Mechatronics

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Lecture - 07
Displacement, Position and Proximity Sensors - I

Welcome you all on this NPTEL online certification course on Mechatronics. Today, I am going to talk about the Sensors. We are starting with the sensors and first we will take up the Displacement, Position and Proximity Sensors. I intend to complete these sensors in two lectures. First of all, let us see what is the difference between the displacement, position and proximity.

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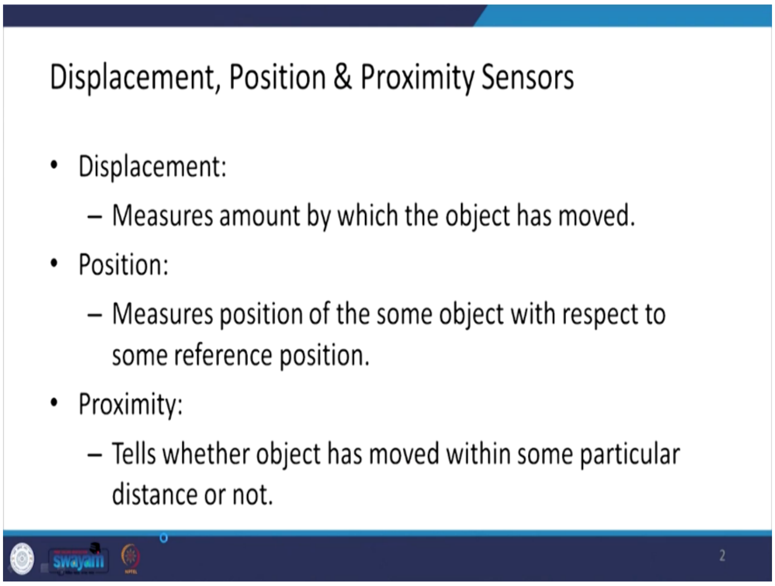

Displacement, it basically measures amount by which the object has moved. And position is basically giving the position of some object when it is described with respect to some reference point.

And proximity basically gives you the nearness or farness, that is it tells whether object has moved within some particular distance or not. So, all these 3 are related with the movement.

So, this lecture and next lecture we are going to devote the various sensors which can measure these 3.

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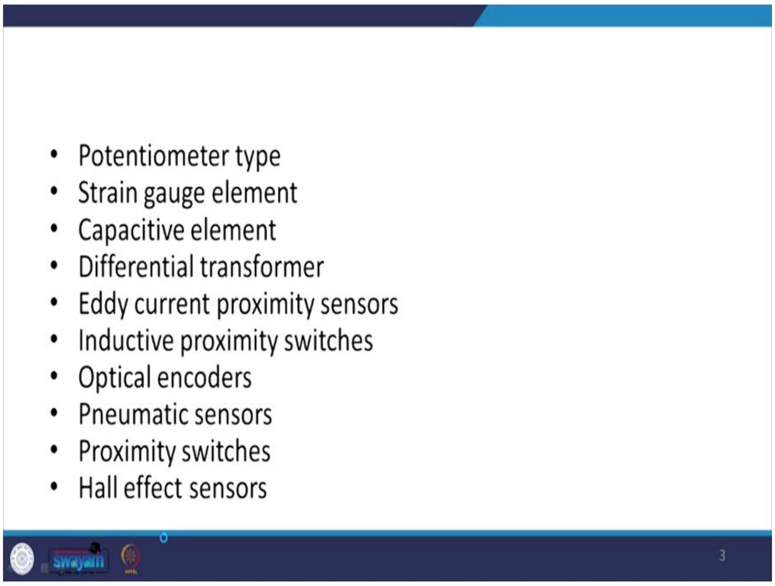

There are many such sensors which are available in the market and which are used for this purpose; for simplest one is the potentiometer type, then we have the strain gauge element, we have capacitive element, differential transformer or what we call it as LVDT.

Then, we have the eddy current proximity sensors, inductive proximity switches, optical encoders, pneumatic sensors, proximity switches and Hall effect sensors. So, these are the some of the sensors which are used for displacement position as well as proximity measurement.

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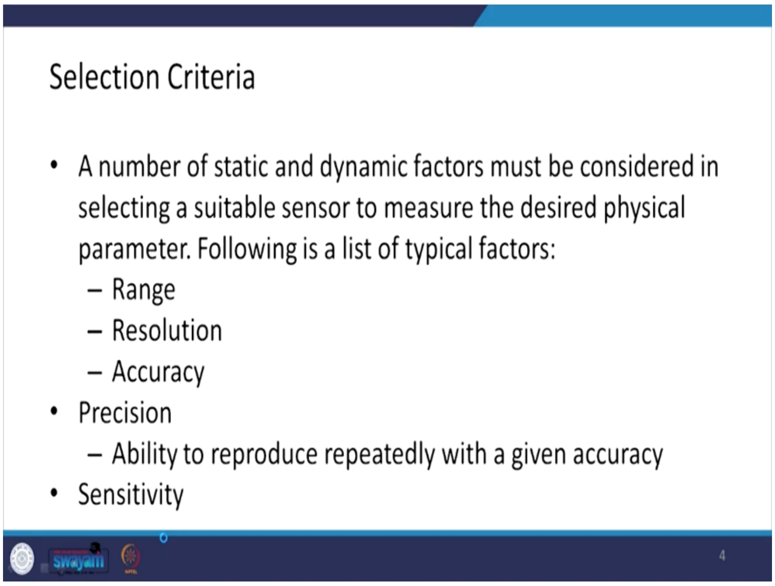

Now, which sensor to select?

So, there has to be certain selection criteria for that and there are number of static and dynamic factors which must be considered while selecting a suitable sensor to measure the desired physical parameters.

These are some of the typical factors such as what range you want, what resolution you want, what accuracy you are interested in, and what precision you want that is a ability to reproduce repeatedly with a given accuracy, what sensitivity you want. So, these are the factor.

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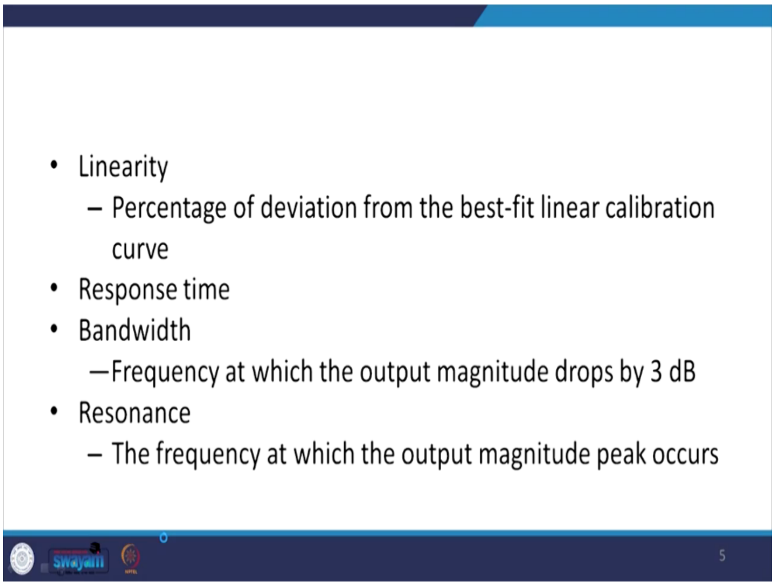

Then, we talk about linearity, it is the percentage of deviation from the best fit linear calibration curve, it is how much we are allowing for that. Then what should be the response time for your sensor. What should be the bandwidth that is frequency at which the output magnitude drops by 3 dB so, what should be the bandwidth of your sensor, and what about the resonance, that is the frequency at which output magnitude peak occurs.

So, these are some of the factors which we take into consideration while selecting the sensors.

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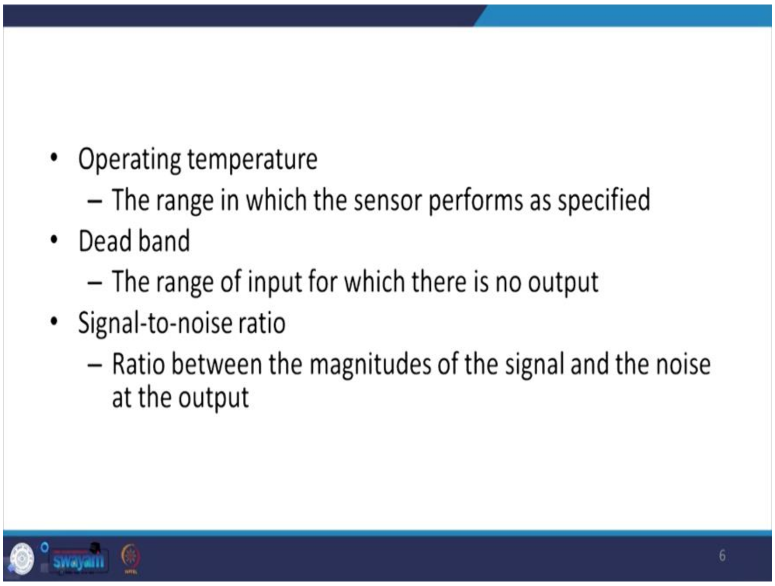

What are the operating range? That is the range in which the sensor performs as specified. Then, what is the dead band? That is the range of input for which there is no output. Some of the definitions of these definitions we have already seen in my previous lecture.

And what is the signal-to-noise ratio? That is the ratio between the magnitude of signal and the noise at the output. So, these are our some of the requirement based on which we can select a particular type of sensor.

Let us begin with the basic simplest one the that is the potentiometer. And the potentiometer is a displacement measuring device. That is, it gives the displacement.

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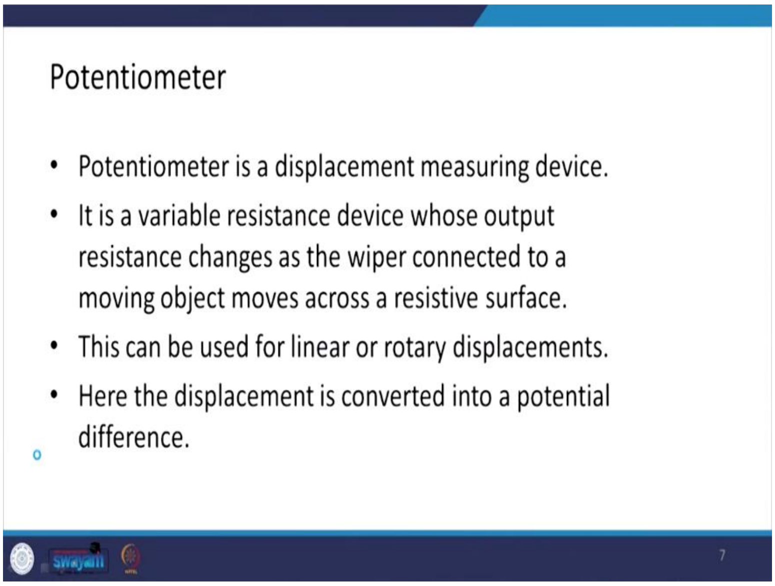

And it is basically a variable resistance device whose output resistance changes as the wiper are connected to the moving objects moves across a resistive surface. We can use the potentiometer either for linear or for rotary displacement measurement, and here basically as a measurable parameter the displacement is converted into a potential difference.

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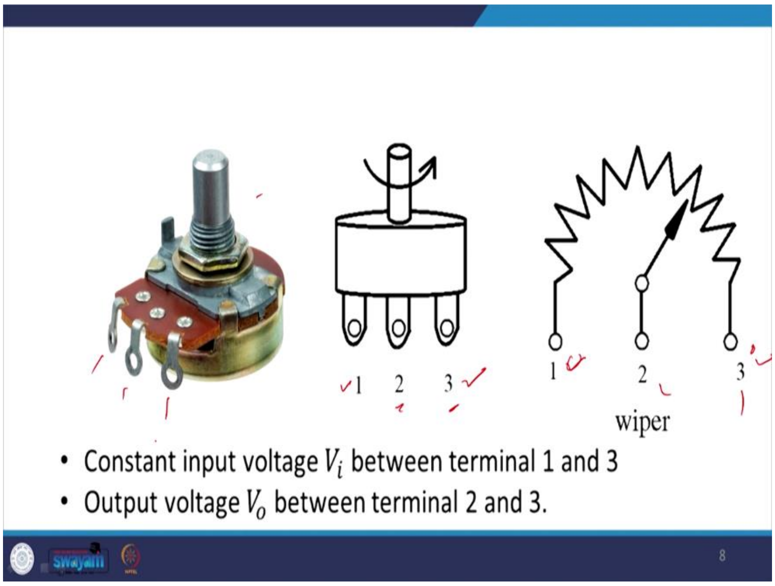

So, here is a figure which we can look at basically. There are 3 terminals in it. We apply a constant input voltage between the terminal 1 and terminal 3. So, this is the terminal 1 and terminal 3 between which we apply a constant input voltage and output voltage is taken between terminal 2 and terminal 3 here. So, from here we take the output and from here we give the input.

And this figure is what we can see in the market it is a commercially available version. There is a knob basically which is rotated and here are the 3 terminals which I talked over here. And this potentiometer we can used for the angular position or angular displacement measurement.

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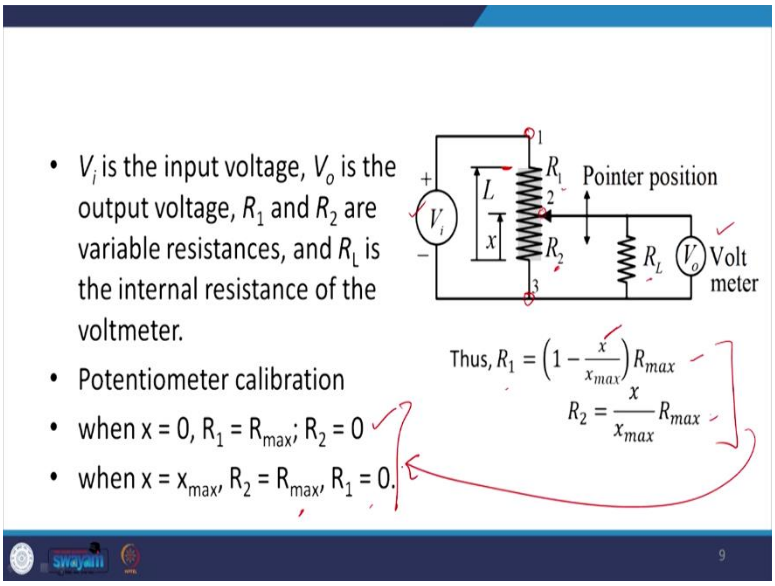

Now, to understand the principle of the measurement let us look at this figure, we can see that we have a variable resistance. So, we can see that here are the 3 terminals, that is terminal 1, terminal 3 and the terminal 2 is on the wiper which is moving.

When we apply an input voltage V_i here and here is the output voltage V_0 and this R_L is the resistance for the voltmeter.

Now, for potentiometer calibration we can see that if, $x = 0$, then at that position $R_1 = R_{max}$, and R_2 =0 in this case.

And when $x = x_{max}$ that is your x is up to here in this position your $R_2 = R_{max}$, and R_1 =0.

So, this description as mathematical relationship is,

$$R_1 = (1 - \frac{x}{x_{max}})R_{max}, R_2 = \frac{x}{x_{max}} R_{max}$$

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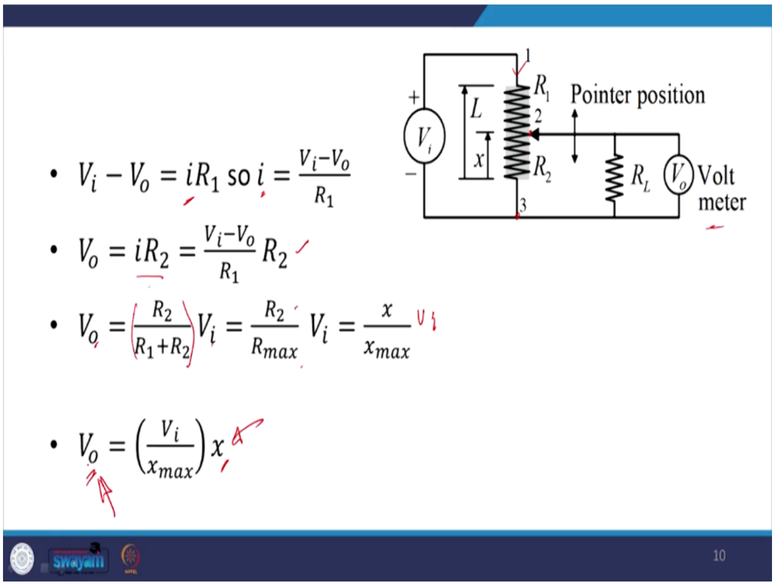

Now, if we write the Kirchhoff's law over here,

$$V_i - V_0 = iR_1, \text{ so } i = \frac{V_i - V_0}{R_1}$$

Similarly,

$$V_0 = iR_2 = \frac{V_i - V_0}{R_1} R_2$$

Or I can simplify this equation and write V_0 in terms of V_i,

$$V_0 = \left(\frac{R_2}{R_1 + R_2}\right) V_i = \frac{R_2}{R_{max}} V_i = \frac{x}{x_{max}}$$

And from here I can write,

$$V_0 = \left(\frac{V_i}{x_{max}}\right) x$$

So, we can see that the output voltage here it is directly proportional to x. And this is how we basically by measuring the V_0 we are able to measure the x. So, we can calibrate the x in terms of the V_0 and, this is how we measure the displacement. Same principle applies for a rotary potentiometer.

Next, sensor I will talk about is strain gauge. We come across many types of strain gauges in our laboratories. In the electrical strain gauge as the name indicates basically it measures a strain and it could be either a metallic wire or a metal foil strip or a strip of semiconductor material which can be pasted on a surface basically. And when subjected to strain basically its resistance R changes.

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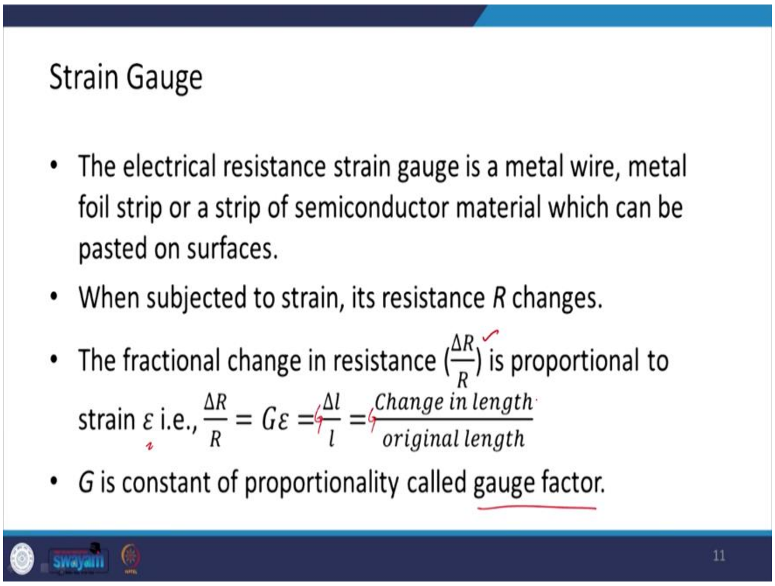

So, the fraction change in resistance that is $(\Delta R/R)$ is proportional to the strain. So, this is a basic principle of it. So,

$$\frac{\Delta R}{R} = G\varepsilon = G\frac{\Delta l}{l} = G\frac{Change\ in\ length}{original\ length}$$

where G is a constant of proportionality which we called as the gauge factor

Now, G for metal or wire foil strain gauges is about 2, whereas, G for silicon p type semiconductor strain gauge is about plus 100, and for n type silicon semiconductor strain gauge G value is a around minus 100, and this G value is usually supplied by the manufacturer.

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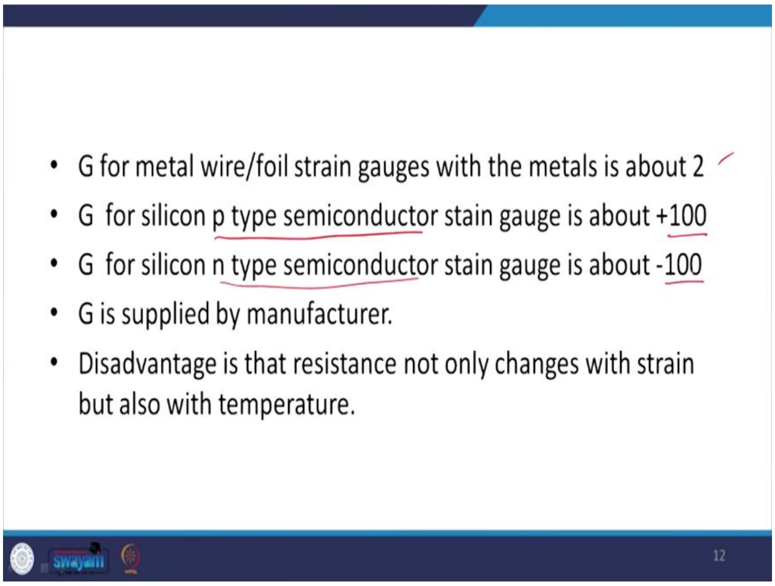

Now, the disadvantage of strain gauges is that the resistance changes not only because of the strain, but also with the temperature. So, we have to keep this factor always in mind. And we have to work on something to eliminate this change in strain because of the temperature or change in resistance because of the temperature.

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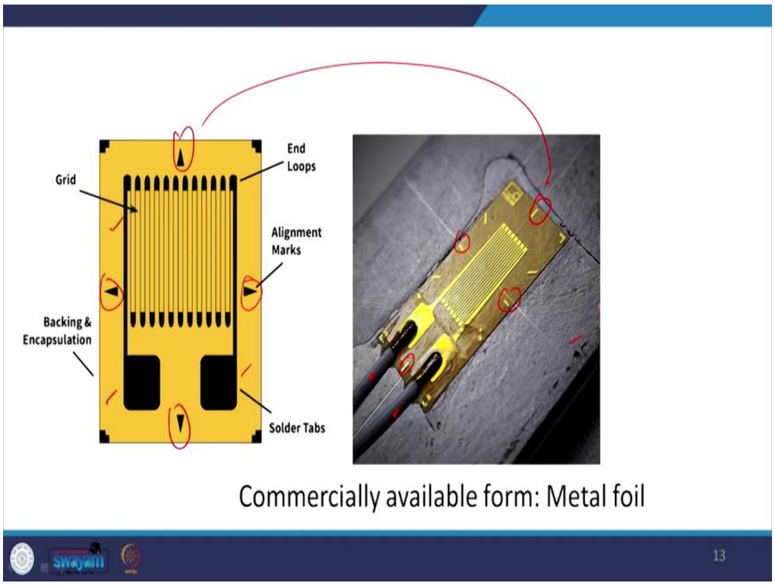

So, this is the commercially available form of the strain gauge. We can see that there is solder tab basically here and we have the grid here, and the here are alignment marks as you can see 1, 2, 3, and 4 and basically these alignment marks are used to fix it up here in a surface. So, you can see that with the help of this alignment mark we can fix it on a surface properly and from here we can connect the two leads. And this is the surface for which you want to measure the strain or say displacement.

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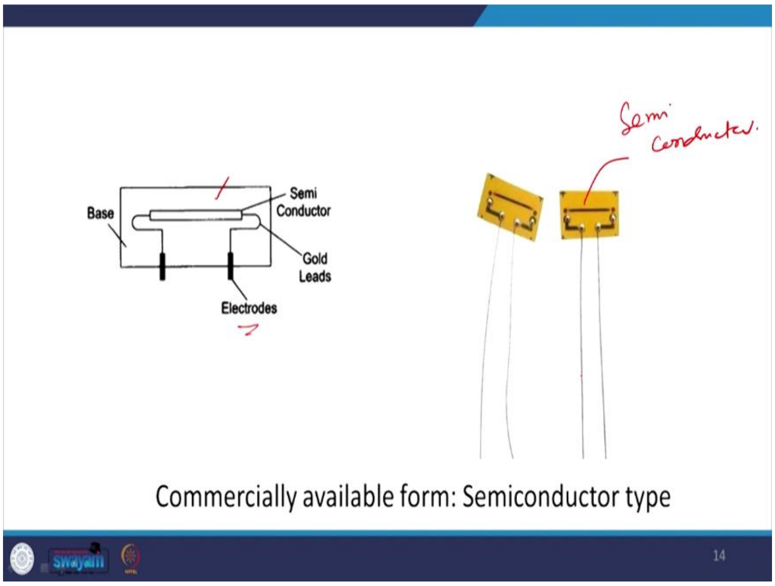

And this is the basically commercially available form for the semiconductor type of strain gauge. Here is the semiconductor and here we can see in the sketch and there are gold leads basically there is a base and there are electrodes over here from where it can be connected. So, this is the commercially available form of the semiconductor type strain gauges.

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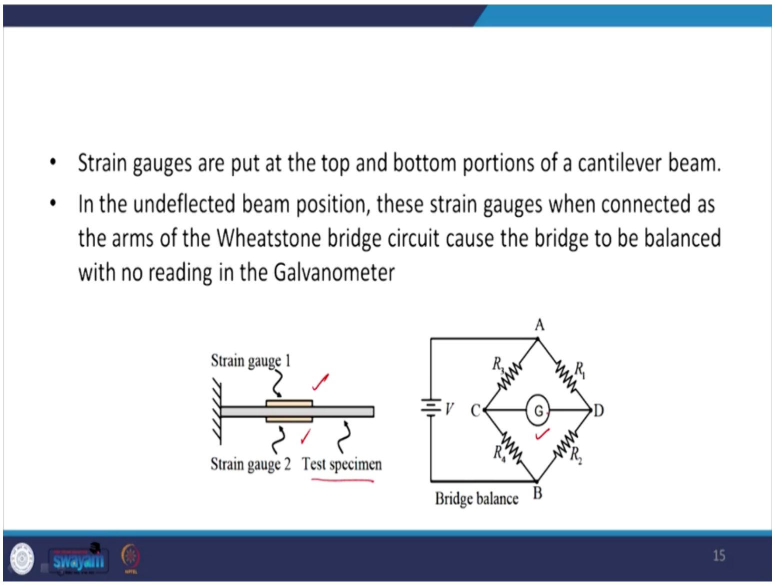

Now, how these strain gauges are used? So, strain gauges are put at the top and bottom portion of say a cantilever beam. There is a strain gauge 1 at the top, strain gauge 2 at the bottom, and here we have the test specimen. And in the undeflected beam position, these strain gauges when connected to the arms of a Wheatstone bridge, the circuit cause bridge to be balanced with no reading in the Galvanometer.

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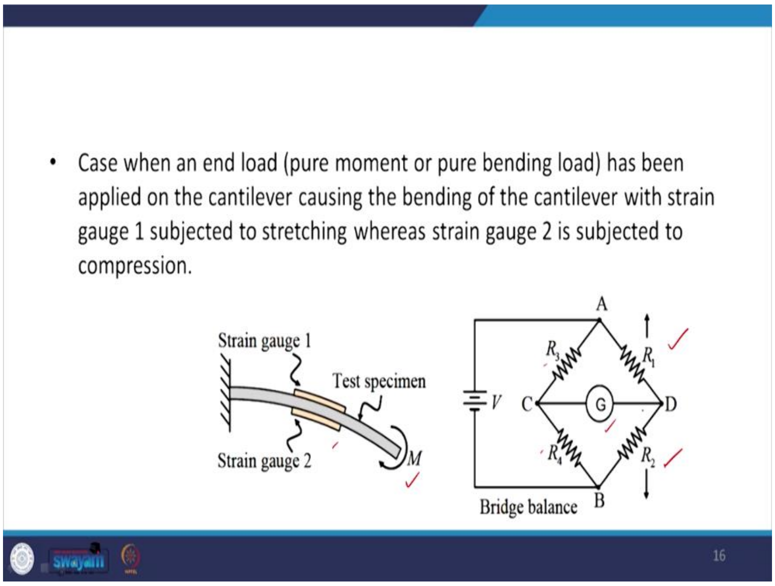

And suppose if we apply say a certain moment over here or we apply certain load over here, either your pure movement or pure bending load it is applied at the cantilever causing the beam to be subjected to a strain. Then, we are going to have their stretching. The stretching at the top one top strain gauge and compression on the bottom strain gauge.

So, here we can see that the strain for top increases, and strain for the bottom one decreases, and there is a deflection in the galvanometer over here. And then we can by varying the magnitude of this R 3 and R 4 basically, we can find out; we can find out by what amount the resistance change has taken place.

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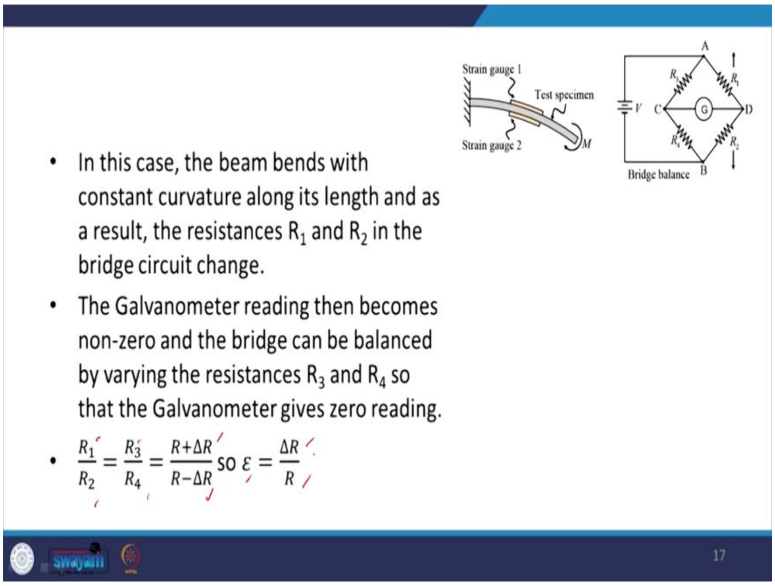

So, here for the Wheatstone bridge we know,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} = \frac{R + \Delta R}{R - \Delta R}$$

At the null position actually R_3 and R_4 are equal basically, so in this new position basically this R_3 and R_4 will be $R + \Delta R$ because for the top one there is an increase in resistance and for the bottom one, we have $R - \Delta R$ because there is going to be a decrease in the resistance.

So, from here basically we can find out what is the,

$$\text{strain } (\varepsilon) = \frac{\Delta R}{R}.$$

This in turns gives us how much is the displacement.

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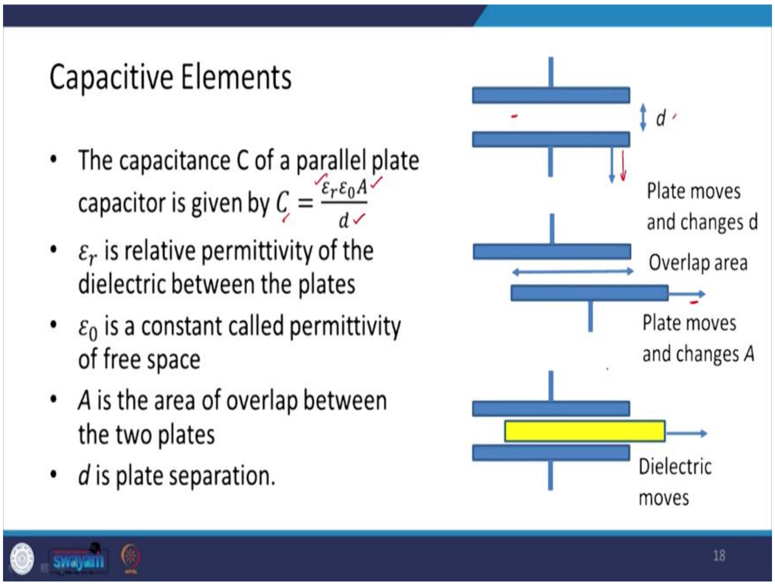

Next, let us look at capacitive type of elements which are used to measure the displacement. We have studied in our higher secondary school about the capacitance of a parallel plate capacitor.

Basically, this is given by,

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

where ε_r is relative permittivity of the dielectric between the plates here, and ε_0 is a constant called permittivity of the free space, and A is the area of overlap between the plates, and d is the plate separation.

So, there are 3 factors that are responsible for the change of capacitance and these factors are either the dielectric medium or the area of overlap or the plate separation. So, here let us consider a case where we change the capacitance by changing the d.

So, if this is the parallel plates capacitor with the two plates, if we change the d here, so this is how if I move this plate in this direction, we are going to change the value of d, so I am going to change the value of C. Or the second case could be if we move this plate say in this direction, then there is an overlapping area which is going to change and the capacitance is going to change.

Or I can give the motion to the dielectric material and I can change the ε_r value. And in this way, we can measure the C. So, we can see that in either of the 3 cases there is a motion involved. So, this motion could be calibrated in terms of the capacitance.

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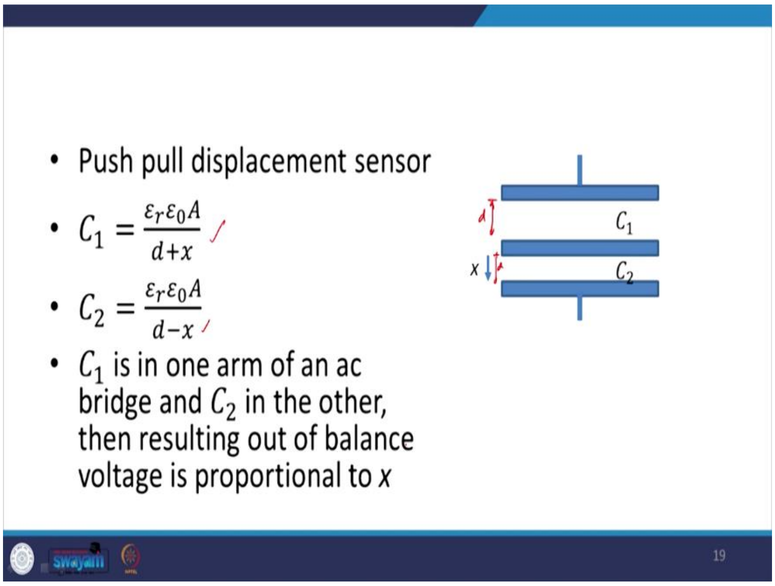

Now, to implement it practically the arrangement is called as a push pull type of displacement sensor. There are 3 plates, and the middle plate if we are moving then the capacitance between the first and middle plate is given by this one.

$$C_1 = \frac{\varepsilon_r \varepsilon_0 A}{d + x}$$

$$C_2 = \frac{\varepsilon_r \varepsilon_0 A}{d - x}$$

And C_1 can be made in one arm of an ac bridge, and similarly C_2 in the other, then the resulting out of balance voltage is proportional to x. And this is how we can measure the x directly.

With the help of two plate capacitor if you try to measure the x, then we will see that there is a non-linear relationship and that creates some problem for us. So, the push pull type arrangement is used where we have a linear relationship.

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This is the commercially available form of the capacitive sensor which is available in the market.

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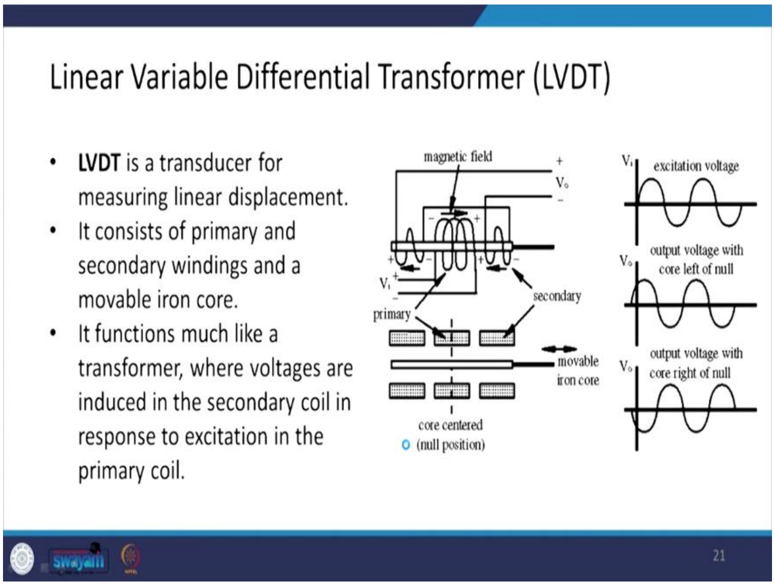

Next, let us look at the linear variable differential transformer. Another very important displacement sensor, and in short it is called as LVDT. This is used for measuring the linear displacement and this basically consist of a primary coil, and there is a secondary coil, and there is a movable iron core in between. It's working principle is similar to that of the transformer, where voltage are induced in the secondary coil in response to the excitation in the primary coil.

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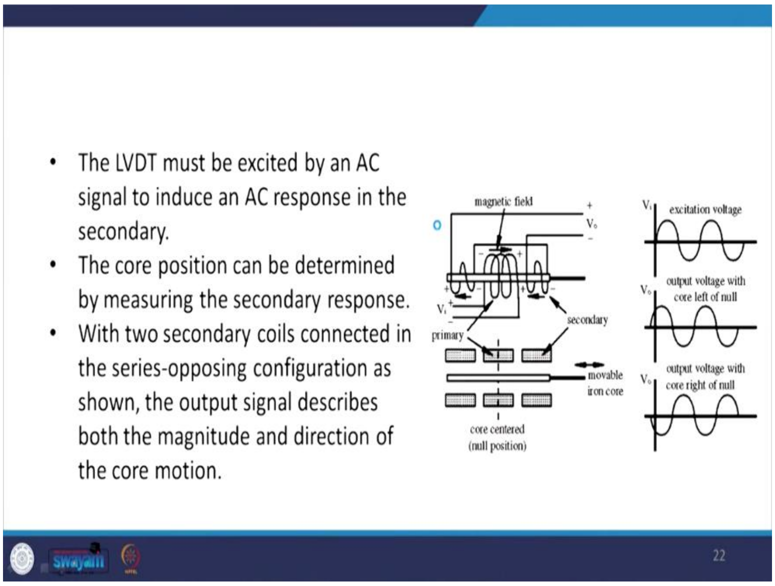

So, this LVDT must be excited by AC signal to induce an AC response in the secondary coil and the core position can be determined by measuring the secondary response. When the two secondary coils are connected in the series in the opposing configuration, as we can see here, that is a '±' and then you have '-' here and '+' here. This configuration is what is called as the opposing configuration.

And in this configuration basically we can see that when the core is in a centrally position and by moving from the centre, we can see the response that is the output one. So, if this is the excitation voltage V_i, output voltage with core left to the null is this one, we can see that and output voltage with core right of the null is actually this one. So, this is how it can be seen.

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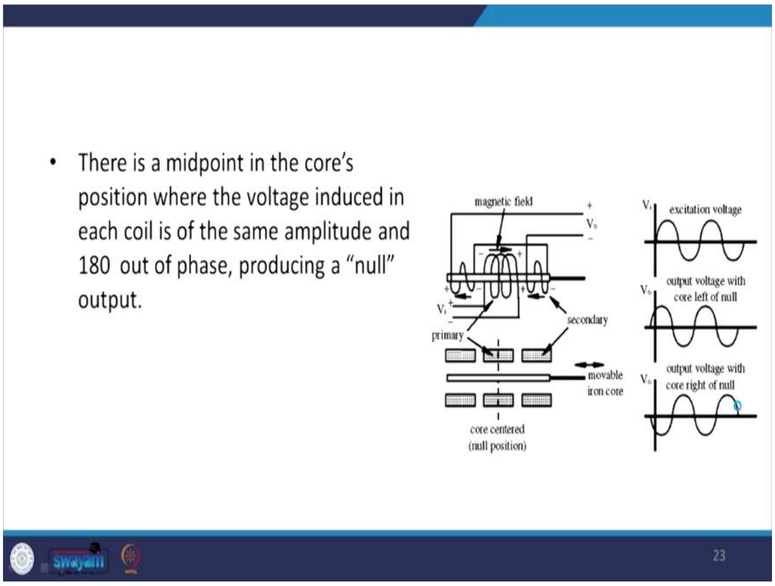

So, there is a midpoint in the core position where the voltage induced in each coil is same amplitude and 180^0 out of phase and producing a null output. So, this is how we identify that null position and then with respect to that null position we can see whether the core is moving towards left or it is moving towards the right.

And as the core moves from the null position the output amplitude increases. Here, we can see that linearly. Whether we are going towards, right or we are going towards left there is a linear range and after which it becomes non-linear. So, we have to operate it in this linear range only.

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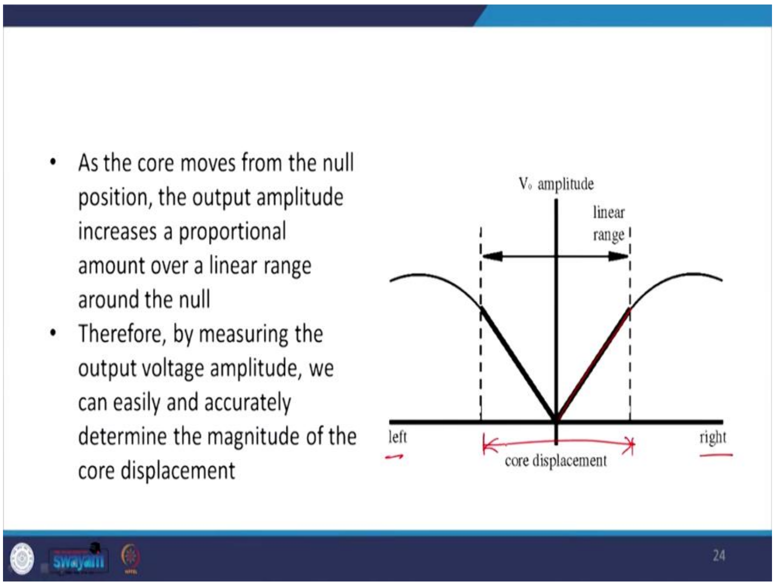

This we have to ensure by measuring the output voltage. Here, we can see by what amount the core has got displaced.

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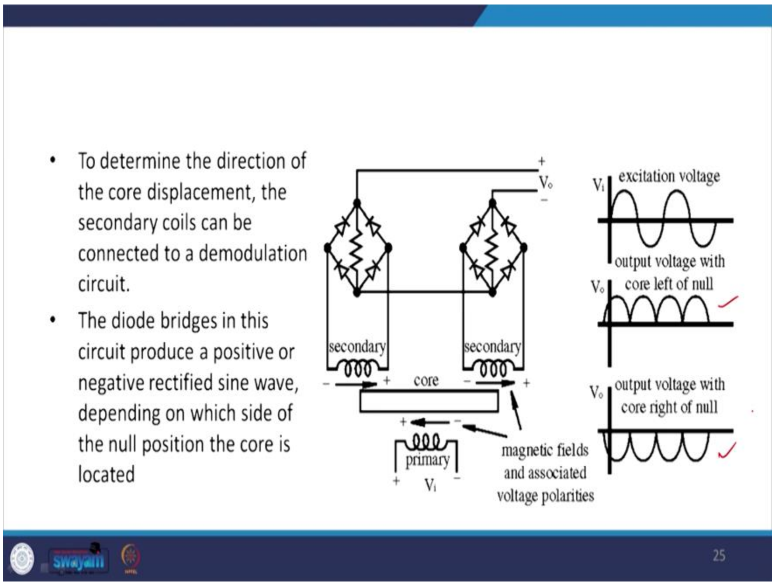

And, further this voltage we can make a unidirectional by using a bridge circuit. That has been already discussed during the semiconductor electronics.

So, the diode bridges in this circuit produce a positive or negative rectified sine wave depending on which side of the null position the core is located. It is either all positive side or all the negative side. So, this way basically we can measure the linear displacement.

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And this is the commercially available form of the LVDT which is available in the market.

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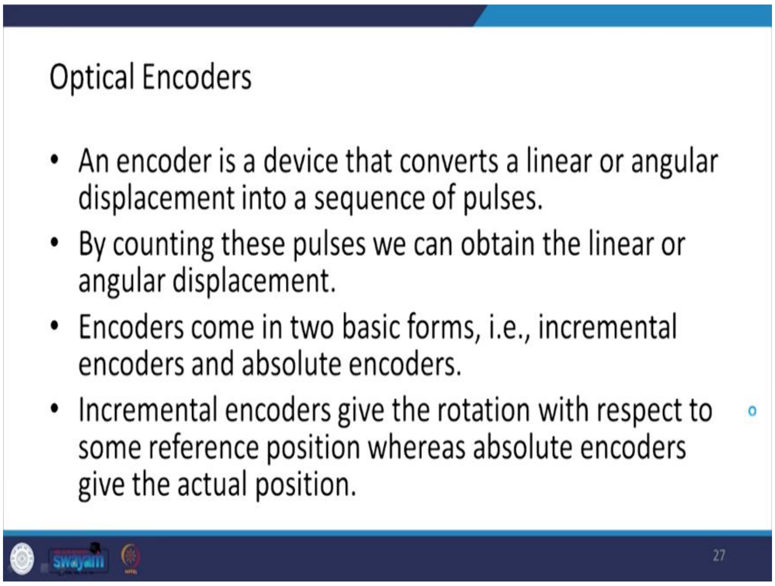

Next, let us look at the optical encoders. It is an another very important device to measure the linear and angular displacement. So, in this lecture, I will be considering one type of an optical encoder and in my consecutive lecture I will be taking another type that is the absolute one. So, an encoder is a device that converts a linear or angular displacement into the sequence of pulses, and by counting these pulses we can obtain the linear or angular displacements. As I said they come basically in two forms, one is the incremental encoder and another is the absolute encoder. The incremental encoders give the rotation with respect to some reference position, whereas the absolute encoder they give the actual position. Here basically we can see the is schematic diagram for the incremental encoder.

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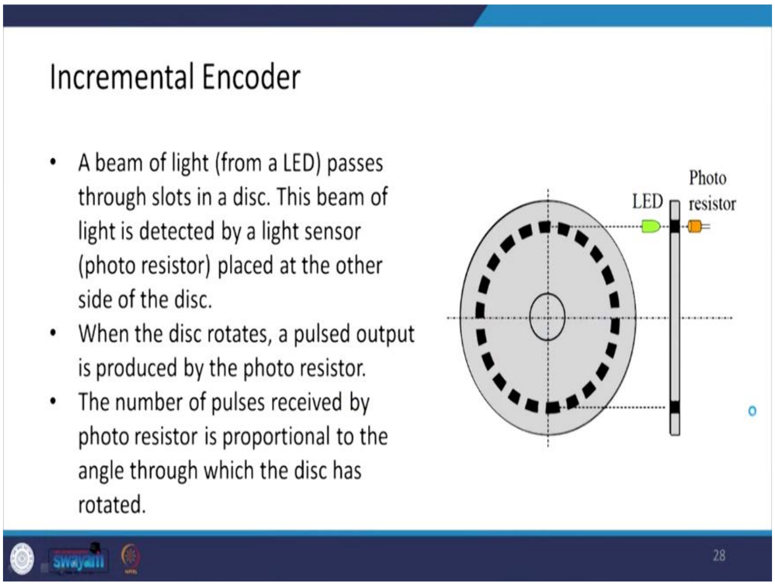

Here, we have a slotted disc, at one side of the disc there is a light emitting diode and at the other side we have a photo resistor. So, a beam of light from LED passes through the slot in a disc. The beam of light is detected by a light sensor usually the photo resistor placed at the other side of the disc and when the disc rotates the pulse output is produced by the photo resistor. Now, the number of pulses are received by the photo resistor is proportional to the angle through which the disc has rotated.

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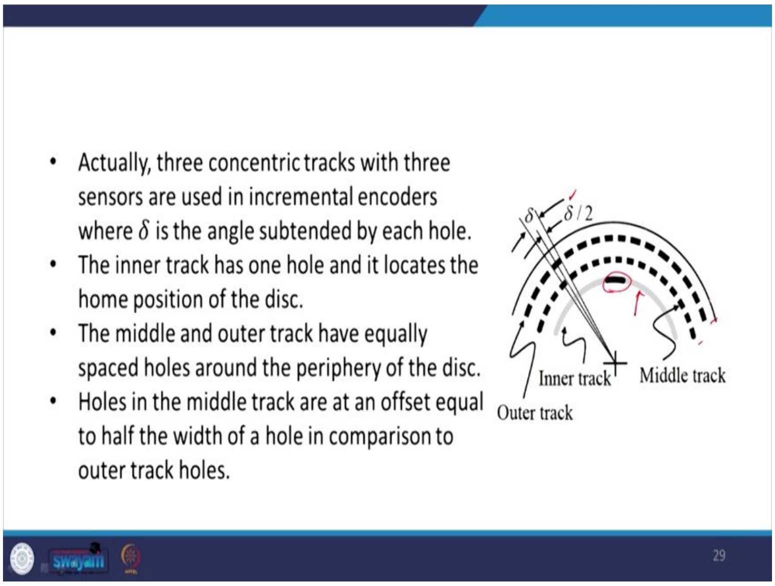

Actually, there are three concentric discs, there is an inner disc, then that is the inner track, there is a middle track, and there is an outer track. So, there are concentric track. As I said the three sensors are used in incremental encoder and this delta is the angle subtended by each hole. So, for referencing purpose there is an inner track has one hole and it locates the home position of the disc. The middle and outer track have equally spaced hole around the periphery of the disc as we can see over here, and holes in the middle track are at an offset equal to half of the width of the hole in comparison to the outer track. So, there is an offset that actually helps us in sensing the direction.

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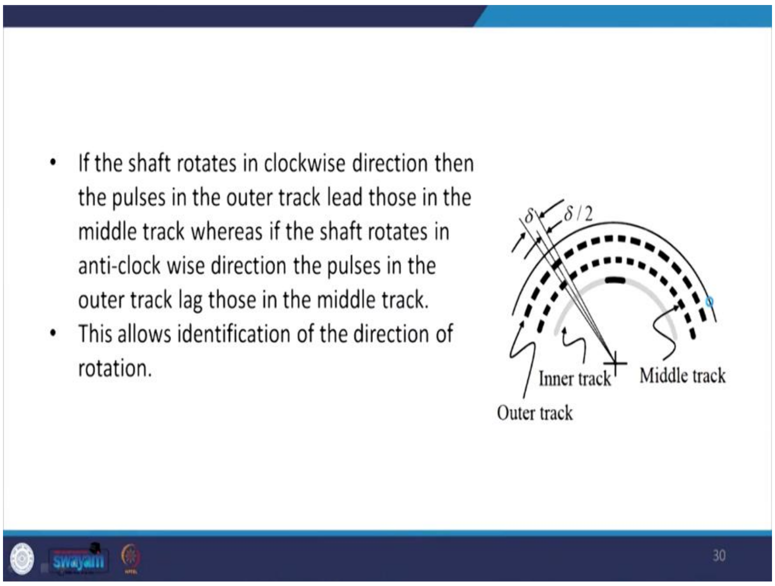

So, if the shaft rotates in clockwise direction, then the pulses in the outer track lead those in the middle one, whereas if the shaft rotate in the anti-clockwise direction, then pulses in the outer track lag those of the middle one. And as I told you earlier basically this tells us in which direction it is rotating, whether it is rotating in the clockwise or it is rotating in the anti-clockwise direction.

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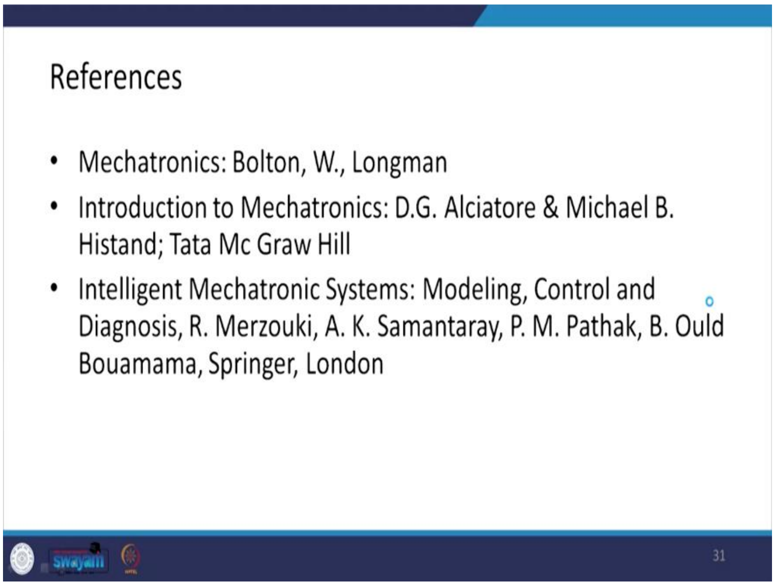

So, these are the references which you can use. Mechatronics by Bolton, then Mechatronics by Alciatore and Michael, and also there is our own book on Intelligent Mechatronic System which you can refer for further reading. In next video, I will be talking about the absolute encoder as well as we will be seeing some of the proximity sensors also.

Thank you.