Chemical Process Instrumentation
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Lecture – 18
Transducer Elements (Contd.)

Welcome to lecture 18. We have started our discussion on Transducer Elements. In our previous lectures, we have talked about Pneumatic Transducer, Flapper/Nozzle systems and Electromechanical Transducer, LVDT or Linear Variable Differential Transformer. Today we will talk about another Electromechanical Transducer known as strain gauge.

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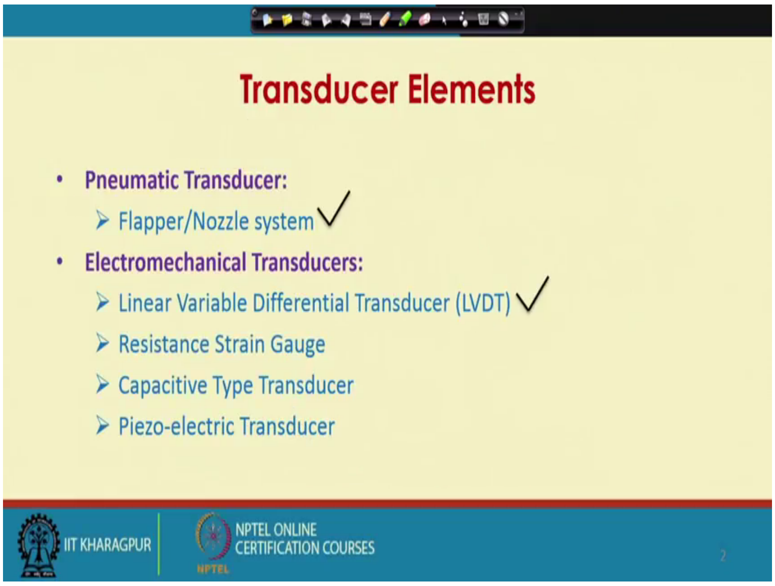

So, today's topic is Resistant Strain Gauge. So, we have covered the Flapper/Nozzle system. We have also covered Linear Variable Differential Transducer of transformer.

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So, today will talk about Resistance Strain Gauge.

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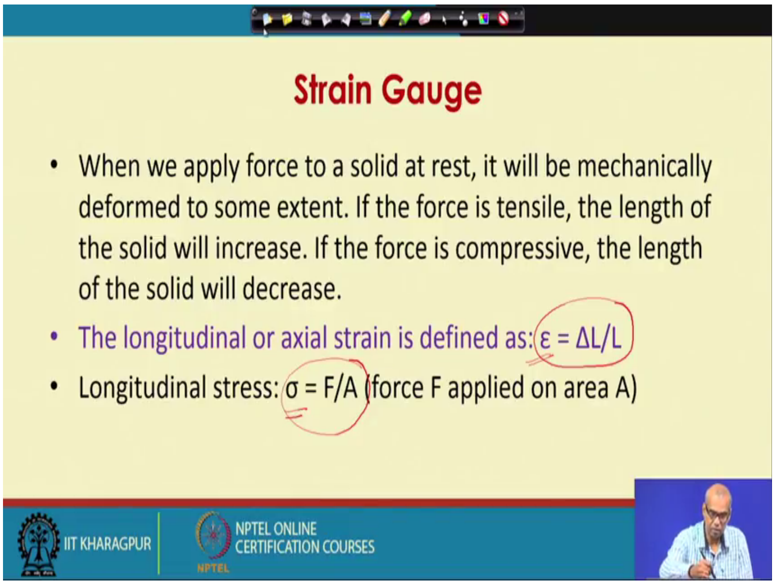

When you apply force to a solid at rest, it will be mechanically deformed to some extent. If the force is tensile, the length of the solid will increase. If the force is compressive, the length of the solid will decrease. The longitudinal or axial strain is defined as change in length delta L divided by original length. And the longitudinal strain or axial strain, we commonly represented by epsilon which is delta L divided by L. And longitudinal stress sigma equal to F by A. So, force applied on the body divided by area of the body over which the force is being applied.

So, longitudinal stress is force F applied on area A.

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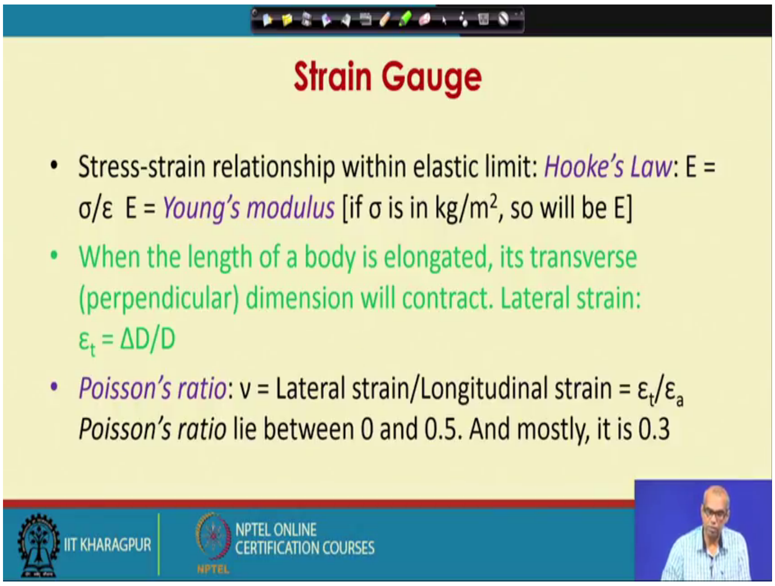

Stress-strain relationship within elastic limit is represented by Hooke's law, where E or Young's modulus is equal to sigma by epsilon. So, stress divided by strain. Remember strain is delta L by L, so does not have any unit. But stress is force on area. So, it has unit. So, if stress is in kilogram per meter square, modulus of elasticity will also have the same unit, kg per meter square. When the length of a body is elongated, it transverse or perpendicular dimensional contract. Imagine you are stretching an electrical wire, so if the length increases the diameter will decrease.

So, lateral strain then can be defined as: change in transverse dimension divided by original dimension. So, for an electrical wire when you stretch it, the axial strain will be delta L by L which is change in length divided by original length. And lateral strain will be delta D by D, which is change in diameter divided by original diameter. Poisson's ratio is defined as lateral strain divided by longitudinal strain. Commonly, Poisson's ratio lies between 0 and 0.5, and most of the time it is 0.3.

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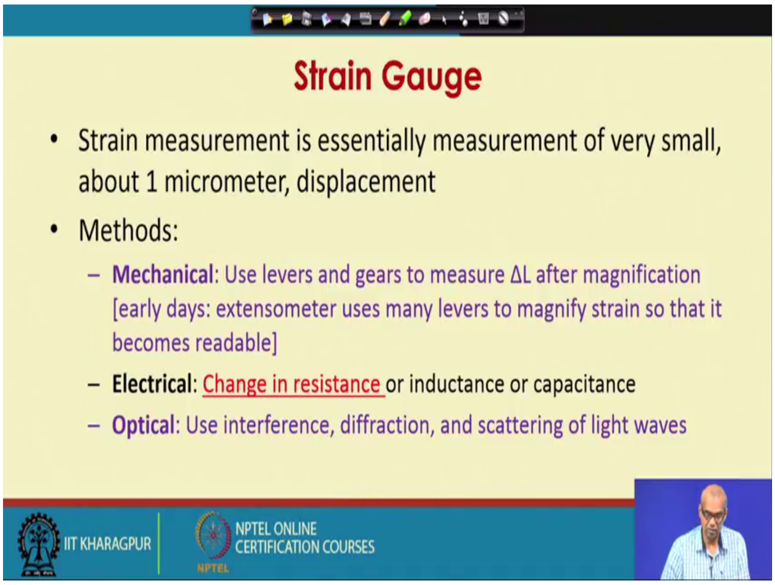

Strain measurement is essentially measurement of very small displacement. It may be as small as 1 micrometer. There are various methods for measurement of small displacement. There are Mechanical methods, there are Electrical methods and there are Optical methods.

Mechanical methods use levers and gears to measure the change in length after magnification. Extensometer uses many levers to magnify strain so that it becomes readable. Under Electrical methods, we can measure the change in resistance or change in inductance or change in capacitance due to strain. And the strain can be related to the change in resistance or change in inductance and change in capacitance. Under Optical methods, use of interference diffraction and scattering of light waves can be made to measure small displacement or strength.

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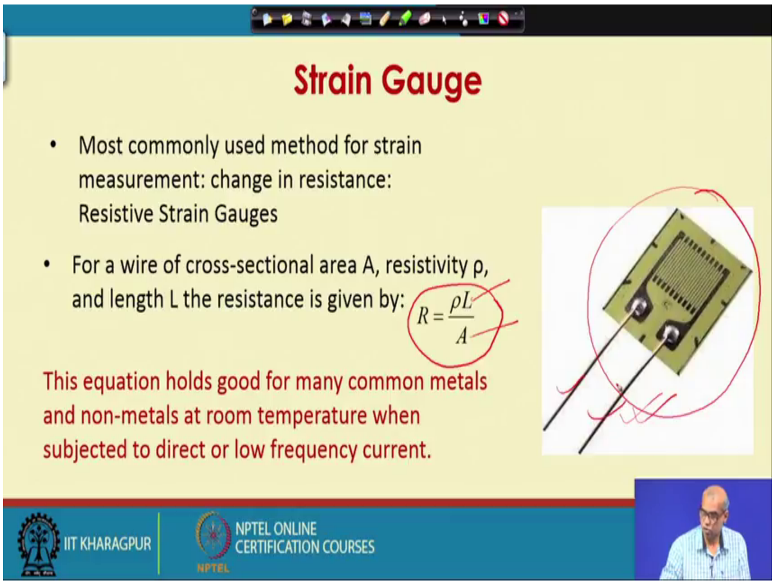

But most common method for strain measurement is Electrical method. And most commonly we use change in resistance to measure strain. And the transistor that we use most commonly is known as Resistive Strain Gauge. You know that for a wire of cross sectional area A, resistivity rho and length L, the resistance is given by R equal to rho L divided by A. This equation holds good for many common metals and non-metals at room temperature when subjected to direct or low frequency current.

So, resistance is a function of L as well as A. So, if a resistance wire is under strain, its length will change, this area will also change. So it means that, if I can measure the strain or change in length, I will be able to relate resistance with the change in length. This is the principle on which a Resistive Strain Gauge will work. So, Resistive Strain Gauge is basically nothing, but an Electrical wire which can be strained. So, this is the picture of a typical Resistive Strain Gauge. So the change in resistance that occurs in the wire due to strain can be measured by use of Wheatstone Bridge principle.

So, one arm of this, one arm of the Wheatstone Bridge will be connected to this Strain Gauge.

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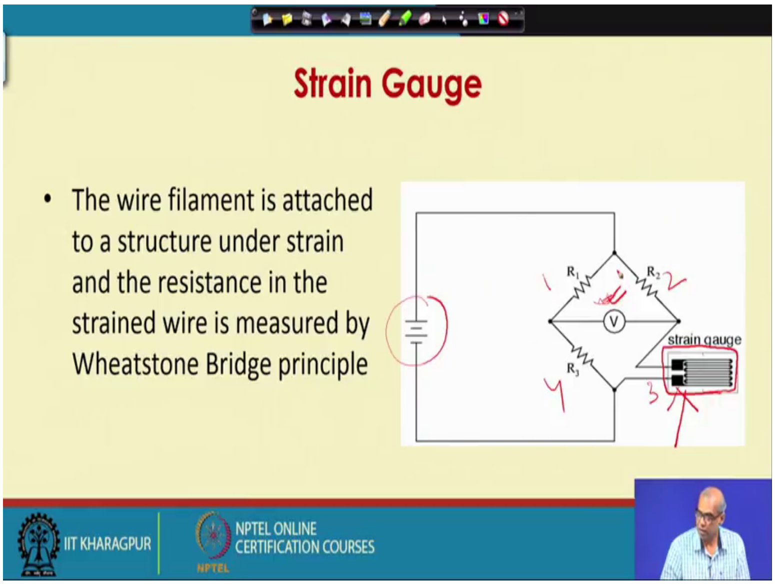

So, this is how we measure strain using a Strain Gauge. The wire filament is attached to a structure under strain and the resistance in the strain, where is measured by Wheatstone Bridge principle. So, you have these 4 arms or Wheatstone Bridge. So, worn is connected to the Strain Gauge. Let's say the Strain Gauge is an conducting wire.

So, b square or the strain gauge is connected or attached to the sample which is under strain. So, this is the sample which is under strain. So, on the surface of that, I rigidly borne or attach the Strain Gauge. So, when the sample undergoes strain, the Strain Gauge also undergoes strain. So, when the sample undergoes strain, the resistance will undergo strain and that will cause a change in the length of the wire and that will cause a change in the Resistance of the Strain Gauge. So, this is the bridge exciting voltage and this is the output of the Wheatstone Bridge.

So initially, the strain gauge is not under strain. So, the bridge can be balanced. So, the output voltage is 0 initially. Now, I apply strain to the sample so, the resistance wire is also under strain, there will be change in resistance, so there will be an unbalanced current in the Wheatstone Bridge. So, the output voltage will no more be 0. So, the output voltage can be related to the strain through proper calibration.

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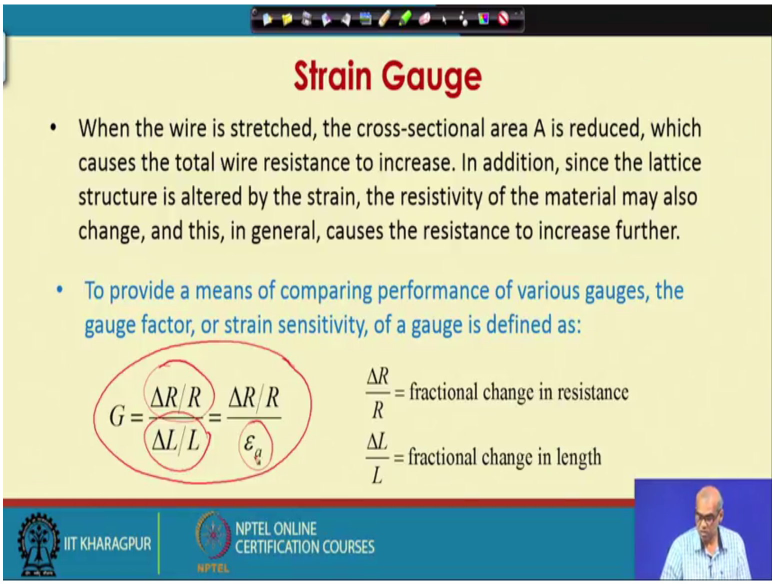

When the wire is stretched, the cross sectional area A is reduced, which causes the total wire resistance increase. In addition, since the lattice structure is altered by the strain, the resistivity of the material may also change, and this, in general causes the resistance to increase further.

Resistance, Resistive Strain Gauge or Resistant Strain Gauge can be made of various conducting materials. Commonly used wires are copper nickel, chrome nickel, nickel iron alloys. Now to provide a means of comparing performance of various Strain Gauges, we define something called gauge factor or strain sensitivity. So, the gauge factor, or same strain sensitivity is defined as this. So, the gauge factor is delta R by R divided by delta L by L. So, it represents in the numerator, change in resistance divided by resistance and in the denominator delta L by L which is strain longitudinal or axial strain. So, delta R by R divided by strain, axial strain is gauge factor. And delta R by R represents fractional change in resistance. And lateral strain represents fractional change in length. So, the gauge factor is fractional change in resistance divided by fractional change in length.

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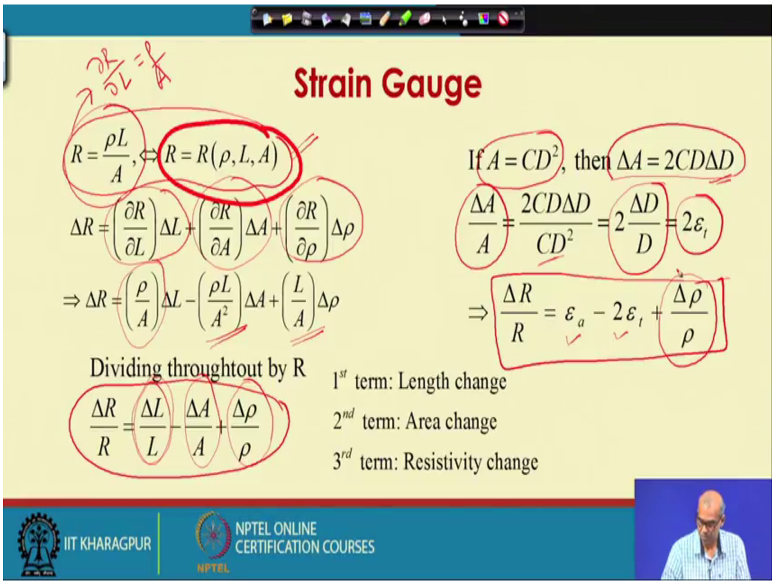

Now, let us try to get an expression for gauge factor. We start with this expression for resistance that relates resistance with length of the wire and cross sectional area of the wire. So, well known equation R is rho L divided by A. So, we can write R as a function of rho L and A. Now change in resistance, delta R, can be represented as you take partial derivatives. So, delta R delta L into del L plus delta del A into del A plus delta del rho into del rho. So this represents the change in resistance due to change in length. This represents the change in resistance due to change in cross sectional area, and this represents the change in resistance due to change in resistivity of the material. If you take the derivatives delta R delta L, using this functional relationship, will get delta R delta L. So, delta R delta L is rho by A.

So, that is what I have put, rho by A here. Similarly, you find out delta R by delta A as this, and delta R by delta rho as L by A. Now divide this equation throughout by R, you will get this equation; which on the left hand side is delta R by R, which is fractional change in resistance that is equal to delta L by L minus delta A by A plus delta rho by rho. So, the fractional change in resistance is equal to fractional change in lane. Fractional change is cross sectional area plus fractional change in resistivity of the material.

Now, let us consider that area A can be represented as proportional to diameter square. So, if I use A equal to some constant C into D square, it is like A equal to pi D square by

4, then I can calculate delta A as 2CD delta D. So, delta A by A can be computed as 2CD delta D by CD square, which can be rearranged as, 2 delta D by D. Remember delta D by D is transverse strain and delta L by L is axial strain. So, by putting these 2 values, I get delta R by R, which is fractional change in resistance as axial strain minus 2 into transverse strain plus delta rho by rho which is fractional change in resistivity.

So, this term represents Length change, this term represents Area change and this term represents Resistivity change.

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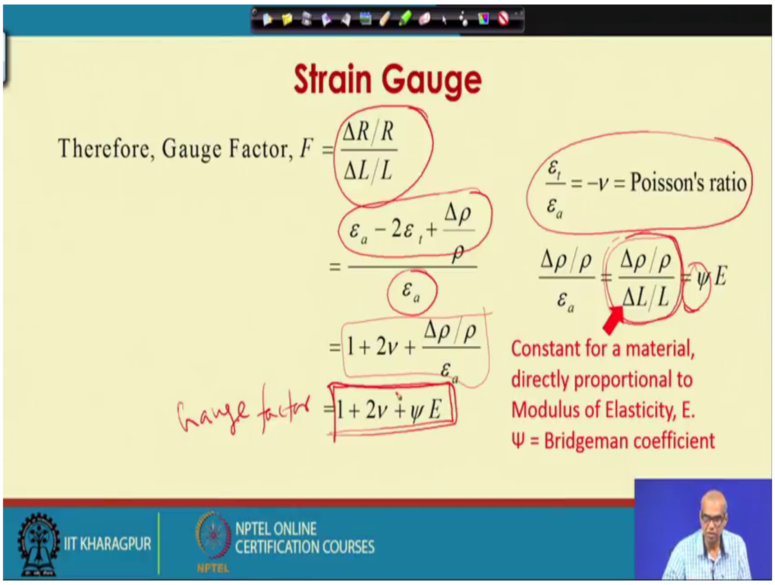

So, now we are able to calculate the Gauge Factor because now we have all the informations. So, the Gauge Factor is delta R by R, divided by delta L by L. So, delta R by R, we just derived this and delta L by A is axial strain. So, this can be represented as 1 plus 2 nu plus delta rho by rho divided by axial strip. Just divide all these terms by epsilon A.

So, this will be this, note that transverse strain divided by axial strain is Poisson's ratio. So, I replace that here. Also delta rho by rho divided by axial strain can be written as delta rho by rho divided by delta L by L. And, this term is constant for a material and this is directly proportional to modulus of elasticity E. So, delta rho by rho divided by axial strain is constant for a material and this is directly proportional to the modulus of elasticity. So, this can be written as some constant into modulus of elasticity; that constant is known as Bridgeman coefficient.

Finally, the Gauge Factor can be expressed as a simple looking expression 1 plus 2 nu plus psi into E. So, this becomes 1 plus 2 times Poisson's ratio plus Bridgeman coefficient time's modulus of elasticity of the material.

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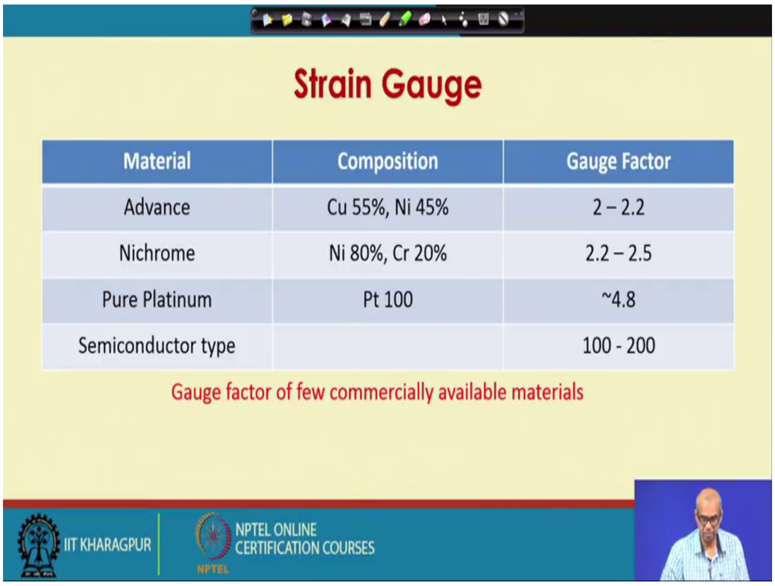

Here, we report some Gauge Factors of commonly used materials for Strain Gauge. Advance, the name of a material whose composition is 55 percent copper and 45 percent nickel. Typically the Gauge Factor lie between 2.2. Nichrome, another alloy of nickel and Chromium; Nickel 80 percent, Chromium 20 percent. Again the Gauge Factor is 2.2 to 2.5. Pure Platinum, the Gauge Factor is higher around 4.8. Strain Gauges are also made of semiconductor materials. A semiconductor material has very high Gauge Factor, it is something like 100 to 200.

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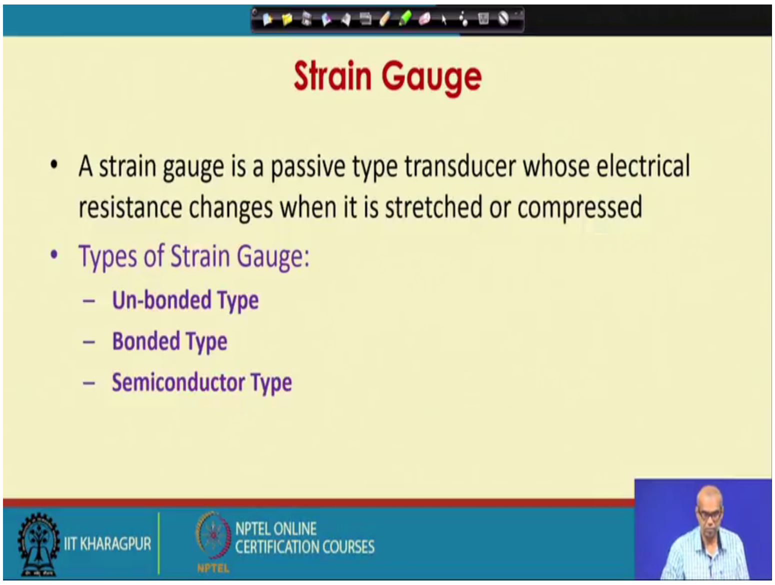

A strain gauge is a passive type transducer whose electrical resistances changes when it is stretched or compressed. There are 2 types of; there are actually various types of strain gauges. 2 very common types are unbounded type and bonded and also there are semiconductor types.

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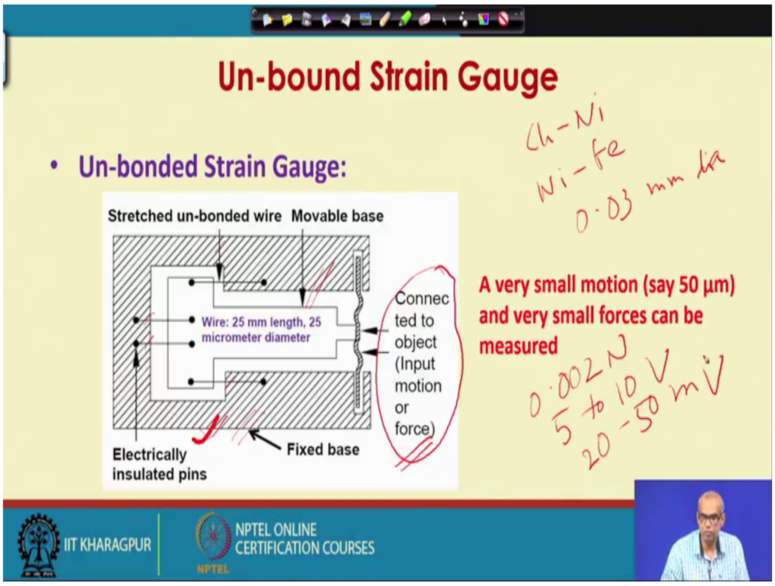

So, let us first look at Un-bounded or Un-bound Strain Gauge. The Un-bounded Strain Gauge consists of a set of electrical wires, strain gauge wires. Look at the diagram. You have a fixed base and you have a Movable base. There are set of electrical wires, their strain gauge wires say made of copper nickel alloy or chrome nickel alloy so on and so forth.

Now, here we show a set of 4 wires. These 4 wires are pre loaded and connected on to this frame as shown. This Strain Gauge will be connected to the 1 arm of the Wheatstone bridge. Initially, the tensions in all these 4 wires are equal because they are equally loaded. Under these circumstances, the bridge, Wheatstone Bridge will be balanced. So, there will not be any output voltage from the Wheatstone Bridge.

Now, let us say this part I connect to the object whose strain has to be measured. Now strain is nothing but a displacement, which is a motion. You can also apply force here. Now when you apply force here, all connect this part to the object whose displacement or stain is to be measured. These wires are so connected. Thus these 2 wires, tension will increase and the tension of 2 other wires will decrease. So now, the wires will be differently loaded. There will be different tensions in these wires. Tensions of 2 wires will increase; tension of 2 wires will decrease.

So, the bridge will no more be balanced. There will be an unbalanced current in the circuit and the output voltage will be a measure of the strain in the object. A very small motion say about 50 micrometer and very small forces can be measured using a Strain Gauge. As we discussed, different wires can be used such as copper nickel alloy, chrome nickel, nickel iron alloy so on and so forth. Typically, the diameters of these wires are 0.03 millimeter. This can sustain a maximum force of above 0.002 Neutron. The excitation, the Wheatstone bridge excitation voltage is typically between 5 to 10 volt and the output from the Wheatstone bridge is typically 20 to 50 millivolt.

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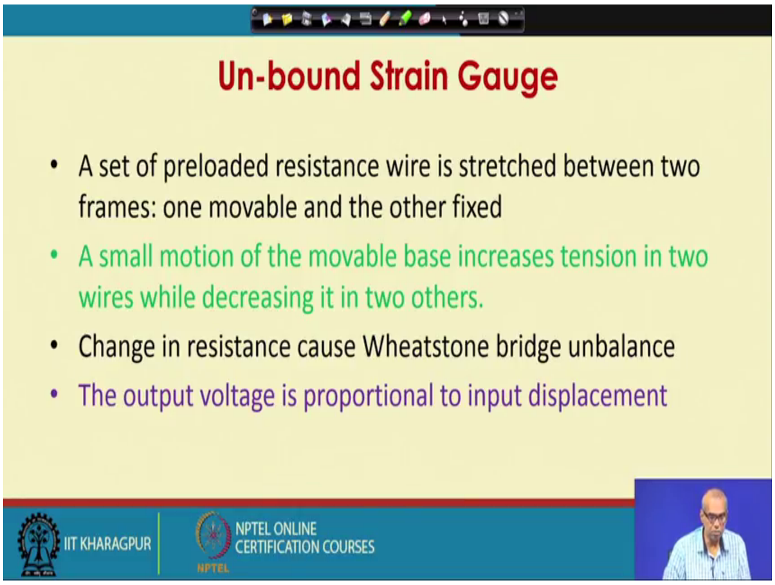

So, one more time, a set of preloaded strain, a set of pre loaded resistance where is stretched between 2 frames; one moveable and the other fixed. A small motion of the moveable base increases tension in 2 wires while decreasing it in 2 others. Change in resistance cause Wheatstone Bridge unbalance. The output voltage is proportional to input displacement.

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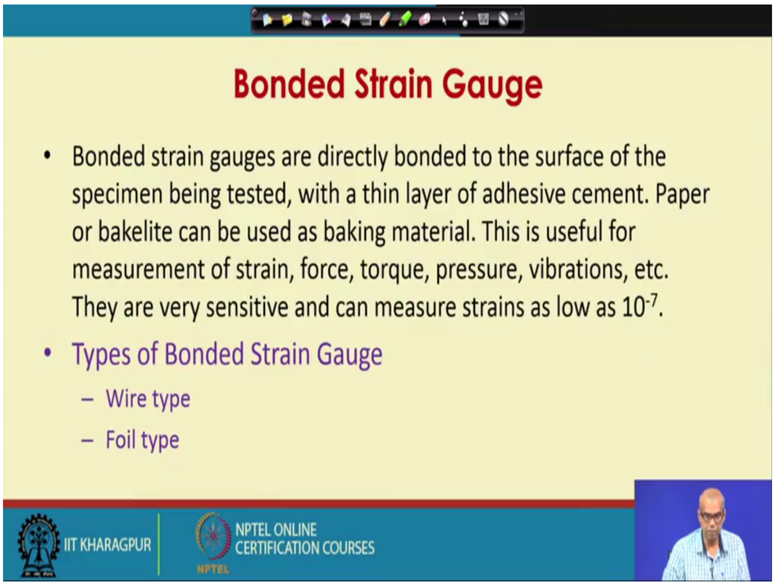

Bonded Strain gauge as the name suggests, the Bonded Strain Gauges are directly bonded to the surface of the specimen that is being tested, with a thin layer of adhesive cement.

So, the sample that is undergoing strain onto the surface of that sample, we attach or bond directly the Strain Gauge. Paper or bakelite can be used as baking material. This is useful for measurement of strain, forced or presser, vibrations etcetera. They are very sensitive and can measure strains as low as 10 to the power minus 7. There are 2 types of bonded strain gauge: Wire type and Foil type.

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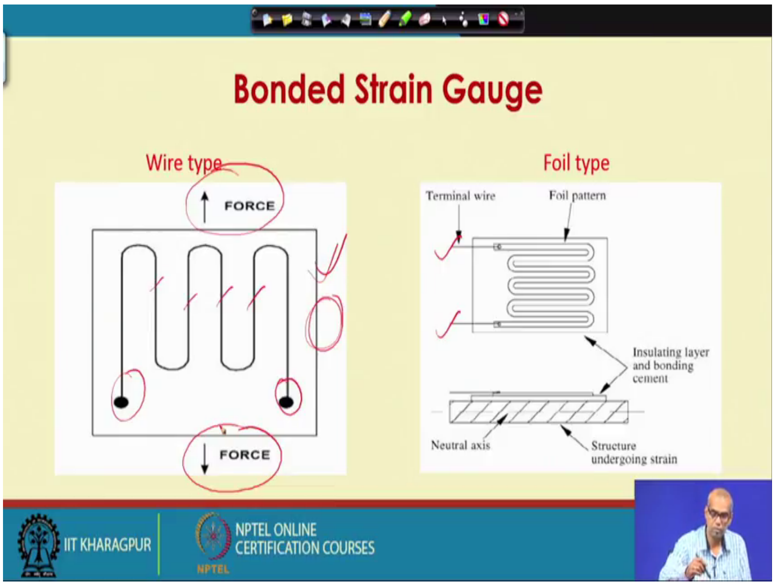

So, this is a schematic of wire type. So, this is and wire which is rigidly bonded onto the surface of the specimen and the specimen is undergoing strain, this is under stray.

Foil type instead of where, we have foils! These are the terminal wires which will go to be connected with the 1 arm of the Wheatstone bridge. So, this will be connected to the Wheatstone bridges.

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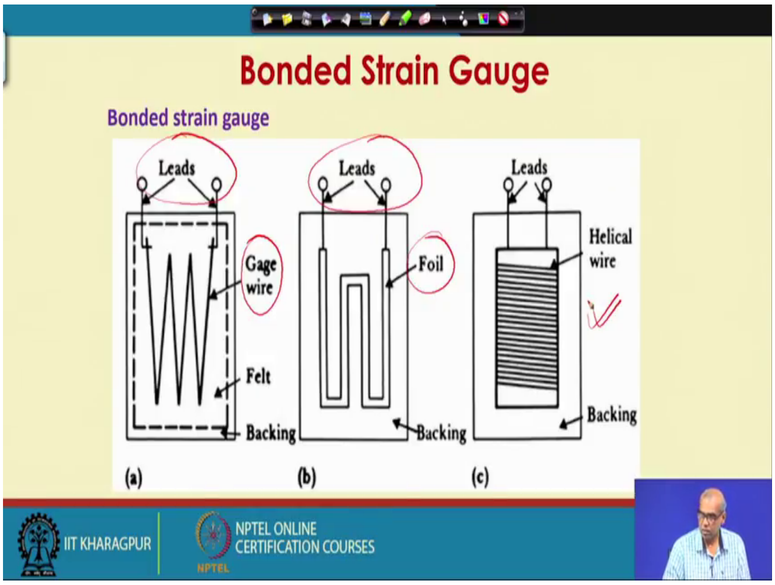

These are some more examples of Bonded Strain Gauge. So essentially, the gauge is made of wire or the gauge is made of foil. These are the leads of this gauge wire; these are the leads of this foil. These leads will be connected to the arm of Wheatstone bridge. Here the gauge where is wounded like helical.

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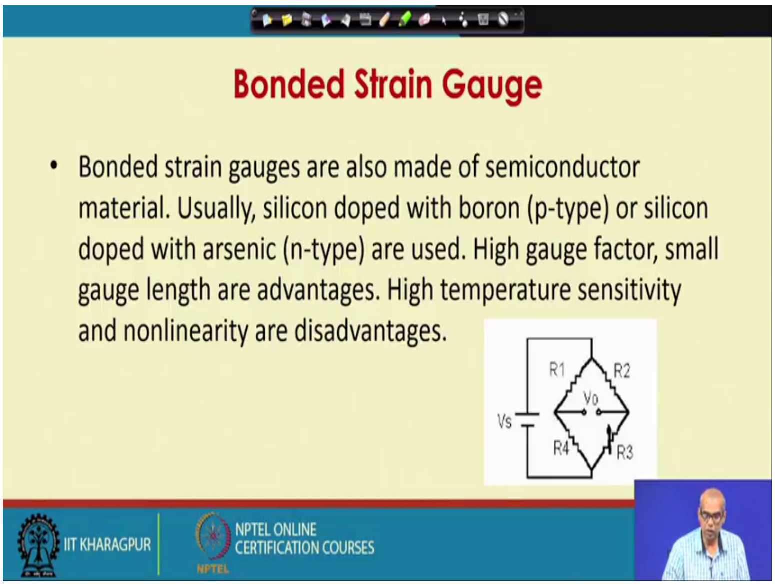

So, Bonded Strain Gauges are also made of semiconductor material. Usually, silicon doped with boron (p-type) or silicon doped with arsenic (n-type) are used. High gauge factor, small gauge lengths are advantages of semiconductor type strain gauge. But high temperature sensitivity and non-linearity are disadvantages. So, semiconductor type Strain Gauges has advantages such as high Gauge factor, small gauge length. But the disadvantages are that the gauge material is highly sensitive to temperature and the relationship is non-linear.

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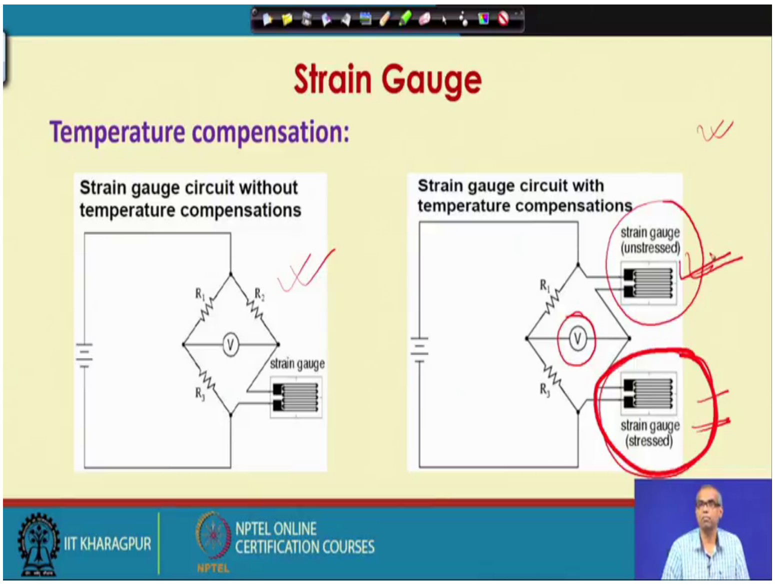

Since, the strain is measured in a Strain Gauge, by measuring the change in resistance, you can imagine that the measurement of strain by Strain Gauge will be sensitive to changes in temperature. Because change in temperature, change in ambient temperature will also cause a change in the resistance. Because resistance is a function of temperature. So, there has to be compensation for the temperature changes.

So, this is how the compensation for the effect of temperature change is done. Look at this; this is a Strain gauge circuit without any temperature compensation. This is a Strain gauge circuit with temperature compensation. So what we do is, this is the Strain gauge which is measuring the strain on the specimen. On the adjacent arm, I attach identical strain gauge. But this is not under strain. Now both the strain gauges are subjected to the same temperature change. So, the change in resistance in this Strain Gauge wires due to change in temperature will be same. But this strain gauge, resistance also changes due to strain. So, therefore, this output voltage will be a function of this strain alone. Because the effect of change in ambient temperature will be canceled by change in resistance in this, Strain Gauge which is not under strain.

So, the temperature compensation can be done by attaching an identical strain gauge to the adjacent arm of the Wheatstone bridge. And that will not be under strain.

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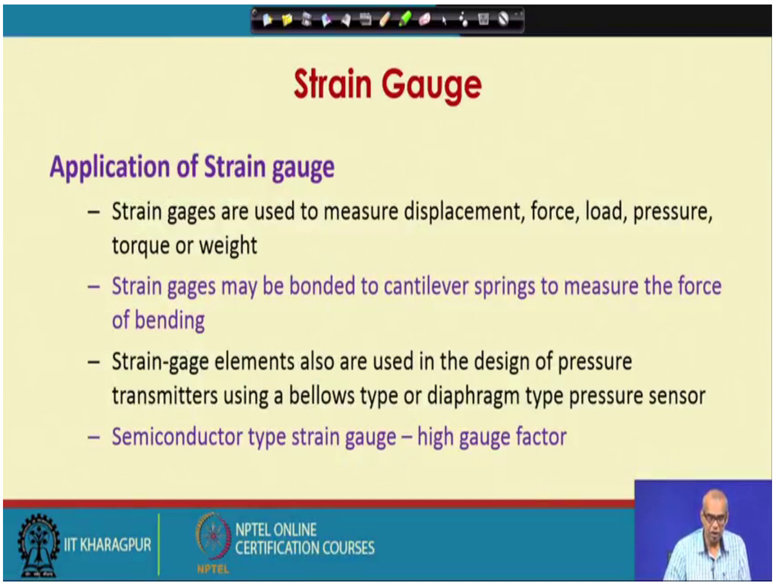

Here some applications of Strain Gauges. Strain Gauges are used to measure displacement, force, load, pressure, torque or weight. Strain Gauges may be bonded to cantilever springs to measure the force of bending. Strain Gauge elements also are used in the design of pressure transmitters, using a bellows type or diaphragm type pressure sensor. We will have more below type and diaphragm time pressure sensors, when you talk about pressure measuring instruments. Semiconductor type strain gauges have very high gauge factor, but sensitivity to change in temperature and non-linearity of disadvantages. So, we stop our lecture 18 here.