NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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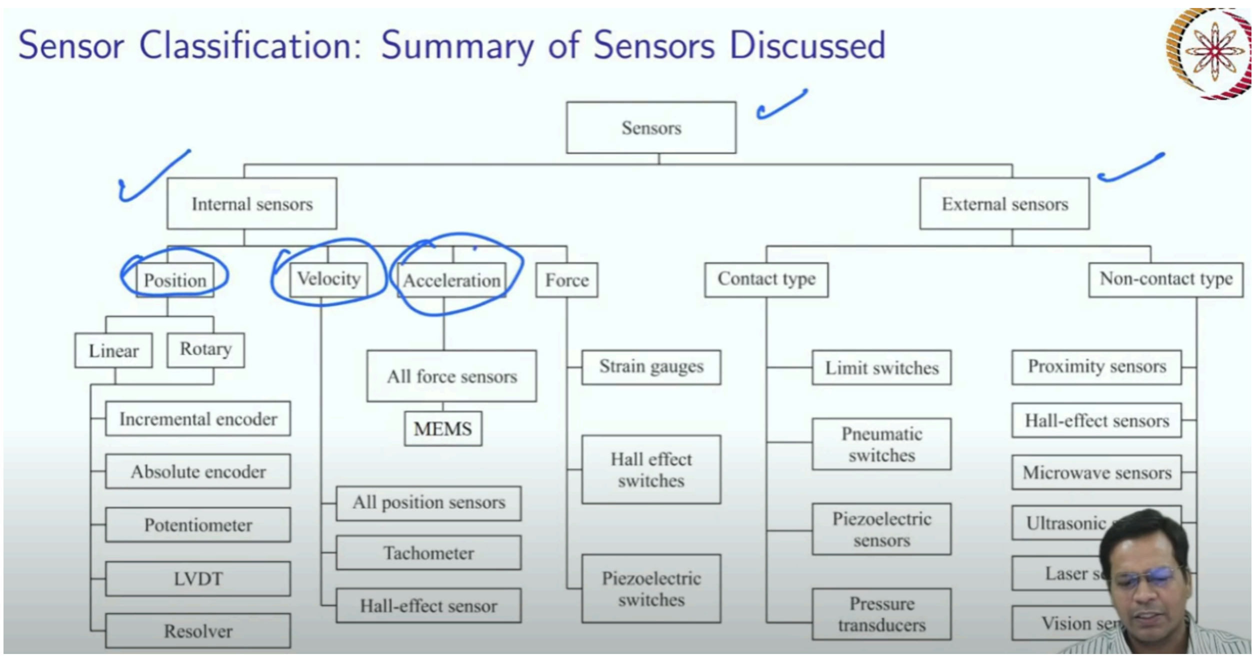
Week: 03
Lecture: 15

Limit Switches, Classification and Characteristics of Sensors.

Hello, and welcome back. So far, we have seen most of the kinds of robotic sensors which are used in the industry. We have seen an optical encoder. We have seen position sensors of various other kinds. We have seen how to convert a position sensor signal to a velocity sensor signal, how an accelerometer is made and hall effect sensor in general, and how it can be used for various purposes. We have seen four sensors. So, with these, most of the kinds of sensors are there in the industry. So, let us just discuss how these sensors are classified, how the property of each sensor is mentioned in their technical data sheet, and what are major factors with which you can compare different sensors. So, that is what we will be covering today. So, let us begin.

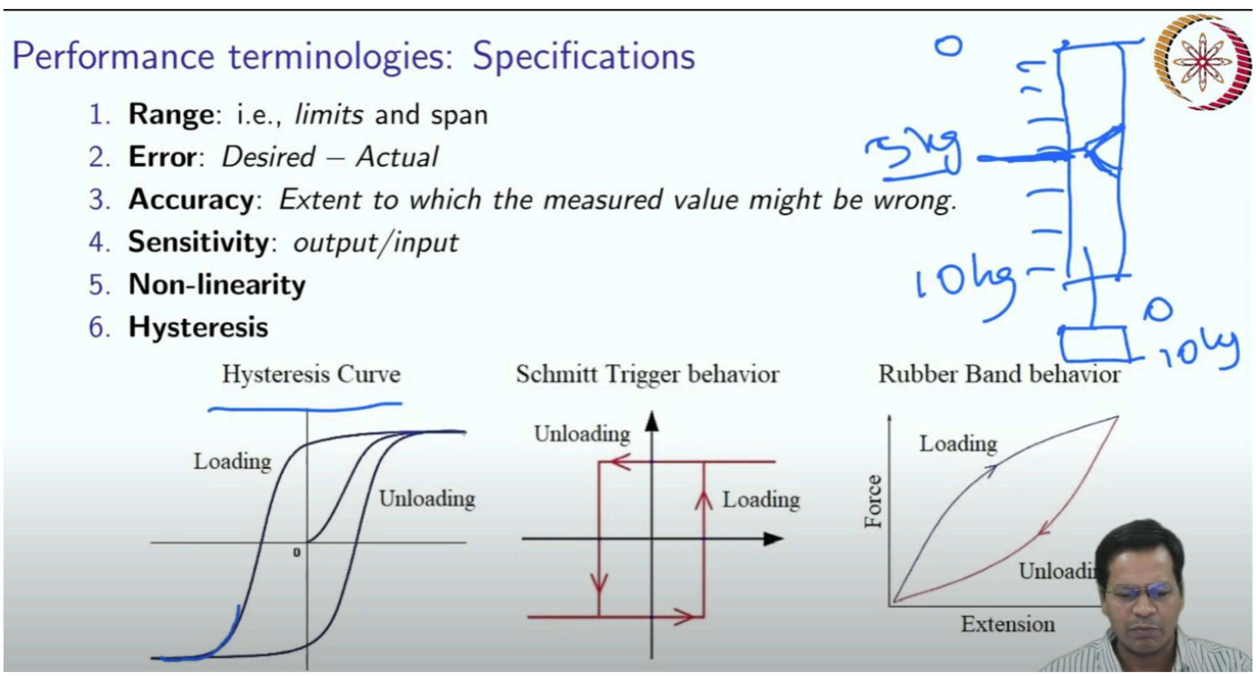
It is one leftover portion of our syllabus, but yes, this is quite simple as well. So, what is this? You must have seen it quite a number of times at various places. So, these are known as limit switches, which is what this roller is basically doing. This particular item is mounted using these bolts-bolts over here, and they are fixed to the mounting- and this lever can move like this. So what is this? This is nothing but a limit switch, as rightly told, so that it can be normally open type. Normally open means a switch is normally open. If you press it, it is closed. So, there are many other switches which are normally closed type-normally closed type. So if you just press it, it will become open. Apart from that, there are many other types which can be double pole type, in which you have just one single lever that has got two different wires which are made which are cut. So that is how it can directly switch on two wires at a time, or it can make two wires at a time. So, yes, these are different ways.

So, it looks like this. A number of places include: this may be included at the printer, in your printer or 3D printer. This is nothing but a pedal switch. Probably, you have seen it on a swing machine. Sometimes, they are not just switches; and they are gradual switches. That is not a switch as such, and it can be a potentiometer. This type of lever is quite common, and these are like joysticks, and it is there in earth-moving vehicles with commonly. So yes, these are a few of its kind. Yes, If you remember, your fridge also has such a switch. So as soon as you lock your door, shut your door, your light goes off right In your car. Maybe when you open your door, your light switch is on. So yes, that also has this type of switch.



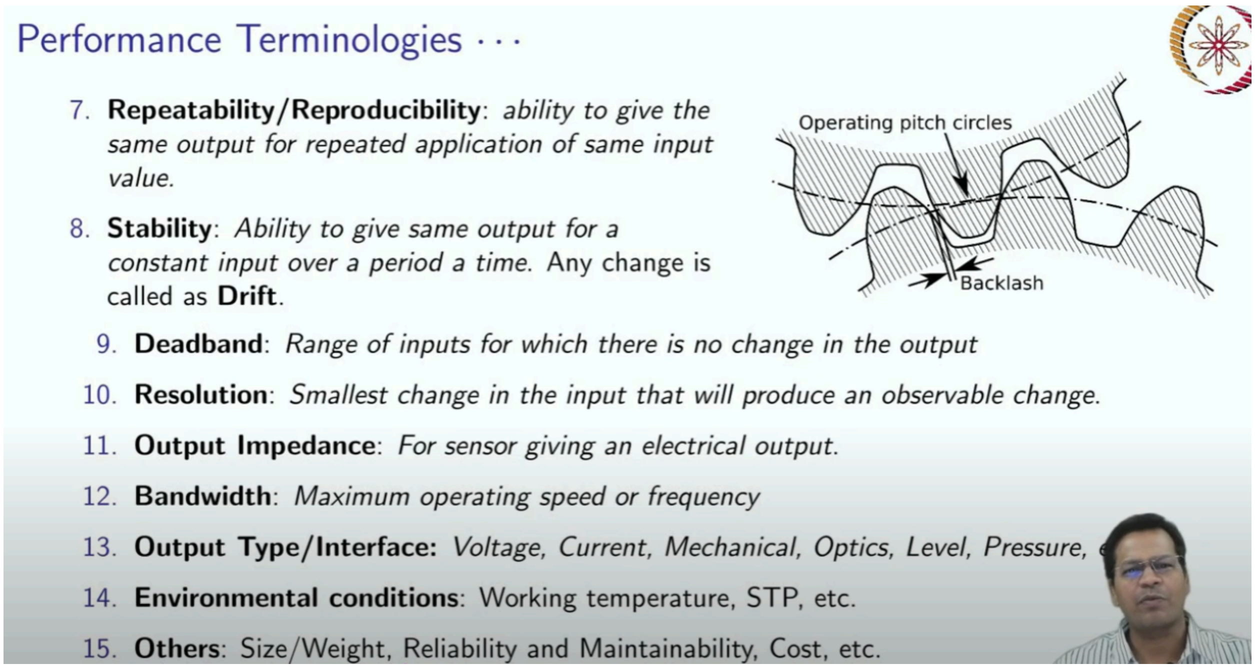
So, yes, let us just see how sensors are classified. So yes, we have covered sensors. Sensors are internal sensors and external sensors, so internal sensors basically give you the state of a machine. So, this can be position, it can be velocity, it can be acceleration, and an acceleration sensor can be used like a force sensor or otherwise. So, yes, these are four major kinds which give you states. Then, position sensors can be linear and rotary, linear sensors and rotary sensors. Both can be of incremental absolute. Its potentiometer- it used to do our job. Apart from incremental optical, which you have seen, it can be a potentiometer linear variable differential transformer. We did not go through this resolver, you have seen. It is an AC sensor, an AC signal sensor, okay. So, velocity sensors can be of multiple kinds, and it can be of position sensor, tachometer, hall effect sensor, you see, okay. And acceleration sensors can. Any force sensor can be used, like an acceleration sensor, as we saw in our module and MEMO micro-electro-mechanical sensors that you have seen, okay? Force this in detail, you know how- it can also be a hall effect switch or a piezoelectric switch, which can also be used like this. So, yes, these are some internal sensors. External sensor gives you the state of an object and how your machine is encountering the environment. So, where is mine? What is the status of this table may be when it is marked at the corner of this too.m. So if it is aligned, there may be some switches which give you exactly the state. When it is perfectly aligned, both the switches should be ON.

So, these are a few ways these are used. So this is a limit switch. It can be a pneumatic switch, it can be a piezoelectric switch, it can be a pressure transducer which can be used like this. So all these are external switches which give you the state of the environment, okay? So, the proximity switch is there. That is a similar kind, but it gives you proximity without having any contact with the environment. So those were, let us say we have discussed at least capacitance sensor or inductive sensor. Right, we have also seen a hall effect sensor. The microwave sensor is also there, but we have not gone through that in detail. Ultrasonic sensors and laser sensors are there, which are very precise, and vision sensors use machine vision to do their job. So, just broadly, we have gone through most of these types of sensors as we have discussed in different lectures of this module, that is, sensors.



So, yes, now let us move ahead. How to indicate the performance of such a sensor? How about these sensors? When you go and check their data sheet, what parameters are there that specify that particular sensor? So, one of the very important parameters is the range. Let us say you want to inflate your simple balloon or type of tyre which is there in your car, so yes, in order to do that for cars it can be 0 to 35 bar should be quite good enough. Sometimes, they have different specific units depending on the tradition which is being followed, and sometimes they are SI systems. So, definitely, the unit is one of them. That also will specify the type of reading which is graduated on the dial or, if it is an electronic sensor, the output may be linearised based on the unit also okay. So yes, that is the range which can tell you that is there. And then error. Error is, let us say, you know this pneumatic pressure line is 6 bar, but it is showing you 6.5 bar all the time. So, that is the desired one is what it actually is, and the actual one is what your sensor is showing you. What your sensor is showing, so desired minus actual, is the error signal. Mostly, your datasheet shows errors can be plus or minus 1 percent of the full-scale reading. That means if it is 100 bar, it can tell you, let us say, 99, or it can tell you 101 bar, okay, but that is the maximum error that they have found through experiments. Accuracy is the extent to which a measured value might be wrong. So how much is the maximum error which is possible? So, the extent to which the value might be wrong. Okay, so wrong is this. That is the error. Whatever is wrong, it comes under this. So, that is there. And sensitivity is the device. Sensitivity is not always desirable. If it is oversensitive, it becomes very difficult to measure something. Okay, so, just like your, let us say, weighing machine, which is there, so you just put in one small we get on top of it, it immediately starts fluctuating. It goes very high, and then, over suits, it comes back. So, they may be very, very sensitive to even a small amount of weight. It becomes very difficult just to see the actual value which it should give. So it is naturally sometimes damp to make it happen or sometimes so, it is the output versus the input. Okay, so input is the signal which is coming and output is the actual value that it should show. So, depending on the value, how they are calibrated. So, yes, it is sometimes digitally controlled, or sometimes it is a property of a system, in the case of mechanical sensors. Okay, so non-linearity is something which is again not desirable, because it becomes very, very difficult to estimate the kind of signal which is there. Okay, let us say if it is a displacement sensor which is coming out of a potentiometer, you know it is linear. Okay, so the output voltage is proportional to your input displacement. So if it is 0 to 180 degrees for 0 to 5 volts, if it is showing, 2.5 volts, you can directly say, yes, it is 50% of what is the full-scale thing. Okay, so that is how linearity helps you in estimating the value and understanding the value which is coming out of it. Otherwise, if it is non-linear, it is very difficult to predict that, very difficult programming that you have to have a complete set of tables, look up, table kind of thing in order to understand the actual parameter which you are measuring.

So, yes, also the parameter, which is known as hysteresis. So, while loading, it has, let us say, you have a spring balance with an indicator which is on this. So if you keep on increasing the weight, it comes here exactly when it was. You were going from 0 to 10 kg, let us say. So, 0 to 10 kg, it came exactly here while increasing the load, while increasing the load when you started with 0 kg and then went on to 10 kg. So, it came here for the 5 kg load. So, while going back also, it should come exactly to this place, right? So it should show while unloading. Unloading it should follow the same pattern and go back, but normally, that is not the case with some old types of sensors in which this is not taken care of. So, yes, it follows a line which is something like this: while loading, maybe it is following this, so unloading, it follows a different curve and comes back. So, for 0, it is 0. For 10, it is 10, but for 5, it may not be 5, got it? So, there is a different way in which hysteresis or behaviour can be explained. So, one of them is Schmitt. Trigger behaviour in this line is almost like this, which is rectangular, okay. Another one is a Rubber Band kind of behaviour. So, it is a curved shape while going up and a curved shape while coming down. So 0 to 10 is something like this. So, anything which is 5 will be somewhere over here. So you got the idea basically what it is. So it is a very, very undesirable thing- and normally, they are very well compensated not to see this kind of behaviour in your sensor.



So, yes, another very important parameter is rope stability, which is the ability to give the same output for repeated application of the same input. For the same input. Again, I will give you a very good example, like a potentiometer. A potentiometer is my favourite example. So, for the same input, that means for the same position. If is total scale is 100 mm, you are at 50 mm, so it gives you 2.5 volts. Every time it is at 50 mm, it should give you 2., 5 volts as an output. So it is highly repeatable. But yes, over time, you know, this particular slider gets worn off, so it goes bad due to dust on top of it, maybe moisture. In that case, this will not be the case. So it is not repeatable. If it is accounted, if the value is accounted for over a period of time, things have gone bad. So, yes, that definitely does not come under the purview of repeatability definition. So, in case of repeatability at the same period of time, we will say maybe on the same day, you have multiple times, you have measured, and you got a different output. So basically, if this should be the output, and. You are getting signals somewhere over here. So, what is repeatability? Repeatability is defined as the smallest circle which should contain all the data for a given value. So, that is how repeatability is defined. We have discussed this also while we were discussing our robot's repeatability, that is, the actuator repeatability we saw. So it is exactly in a similar way. Most of the terminologies which are here also apply to your robot or maybe to an actuator. So most of them. So, over here we are concerned mostly about sensors. Quite a few of them also apply for actuators or even for a complete robot, at least for repeatability, now you know.

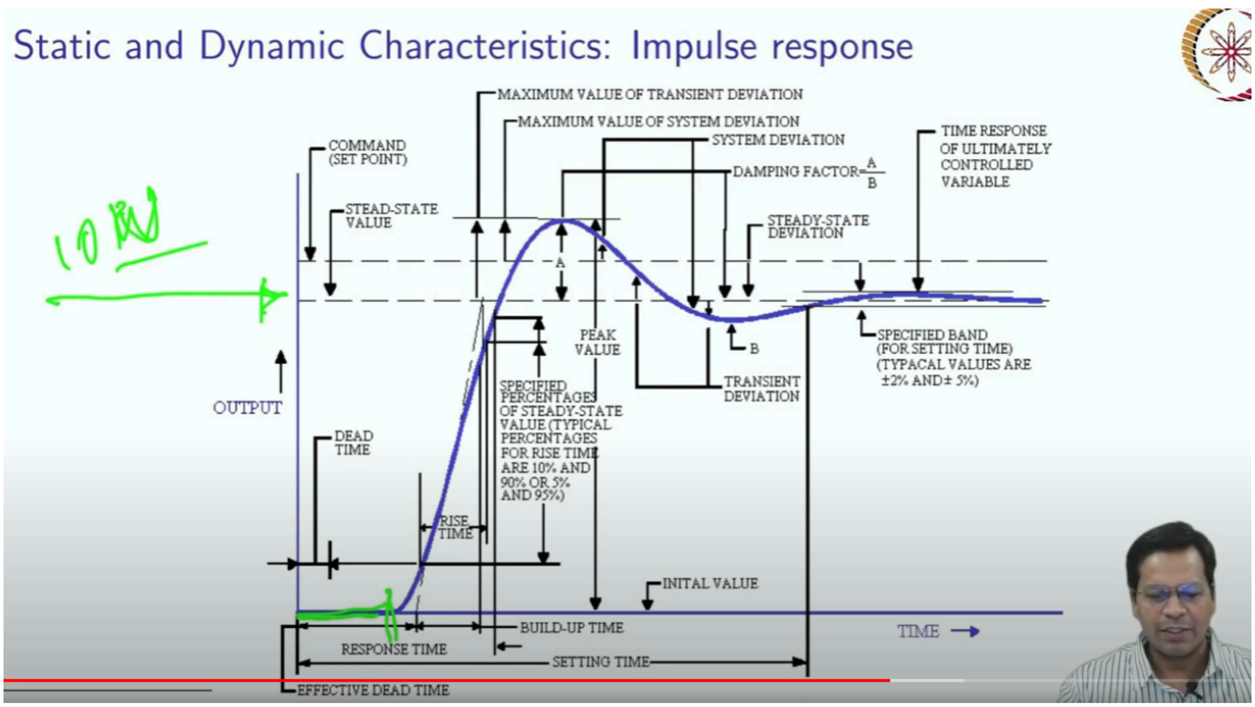
So, the next one is stability. It is the ability to give the same output for a constant input over a period of time. So, if it is giving you a constant output, it should remain there. As long as the input is not changing, the output should also not change. That also should remain constant. But what happens sometimes? Due to changes in temperature, output varies. Even when iNput is not varying, that is known as a drift. So, it can be due to the temperature- that is one of the major causes of this- or sometimes due to the material deformation which is happening. If it is a beam on which you have applied a strain gauge sensor somewhere over here, it is giving you in terms of voltage. So, this voltage for the same load may change with time. This voltage may change with time. So, that is because of maybe a creep deformation of this beam if it is for a longer duration. So, that is one of the causes. So, there are many other causes which cause this. So that is what it is. The stability should remain there.

So, deadband is a range of inputs for which there is no change in output. It is very clearly explained by the backless, which is there in mechanical gear. If one of them is driving, the other one is the driven gear. So, what happens? There is some clearance. If this is driving this, the clearance is on this side. So, when this starts rotating in the opposite direction, this will pick up. But After a lag of after a period of time. So, this will start. This will take at least this much amount of time before it establishes contact. The driven shaft is not going to move. So, that delay is there. So, that is the deadband. When your output is not changing even though your input has changed, that is a deadband. That also is there in a few sensors. So, mostly in the case of an amplifier, you may have some deadband where a small, very small change in the input your output is not responding only. So, it is sometimes given as your amplifier picks up after a period of time. So, that is the deadband which is there.

So, yes, and then you have a resolution. It is the smallest change in input that will produce an observable change in the output. So again, your device may have an analogue to a digital converter. So that has further resolved your voltage to further digital values. Let us say if it is 1024 number of graduations you have in your dial, which gives you an output in the case of an optical encoder. So, you cannot see any displacement if it is less than 360 by 1024 angle. So, for that small angle, it is not giving you any pulse. If it goes beyond that, it will definitely give you one high pulse. So that is the idle time within that is not going to give you any change, and all the changes that you see are in slots. All the slots will give you output in this fashion, and this is the least amount of distance that you can measure, at least angular distance in the case of an optical encoder. So that is what is your resolution.

And then you have output impedance. Normally, for electrical devices and electrical sensors, output impedance is very important because connecting this sensor to any input device may be a PC, maybe a DAC- should not change the behaviour of this sensor. So that is why this impedance is very, very important. So, actually, when you connect it to this, the total resistance of this device changes because it becomes something like a parallel resistance, which is there. So its effective voltage, a.Cross, that changes. So, connecting this device changes the property of this. Let us say it is giving you 0 to 5-volt full scale. When it is connected, it gives you 0 to 4.98 full-scale value, so that impedance matters here. So, normally, it is very, very important. In the case of electrical output, bandwidth is the maximum operating frequency. How fast your device can change that again is very, very important. At least you have seen such a case in the case of proximity sensors. If it goes beyond 20 kilohertz, off and on, it is behaving as if it is completely, totally on all the time. So, instead of giving you off and on, off and on, it is giving you uniform, constantly on signal. So, it is giving you this. So, beyond a certain frequency, it gives you bad results. It is not getting switched off properly. So, there are devices with different frequencies, which are to be selected well before implementing in your application.

Output types can be many. So, in the case of a potentiometer, it was voltage. Sometimes, they are giving you output as a current, or it can be mechanical output. In the case of the optical encoder, however, the output was optics, but yes, it was later converted to an electrical signal. So, it can be optical fibre, which is used to transmit long-distance data. So, in that case, your output is in optics, which later on requires a digital-to-analogue converter or maybe an optical-to-electrical converter. So, yes, again, the level output of a potentiometer, you can find an analogy to it. So, if is maximum full-scale value is 0 to 5 volts in the case of an embedded system. So, it can be 0 to 24 volts in the case of the industrial electrical system. So, yes, this is pressure. Pressure can be another type of signal which is commonly used in the case of pneumatic sensors, at least in the case of nozzle flappers that I see that we have not covered. But yes, you should now understand the different outputs, what they can be, and then environmental conditions. That is also specified in the data sheet, working temperature, although it is a pressure sensor. But you should have remained within this band of temperature to get the precise or claimed value which is there by the manufacturer: standard temperature and pressure. So, that is mentioned in this. Apart from this it can be ingress protection also may be. So, it has to work in that particular kind of environment where dust and water molecules should not go beyond the size. So other things are like size and weight. Sometimes, they are very, very important. I will give you an example: when in earlier days, we used to have gyroscopes, so gyroscopes were very, very big. Those were something around 5 to 6 kg or maybe 12 kg in load. Nowadays, with ME sensors, it can be in a few milligrams. So that is the difference. So, 5 kg to this is almost like 0 kg now. So you have used a lot of difference with technology so that 5 kg additional ammunition that our aircraft can nowadays carry. So, that is one of the very good examples of when the weight of these sensors does matter if it is your wristwatch or maybe a mobile device. So, sensors you see there are.Plenty of sensors. Each one of them accounts for a certain weight. So if those are very, very big, it is very difficult to manage your mobile phone in your pocket. So yes, reliability is another thing. So yes, it is very much related to many other properties, like your system parameters. They do vary with time, or they do vary with environmental conditions. If it goes bad, even by a small amount of time, it goes bad. So, I will show you, at least for a force sensor: force sensor: it is ready to take up, even if it is designed to take up a load of up to 100 newtons. But when a robot collides, it can go up to maybe 1000 newtons. But if that force sensor is able to take up that load, at least for a second, you are done. Your device will not go bad. Those are very expensive sensors, so at least for a small period of time, you can overshoot. But the normal range is 100 newtons. So, you got my point. So, that is there. So, that is the reliability of such a thing. Maintainability, let us say, in the case of a standard load cell. So, it needs calibration every one year. So that is maintainability. Every year, you have to go for a test, which is to get this calibration done so that it gives you the same similar value as it was when it was new. Then the cost is sometimes force torque sensor at least, which we normally use in robots. They are usually expensive, usually expensive even for a very small scale, sometimes 100 newtons or 200 newton capacity. They are very, very expensive. So yes, that cost does matter, at least for our research and not for at least for defence, but at least for research and maybe for medical application. That cost does count a lot because it is ordinary people who are paying for it.



Now, we will look at the static and dynamic characteristics of the sensor. This is why this is so important: because as soon as your sensor gets the signal, it does not give you an output which is exactly what was desired. So, it takes some time to stabilise before it gives you an actual output or may be very near to an output. So this is the dynamic behaviour of a sensor is very, very important. So, how much time? What are the different parameters which are important in order to deal with such behaviour of your system? The one which we discussed so far where static characteristics of a sensor, so This does not change with the type of input or behaviour in the input kind, so they remain the same. But yes, your output, let us say, if it is in terms of voltage, the dynamic, based on the dynamic inputs, so that output is not that the way it should be. So, how it is actually, it behaves something like this: let us say your sensor came, should show this value somewhere over here like it is 10 Newton over here, which is input to your sensor, your force sensor. So, what happens? Your device immediately starts sensing the value, and it takes a certain amount of time actually to start also, so it took at least this much time to begin. Then it started rising, and your output started going up. It over-suited a bit, and it came down, and it is stabilised to the actual value, which is there. So, it took at least this much time to come to that value. So that is the problem with this type of sensor, or any sensor, to say because they have a lot of components which are there inside sometimes, at least in the case of optical sensors, at least in the case of inductive or a capacitive proximity sensor. You saw there are components. You had an oscillator circuit, you have a pickup circuit which is used to pick up, and then ADC, then a digital converter, then a communication device. So, there is latency sometimes, or there is internal system behaviour due to electronic systems which are there. That is something like a spring mass damper system. So, it takes some time, it goes over suits, and it comes back. It gives you a good value. This time should be very, very small if it is to work with robots. It should work in real-time, got it? So, this curve explains it all. So, how is your device? This curve is normally not there in most of the data sheets, but they will specify some parameters. Specific parameter. Which is related to this curve. So what are they? Let us discuss that.

So, the first parameter, which is there, was your response time. It is expressed as a percentage of input. So, what is the response time? You see here. So, this is your response time. You see, it is marked in this. It is marked here. You see this: from value: from here to here is the response time. After that your device actually started moving, actually started going up. So, hope you got this. So, mark till here. This is the time it took to start giving you some value. At least initially, it was giving you a 0 value. Later on, it picked up, and it gave you some value, so now, let us move ahead to other parameters.

So, the next one is time constant. The time constant is expressed as 63.21 percent of response time. Actually, it is very much related to the kind of you have studied in radioactivity, half-life or something like that. So, this fractional value comes very similar to a value one minus one by e. It is given by one minus one by e.

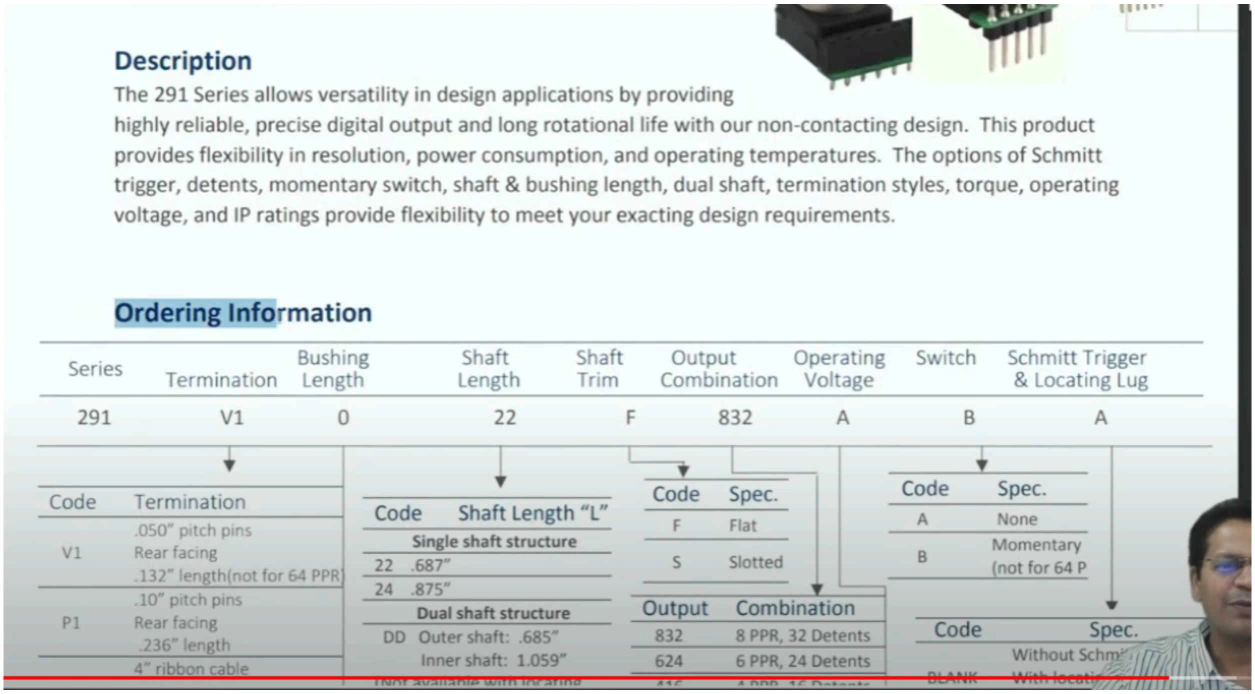
$$1 - \frac{1}{e}$$

So, this is the factor, so this is given as 6312. So, in percentage, it is equal to 63.21 percent. So, this is what is the time constant, this much percent of your response time, and then you have a rise time.

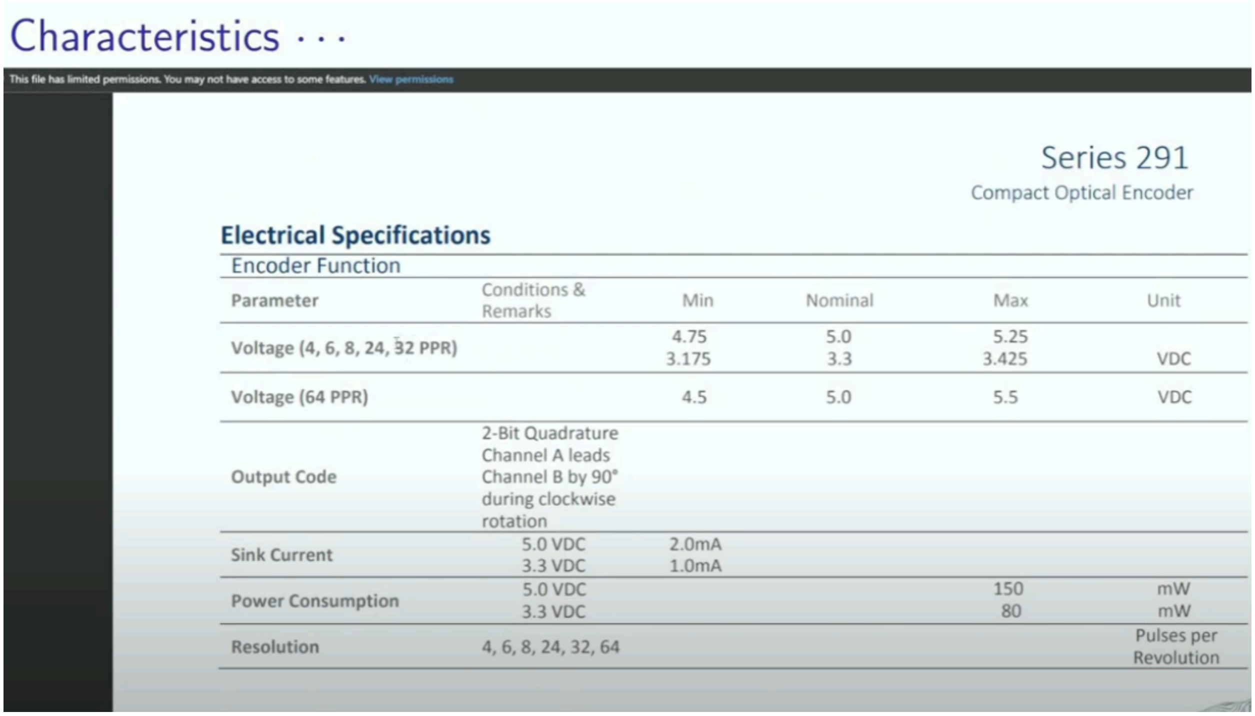
Rise time is actually specified as a percentage of steady state. So, if it has to come up to this state, normally it should reach till here, so this is the time from here to here, from this point in your space. Basically, this is the point, and you have this point. So it took at least this small gap of time to actually come up to a real value which is actually input to this device. OK, so this is the rise time: the amount of time which it takes to reach that, at least 95 percent of the actual value. So that is your rise time.

Then comes your next parameter, which is the settling time. So, how it is expressed as output settles within some percentage of steady state. Almost just two percentage remaining, so it is in a steady state, so that is what is your steady state time, so that is where it has almost settled. So, it is specified somewhere in this region. So that is the region where it has almost near to the actual value which was input from your environment. So that is what this sensor is also showing. So, there is not more than a 2 percent to 5 percent deviation in that region. So, the amount of time, this is your settling time, so now let us see a few of these if it is there in the technical data sheet of a few of these sensors.

Now, I will move on to some datasheets and physical data sheets of a few sensors. So, this is, this is one of the sensors, which is a typical rotary encoder, or optical encoder, so see what all parameters are given here.



So this is ordering information. This is there, basically, they are the type of nomenclature this company may be using. So it is. It belongs to the 291 series. Termination of kind of V1 means so many pins of some pin size are given. So, these are some of the more detailed explanations which are here: bushing length and shaft length: What is the length of this shaft which is here? The shaft is trimmed with the kind so that it can have just a slot. It can be C cut, so different cuts which are here so that it can be slotted. It can be flat cut. Operating voltage can be different, different, so a switching kind of class suit trigger. So, these parameters are specifically given, so this is one available with different kinds of pulses, so 64 pulses per revolution. This is a small optical encoder. It may be useful for some small kind of stuff, but yes, it is there.



Characteristics · · ·

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Series 291

Compact Optical Encoder

Electrical Specifications

Encoder Function

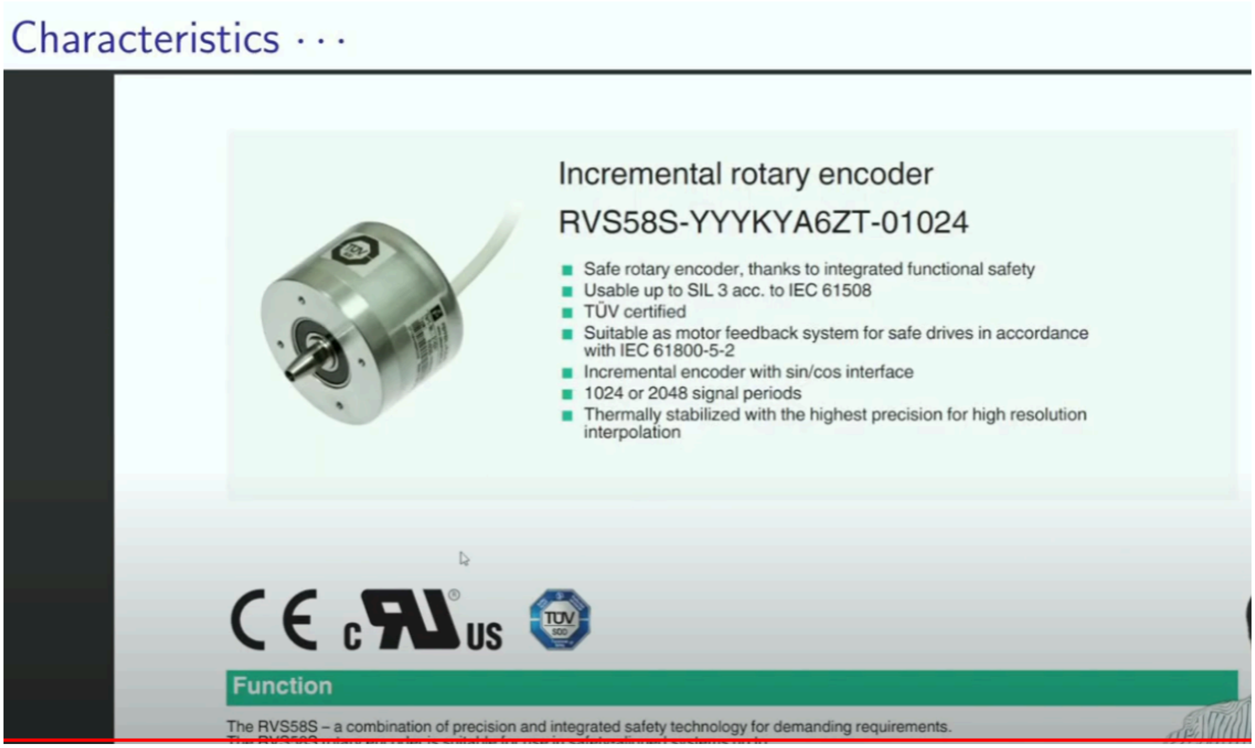
Parameter	Conditions & Remarks	Min	Nominal	Max	Unit
Voltage (4, 6, 8, 24, 32 PPR)		4.75 3.175	5.0 3.3	5.25 3.425	VDC
Voltage (64 PPR)		4.5	5.0	5.5	VDC
Output Code	2-Bit Quadrature Channel A leads Channel B by 90° during clockwise rotation				
Sink Current	5.0 VDC 3.3 VDC	2.0mA 1.0mA			
Power Consumption	5.0 VDC 3.3 VDC			150 80	mW mW
Resolution	4, 6, 8, 24, 32, 64				Pulses per Revolution

So other parameters are. You see, the voltage is 32 pulses per revolution. The voltage maximum is 64 pulses per revolution. Output is a 2-bit quadrature in the form of channel A and channel B, and two channels are there. The sink current is 5 volts and power consumption is 5 volts of something around 80 to 150 milliwatts. Resolution of different kinds it supports. There are many other parameters which are here.

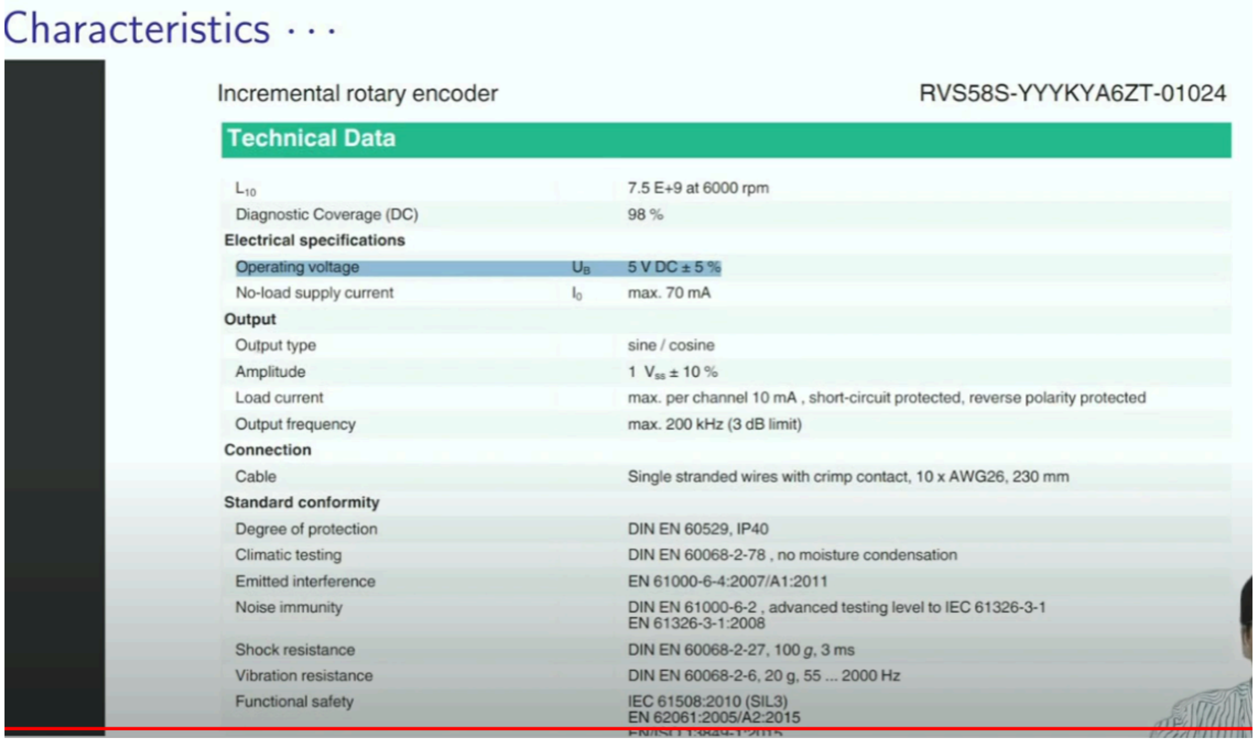
Mechanical and Environmental

Manual Soldering	Maximum temperature of 350°C for 5 seconds	
RoHS	Lead-Free. Fully compliant to RoHS Directive	
Shock :	Per MIL-STD-883F (100G's)	
Vibration :	Per MIL-STD-883F (15G's)	
IP Rating (4, 6, 8, 24, 32 PPR):	IP 50	
IP Rating (64 PPR):	IP 40	
Packaging :	Standard anti-static tray packaging	
Operating Temperature:	-40°C to +85°C	
Storage Temperature:	-55°C to +100°C	
Storage Temperature: (32, 64 PPR)	-40°C to +100°C	
Rotational Life	No detent @ 30 RPM	3 Million Cycles
	With detent @ 30 RPM	1 Million Cycles
Push-Pull Strength of Shaft (4,6,8,24, 32 PPR)	10 seconds	20 kg
(64 PPR)	10 seconds	13.6 kg
Terminal Pull-out Strength	10 seconds	6 kg
Rotational Torque (4, 6, 8, 24 PPR)	Running	10 to 30 gf-cm
(32 PPR)	Running	30 gf-cm Max.
(64 PPR)	Running	100 gf-cm Max.
	24 Detents	90 to 190 gf-cm

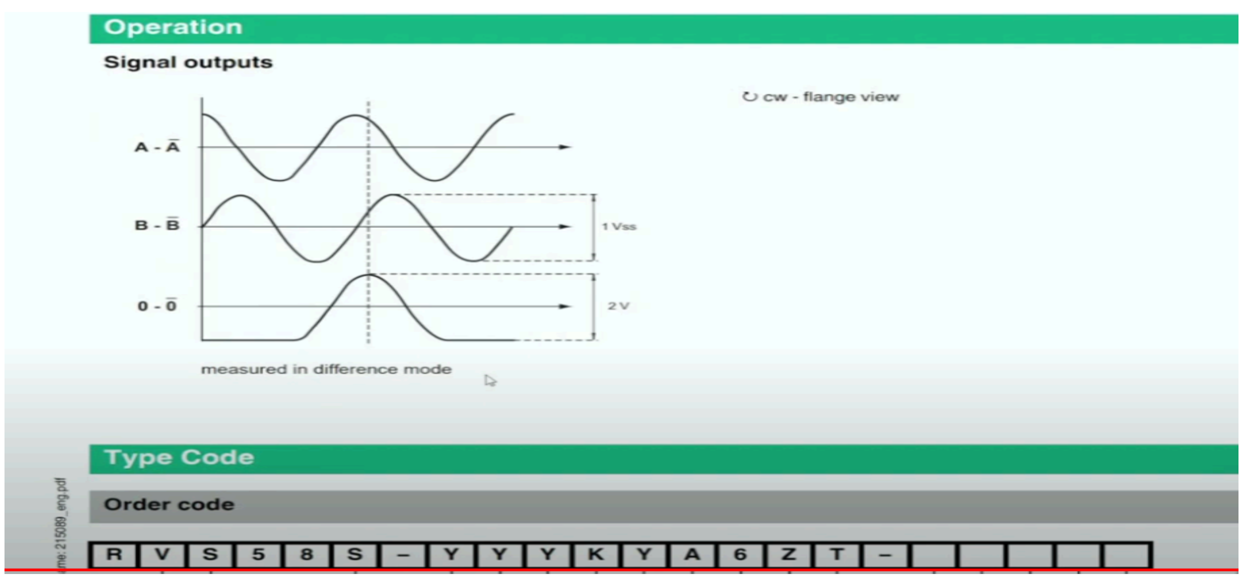
One of them is the IP rating. So, if it is 32 PPR maximum, the best possible is IP 50, but for 64 PPR kind, it is IP 40, which is below that. Anti-static tray Packing is there. Packing is very, very important. Sometimes, these sensors are picked up by some robots in the electronic assembly industry. So, in that case, that packing tray size is also very, very important. So, if this is a raw material for this kind of PCB manufacturing or device manufacturing company, that is very, very important. This is the operating temperature environmental condition. It is given. Storage temperature is different, working temperature is different for different PPR, it is different pulse per revolution. So, different kinds of sensors. It is the same range: rational life. So, you see these many parameters which are there. OK, so physical dimensions are given.



So, this is another kind of incremental rotary encoder, but this is a very special kind. That is the reason I showed you today. So, it can give you 1024 to 22048 signals for a period of 360 degrees. But it also gives you an incremental encoder with sine a cosine interface. That means it is just like a resolver. It can behave like a resolver. So, this is an external parameter. So, the pulse count is fine.

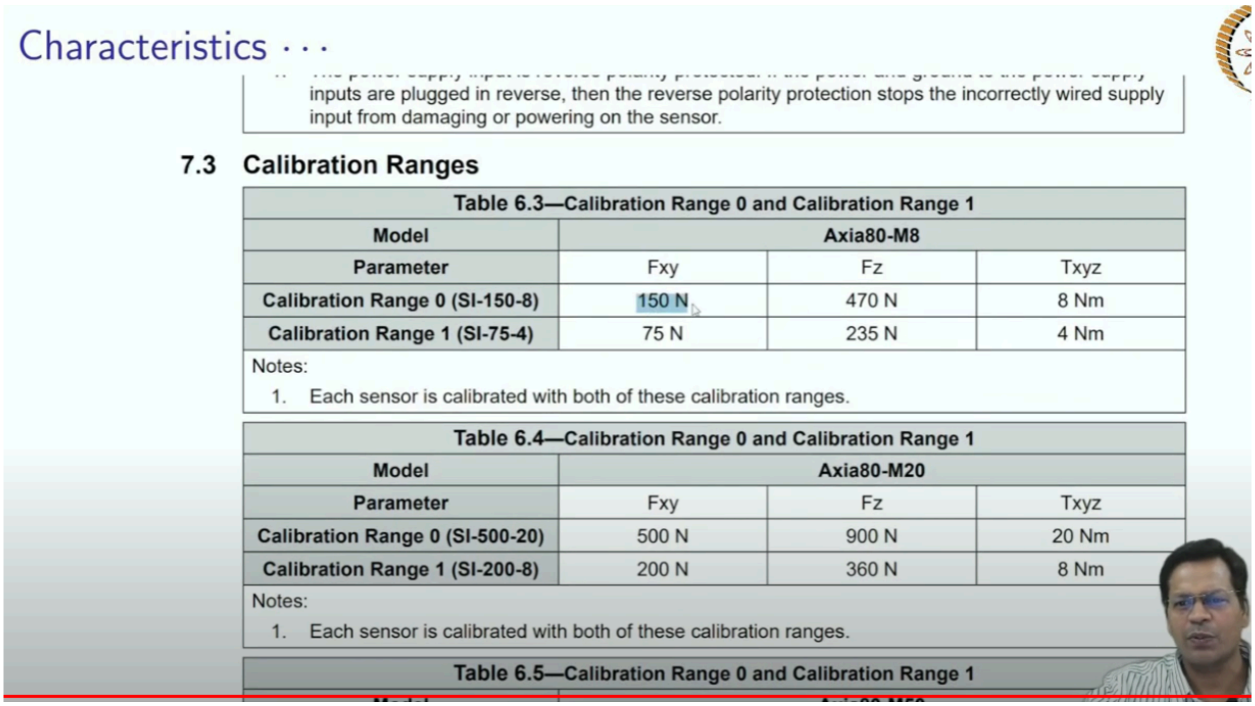


Then, there are many other parameters. The operating voltage, you see, is just 5 volts. So, if at all you are interfacing this sensor to any industrial interface card, that should have a dedicated output of 5 volts. You cannot feed in 24 volts. Here. Output is sine a and cosine signal, apart from that. So, there must be some configuration software or kind of thing which can change the output type. Sometimes, they do have some kind of switch which is there, which can change the type of signal that it gives. So, there are various certifications, and you see standard conformity certifications which are there.



So, here is your output. So, you see, two phases are there, a and a bar, b and b bar. One of them is sine, and the other one is cosine. So, the difference in voltage will let you know the exact position of your shaft. That is one way of doing it. This is an ATI force torque sensor.

Let me just say there are many, many parameters that the datasheet can give. The very important one is the electrical parameter. So, that is here.



Characteristics · · ·

inputs are plugged in reverse, then the reverse polarity protection stops the incorrectly wired supply input from damaging or powering on the sensor.

7.3 Calibration Ranges

Table 6.3—Calibration Range 0 and Calibration Range 1			
Model	Axia80-M8		
Parameter	Fxy	Fz	Txyz
Calibration Range 0 (SI-150-8)	150 N	470 N	8 Nm
Calibration Range 1 (SI-75-4)	75 N	235 N	4 Nm

Notes:
1. Each sensor is calibrated with both of these calibration ranges.

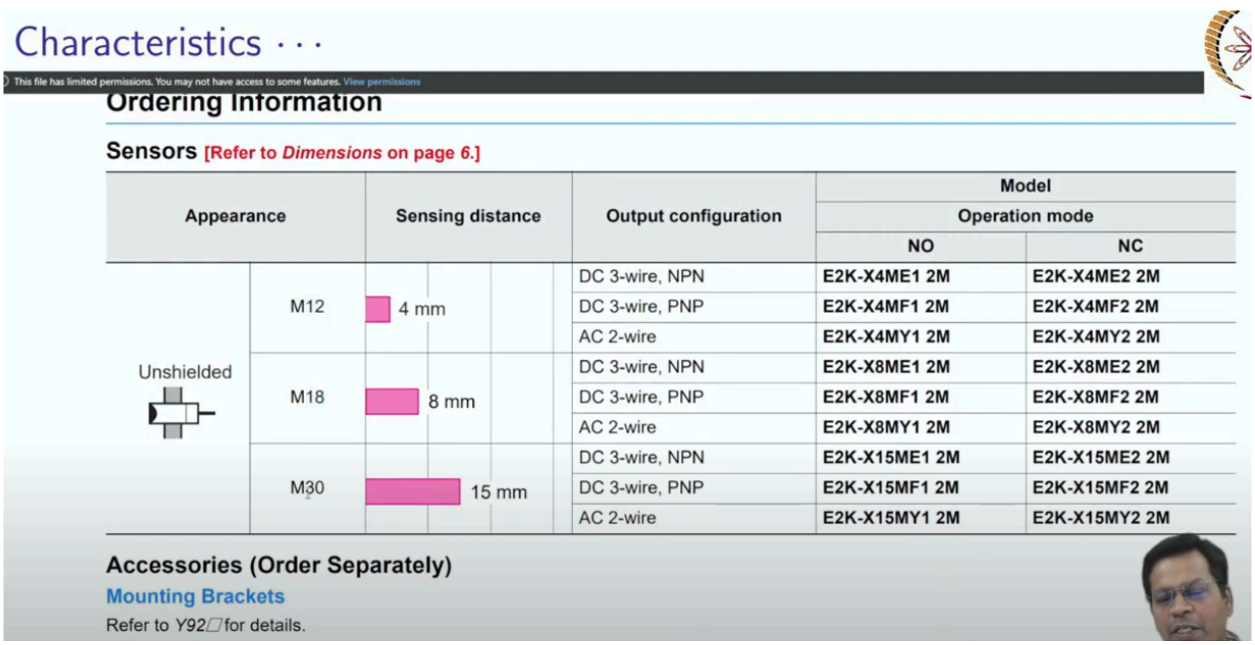
Table 6.4—Calibration Range 0 and Calibration Range 1			
Model	Axia80-M20		
Parameter	Fxy	Fz	Txyz
Calibration Range 0 (SI-500-20)	500 N	900 N	20 Nm
Calibration Range 1 (SI-200-8)	200 N	360 N	8 Nm

Notes:
1. Each sensor is calibrated with both of these calibration ranges.

Table 6.5—Calibration Range 0 and Calibration Range 1

So, you see, it can measure something around 0 to 150 newtons along a different axis. This is 6 degrees of freedom. So, torque along all the axes. XYZ is this, Fz is this. Along the axis, it has more value, whereas on the x and y-axis, it can take up less force. OK, and there must be some default peak values so if it is a regular kind of force, which it is measuring. That is fine, but how much is the peak that is encountered while it is encountering any sort of accident or those things? So, these are your peak values, which are there.

So yes, this is a cylindrical proximity sensor. You see, different models are there. They depend on size. Basically, M12 size, that is, the size of the kind of thread which is here with which it can be mounted to one of the panels, maybe.



Ordering Information

Sensors [Refer to *Dimensions* on page 6.]

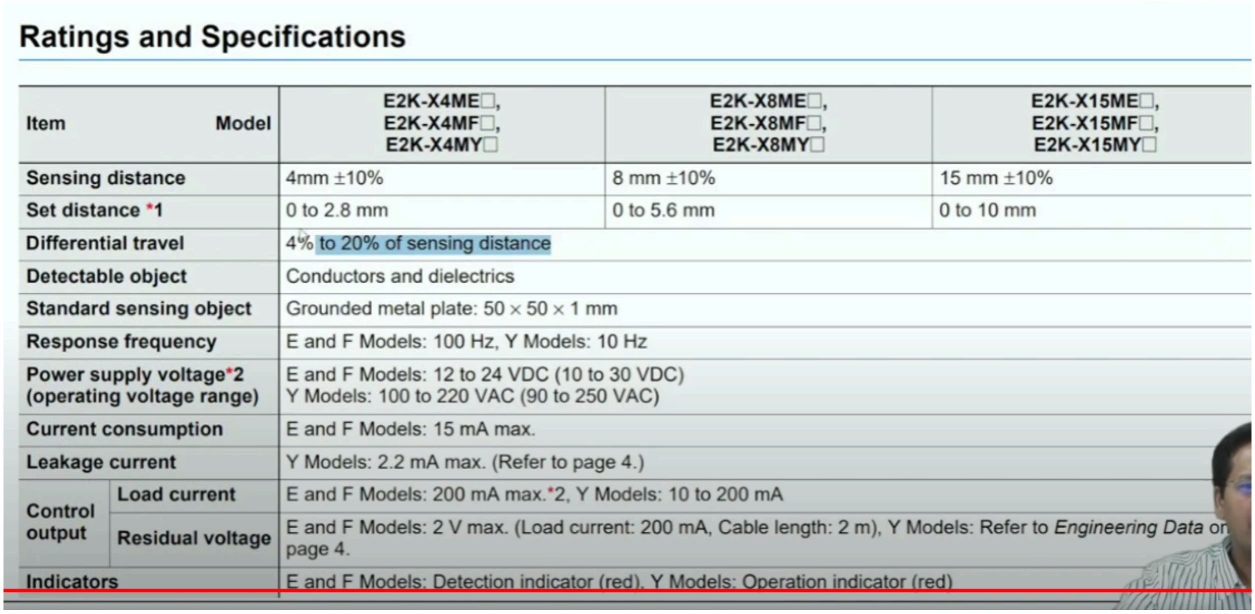
Appearance		Sensing distance	Output configuration	Model: Operation mode NO	Model: Operation mode NC
Unshielded	M12	4 mm	DC 3-wire, NPN	E2K-X4ME1 2M	E2K-X4ME2 2M
			DC 3-wire, PNP	E2K-X4MF1 2M	E2K-X4MF2 2M
			AC 2-wire	E2K-X4MY1 2M	E2K-X4MY2 2M
	M18	8 mm	DC 3-wire, NPN	E2K-X8ME1 2M	E2K-X8ME2 2M
			DC 3-wire, PNP	E2K-X8MF1 2M	E2K-X8MF2 2M
			AC 2-wire	E2K-X8MY1 2M	E2K-X8MY2 2M
	M30	15 mm	DC 3-wire, NPN	E2K-X15ME1 2M	E2K-X15ME2 2M
			DC 3-wire, PNP	E2K-X15MF1 2M	E2K-X15MF2 2M
			AC 2-wire	E2K-X15MY1 2M	E2K-X15MY2 2M

Accessories (Order Separately)

Mounting Brackets

Refer to *Y92*□ for details.

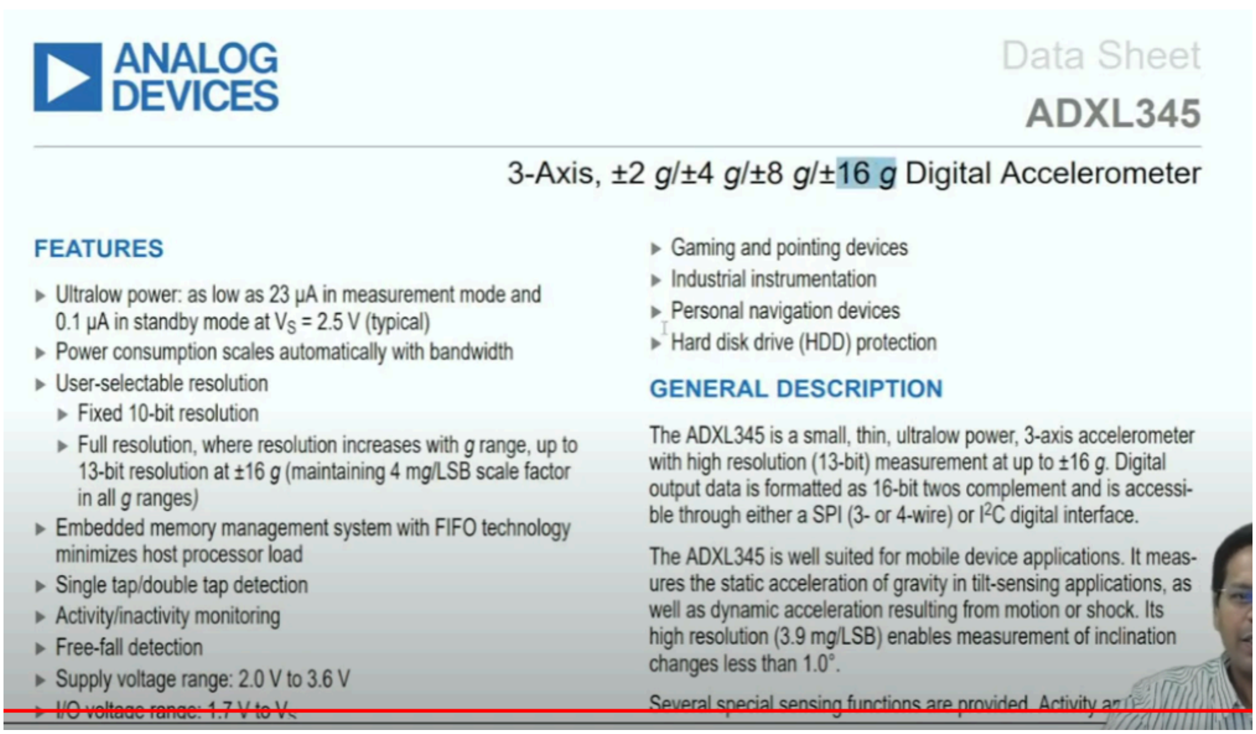
So, yes, M18 or M30, so these are standard sizes. Sensing distance varies by 4 mm, 8 mm, and 15 mm. So, all of them are of 3 wires. The wire kind can be a PNP, or it can be NPN type, so three wires. Basically, the output is just 1. 2 of them are supply, so 0 and maybe 24 volts and output are in the range of because it is digital in nature, it is 0 or 24 volt or 0 or 5 volts, it depends on the type of device it is given.



Ratings and Specifications

Item	Model	E2K-X4ME□, E2K-X4MF□, E2K-X4MY□	E2K-X8ME□, E2K-X8MF□, E2K-X8MY□	E2K-X15ME□, E2K-X15MF□, E2K-X15MY□
Sensing distance		4mm ±10%	8 mm ±10%	15 mm ±10%
Set distance *1		0 to 2.8 mm	0 to 5.6 mm	0 to 10 mm
Differential travel		4% to 20% of sensing distance		
Detectable object		Conductors and dielectrics		
Standard sensing object		Grounded metal plate: 50 × 50 × 1 mm		
Response frequency		E and F Models: 100 Hz, Y Models: 10 Hz		
Power supply voltage*2 (operating voltage range)		E and F Models: 12 to 24 VDC (10 to 30 VDC) Y Models: 100 to 220 VAC (90 to 250 VAC)		
Current consumption		E and F Models: 15 mA max.		
Leakage current		Y Models: 2.2 mA max. (Refer to page 4.)		
Control output	Load current	E and F Models: 200 mA max.*2, Y Models: 10 to 200 mA		
	Residual voltage	E and F Models: 2 V max. (Load current: 200 mA, Cable length: 2 m), Y Models: Refer to *Engineering Data* on page 4.		
Indicators		E and F Models: Detection indicator (red), Y Models: Operation indicator (red)		

So, differential travel is there. Sensing distance is there? The set distance is this for this device 0 to 5.6mm, and this is 10 mm. So, you cannot. There is no setting screw somewhere. You have to change the device altogether. So, the maximum distance that it allows is something around 10 mm. It can detect, you see, conductors, that is, metallic conductors, and it can also be any sort of dielectric which changes the dielectric of the environment nearby, so this may be a non-metal also, OK. So leakage voltage. There are many other parameters.



ANALOG DEVICES

Data Sheet

ADXL345

3-Axis, ±2 *g*/±4 *g*/±8 *g*/±16 *g* Digital Accelerometer

FEATURES

- Ultralow power: as low as 23 μA in measurement mode and 0.1 μA in standby mode at V_S = 2.5 V (typical)
- Power consumption scales automatically with bandwidth
- User-selectable resolution
  - Fixed 10-bit resolution
  - Full resolution, where resolution increases with *g* range, up to 13-bit resolution at ±16 *g* (maintaining 4 mg/LSB scale factor in all *g* ranges)
- Embedded memory management system with FIFO technology minimizes host processor load
- Single tap/double tap detection
- Activity/inactivity monitoring
- Free-fall detection
- Supply voltage range: 2.0 V to 3.6 V
- I/O voltage range: 1.7 V to V_S

- Gaming and pointing devices
- Industrial instrumentation
- Personal navigation devices
- Hard disk drive (HDD) protection

GENERAL DESCRIPTION

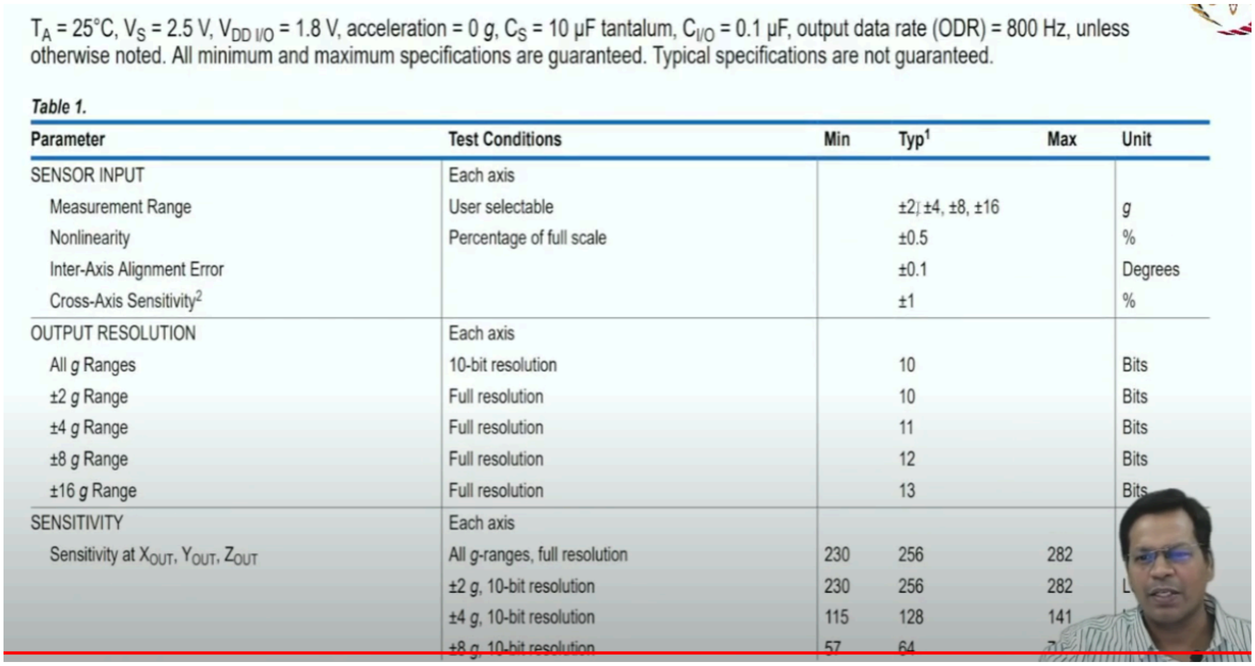
The ADXL345 is a small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I^{2}C digital interface.

The ADXL345 is well suited for mobile device applications. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution (3.9 mg/LSB) enables measurement of inclination changes less than 1.0°.

Several special sensing functions are provided. Activity ar

This is for an accelerometer, ADSL 345, so you see, it can go up to 16 G of external acceleration.

So, let us just see the functional block diagram. It is exactly similar to the one which I discussed in the class also. So, this is there.



T_A = 25°C, V_S = 2.5 V, $V_{DD\ I/O}$ = 1.8 V, acceleration = 0 *g*, C_S = 10 μF tantalum, $C_{I/O}$ = 0.1 μF, output data rate (ODR) = 800 Hz, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

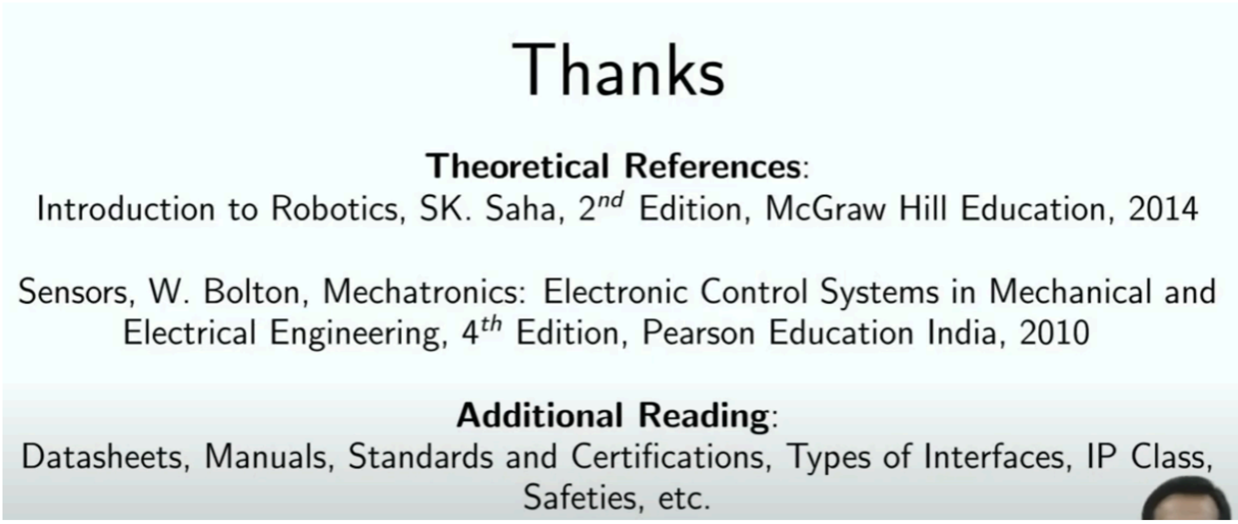
Table 1.

Parameter	Test Conditions	Min	Typ[1]	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range	User selectable		±2, ±4, ±8, ±16		*g*
Nonlinearity	Percentage of full scale		±0.5		%
Inter-Axis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity[2]			±1		%
OUTPUT RESOLUTION	Each axis				
All *g* Ranges	10-bit resolution		10		Bits
±2 *g* Range	Full resolution		10		Bits
±4 *g* Range	Full resolution		11		Bits
±8 *g* Range	Full resolution		12		Bits
±16 *g* Range	Full resolution		13		Bits
SENSITIVITY	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	All *g*-ranges, full resolution	230	256	282	
	±2 *g*, 10-bit resolution	230	256	282	L
	±4 *g*, 10-bit resolution	115	128	141	
	±8 *g*, 10-bit resolution	57	64	[illegible]	

So, let us directly go to the parameter sensor input. So, the input can be this: 2G, 4G plus minus 2G, plus minus 8G plus minus 16, so it can be used as a collision sensor also. Non-linearity is there, so it is expressed as a percentage of the full scale. So, the maximum will be 0.5 percent of non-linearity is the error that you can see. A misalignment error is there. So, cross-sensitivity is there, so there are different ranges. So this is your resolution: 10 bits of resolution. That means 0 to full scale.

Let us say, it can go up to 2G of measurement, maximum 2G. So, the smallest part of G that you can see is 2G by 2 to the power ten. So that is the least value that it can give you. It can show you as an output. So that is the 10-bit. That means 2 to the power ten.

Sensitivity is here. You see, that is there. So, even smaller. So, what is how it is expressed? Per G, it is the least significant bit that is going to change. Offset is there. That is, it should not be there normally. You do not expect it. So, the noise level is also given here. Specific operating voltage range: 0 to 2.5 volts. The temperature range is also there, minus 42 to plus 85. Device weight. This is very, very important if it has to go on top of any mobile device. Also, ODR is given. You see, the output data rate is 100 hertz. So your output data is in. This is the maximum sampling frequency with which you can get the data. So that is where the supply current is mentioned. So you see, these are some parameters.



So, that is all for this module. That is sensors. These are a few of the references that I have given you. One of them is Introduction to Robotics. It is a robotics book, but it has a very good chapter on sensors that you can go through. One very important book is A Sensor by W Bolton, a mechatronic book that will give you an insight into different sensors, electrical devices, along electrical circuitry, which are there in a few of them. So, this is a very good book and at least a test book. Apart from this, you should go through the datasheet. You should go through the manuals, standards and certifications, types of interfaces, different types of IP classes and different safeties you should go through.

So, that is all for this module. We will start with robotics. After this, we are now ready with almost all the prerequisites for robotics. We are familiar with actuators. We know different kinds of robots its classifications.

Furthermore, we have already gone through actuators and how to move a robot. So, you are ready with all the gadgets now. So now, you should start making the robot, and from the next module, we will start doing that. That's all. Thanks a lot.