Design of Mechatronic Systems
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Lecture 3
Elements of Mechatronic Systems – Part II

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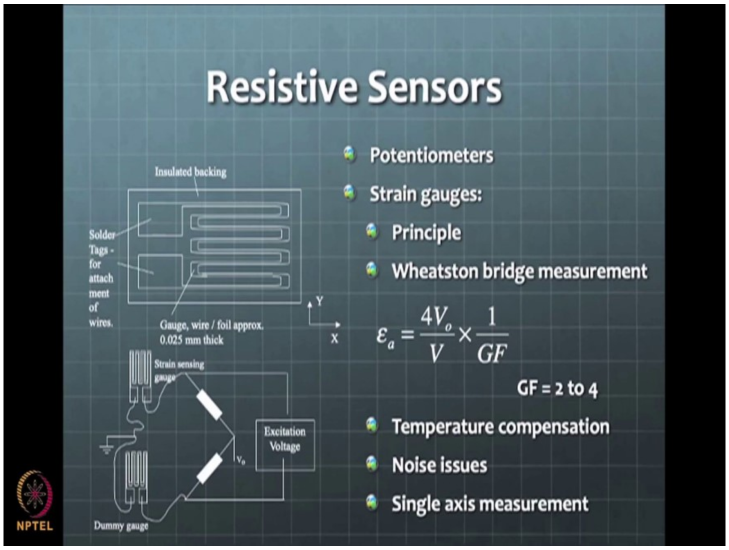

Resistive sensors, you might have already seen or maybe you might be seeing for the first time I do not know. So, these are typically the strain gauges are resistive sensors. So, what people do is they lay down this architecture of a wire which is running across this batch of the sensor and this wire is actually some kind of a metal which is laid on some small very thin plastic substrate and when you when you stick it to some metal or someplace where you want to sense the strain then when it is stuck there and you start bending that beam or say for example, you have your steel ruler that you use for measurement.

That steel ruler, if you imagine this patch is stuck on that steel ruler at one end and you hold that end firmly and then you apply some a bending force and the other end then the strain that will happen at this end will get sense by using this strain gauge sensor. Now, you might have seen this formula principle and so, the principle of operation here is just that the resistance value R which is equal to $\rho L/A$ where ρ is resistivity, as the length changes δL change in the length will cause a change in the resistance.

That is the basic principle on which this typical strain gauges or metallic strain gauges are based on. So, typically the gauge factor will be 2 for the metals, but then there are some other ways in the resistance in the material can change. So, if you have the resistivity change itself ρ change itself happening then your gauge factor can be enhanced to higher values.

So, nowadays there are sensors that are coming up in the market, which will have much higher gauge factor. So, these are what kind of sensor can you think, whether analog or digital? They are analog sensors. There is nothing digital here. So, you apply the voltage and in some a Wheatstone bridge configuration and you keep the strain and then continuous change in the voltage will, will happen the output of the sensor.

And then to interface it with microcontroller you need some kind of conversion of analog to digital, then you can interface with it. There will be some of the issues when you start practically using these sensors. There will be temperature considerations, there will be noise issues and then if you want to use whether you want to do single axis or single sensor kind of a measurement or you need to kind of use what kind of configuration that you want to use, that depends.

So, we will see some I will post some material on that in the thing to you to refer to and see half bridge configuration, full bridge configuration. Now, what are the formulas that are available? There they are directly available. One can derive them by using Kirchhoff's laws, but we do not need to get into probably in details. Mainly it is just application of Kirchhoff's laws and like using that for finding out some output for the strain gauge, that kind of exercise.

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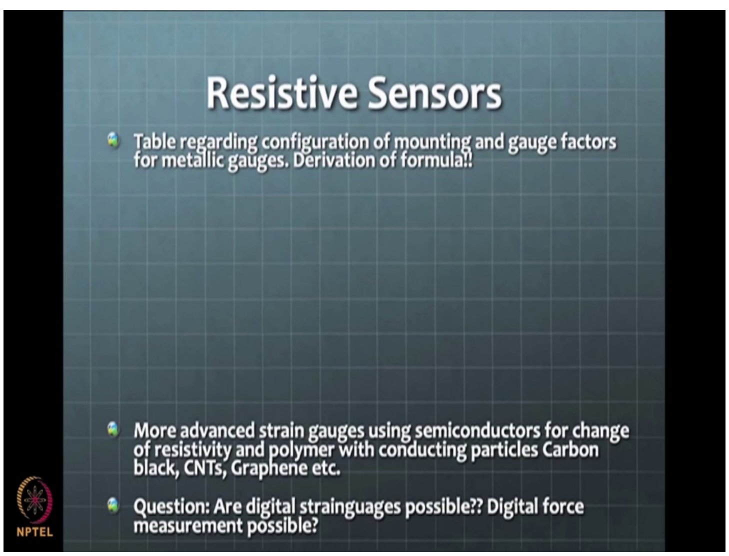

So, this table I will post in the notes. Then you can have this more advanced now semiconductor based in this silicon for example, when used as a strain sensor, the basic difference is that we are not just dependent upon the length of change there. So, suppose we lay a silicon strain gauge, then the difference from the metal is that like you know in the formula you have ρL/A as a resistance.

So, ρ is a resistivity. Now, this resistivity itself changes in the semiconductor strain gauges. So, it is basically based on the principle of the flow of electrons that happen inside the semiconductor. So, that the distances change for the electron to jump from one kind of a molecule to other molecule to create a flow path that change itself affects the resistivity in the in case of semiconductors, in case of metals you will have a free electron.

So, there is no such need there, but in in semiconductors you will have that possibility happening and based on that you can create a invariant very very highly sensitive strain gauge sensors based on the semiconductor principle and that sensitivity is important for the noise consideration. So, if you have very highly sensitive sensor then typically the sensor to noise ratio can be minimized. So, that is a principle that one can use for having to deal with noise in some way.

Then we can have particles of conducting material in some non-conducting polymer. That can also create some resistive sensor, which will have a very high gauge factor possibility. The same principle, you have a polymer matrix in which the carbon particles for example are there and carbon particles conducting or convert carbon nanotubes for example, or graphene for example, there is conducting domains in non-conducting material. So, the I mean the boundary is very very small I mean it is not very far away a body.

It is a dense packing of these particles in the parliament matrix and just electrons have to jump between the in the gap that is created by the polymer between the two say carbon nanotubes for example and this jump will be kind of creating resistance for the path and as you bend or as you give a strain the length of the jump starts increasing.

So, amount by which the electron has to jump to get to the next conducting path that increases and that because of that, you can imagine that, small increase in the distance will have a large possibility for the large voltage needed for this jump to happen in some sense. So, the resistance change would be very drastic for a small even a small change in the strain.

So, this is how the newer ways of creating these strain gauge sensors are typically coming up in the market. So, think about this question, can you have a digital strain gauge possibility? The output strain gauge can be digital. So, think about this. So, once you have some ways of thinking this classification, can we see, Can I have this digital domain sensing possible? That can open up some interesting innovative ideas in your mind.

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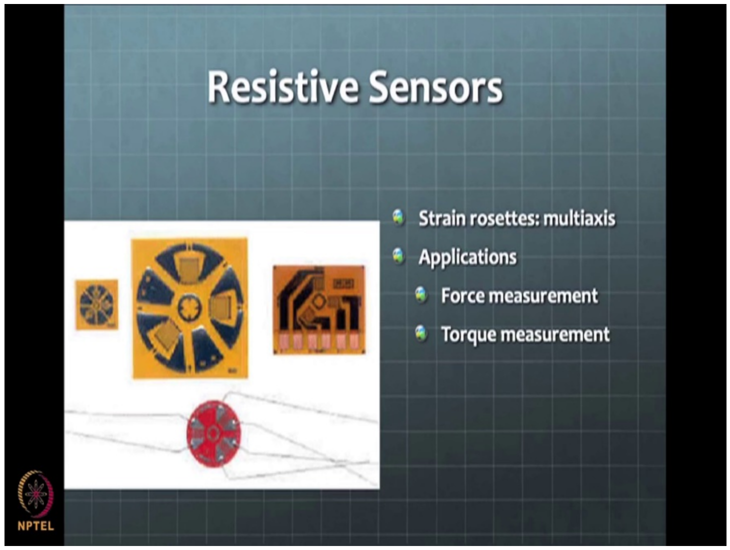

So, these are some pictures of actually strain gauge sensors for different kinds of configurations and making sure, we want to measure something torque measurement, if you want to do in place it in some, so this is called strain rosette. So, there are multiple sensors put together to get a specific measurement.

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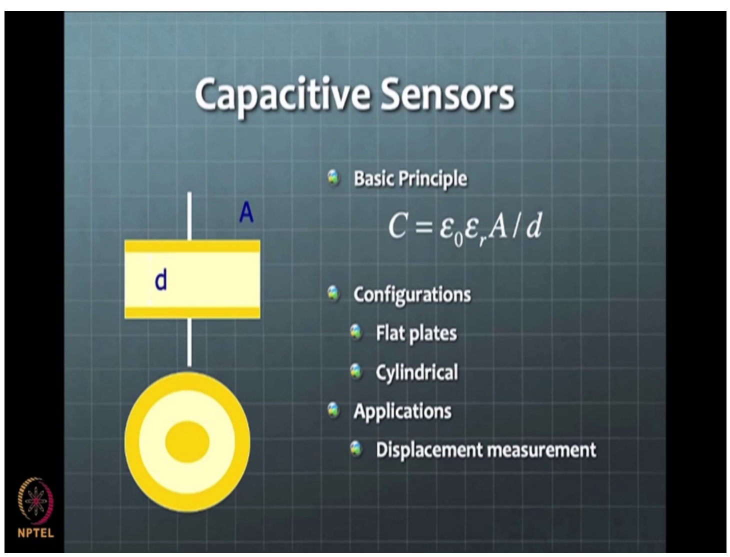

Then you can have a capacity principle to operate, the basic principle of capacitance, is εA/d. So, this A is the area of the capacitor, d is the gap between the two electrodes that are used in the capacitor. So, you can have many different kinds of configurations here, flat plate configuration, cylindrical configuration and things like that and typical application to capacitive sensors are used in are displacement.

So, there is normally this formula is applicable when there are no fringe field but typically there will be a fringe field from here to here from plates, from the side of the plates the electric lines or lines of electric field may not be completely going straight from the corners and the corners may they may have some small bend that is happening. So, this bend will contribute to some change in the capacitance which is not captured by this formula, but typically that may that may have to be done in or dealt with in some way in the application depending upon how much accuracy that you would need in these measurements.

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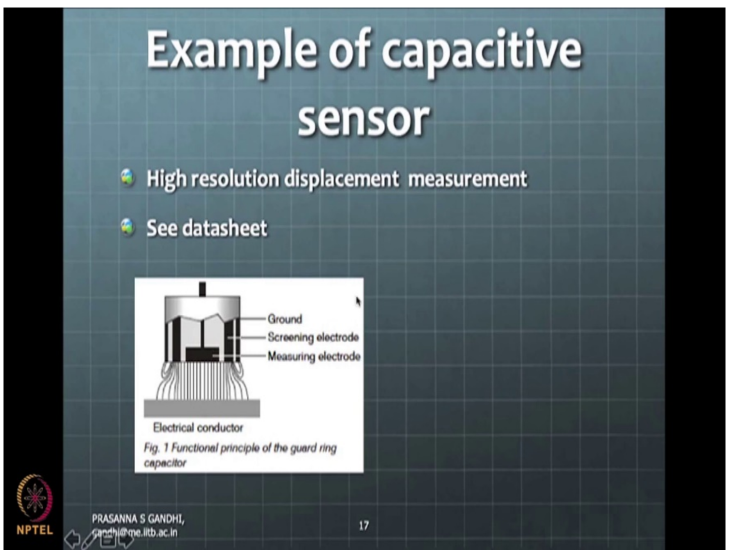

So, one of the examples of this capacitor sensor is this, this way of doing things. Where you have a surface which is electrical conductor and but it is not participating really in a capacitive measurement actively in some way. So, for example, you have this measurement electrode which is giving the field.

So, to avoid fringe field they have this additional secondary screening electrodes around here and then there is a ground. This is like how they place typically the sensor elements in the system and this electrical conductor is where surface which from which we want to measure the distance of the probe. See, this is the probe here.

So, this electrical conductor is grounded. So, that you form a capacitance between these two. So, that way it is active part of the sensor, but it is not really you do not need it to be constructed with sensor. You can have this probe separately and then you just put a ground on this electrode and you form this capacitance here and this can be extremely high sensitivity displacement measurement possibility.

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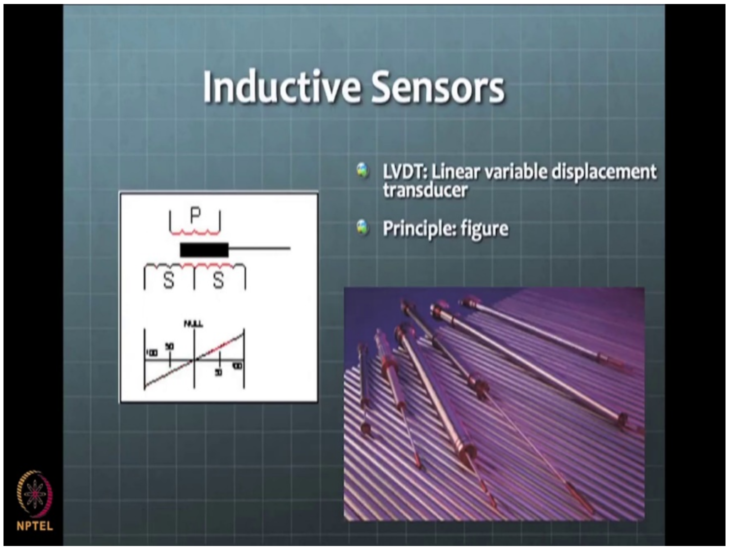

So, typical displacement measurement with these units is can be possible to the extent of some few nanometers not just 10s of nanometers but some 5 or 10 nanometer, less than 10 nanometer positioning can be sensing can be possible with such sensors. We do have such sensor in our lab, I mean whenever you want to in the future you want to take a look at, you will be able to amazed to see what how accurately and nicely it gives the positioning data.

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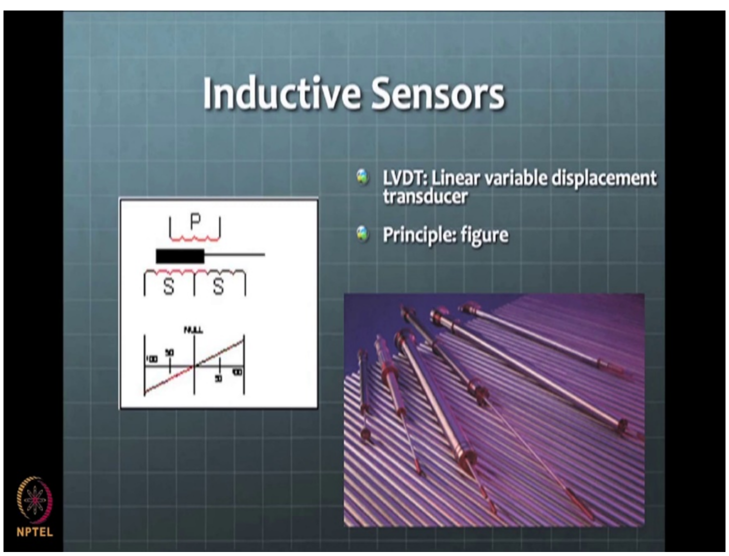

Maybe I would post the datasheet also for such a capacitive sensor I will post it to watch. These are like inductive sensors where you might have seen these already. This is called linear variable displacement transducer LVDTs. They have this primary coil and primary coil is excited and secondary coils is where we are measuring the voltage and this magnetic core when it is moved inside then the coupling of the voltages to these secondary coils changes. That is a principle these abilities are based on based on. So, these are some industrial LVDTs that are there in the in the market and these are also very extremely high resolution sensors can be possible with LVDTs.

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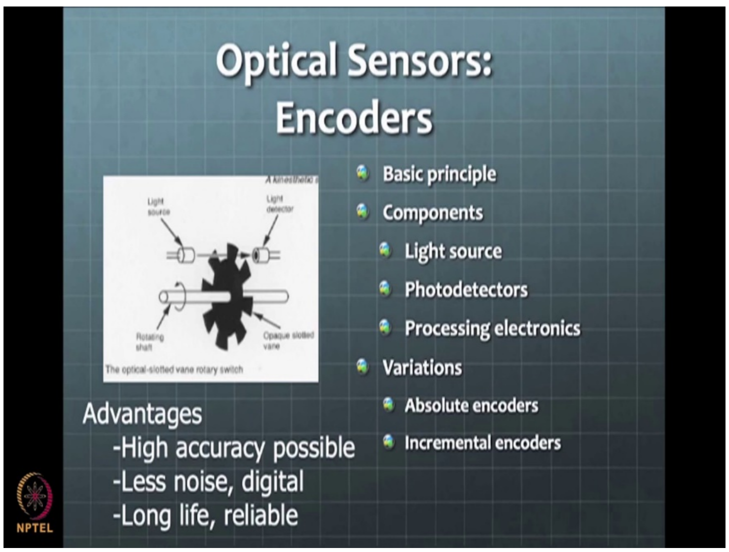

Then in the optical domain you can have is a very very what you say interesting or important sensor for a lot of mechatronics systems encoders. So, these are different from the encoder word that is used in the electronics domain. So, we need to be careful about this mechanical, this is mechanical encoders where you want the sense the position then you do this based on the principle as demonstrated in this figure.

What we do here is, we have a light source here and then the light detector on the opposite side and there is a wheel which is having the slits. There are some dark portions and some bright, the transparent portions, some opaque parts and some transparent part or some gaps, either way.

So, when the light is, so this is powered up, light is powered up and it receives, detector receives light to begin with maybe and then when you start rotating the wheel and the light will get cut by the wheel. As the light gets cut, the detector will respond to that, this is a light detector.

So when the light is not falling, it will respond and give some signal and that is how one can get a signal out of these different sensor. So, you count these number of pulses that are coming on this light detector here and once you count that, that count will indicate the position of the of the wheel.

Now, the question is, how do you sense the direction of rotation? So, we will come to that in a minute. But think about how do we sense a direction, if you did rotate in this direction or this direction, only the thing is happening is that the light is getting cut and some pulses there. So, for these very interesting ideas that are used for getting their direction sensed, we will come to that.

So, this is one kind of a sensor which is called which is of the incremental type. It just gives you increment information about the displacement. So, you can count the number of pulses, from some reference, you will get to know the total displacement but you do not get absolute displacement here. So, there could be possibility of absolute encoder also, but that is very people are, that is not very widely used, it is very rarely used absolute encoder although the construction is little difficult, but maybe we will have a chance of looking at some principles and how they are absolute encoder are designed?

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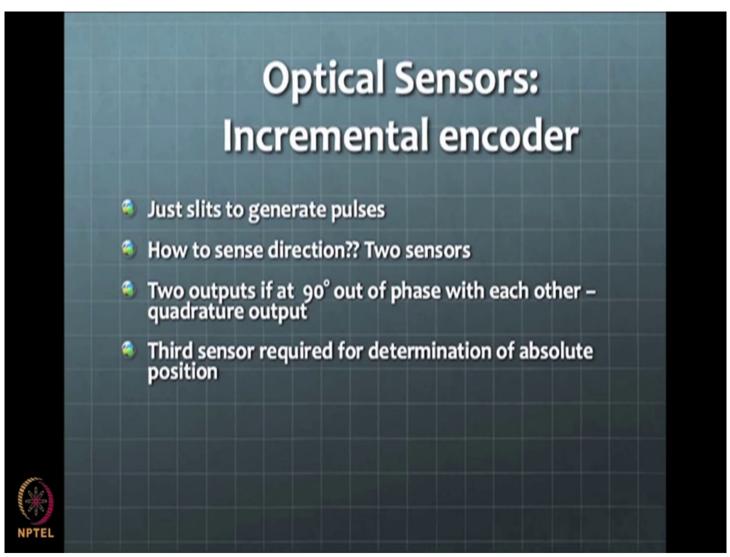

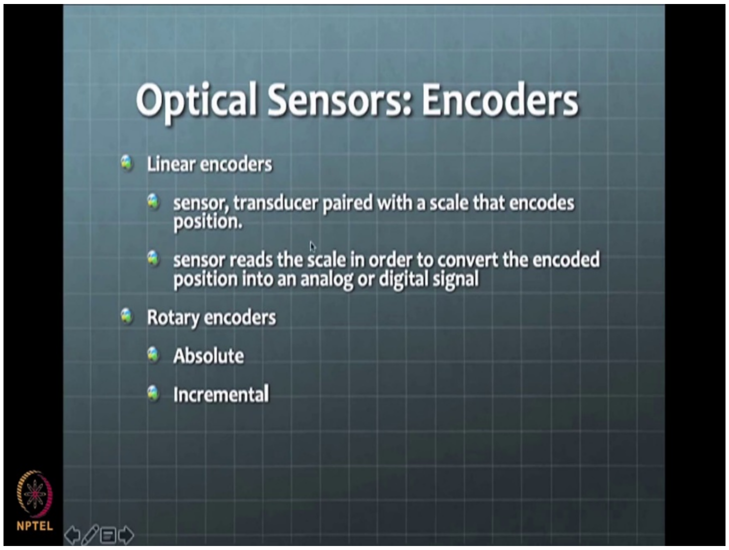

So, you can have a linear possibility for sensing or you can have a rotary possibility for sensing with the encoders. So, in the linear case, there is a scale which is having these strips on the surface. Now, as you can see, here, we are having this transmission principle and the same thing can be possible if I have a reflective principle here.

Such that the light reflects from some surfaces and comes back that, I do not need to have this complete pathway for the light. So, that this rotating wheel needs to come in the path rather than I can put this light detector on the same side as the light source and have this source and detector act in a reflective mode.

So, the light falls on some surface and reflects from the surface and maybe we register or is it a principle typically used for the linear encoders, where they have a linear input our head, which is running on the scale, that inputs that gives some a that includes the stripes I mean, the position scales.

So, the idea is like you shine a light on the scale and you take the reflection there are some reflective parts and some transparent, non-reflecting parts on the surface of the scale. And that is how you have a distinction between the two parts. Now, there are many different additional principles that can be used where these reflection happens as a as a reflective grating kind of thing.

If you have these reflective parts very, very tiny, then the light start behaving in a very different way. So, this has different repercussions for actually this becomes even more complicated to do the encoding in a sense. The thing that is coming out from the although the strips has say one micron a line spacing, the spacing that is registered by encoders will be obvious, answers may be different, based on the grating of the diffraction patterns that are produced by reflation transistor small distance.

When the distances are larger, you do not have the light diffraction effects, but when the distances get smaller and smaller, then you will have typically you will have to deal with the diffraction effects and then consider that in your analyses or your calibration or your detecting your output of the sensor whatever you want to say. In rotary there are there is two possibilities absolute and incremental. The linear encoders can also have absolute encoding possibility, but not very widely used at all.

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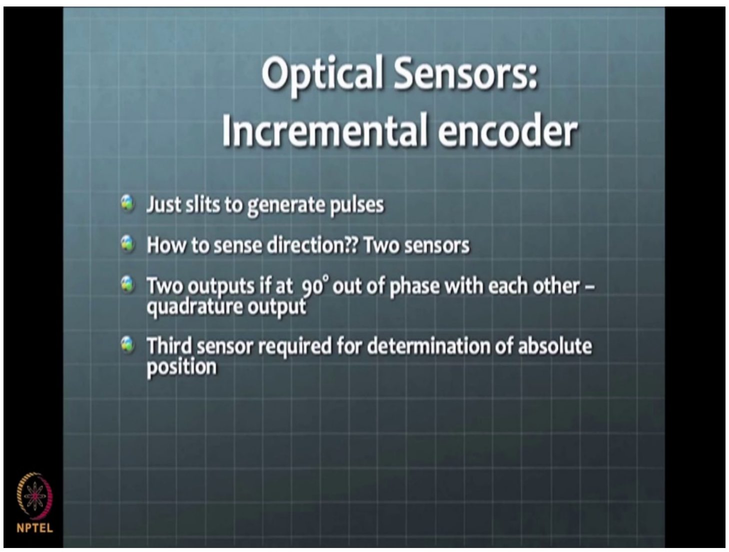

Now, we come to this question how we sense the direction of these pulses? These pulses that are coming then like know do we sense direction? So, the idea is to use instead of 1 we use 2 sensors and 2 sensors are put in such a way that outputs of them are 90 degrees out of phase with each other.

So, that has 2 advantages one is that it is, it enables the detection of direction and other advantage is it enhances the resolution, you are putting instead of one sensor you are putting two sensors which are out of phase then you are expecting that resolution also be increased because we have two sensors now.

The third sensor maybe put if they want to know like that is called incremental pulse , this is a, over one recomplete revolution you get one single pulse. So, that is output that you get is defined as i output, output i for the sensor and all these two phase outputs that are coming in there phase A phase B is what is the standard terminology that is used in the encoder instrument.

So, we will see now, this A and B pulses that are coming and this increment of revolution that is I pulse will typically be simple single pulse that is coming also, you do not need to look at it in more details. We look at these 90 degrees, how this 90-degree phase difference helps us detection of direction is what we need to focus on now.

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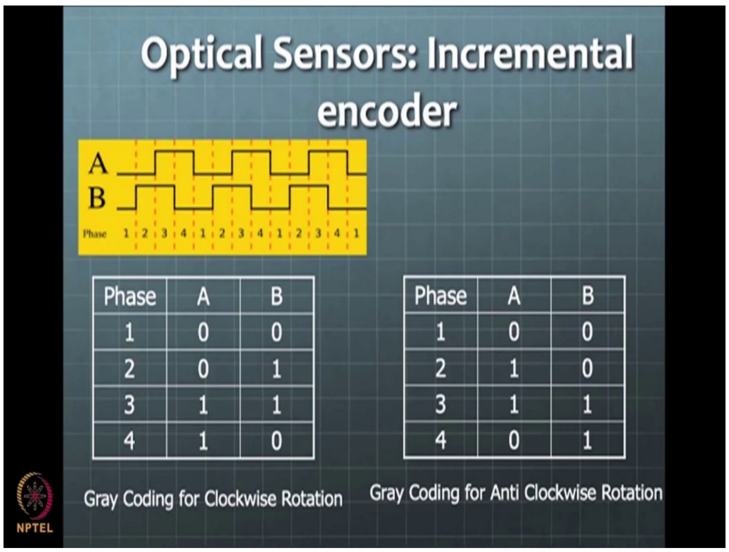

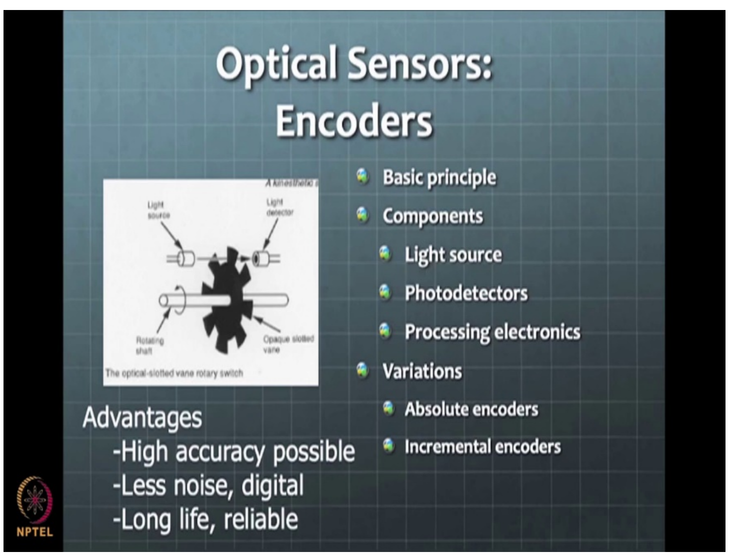

So, imagine that you have these two sensors which are two pulses which are come in as a, as a rotation happens. So, in this particular case, if you see at position one, you have 00 output A and B, , B switching to these but type, let us start with some , they are both zero.

Maybe we can start here itself say it is just like you know you can consider that just before this red line, what is position what is the thing that will get recorded. So, that will be 0, 0 for this. So, if we imagine maybe there is 0 here and this also is 0 just before this red line, this timer timing marks I have put it in a, so in a way that we can just kind of think in a same kind of a logic in the red line case.

So, here this is 0 0 then if you go for the next position, then A still 0 but B has gone to 1. We are now reading just before the red line. So, red lines are drawn where the transitions happen, but we need to pick assistant with the where we consider these phase output. So, second third part you have 11 here and fourth part you have 10 here.

This is how these pulses are coming. Now, you need to imagine that when the direction is reverse. So, when the direction is one in the forward direction, these are the pulses coming when the reverse direction happens. So, say for example, you have this strips, which are these, this requires a bit of imagination or you need to do a little bit exercise.

You can take a pause here and then use this slide as I have shown here in this diagram and you put actually the two sensors such that you have the A and B output coming as shown in the first kind of a table, in the forward direction motion is happening and now if the direction of the wheel is only rotated, the sensor position is kept the same then what a signal is that you expect to come here is what we want to understand.

So, do that little bit of exercise by pausing up here and then you will find this is we will again take this little bit of a discussion when we when we talk about in the discussion class. So, this is this you may or may not be able to crack it at this point, but just give it a fair trial and then we will come back in a class to talk about this. So, we will do that.

So, is like clockwise direction of rotation and then the anti-clockwise direction of rotation will have the output producing this fashion, 0 0 followed by 1 0 now and then 1 1 and 0 1. So, based on these and 0 0 is followed by 0 1 or 1 0, you can see that the direction of the incremental encoder can be found out. So, this is how one can go about getting the direction by using these 90-degree phase shifted signals and seeing how they are coming with respect to each other. So, you think about and then if you have doubts we can take it in the discussion class.

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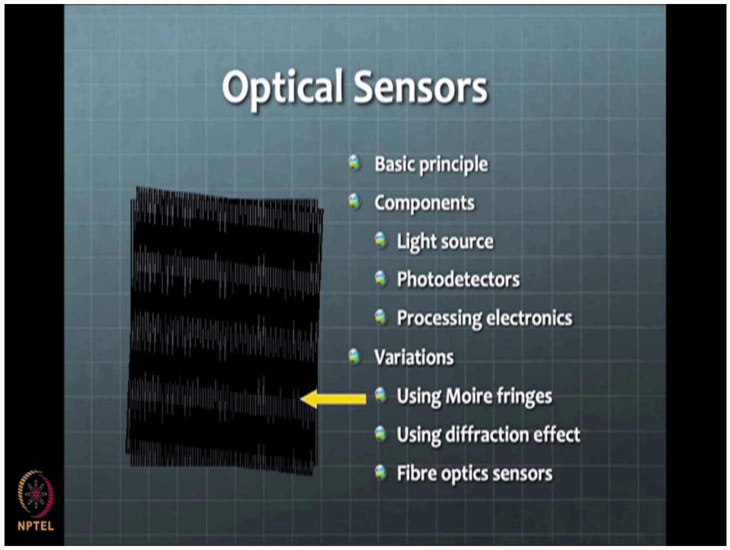

Then you can have something called Moire fringes. You might have seen you have this gate which will have to say basically, some kind of a matrix for example or gate which is having these bars which are vertical and you run other kind of a set of bars, which had slightly at an angle to it and you start moving around you can see these kinds of fringe pattern coming.

So, you can simply maybe, we have experiment, maybe I can show some experiment or see the or maybe, is it difficult or maybe some video maybe you can see, See, it is basically, you have these parallel lines drawn on the surface and then you are moving with an angle these lines with respect to each other.

And then there is some a pattern that you see for called Moire fringes. Now, this effect also is used in many different ways in the in the research these days. So, these diffraction effects will give these kinds of patterns. So, one can use these patterns to do the sensing, for example, for very small motion at a very small angle between them, these patterns will start moving very fast actually. So, even for the small motion, these patterns will move in the perpendicular direction fast and that can be a source of information or sensing in optical encoder based on this principle.

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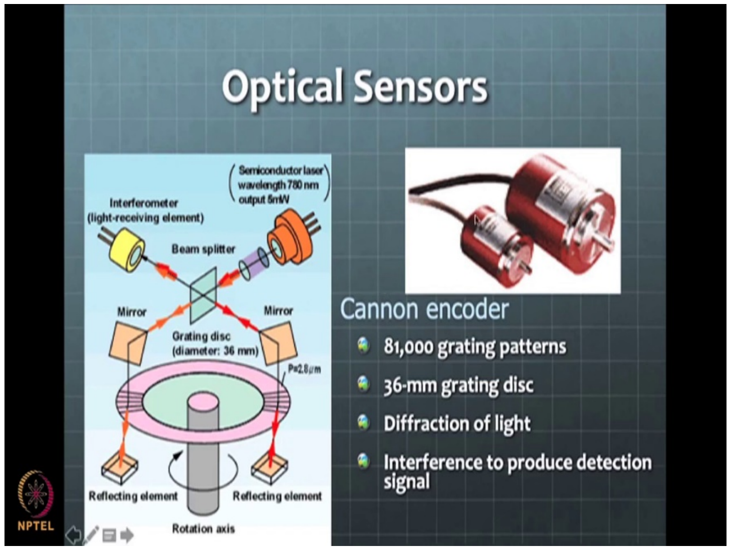

Then this is another we can have more complicated examples, where we are using some a light path with the additional light elements, reflecting elements, mirrors including that beam splitters something like that to put together very highly sophisticated sensors. So, that is possible. This is the sensors we use in long back in my PhD days we use such kind of a sensors.

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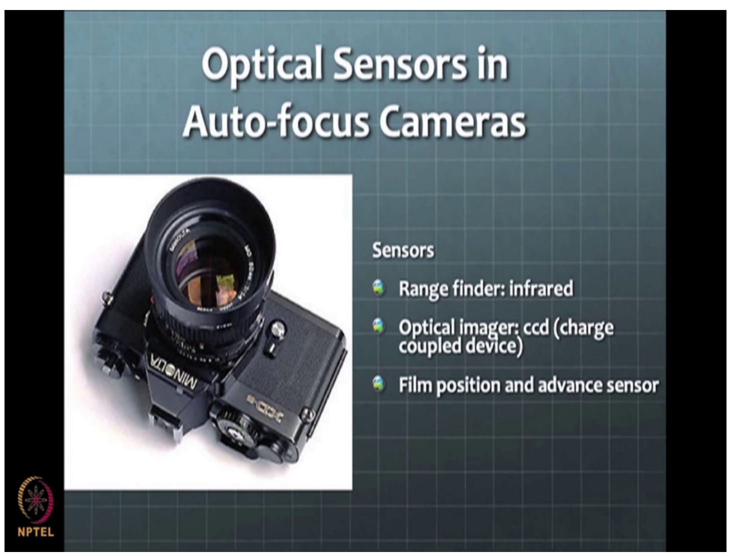

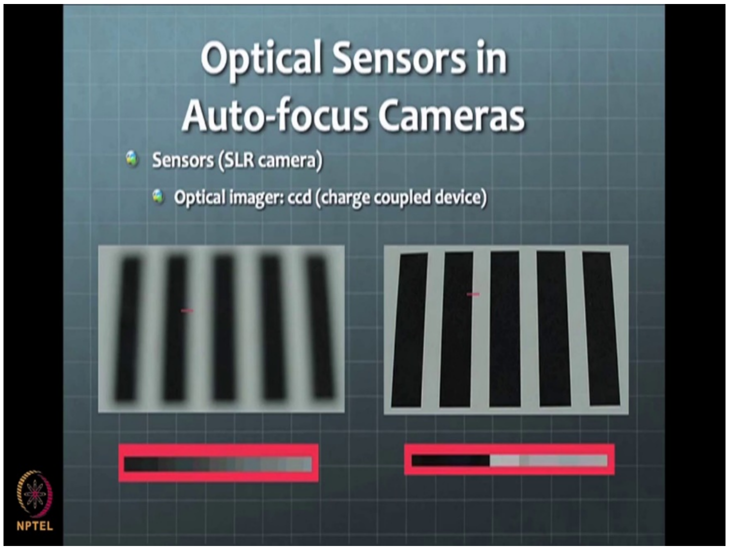

Then autofocus camera as you can have these different kinds of optical sensors, you can see these are the SLR camera in which you have this array of CCD and this CCD will record image and if the image if your so this is some example of some pattern that is imaged by the CCD, It may not be you may not have always this pattern, you can have whatever image you are focusing on at that time, but I am just kind of this is for such a pattern.

You see the left part is a blur part of the image and you do not have very sharp distinction between you see, bottom side that is an array of CCDs. So, these CCDs are actually acting, giving this output which is blur in the sense, you do not have a sharp kind of a distinction between the two adjacent CCDs.

So, as you start moving the lens and the image started becoming clearer, you get this distinction very sharply so sharp boundaries found and that is why fineness can be built in the new system to say that now it is in the focus. So, the more is it contrast in the CCDs and a sharp kind of line that you find in the under CCD, then you can see that, this is images in the focus. So, that you can have this auto focus sensing possibility.

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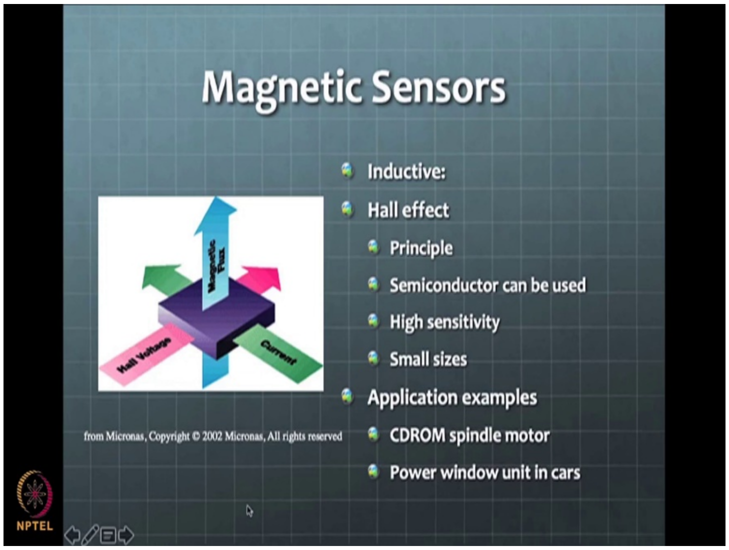

Then, there are these magnetic sensors which are based on the Hall Effect principle. The principle is very simple. You have the semiconductor which is flowing current in one direction. There is a direction of current in the semiconductor and then you have a magnetic flux which is applied in a direction perpendicular to it and then you find that because of the flow of current and in this magnetic field which is perpendicular to it, the electrons will get deflected in one direction.

And that deflection of electron will create a charge on that side. So, that charge is basically sense for the is called Hall Effect. So, this is a principle that is that Hall Effect sensors are based on. So, a CD ROM spindle motors, these Hall Effect sensors are used in BLDC motors to sense the magnetic field or magnetic flux happening in the system to have some feedback mechanism is there based on that. So, we will see some examples as we go along. When we open the CD ROM drive the spindle motor will be able to see these Hall Effect sensors.

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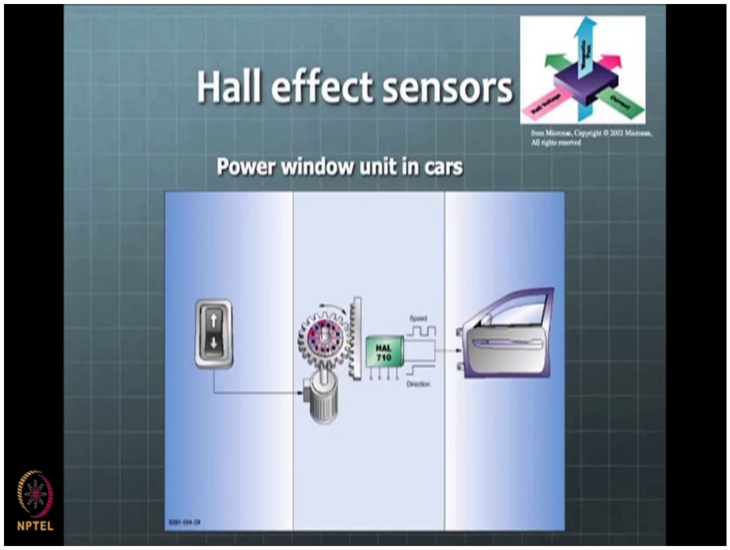

Then these are the other example for the car window opening operation.

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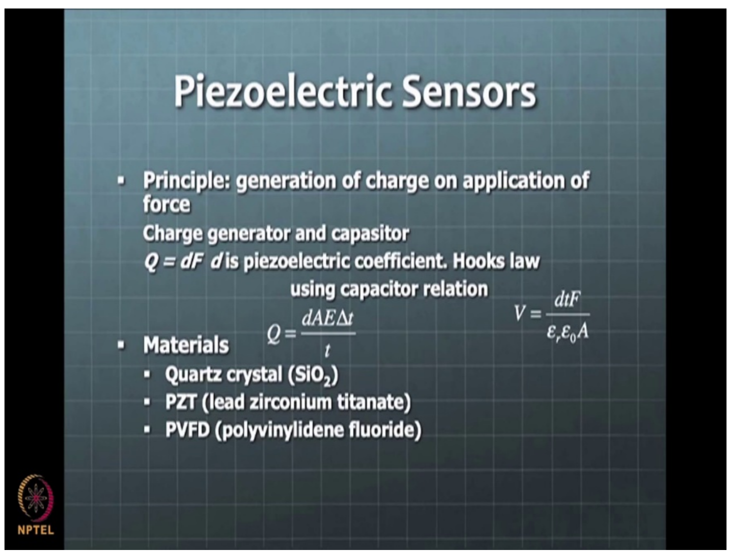

Then we can have a Piezoelectric sensors based on the piezoelectricity principle. So, this is typically the charge that is generated on the surface of a Piezoelectric element when some force is applied. So, you have two possibilities one is you can apply the force generated charge or you can have a give a charge and to generate the force both ways these piezoelectric sensors work typically.

So, there are these typical materials you shall use like quartz or PZT or PVDF, these are different different kind of a materials are used and nowadays people are using these piezoelectric as energy harvesting elements. So, you can have some a small micro cantilever that is sitting in the on the sensor itself and it senses ambient it is not for sensing with ambient vibration, it is vibrating and because that vibrations the charge is generated.

So, the energy of this vibration is converted into the electric machine from this charge and then you can use this charge to store this electricity and use it for the powering of the sensors. So, one can have this wireless sensor nodes based on this kind of a idea. So, idea is that the sensor is sitting in some industrial environment where some vibrations are. Based on those vibrations it is generating energy to sense, to power itself.

So, the sensor does not need extra battery or any solar or other power source to be there with the sensor. In the industrial environment whatever vibrations are at generating a power for itself from those vibrations. That is the kind of idea that is used in the piezoelectric energy harvesters. And as well, this is principles of piezoelectricity is going to be important and they are used of course, they are used as sensors in the in accelerometers, for example, and they are using sensors in say pressure sensing kind of applications.

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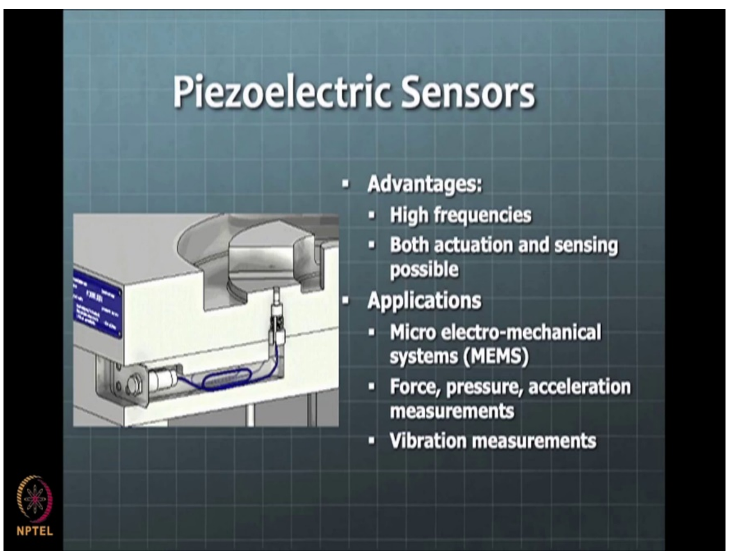

So, I think this is one of the applications of piezoelectric pressure sensing. Then, maybe we can now pause here for this lecture. I think we spent a good amount of time over pondering over these fundamental principles and then maybe we can start in the next class with some other aspects or other elements of mechatronics system.

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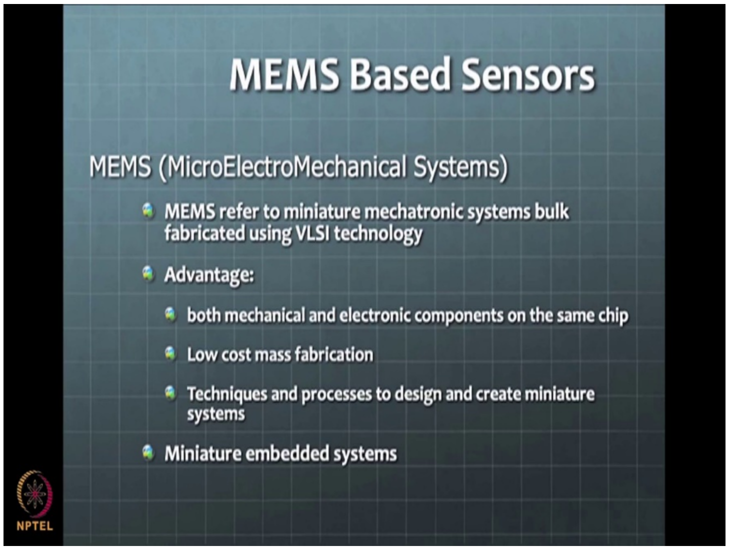

So, and then MEMS sensors, I will talk briefly about some in the next class and we can move on to the actuators from there. So, for here we will stop now.