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Industrial Robotics: Theories for Implementation
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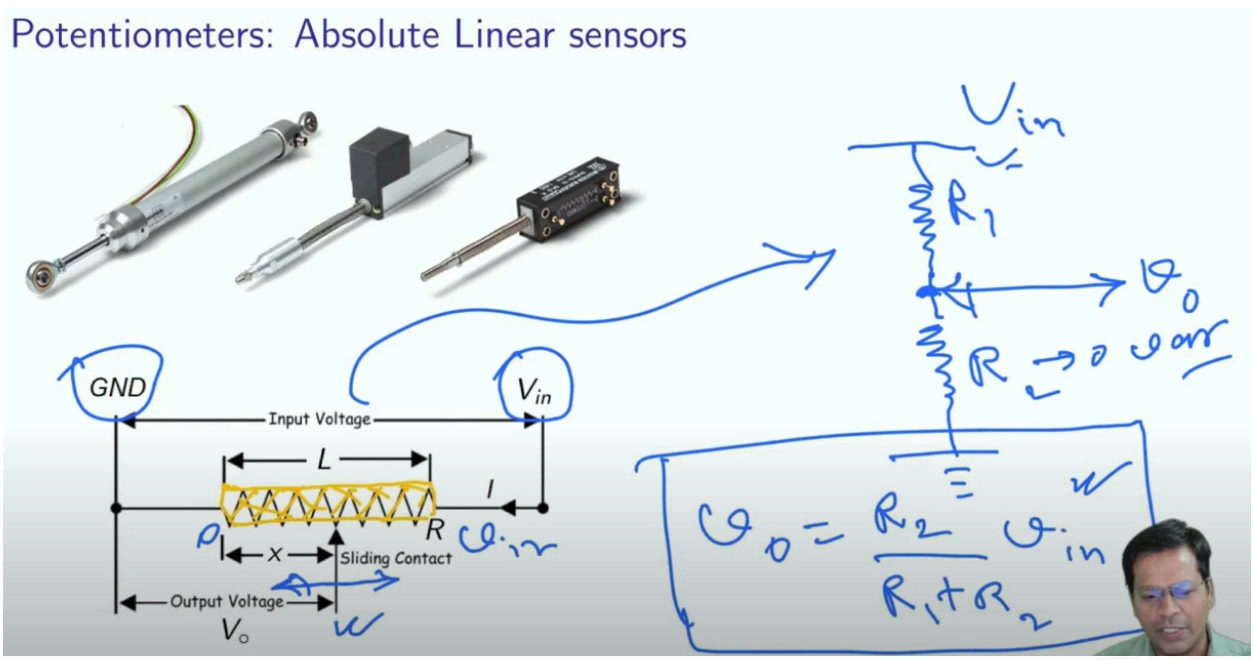
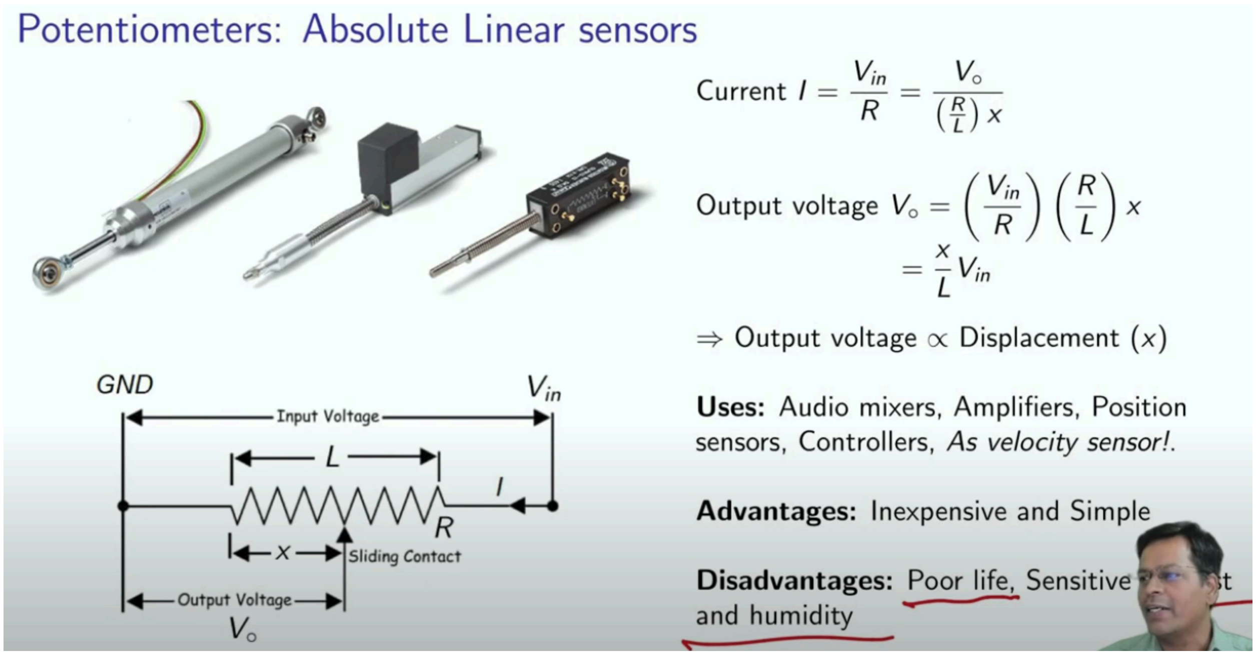
Position Sensors, Potentiometers and Hall-effect Velocity Sensors

Hello, and welcome back. So, in the last class, I covered position sensors, especially optical sensors. Optical sensor encoders, which are incremental in nature, as well as optical sensors which are absolute. So, today, continuing further, I will be discussing a special type of sensor which is very, very simple, that is, potentiometers. That also can be used as a position sensor. So, we will be covering today, and we will also see the Hall effect sensor that I initiated in my last lecture as a magnetic sensor, Continuing further with that. Today also, I will be covering. I will be using that hall sensor as a position sensor and velocity sensor I will be talking about today. So, yes, let us continue further.



So, let me just take you back to your high school when you first encountered this type of sensor, not as a sensor, but as a simple Ohm's law. You did this experiment, maybe. So, that is what is a potentiometer? I will be using it today as a position sensor. Let me see if I can demonstrate you like that. So, yes, let us continue. So, hope you know what is voltage divider is. So, you very well remember this fundamental thing. So, you have a voltage here, you have a resistance here, you have another resistance here, and this is your ground, right? You supply anything over here as an input, if at all. I tell you: this is resistance 1 (R1), this is resistance 2 (R2). So, what is the voltage (Vo) which is output here? So, this can be quickly given: as Vo is equal to R2 by the sum of both of these resistances, R1 plus R2- into V input ((Vo=R1/R1+R2)Vin). So, this is very straightforward. If R2 goes to 0, if R2 tends to 0, voltage output becomes 0. If R2 becomes equal to R1 plus R2, that is, this point shifts to this end. So, what do you see as the output is straight away, exactly the voltage input? So, this is the first principle I will be using to go to this type of sensor. So, you see, the arrangement is like this arrangement is very much like this the way it is shown here. So, you have a slider here. You have a slider here.



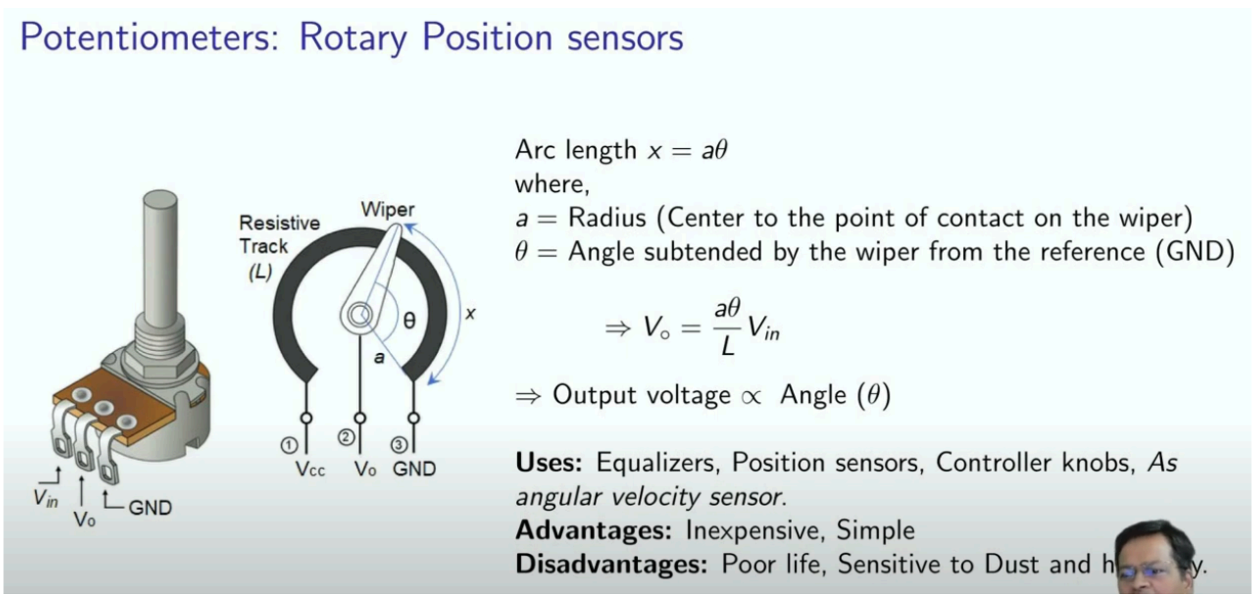
So, this is your resistance strip. OK, so this is your strip, on which you have a pointer that continuously keeps in contact with that. This is a sliding contact that slides over that. So, here is the supply which is entering here and this is your ground. The same circuit is here, which is implemented vertically. Here, it is shown as a horizontal one. So, you see, this can be compared with this, where R2 is a variable. R2 is a variable because this slider can move in this direction, up and down. So, this slider can touch this point which is 0 potential. Or this slider can touch input potential. So, anywhere in between, it will give you some voltage as an output, which is somewhere between 0 to Vin, that is the supply voltage. So, this is the first principle of this. Let us see how it is.

So, yes, this can be derived using the way it is shown here. So, yes, here is the current that is entering from here. This is your current. It passes through. It goes here. The same current passes through the whole of this line. So, yes, the current can be taken up in two ways. First, it is equal to voltage input, that is, the total voltage input divided by total resistance, which is R. This is the current which flows through this small resistance. OK, and if you take in otherwise from here, so current is also equal to this voltage output. That is the voltage output, and this is R by L times X. As it is, it is linearly proportional. If the total is your resistance strip of total resistance R and total length L, I assume that this resistance varies uniformly. Resistivity is constant. So, any place in between which is at a distance X resistance from here to here will be given as resistance is equal to for the strip is X by total length L into total resistance. So, this is your resistance for this small strip, which is covered here (Rs=(X/L)R). So, this is the resistance. So, this goes here. I moved ahead and just did some cross-multiplication tasks from here to here. You see, voltage output is equal to VIN by R, R by L times X. So, if you strike off these two, you are remembering that voltage output is equal to X by L times voltage input. So, this is the voltage input. So, yes, what you see, voltage input is constant. This is constant. The total length of this strip is constant. So, voltage output is equal to VIN by L, that is, a constant time of X. This is equal to. So, the output voltage is proportional to displacement. So, you see, output voltage is proportional to displacement. Let us say I have a maximum voltage of 5 from here to here, and the total displacement is something around 100 mm of this strip. So, you see, if I am somewhere in between, if I am tapping from somewhere in between, that is, if this is 50 mm, OK, so voltage output will be 2.5 volts, got it? So, if I am again further going here, that is, 25 mm, my voltage output becomes 1.25 volts. OK, so that is the way. So, voltage is linearly proportional to the displacement. So, if it touches 0, the output becomes 0. If it touches 100 mm, the output is 5 volts. So, 0 to 5 volts, 0 to 100 mm. So, it is linearly proportional. So, this is the way this sensor is designed. This is very, very, very, very simple, and yes, it can be used to measure your displacement. So, it looks like this. It has one in my hand. It is a German make. So, yes, you see, it has a slider. It has a slider that can slide from here to here. OK, that gives you an output. So, it looks like this. It has three wires. You see, it has exactly three wires. So, the red one is for voltage input, the ground is ground, and the output is in the yellow wire. So, it is a three-wire system, it is. It looks like this. So, it is something around 200 mm maximum displacement I can make. That is 20 cm the, and this is the mounting Blanche with which it can be mounted anywhere, and the wire goes on out from something like this. So, yes, this is very, very simple. This is a linear slide, OK, and it can measure 0 to 200 mm.

So, it is similar to the audio mixer. If you have seen it, it is very, very similar. So, it goes like there are multiple sliders in your audio mixers. You must have seen if you have attended any music shows or anything. So, they have multiple, you have a microphone, you have a piano, you have other instruments, input from all of them, they come together, and they are mixed using this. So, you have something which is called sliders: different sliders to control different volumes. So, this is the way it is done. So, the same instrument and the same tool are used to mix different inputs. So, that is what. So, the? In amplifiers, it is used position sensors-yes, that is what it is meant over here we are concerned more about this and controllers. There are knobs, linear slides also, and a velocity sensor also. I will tell you how it can be used as a velocity sensor, and towards the end of today's lecture when I will be covering this.

So yes, advantages. Yes, you know it is from your high school physics. It is very, very simple to understand. It is linear already. You don't need any additional circuit to linearise it. Voltage output can go from 0 to voltage input. So, if you have to make this signal, go a long distance. This voltage can be as high as 24 volts, which is used in the industry and does not require any kind of amplifier. As such they are very, very inexpensive because it is made up of just the slider and some enclosure to cover your resistance strip.

So yes, disadvantages are definitely there. They have a very poor life because they know this slider is going to rub against your resistance slide. So, with time, it becomes a little noisy. After all, you have some bearing on what is happening. They are sensitive to dust and humidity if you allow dust to get in. but the kind of potential meter that I showed you have. It is very nicely enclosed, so this does not allow dust to get in, probably. So, very little amount of dust can get in. Even a small amount of water is placed. They are very, very safe. So, that can be taken care of. So, it is very good. So, dust and humidity are sensitive because your resistance strip, if at all, there is any moisture in between, so resistance will not be uniform. Output will not be that reliable, but still, this is very widely used as an absolute position sensor.



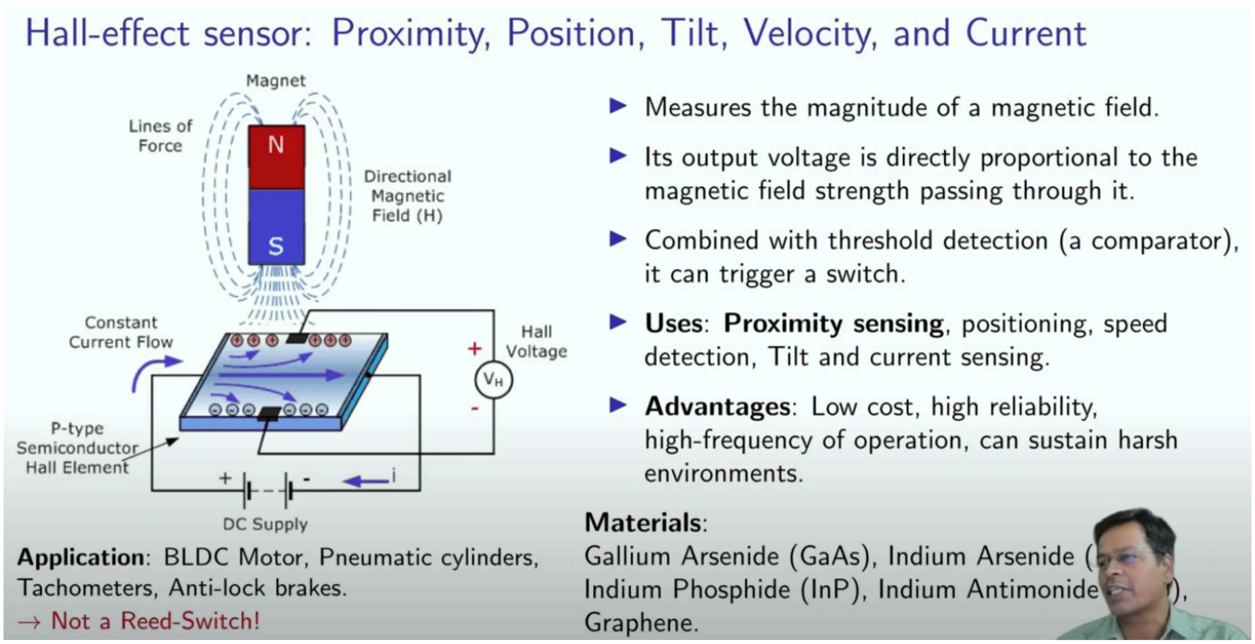
Now, moving ahead similarly, if you are familiar with your audio amplifiers, even your radios, you remember this small device that is there as a volume control knob, bass treble. So, various inputs are there. They all use this kind of thing, which is known as a rotary potentiometer. Again, the principle is the same. OK, so you have an output. You have an output here. So, this is your resistance strip. This is your resistance strip. OK, one end of it. You have voltage. That is input here. The other end is connected to the ground. OK, and somewhere in between, it is establishing contact. OK, from where you are tapping in, and you are taking the output voltage. So, the system is almost the same. The only thing is your resistance strip is arranged circularly. See how it works. This time, this length x, the one that you had in your earlier scenario, was x. This time, this x is straight away in a circular way, and this x is proportional to the angle. If I write down this, x is proportional to the angle. This radius is there. So, x is equal to a time of theta, where theta is an angle, subtended by the wiper, from the reference point that is ground. So, this is ground. So, from here to here, that is the contact point, that is the angle which is subtended. So, displacement x now is proportional to theta. OK, the same equation now can be written as the output voltage is equal to, instead of x by l, I can write a theta. So, times of v input. So, finally, the output voltage is now proportional to theta because the voltage input is constant. The length of the total strip length is constant. That is radius of this is constant. So, overall output is proportional to theta. You got it. So, this tool can now be used as an angle sensor. So, if theta is equal to 0 degrees, the output will be 0. If theta is equal to a complete angle from, let us say this is 270 degrees. OK, if it is 270 degrees, it is output. The voltage is VCC, which is the supply voltage. So, the output voltage varies from 0 to the supply voltage. In industry, it is 24 volts. So, let us say if this is fitted in industry, your output will go from 0 to 24 volts. Right, for 0 to 270 degrees. There are a bit of problems with this kind of thing. It cannot keep on running. You cannot have continuous rotating potentiometers. There are a few designs which make it happen. So, which continuously gives you from 0 to maximum for 0 to 360 degrees, again goes back to 0 here, 0 again it goes from 0 to maximum, 0, like that. So, multi-turn potentiometers are also there which can give you a saw tooth. Sawtooth like a waveform, but that, if you can count this, every time it comes to the peak. So, the number of times it came to the peak, if you can count, you can precisely calculate the angle that you have turned. OK, so more than 360 degrees also can be measured.

OK, so again, this can be used as a graphic Equaliser or audio Equaliser. Position sensors: position sensors as an angle sensor, controller knobs, knobs that you see as audio mixers, same and an angular velocity sensor. Again, I will talk about this very much in detail. If you get a voltage which is proportional to displacement ($V_o \propto x$). So, this parameter, this particular relation, can be used to measure voltage output is proportional to displacement. So, the rate of change of voltage is also proportional to the rate of change of displacement, got it?

$$dv/dt \propto dx/dt$$

So, this is what we will be using to find out the velocity. So, this is the velocity. This is the rate of change of voltage. If somehow we can measure the rate of change of voltage, we are done, and we can find out the velocity also. So, that is the first principle that we will be using later on. So, it is this one is used for various things which are mentioned here. So, it is a position sensor, controller knobs as a velocity sensor, and angular velocity sensor. They are again inexpensive, very, very simple.

But yes, this also has a similar problem, that is, poor life, sensitive to dust and humidity. It looks like this. In the last class also, I showed you something like this, but this is different. This is a potentiometer. You can quickly identify this by counting the number of wires which are there. So, you see, one is for the shielding, that is, system earth, and then it remains with just three wires. So, one is ground. The other one is voltage. One of them is signal. That is also three wires and done. In the case of an optical encoder, it was five wires. One is casing ground, just like this. And then voltage, ground, and phase a, phase b, sometimes index, is also there. So, it may have five or four wires, but this always has three or four wires because of this shielding ground. So, that is there. OK, so this is what it looks like. So, they are the same. Flanges are such a design that you can quickly replace your optical encoders with this, so they are interchangeable.

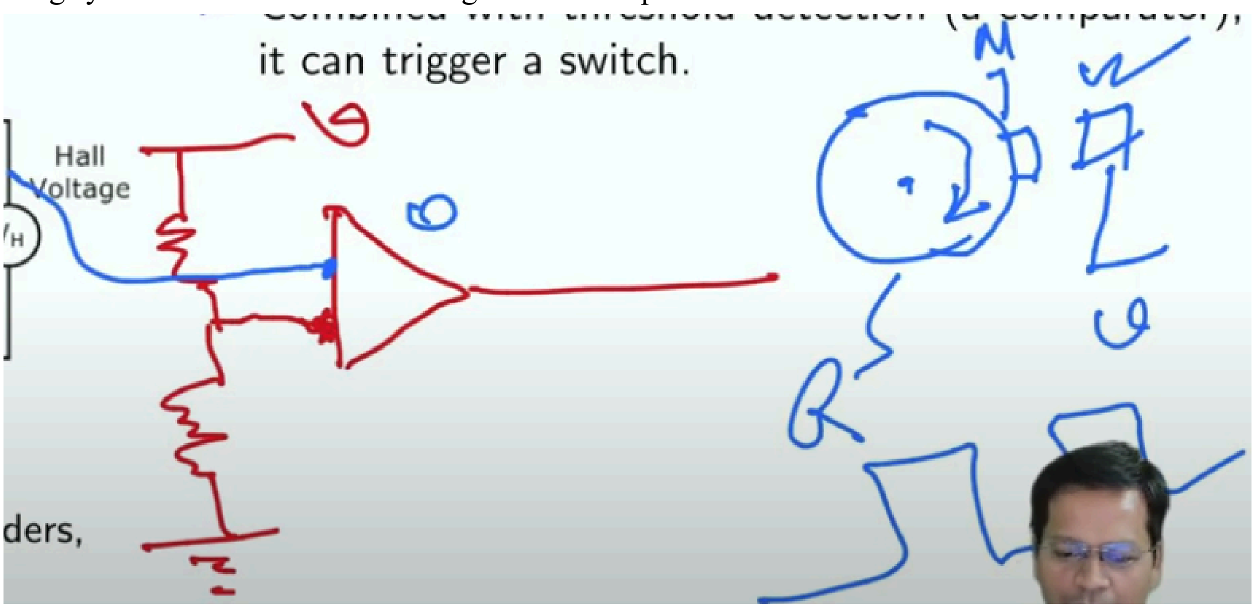


We have already used hall sensors for the BLDC motor to detect rotor position. OK, so today, we will learn about the principle and how it works. So, yes, there are many materials which can be used, like hall effect sensing materials. So, a few of them I will be mentioning here, I will discuss. Let us first understand the principle. So, what is it? How is it physically arranged? It is something like this: so you have a p-type semiconductor, which is called a Hall effect element. OK, that is the hall effect element which is here, and it is made to flow without constant current using an external DC supply. So, current continuously flows through this one. OK, it comes out from here. So, now this current continuously passes on. Then, there is an orthogonal place. OK, there are two other points from where you continuously measure the voltage, hall voltage, you call it here. So, the hall voltage is measured. So, on one side of it, you are entering the voltage that is the constant supply, and on the other side, you are measuring the hall voltage, which is the output voltage. OK, so as long as there is no magnetic field, you may see a small number of voltage fluctuations here due to the surrounding magnetic environment, maybe due to some other sources, but yes, as soon as it encounters a directional magnetic field by some strong source, What do you see? You see, here is a voltage. OK, so this voltage output is proportional to the magnetic field strength that comes from this direction. So this is how it works. So, yes, it is not a reed switch. There are many other magnetic switches. This is not a switch. This is an analogue variation of voltage across the hall sensor, and it is analogue, not like a switch on and off. Yes, it is mostly used like a switch, as I will tell you now. OK, so yes, it measures the magnitude of the magnetic field in terms of hall voltage. Its output voltage is directly proportional to the magnetic field strength passing through it. So, you also know magnetic field strength for a solenoid is equal to $\mathcal{M}0NIL$ ($H = \mathcal{M}0NIL$). So, I rest everything is constant. So, the field is proportional to the current. So, now you can understand if voltage output is proportional to the field and the field is proportional to the current. $Vo \propto H \propto I$

So, the output voltage is proportional to, let us say if you have a wire which is at a constant distance. So, that is surrounded by the magnetic field all around. So, yes, you can. So, how can you link this wire's flux to this plate? In that case you can measure current flowing through this wire also, so this can be used to measure current. OK, so if you can estimate the current of a motor, you also know torque is proportional to current. So, yes, this voltage can measure current, and it can also measure torque.

$$T \propto I \propto \tau$$

So, this is how it goes on. So, you keep on relating things next to the next level, keeping the constant aside, so you can take this voltage output to measure torque, to measure current, to measure directly the magnetic field also. So, these are little stuff that you can measure. Other things you have to make some arrangements on top of it.

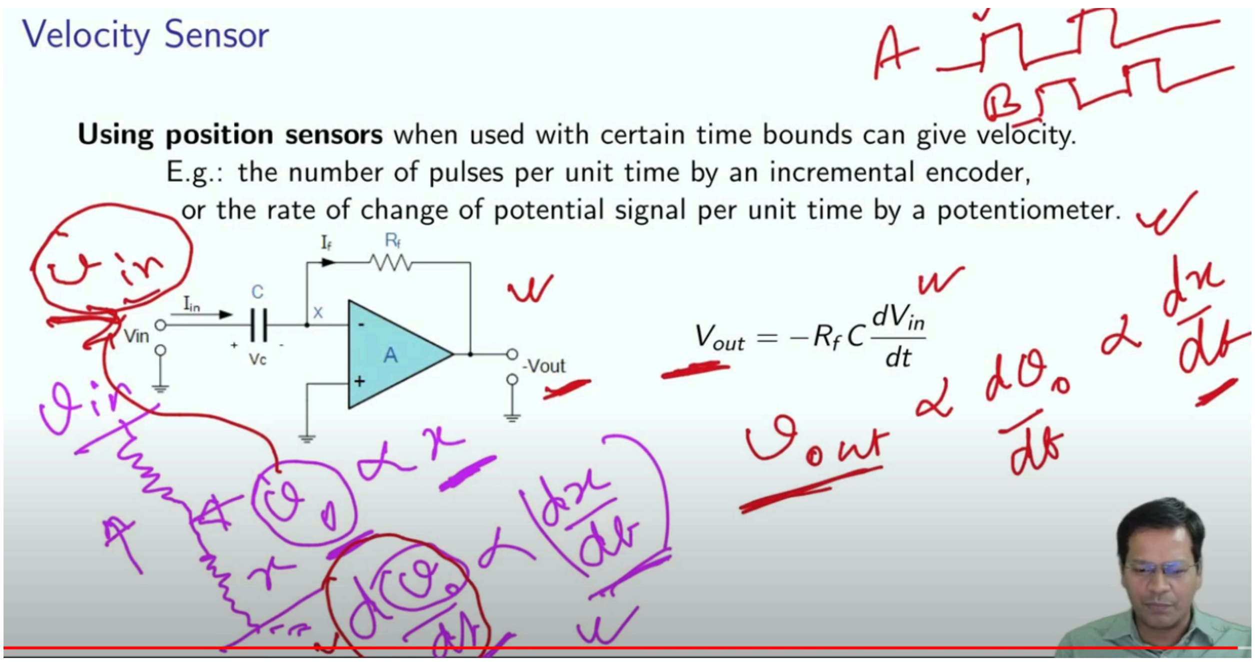


So, how to do it I will just explain here. If this voltage comes here, you have a comparator which is here that can give you output. So, there is a voltage level which is set here, using again like a potentiometer. We can set it. OK, so this is the voltage. This is the level with which I want to compare. So, here goes your input voltage so you can compare it with this. And so, as soon as it crosses some threshold level. It is an operational amplifier, I tell you. So, yes, this output now will be high if it goes above this level. If it is below that, it will give you a 0 signal. So, using a comparator, you can trigger a voltage. OK, you trigger like a switch. So, if the voltage goes beyond a certain value, it is high; less than that, it is 0. So, that is how it is used as a counter. OK, let us say your rotating shaft is now fixed with a magnet, and you have a hall effect sensor, which is here. So, this will give you output every time this shaft crosses this plate. OK, so this is your magnet. This is your rotor. So, yes, the output voltage here will have a square waveform as an output got it. So, every time it comes near, it gives you 1, goes to 0, gives you 1, goes to 0, and so on. So, you can simply count the number of square wave peaks you have seen, and you can directly get the rpm value. So, that is how it can measure the velocity. So, this is. It is how, combined with the threshold detection, combined with the threshold detection, a comparator can be used, and it can trigger like a switch. OK, so this is the way it can be used like that.

So, it can be used as a proximity sensor. So, anything with a magnetic element, if it comes nearby, it detects. So, that is what is the proximity sensor: if it comes nearby, you detect it as high. So, sometimes, in the case of a pneumatic cylinder also, two ends are fitted with a hall effect sensor so that if it is fully extended, you get a signal. If it is fully retracted, you get another signal. So, depending on those two signals, you come to know the status of your pneumatic cylinder. So, this is how it is used, like a proximity switch. And now how the position of the shaft. That day, you got to use the BLDC sensor. You had 3 of them fitted in the BLDC in between the coils. You had 3 of them. So, based on the strength of the signal which is coming from all three hall sensors, you were able to determine your rotor position at least to some precision. To some extent, you were able to get it. So, this is how you can detect the position also. Hall effect is a multidimensional sensor which can be used to detect proximity, position, tilt, velocity, and current. So, current is related to torque, so it can be used to detect torque. So, once you can detect current, current can relate so many things right. So, this is how it is a very useful sensor. It is very simple, and because it is non-contact in nature, so hardly anything is there to get this damaged. But there is a drawback: it has to be isolated. There should not be any external magnetic field apart from the magnetic field that you want to detect. So, any external magnetic field. So, you have to shield it thoroughly and leave just one window open where you are expecting your signal to get in. It can be used as a tilt sensor.

So, let us say you have this plate which can detect the hall sensor, hall sensing, voltage, OK, and now you have a magnet, a long magnet which can pivot about this. So, if this is getting tilted by a certain angle, OK, and it has now oriented like this: now the field which is passing through this plate is different, so changes in the field will have changes in the hall voltage. So, hall voltage is now related to. It is a function of angle theta. If you can detect that function using some calibration experiment, you can use this to find tilt also. So, you got the idea. Actually, anything, any change in hall voltage due to any reason, can be detected.

Any environmental changes can be detected. So, the advantages are many. It is very, very low cost. These materials are very inexpensive and highly reliable. They do not change. It is property over a small period of time or maybe for years. They remain like that: a high frequency of operation with a very high frequency. You can change the magnetic field, OK, and still, it can detect high or low if you are fitted with a very good high switching comparator over here, so you can do that. It can sustain a harsh environment. They do not wear out because there is no contact which is there, and they are free of humidity and dust. It hardly gets affected. OK, so that is why a harsh environment. It is suitable for this environment. The only thing you have to take care of is that it should not get into the environment with other magnetic fields around. These materials are Gallium Arsenide (GaAs), Indium Arsenide (InAs), Indium Phosphide (InP), Indium Antimonide (InSb), and graphene. So, these are a few materials which have this type of property to do it.



So, now let us discuss velocity sensors, that is, using the position sensors, the number of position sensors that we have learnt so far, using a dedicated tachometer and hall effect sensor, just we discussed just now. So, let us begin again. So, yes, using position sensors, when used with certain time bounds, it can give you velocity. So, the way the output you saw just now, it came like this: so there was a resistance, there was a resistance slider which was there, so the output was varying with displacement. So, this was the displacement. So, this is your applied voltage input. So, the output voltage was proportional to displacement.

Let us say this slider is now moving with some velocity on this slider. So, what will you see? You will see output displacement changes, so output voltage also changes. If somehow you can measure the output voltage changes, this output voltage, which is changing, is now also proportional to the velocity. So, using this, if this output from here, if I can feed it to this one, now this output goes here as an input to an operational amplifier, OK, so what this amplifier is doing, this is nothing but a differentiator circuit, OK, whereas the output from this differentiator is, you see, is proportional to whatever comes to the input. So, this is the output voltage. Change input over here. So, if this is your input, the input from here, OK, whatever is the voltage, this voltage goes here, so you can directly get the rate of change of whatever is coming over here. So, output this is a voltage. So, this time, the output from the op-amp is proportional to the output from the Rate of change of output from your potentiometer, and this is proportional to the rate of change of displacement.

$$V_{out} \propto d\theta_o/dt \propto dx/dt$$

So, voltage output now, after this differentiator circuit, is proportional to the velocity. This is just one way of doing it. In an analogue way, the output voltage is proportional to the velocity. Using a simple potentiometer, you can estimate the velocity. But, yes, potentiometers find limited application. Because of its sensitive nature to humidity dust, it is prone to noise after a certain time of usage. So, yes, if at all, I am using an optical encoder. How to go for it in the case of an optical encoder? You saw you had what is output, which is something like this from phase a and similarly from phase b.

There was a shifted voltage output. Also, if I measure the number of peaks per unit of time? So that will directly give me the output of the output from phase a and phase a sense of velocity. So, the number of changes in a high pulse in a or b, any of the channels, is its velocity. OK, so that is proportional to velocity. You have to know how much the width is per unit of time, which changes depending on the resolution of your encoder, so that you can get a sense of velocity. So, using an analogue sensor like a potentiometer or using anything like a magnetic also. Magnetic encoders give you an output as a pulse. In that case, you can simply count the number of pulses per unit of time. That will give you a sense of velocity. So these are various good ways of doing it.

Tachometer: (Used as angular velocity sensor)

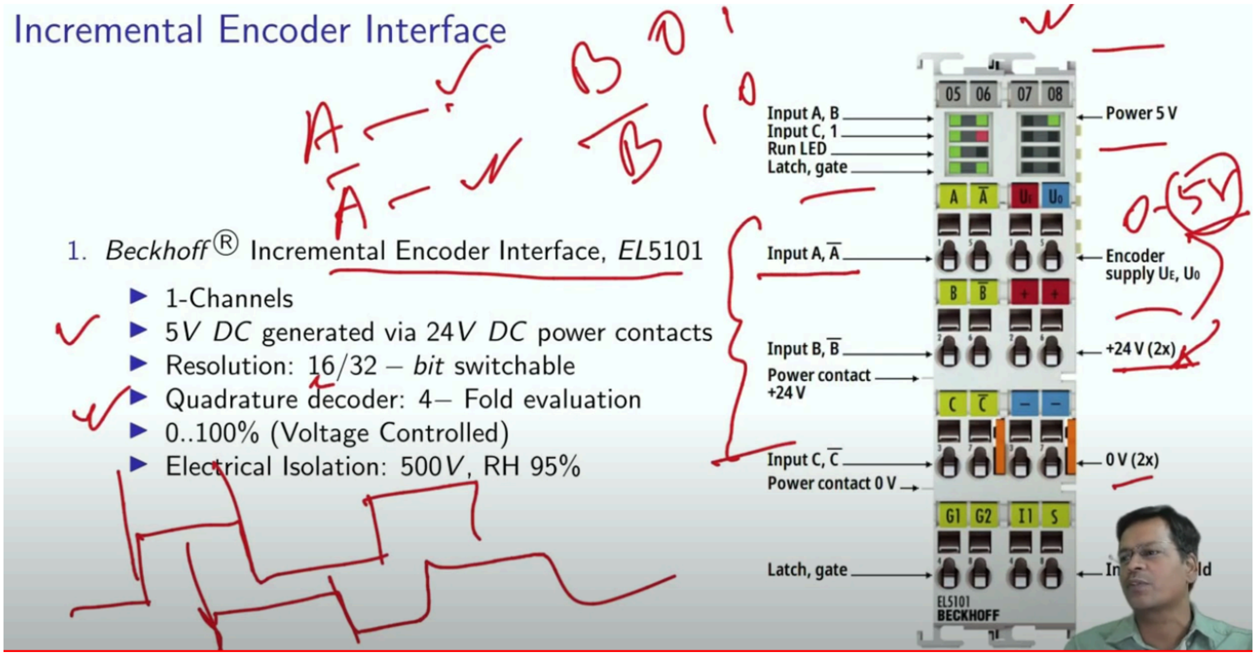
→ Works like an alternator

→ The voltage produced is proportional to the rate of change in flux linkage.

→ Requires a rectifier and an ADC.

Moving ahead, a tachometer can be used in an angular velocity sensor also. What is a tachometer? It is nothing but a simple alternator. The voltage output from an alternator is proportional to the shaft speed. If you increase the speed, your voltage will come up. So, that is proportional to the shaft speed. So, that also can be used. But yes, it may be AC voltage which is coming, which is alternating in nature. So, you may require a DC, AC to DC filter, and then you can use that filtered voltage as a sense. As a sense to measure your input shaft velocity, got it. So, the Voltage is proportional. This time is proportional to the rate of change of flux linkage. So, that is the reason the flux rate of change of flux linkage is again proportional to the shaft speed.

OK, so this needs a rectifier and an analogue to a digital converter called ADC over here. So, these are very good, smart methods to do it.



Yes, there are dedicated encoder interfaces also. You need not count. Let this device do it for you. This is the way the industry works. So, in industry, you need reliability, which is at its peak. So, there are a few ways. Methods of doing it may be, if I am able to acquire this voltage signal, maybe in my software. I can also take software derivatives. I can differentiate things in soft also. You can directly take in the pulses from your standard digital input channel and just count the number of pulses. You will get the velocity. These are a few ways, but yes, in the industry, there are dedicated ways of doing it. So, this is one of them. It is a Beckhoff incremental encoder interface, EL5101. It can interface one of such encoders, like an optical encoder, phase A, or A bar. So, yes, in industry, you have phase A. You also have an A bar phase, which is available. That is to increase reliability. If one of them fails, you can always have this one as a standby. OK, not just as a standby. If both of these are giving you the same input, that means you have the same output. That means your device is faulty, got it? So, similarly, you have B and B bar, which are available. So, if this is 0, this is 1. If this is 1, this is 0. If that is not happening, if simultaneously both of them are 0 or 1, that means your device is faulty. So, that is also used for fault detection. So, and then you have an index, which comes here. C and c bar is to be fitted. OK, so these are the connections to interface your optical encoder and encoder. Supply goes from here. OK, and then this is so. The encoder supply is 0 to 5-volt range. It is only 5 volts, which comes here, although you are inputting 24 volts to the system over here. OK, because in industry, 24 volts is readily available, whereas 5 volts is not available. So, this device makes 5 volts available for this encoder interface. OK, so for this encoder, which takes in 5 volts, only 5 volt signal. These are all indicators which are here. So, there are many other inputs for other diagnostics and controls. So, 5 volts is generated from here.

Resolution, you see, is very, very high. It can go as high as 16 or 32-bit. You can change. So, why should somebody come down from a higher resolution to a lower one? Because every time you do not need a higher resolution, you want to avoid too much flooding of data, too much data which is flooding your system. Your values are going very high. So, in that case, you can switch down to 16 or sometimes even 8-bit, but this does not allow you to go to 8-bit at least. So, yes, the Quadrature encoder is there also. So, as I told you in the last class, if you have phase A and you have phased B, you can simply have rising edge, rising edge, falling edge, falling edge, so one complete cycle of phase A and phase B. there are four instances that you can record, and those can be further used to increase the resolution of your encoder. OK, so that is, this is how it is done, and then 0 to 100%, it is voltage control. That is not over here, at least in this encoder, encoder interface.

Electrical isolation: it is 500 volts. Relative humidity: 95%. Non-condensing nature is there. So, these are a few readymade available things which are there, apart from standard digital input output that can also be used to interface your encoders. But this has quite a good amount of ready-made features in it. It can directly count and give you the velocity. It can give you a position. It can also give you velocity. So, that is the beauty of having such interfaces.

So, yes, that is all for today. So, in the next lecture, I will be discussing acceleration sensors, resolvers and synchro. Those are AC devices, alternating current devices which are mostly used at the rear part of your industrial AC servo motors. So, that is there. And accelerometers, which, again, are a special kind that micro-electro-mechanical systems. So, we will be discussing all of them in the next class. That is all. Thanks a lot.