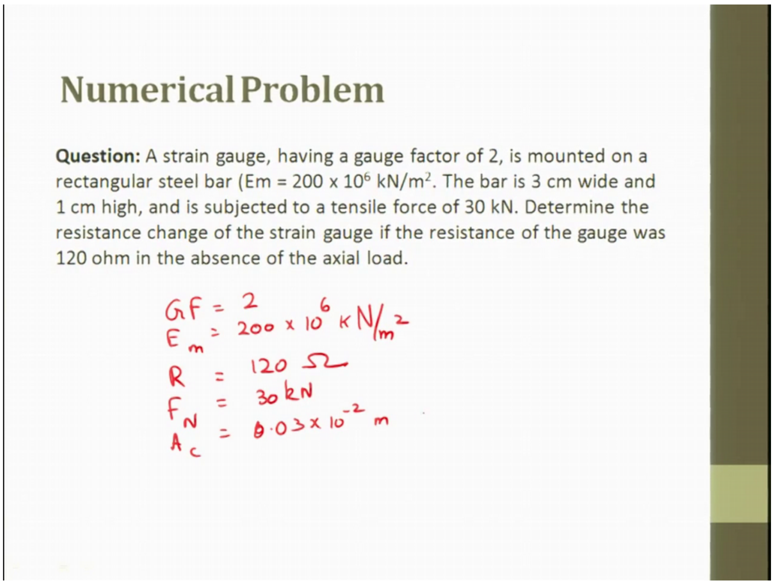

Now, let us see a simple problem a having a gauge factor of 2 is mounted on a rectangular steel bar the bar is 3-centimeter-wide and 1-centimeter-high and is subjected to a tensile force of 30 kiloNewton. So, determine the resistance of change in the strain gauge if the resistance of the gauge was written 20 ohms in the absence of axial load.

So, let us try to solve the problem gauge factor which is given is 2 then E m is 200 into 10 to the power 6 kiloNewton per meter square. We can take the resistance which is given as 120 ohms and then the load applied is 30 kiloNewton and the area of cross section which is given is 0.03 into 10 to the power minus 2 meter ok.

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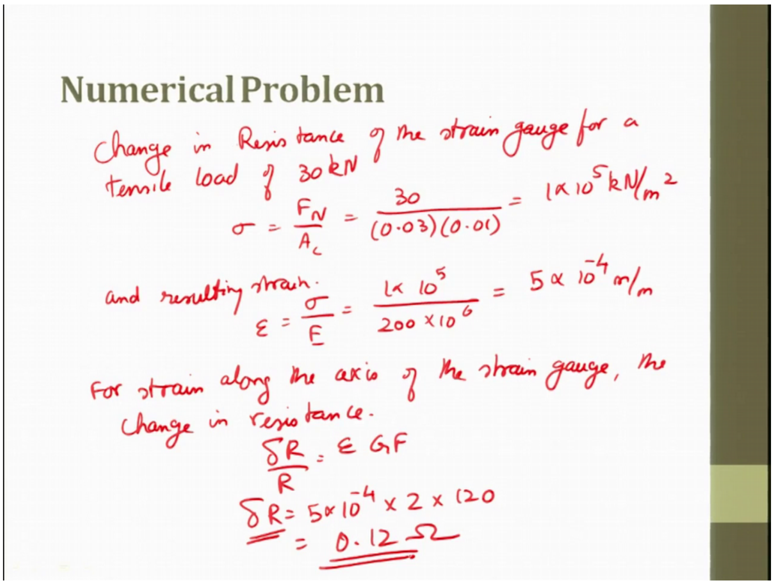

So, fine and then now if you want to find out the change in resistance, change in resistance in the resistance of the strain gauge for a tensile load of 30 kiloNewton. So, how can we do it? We try to find out stress F N applied is nothing but A in F N into a A C. So, this is nothing but 30 kiloNewton divided by 0.03 into 0.01 which is nothing but 1 into 10 to the power 5 kiloNewton meter square, ok.

And the resulting strains, strain is nothing but there is nothing but stress divided by E Young's modulus. So, which is nothing but 1 into 10 to the power 5 divided by 200 into 10 to the power 6. So, which is nothing but 5 into 10 to the power minus 4 meter per meter because strain has it is not a unitary.

So, for strain along the axis of the strain gauge. Strain gauge the change in resistance is given by delta R by R which is nothing but G F. So, delta R is equal to strain which is 5 into 10 to the power minus 4 into gauge factor of 2 into R which is nothing but 120 ohms. So, the delta R is nothing but 0.12 Ohms. So, the change in delta R will be 0.12 Ohm resistance measurement.

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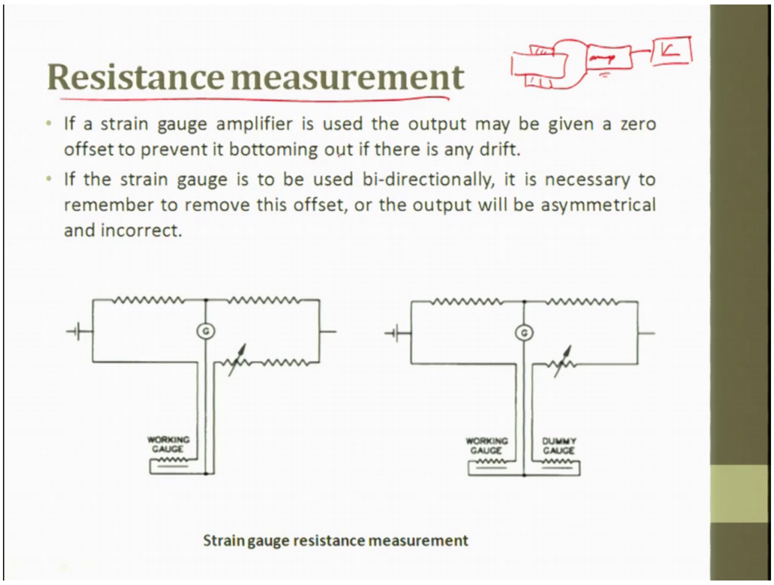

So, if a strain gauge amplifier is used to. So, where is a strain gauge amplifier coming? So, you have a member then you stick strain gauges to the member you track and output from the strain gauge. So, it is attached to an amplifier from that amplifier. It will be shown as a output display whatever it is. So, if the strain gauge amplifier is used is used, the output may be given a 0 offset to prevent it bottoming out if there is a drift.

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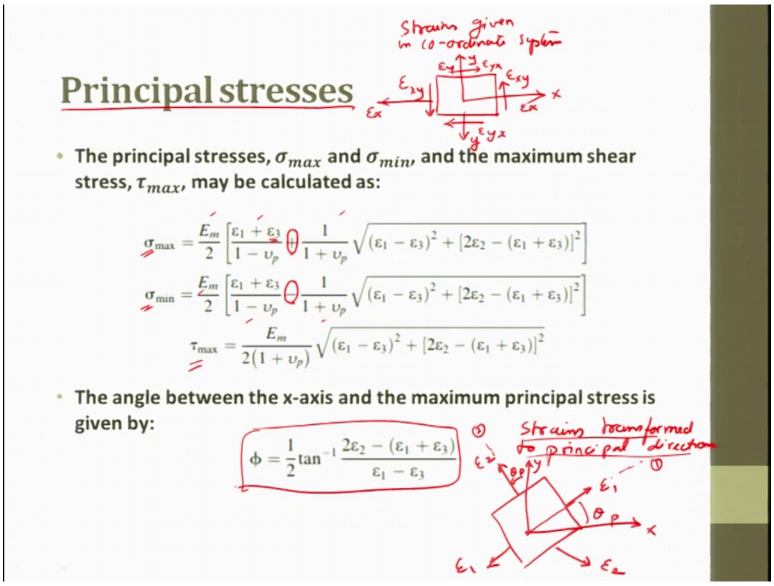

So, principal stresses. So, let me drop first the strains given in coordinates system and then, we will see where does this one direction strain once strain 3 comes. So, this is the coordinate system where the strains are given. So, this is y direction, this is x direction ok. And, this strain which happens here is called a sigma y the strain which happens here is called as sigma x. The strain which happens along this direction are called as x y, then the strain which happens down is y.

So, what happens in this direction is strain y x and here what happens is strain x and what happens in this direction is strain x y ok. And the strain which happens in this direction is called as y x.

So, if I changes this strain given in the coordinate system to strain transformed to principal direction, we will have this is x, this is y, this is your strain 1, this is your strain 2, this is your strain 2, this is your strain 1 ok. So, this is 2 d. So, if you have a 3 d one, it is you will have strain 3 also right. This is I am representing in the 2 form so, that this is theta b, this is theta b ok.

So, this is how and this is your 1, I extend it. This is your 1 and this is your 2 this is in a 2 d form principles. The strain transformed to principal direction in a 3 d you will also have sigma 3. So, if the maximum principal stress sigma maximum is nothing but Young's modulus by 2 the strains are given.

So, minimum is this. So, if you see there, the terminal this is common, this is common this is common. So, the difference between sigma maximum and sigma minimum is this sign alone, rest all the formula is the same. So, tau max can be calculated again this part of the formula is the same which is there and here. There is a small change, we take this value and multiply with this. So, this is what is tau the angle between the x axis and the maximum principal stress is given by this is tau. So, you get the value like this.

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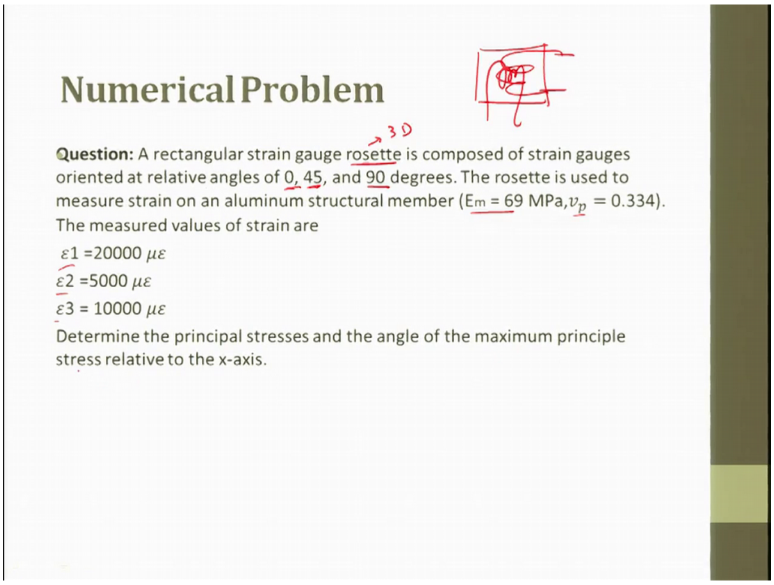

So now, let us try to work a simple problem a rectangular strain gauge rosette. So, rosette is it looks something like you have this way and this way will be at an angle. So, 2 directions a rectangle rosette is composing of strain gauges it will. In fact, rosette is for 3 directions right. So, oriented at relative angle 0, 45 and 90 degree. So, you will have 3 types of strain gauges, in uniaxial you had only 1. So, this 3 strain gauges are located at 0 45 and 90 degrees.

So, rosette is used to measure the strain on an aluminum steel frame whose E m Young's modulus is given poisons ratio is given the strain sigma 1 sigma 2 sigma 3 is also given determine the principal stress and the angle of maximum principal stress related to the x axis.

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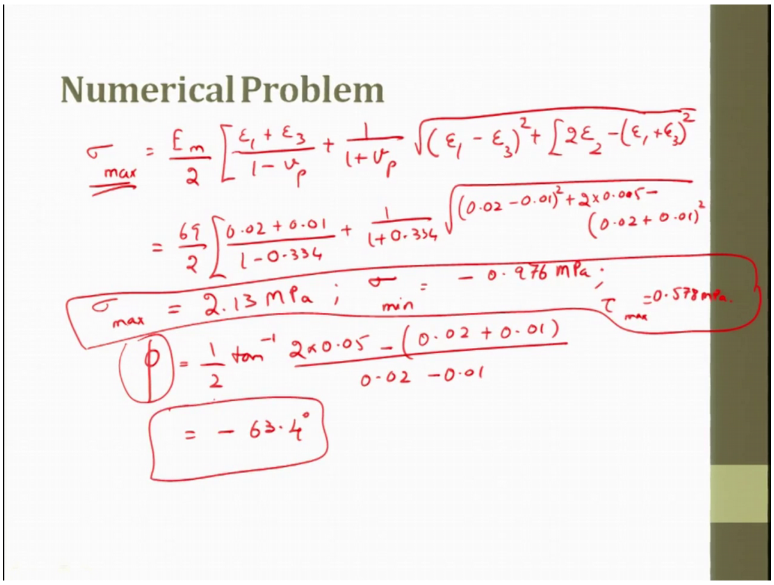

So, sigma max the formula goes like E m by 2 strain 1 plus strain 3 1 minus poisons ratio plus 1 by 1 plus poisons ratio root of strain 1 minus strain 3 the whole square plus 2 times strain 2 minus strain 1 strain 3 the whole square. So, this is for sigma max. So, sigma max with you substitute all the all the things.

So, what we get is 69 MP a MP a divided by 2 strains are 0.02 plus 0.01 divided by 1 minus 0.334 poisons ratio plus 1 1 plus 0.334 root of so, it is 0.02 minus 0.01 the whole square plus 2 times 0.005 minus bracket strain; strain 1 is 0.02 plus 0.01 the whole square. So, this value is nothing but 2.13 MP a. This will be the maximum stress. So, from the strains you can try to find out the principal stress.

So, then next how do you find out phi. So, if you go back and in this equation half tan if you substitute which is half tan inverse. So, you have 2 into 0.05 minus 0.02 plus 0 point 0 one divided by 0.02 minus 0.01. So, if you try to solve this equation finally, what you get you get you get phi is equal to minus 63.4 degrees ok. And, in the same way you can also try to find out sigma.

So, this is sigma max you can try to find out sigma min. So, sigma min is nothing but minus 0.976 MP a. You can solve it. And then, you can also try to substitute the same values in the equation and try to get tau max is nothing but 0.578 MP a.

So, with this, you can try to find out sigma max sigma min tau and then you can also try to find out what is the phi ok. For this, from this problem you can try to determine the principal stresses and the angle of maximum principal stress related to the x axis sigma max sigma min tau max. You can try to find out all by just substituting the formula.

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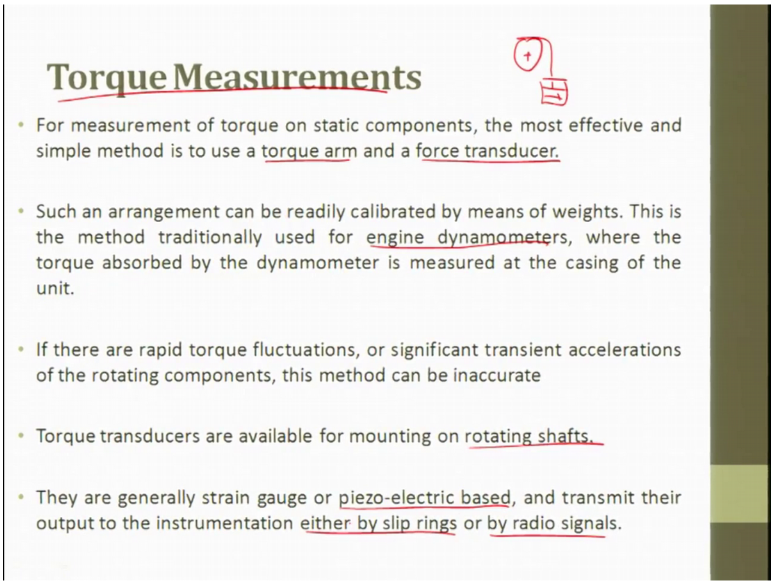

Next one is torque measurement. Torque is nothing but a rotational when there is a member and in this number is fixed at one end and you try to rotate the other end, in the clockwise or anticlockwise direction, what load comes as a torsional load for measurement of torsion or a and static component the most effective and the simple method is to used the torque arm and the force transducer.

If you see a torque wrench, which we use it for spanner tightening also which is spring loaded you can keep tighting. And then, once you set the torque value, for that torque value keep writing and moment it crosses that it start sleeping, the wrench start sleeping.

So, you can you set torque arm and the force transducer to measure the torque, what is involved? Such an arrangement can be readily calibrated by means of weight. So, what we are trying to say is, you can try to have a known weight. You can try to have a known weight which comes. So, known weight and this know weight at some load it start sleeping.

So, you try to find out with a known weight. What is the force, torsion force it undergoes? This is the method traditionally used for engine dynamometer where the torque absorbed by the dynamometer is measured at the chasing of the unit. If there is a rapid torque fluctuation or significant transient acceleration of the rotating component, this method can be inaccurate. So, this is only a calibration method which we use, but if we start using it for a dynamic measurements, it is not good.

Dynamic measurement. I am talking about frequently changing torque transducers are available for mounting on rotating shaft. They are generally strain gauge or piezo based torsional measuring devices and transmit their output to the instrument either by slip rings or by radio frequency. It can be wired or it can be wireless.

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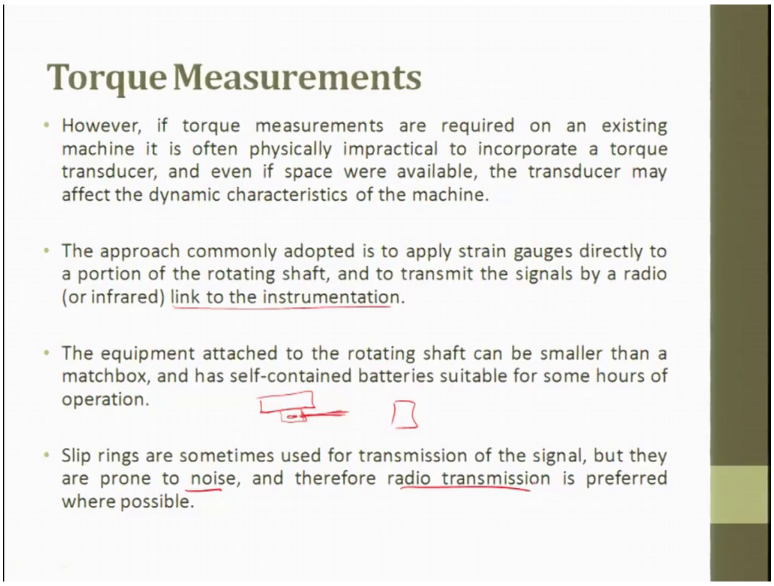

However, if the torque measurements are required on an existing machine, it is often physically impractical to incorporate a torque transducer and even if space where available. The transducer may affect the dynamic characteristics of the machine. So, for an existing machine, torque measurement is slightly difficult. So, we have to make keep that in mind for a developing one. When there are in part wise and subassembly wise, yes, you can do.

We approach commonly adopted is to apply strain gauge directly to the portion of the rotating shaft and to transmit the signal by radio length to the instrument. The equipment attached to the rotating shaft can be smaller than the matchbox and has self-contained batteries suitable for some hours of operation.

So, what you are trying to say is we are trying to say you take a member and then you try to stick this torque measuring and this will start communicating with another instrument which is wireless and it has a self-energized with the battery. The slip rings are sometimes used for trans for the transmission of signals, but they are prone for noise. And therefore, radio transmission is always preferred radio transmission is wireless.

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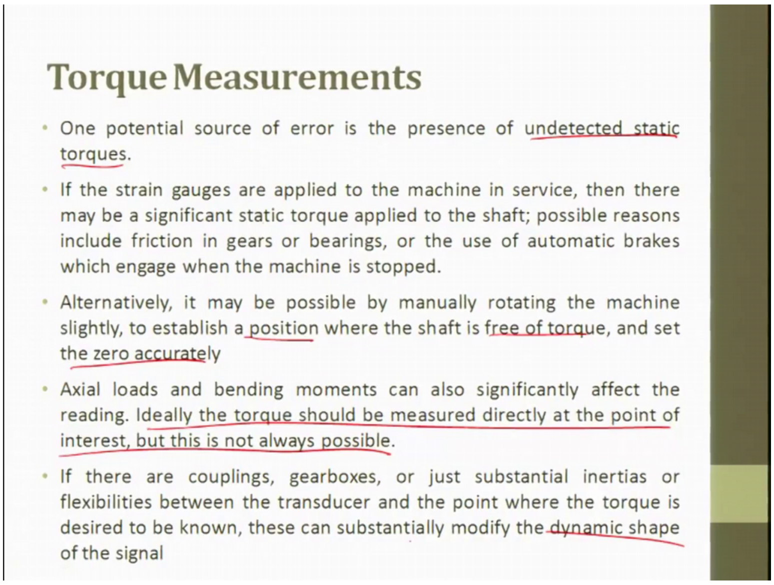

One potential source of error which can generally happened in torque measurement is the presence of undetected static torque. If the strain gauge are applied to the machine in service, then that might be significant static torque applied to the shaft. Initially, even before you start doing experiments, possible reason include friction in gear or bearing or the use of automatic brakes when which engaged, then the machine is stopped alternatively. It may be possible by manually rotating the machine slightly to establish the position where the shaft is free of torque and then set the 0 accurately.

And then, start measuring axial load and bending moment can be significantly affecting the reading ok. Ideally, the torque should be measured directly at the point of interest, but it is not always possible this is a very, very important point. So, we would like to measure torque, but at that point, it is not possible if there are coupling gearbox or just substantial inertia or flexibility between the transducer and the point where the torque is desired to be known those can substantially modify the dynamics shape of the signal.

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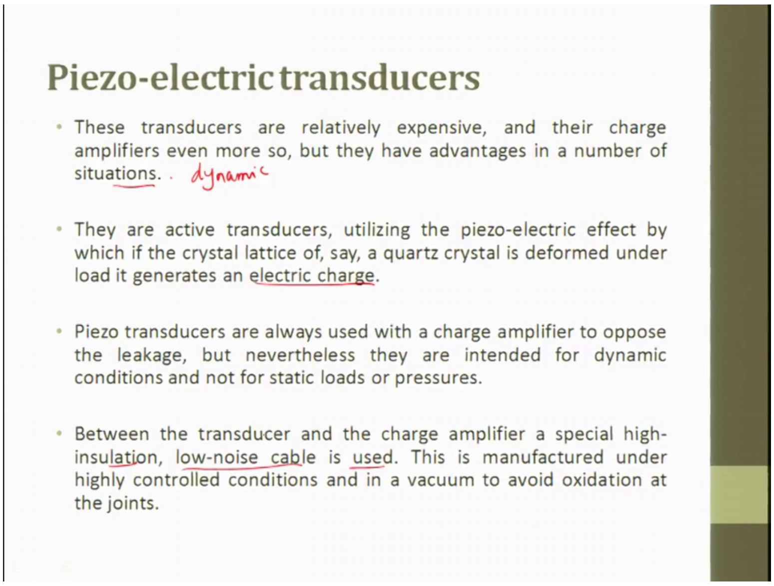

So, torque measurement is always a challenge. It is not like strain measurement of torque measurement. We can use strain gauge type as well as piezo electric; piezo electric is what we are going to discuss now.

But, measuring strain uniaxial in tensile compression and you can also use it for torsional and what we do is we try to attach the strain gauges to a wheat stone bridge principle wheat stone bridge. So, in the wheat stone bridge, we try to do proper balancing and 0 drift all these things. We make sure this is taken care and then, we start giving the measurements or we start taking the measurement uniaxial measurement tensile and compression is straight forward.

But, torsional there is a word of caution we should know exactly whether the shaft is already loaded or it is free, then only you can do the torsional measurement and the member where it is stuck. You can try to reduce the amount of material in the member such that it starts deflecting.

The next topic of discussion is going to be piezo electric transducer. These transducers are relatively expensive and their charge amplifiers even more. So, but they have the advantage in number of situations, they are dynamic used for dynamic measurements, they can measure even very small events. They are active transducers utilizing piezo electric effect by which give the crystal lattice of say a quartz crystal is deformed under a load. It generate electric charge. The piezo transducer are always used in with a charged amplifier to oppose the leakage.

But, nevertheless they are intended for dynamic condition and not for static condition or pressure between the transducer and the charged amplifier a special high insulation low noise cable is used. This is manufactured under highly controlled conditions such that their noise does not get introduced when we do dynamic measurements.

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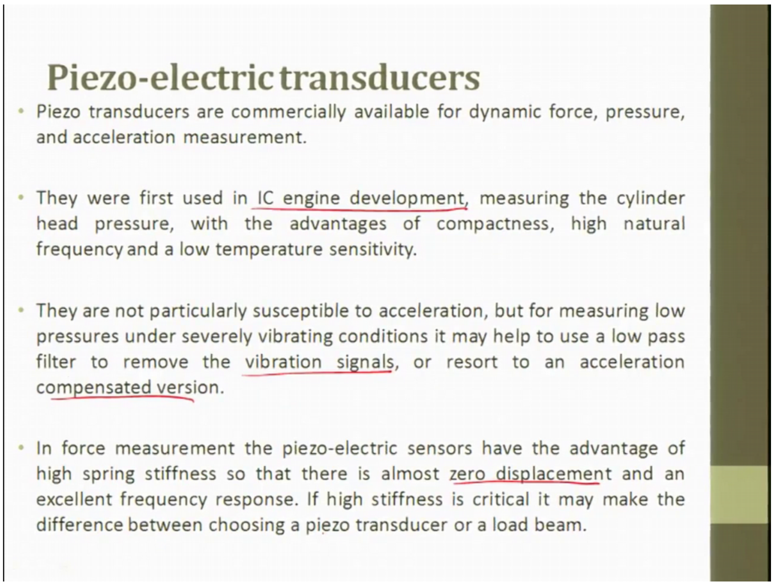

They were first used in IC engine development measuring the cylinder head pressure with the advantage of compactness high natural frequency and the low temperature sensitivity this piezo crystal producers are becoming more and more used in force measurement for example, in cutting force measurement we use piezo crystal dynamometers today. So, I here you have forces coming in 3 directions you the you can do it independently without having any cross sensitivity; that means, to say the effect of x direction force is not communicated to y.

They are not particularly susceptible to acceleration, but for measuring low pressure under severe vibration condition it may help to use a low pass filter to remove the vibration signal to restore to an acceleration compensation version in force measurement.

The piezoelectric sensors have the advantage of high spring stiffness. So, that they are almost 0 displacement and have excellent frequency response.

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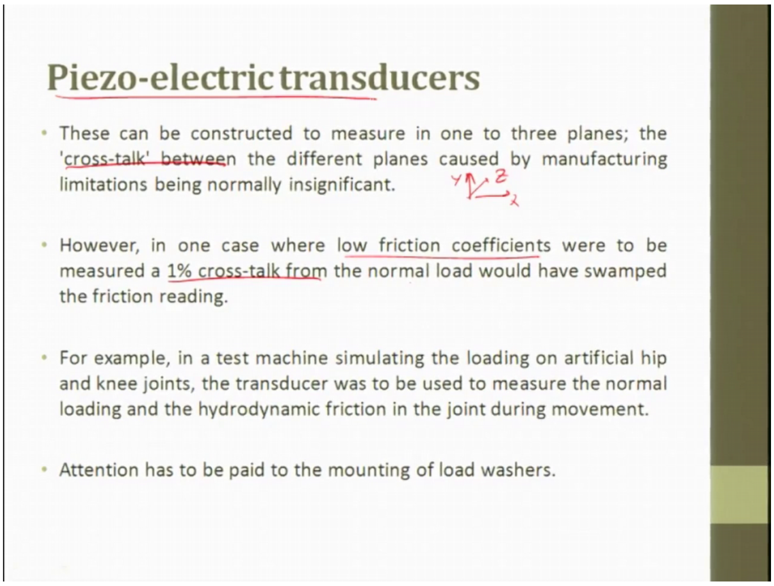

They can be constructed to measure in 1 2 3 planes 1 2 3 planes the cross talking between the different planes caused by manufacturing limitation being normally insignificant. So, you have extraction y direction and z direction y x and z. So, you stick strain gauges in all the 3 directions. So, once response will not be communicated to the second one. So, that is called as cross talking.

So, however, in one case, where coefficient of friction were to be measured, one-person crosstalk from normal load would have swamped the fictional reading. So, piezo crystal dynamometer for measuring strain gauges are becoming more and more popular today.

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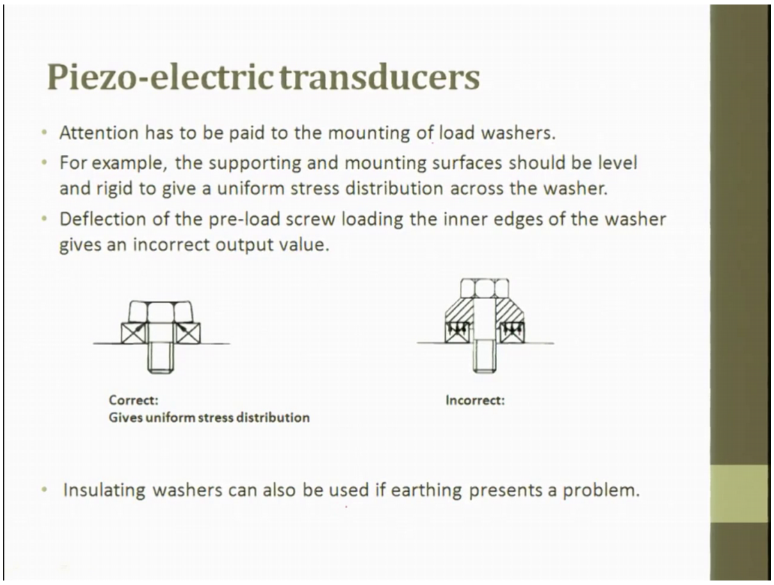

So, attention has to be paid to mount of load washers. So, this is the load washer given uniform stress distribution. So, here it is incorrect. So, you see here for example, the supporting and the mounting surface should be level and rigid to give a uniform stress distribution across the washer. The deflection of a preloaded screw the loading in the inner edge of the washer gives an incorrect output. So, here you get an incorrect output. So, please make sure that uniformly you distribute the loads.

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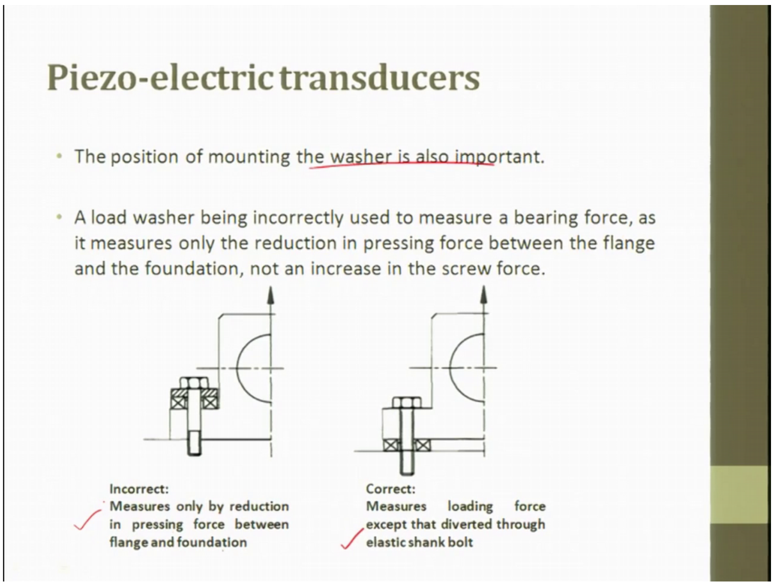

The position of mounting, mounting the washer is also very important. The load washer being incorrectly used to measure a bearing force, as it measures only the reduction in pressure force between the flange and the foundation not an increase in this screw force. So, measures only by reducing the pressing force between the flange and the foundation this is incorrect. So, this is what is the correct thing which has to be done. So, you can use it here. We are trying to show you a demonstration or piezo crystal crystals are used for measuring the forces in high concrete buildings.

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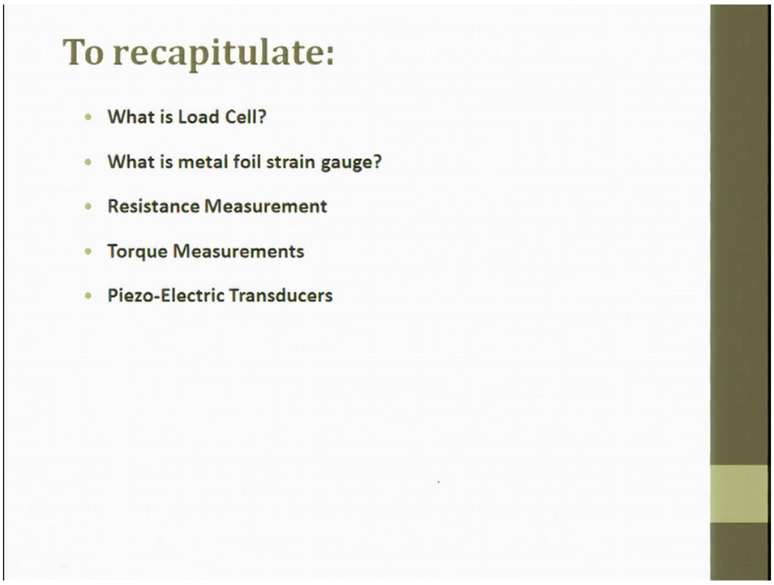

To recap what we studied in this particular lecture is basics of strain gauge how strain gauges can be integrated together to form a load cell, then we saw what is metal foil strain gauges. We saw resistance measurement torque measurement. And finally, we saw piezoelectric transducers how are they used to measure the strains.

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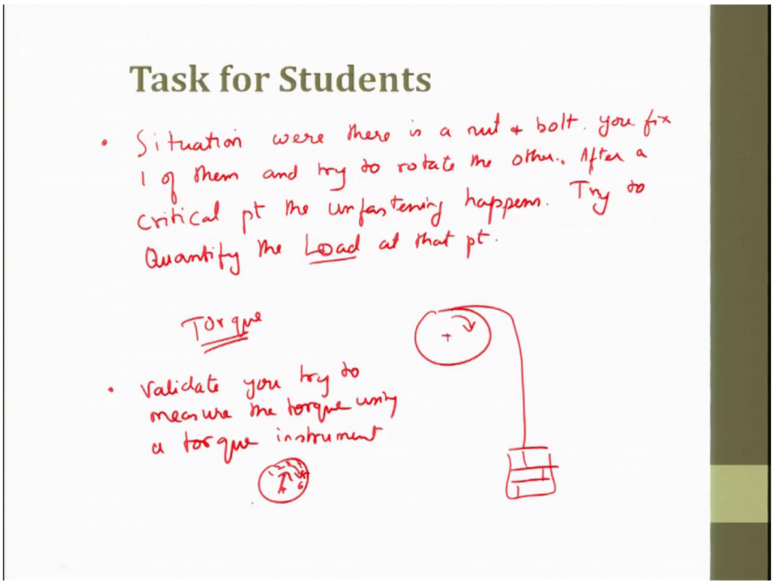

So, task for the student try to take a situation where there is a nut and bolt, you fix one of them and try to rotate the other ok. And after a critical point, the unfastening happens try to quantify the load at that point.

So, basically you are supposed to develop a very small setup and then try to apply load. So, I told you here also you have a system, then you attach a twine to it start putting the load here and at one particular load. This member will start rotating. You can know what is the load, what is the weight. From there, you can try to find out what is the load and then you can try to calculate what is your torque. So, if you do this experiment, you will start appreciating how difficult it is to measure a torque. For this you will have to validate your answer.

So, you try to measure the torque using a torque wrench torque instrument I will say torque wrench. So, here what we do is there is a mechanical lock. So, you can try to move the lock there will be graduations 1 2 3 4 5 6. Whatever it is, you try to move and set the pointer and then start opening the same fastening system. At one point, this will open.

Now, you have experimentally found out the values. Now, you try to see with the torque wrench whether it is able to open the same. So, this will try to give you a feel how to measure the torque on a given system.

Thank you.