**INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR**

**NPTEL**
**ONLINE CERTIFICATION COURSE**

**On Industrial Automation and Control**

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**Topic Lecture – 06**
**Measurement Systems Characteristics (Contd.)**

Welcome to lesson number three of the course on industrial automation and control.

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So typically drift is characterized for temperature and time.

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Now we come to so this more or less completes our static characteristics so generally talks about an input output curve, right? That is the calibration curve so there is no time here if you give an input we will get an output in the steady state and we are only talking about this rate this the characteristic between this input and the steady state output value, right? But we have to talk about dynamic characteristic of the instrument when the input is not steady.

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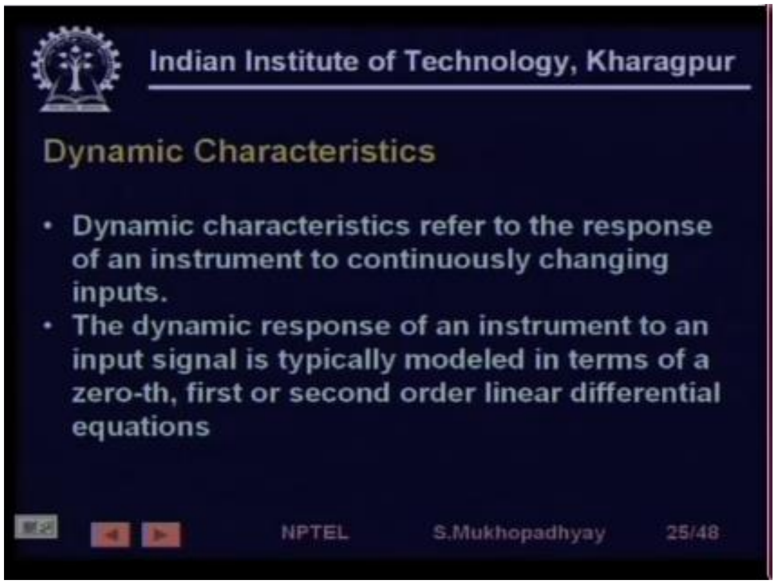


So the instrument is so the input is continuously changing and the dynamic response of an instrument to an input signal is typically modeled in terms so we when we so now we have to we have to worry about that if a signal if the input signal suddenly changes from some value to some value how is the output signal going to change, so we are not only concerned with the steady state new steady state value that the output signal will achieve.

But we are also concerned with how it how it is going to achieve that over time. so when we talk about such characteristics we talk about the dynamic characteristics of instruments.

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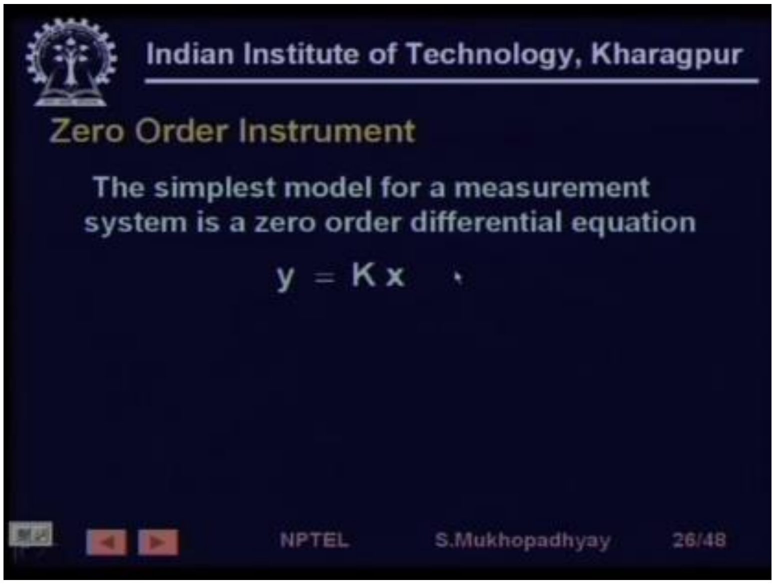


So accordingly we have various kinds of instruments so we call we start with the simplest which is a zero-order instrument whose characteristic is given by y = Kx so it is assumed that for the kind of inputs that are relevant to that censored the output is instantaneously equal to the input so it is like a resistance you know you just apply a voltage you immediately get a current. So the input output ratio is linear and this linearity exists from instant to instant, right.

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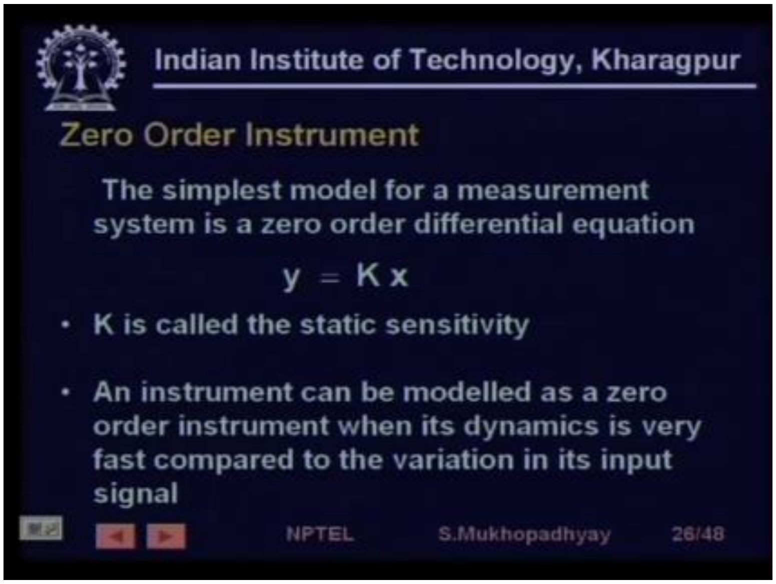


So it is a so for  such instrument there is no dynamics and the static characteristic is the only characteristic that you need to see, so such instruments are called zero order instruments for example typically for example.

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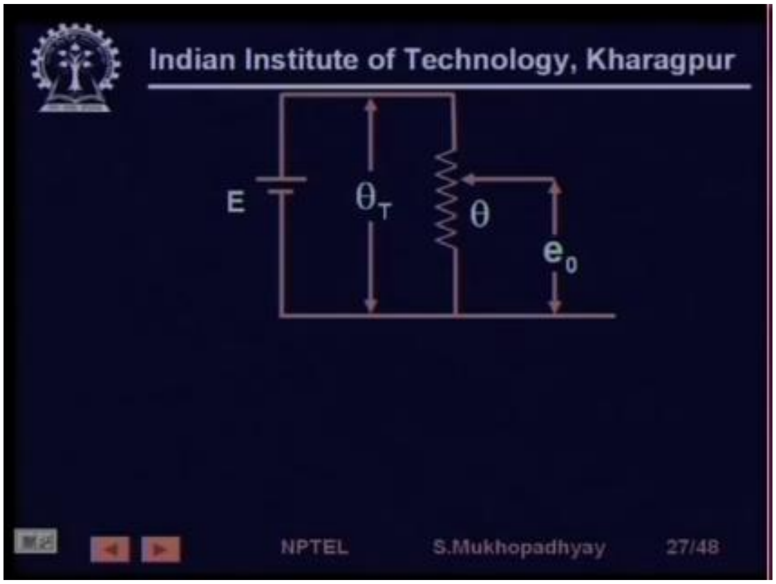


They are a potentiometer when I was talking about a resistance right, so a potentiometer is nothing but a resistance so for a potentiometer the position signals potentiometers typically measure position which.

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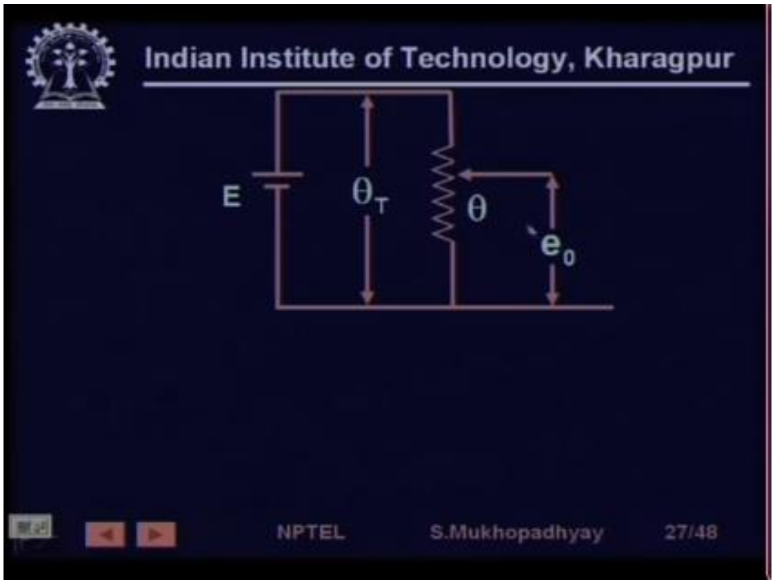


So this potentiometer will be connected to this variable points as the variable point moves the voltage that you will get will be directly proportional to the to the position right, so in this case there will be instant to instant and since the position is the position is actually a mechanical variable so therefore there is not going to be too fast movement, so as far as so the electrical behavior is so fast compared to that.

That you can just assume it to be a to be a pure resistance and then you have what is known as a zero-order characteristics.

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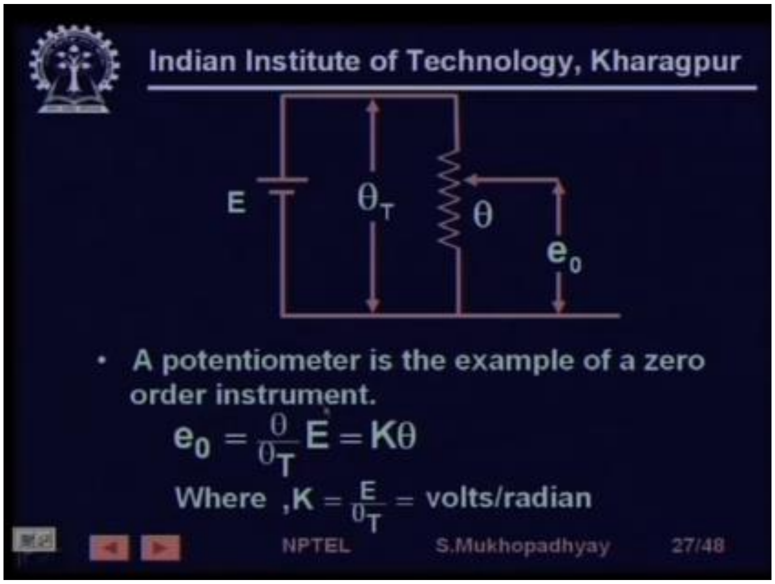


So the output voltage will be directly proportional to the displacement θ, let us say angular displacement in this case if potentiometers can be angular as well as linear.

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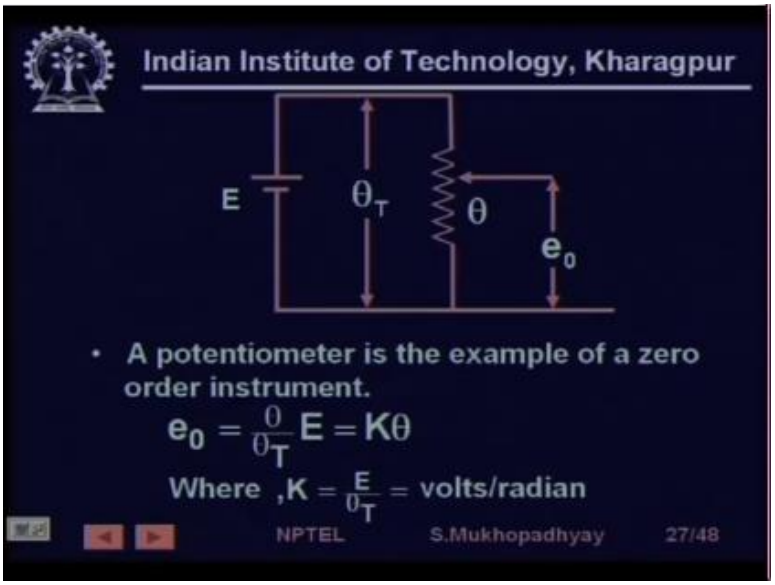


So there is a certain sensitivity called of the potentiometer is volts per Radian.

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On the other hand there are some kinds of instruments where the where if the input changes suddenly the output cannot change suddenly they output take some time to rise.

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For example, let us say let us check temperature measuring instruments for example thermocouple, actually a thermocouple is typically as you will see it is not wherever it is making the measurement of the temperature maybe its team then the bare thermocouple is actually not inserted into the scheme because that will that way that will damage the sensor it will degrade fast.

So it is actually put inside a tube, so you can imagine that even if there Is a temperature change outside the tube which is called a thermo well so it is a tube inside that you have the thermocouple so even if your ambient temp your environment temperature which you are trying to sense even if it changes some time will be required for this temperature to actually flow through the.

That is there has to be heat flow through the insides of the thermo well into the thermocouple Junction an EMF can be developed so because of the thermal properties of this thermo well there is going to be some time required so even if you suddenly fill this space with let us say steam the temperature of the junction will not junction of thermocouple will not instantaneously be equal to the temperature of the steam but it will slowly rise, right. So for such transducers we have a first-order instrument character first order or second order so that will depend on the modeling of the of the thermocouple.

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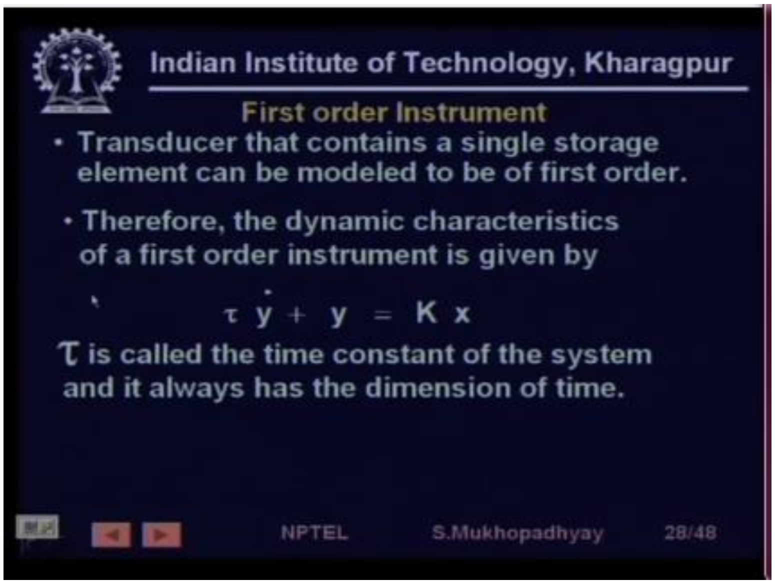


But so typically first-order instruments are transducer that contain a single storage element and can be modeled of a first-order, so in for such cases the output value actually obeys some kind of a differential equation which is of this type, you know and where $\tau$ is called the time constant of the system, so if $\tau$ is larger than the system slowly rise Rises while it if $\tau$ is short then the system is fast.

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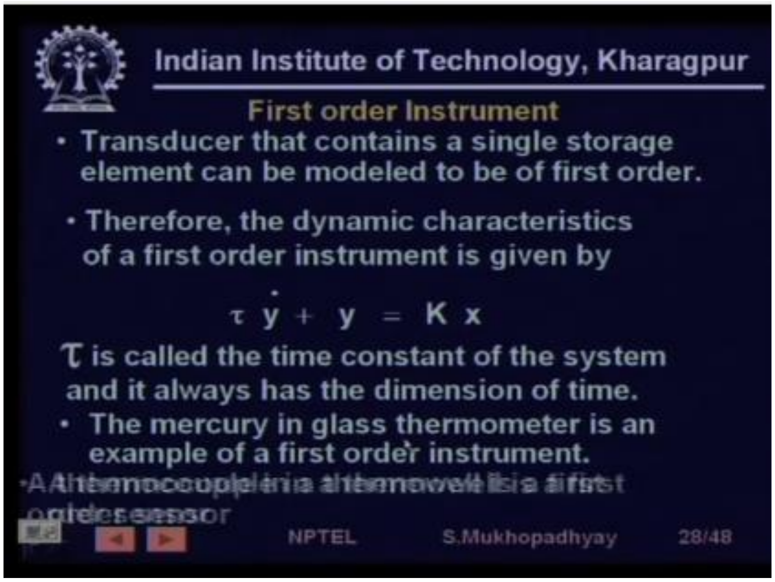


So if so we can easily compute the response of us of a sensor whose input is a step input so we can so let us try to characterize the response of this kind of a sensor to various kinds of changing inputs so the first so these are two examples marketing glass thermometer and thermocouple thermo well.

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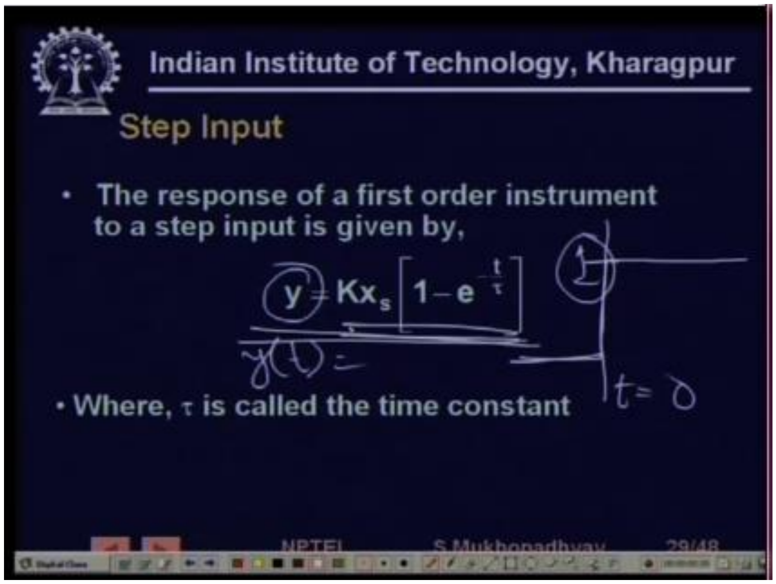


So if you have a step input so the first kind of input that we consider is a step input so step input means it is it is at zero and then suddenly it rises so t= 0 the input is 1 suppose so then we actually we can you can compute that the time response or y(t) is going to be such a function of time, so the graph will show what kind of function it is.

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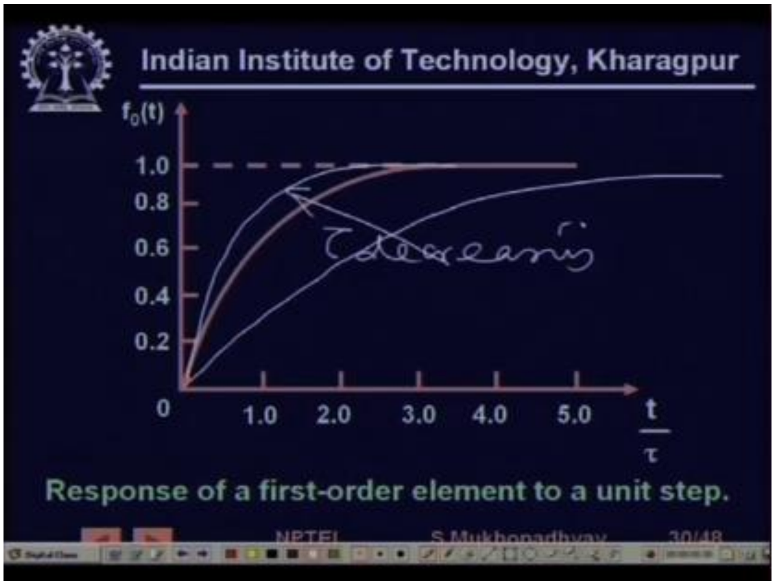


So you see that it will gradually rise and then it will become one, so if you have a if you have a large τ if you have a large τ it will rise slowly if you have a small τ it will rise fast, so this is τ decreasing right.

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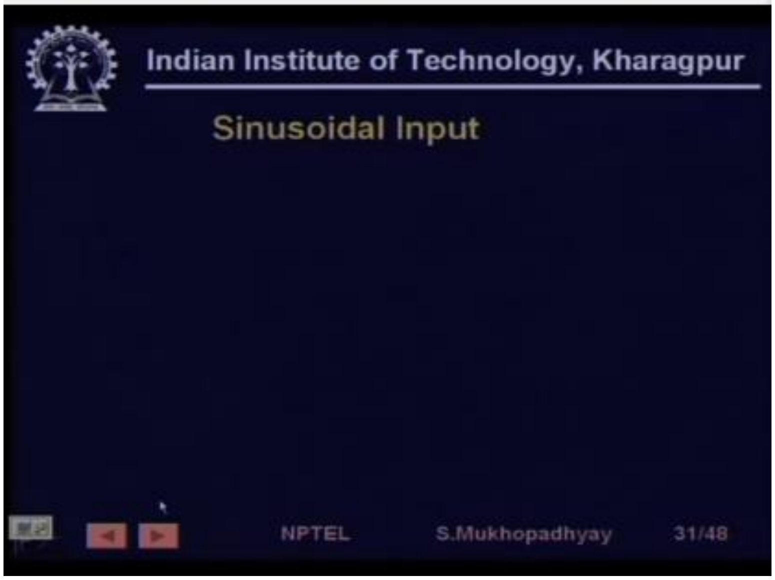


On the other hand you know as we all know I mean the response to a dynamic sensor to arbitrary input is of interest because if such a sensor is actually put in a control loop all kinds of it is not going to be regular as a step input, so we sometimes since we know that any arbitrary waveform most arbitrary waveforms can be thought of as the sum of sinusoids sine and cosine waves, so it is very useful to actually characterize the behavior that is the response of the instrument to a sinusoid of different frequencies.

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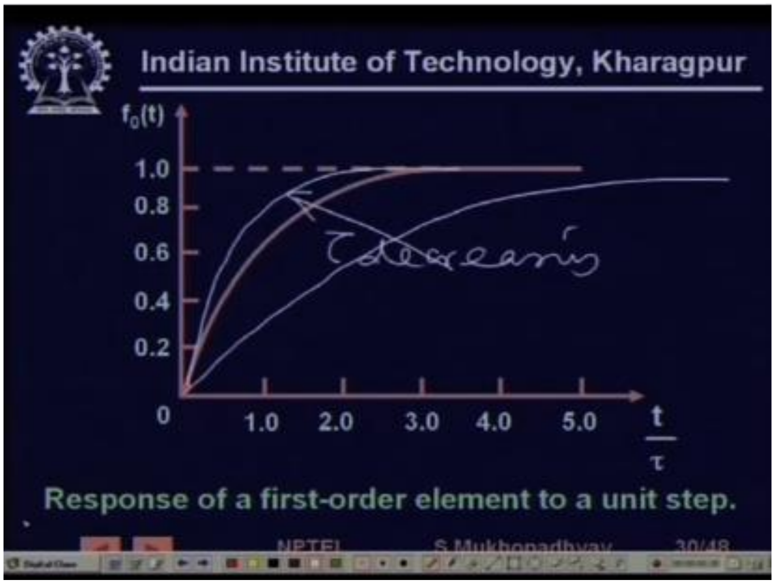


So this is called a frequency response and this is very important for an instrument.

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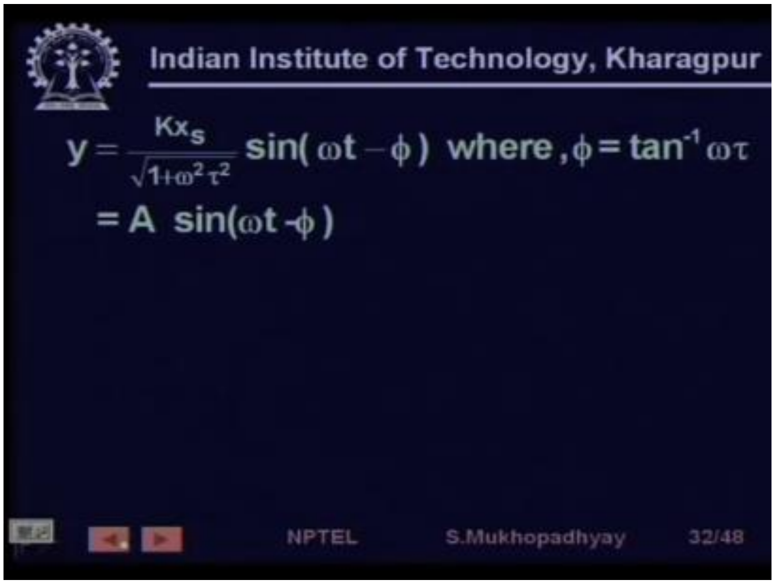

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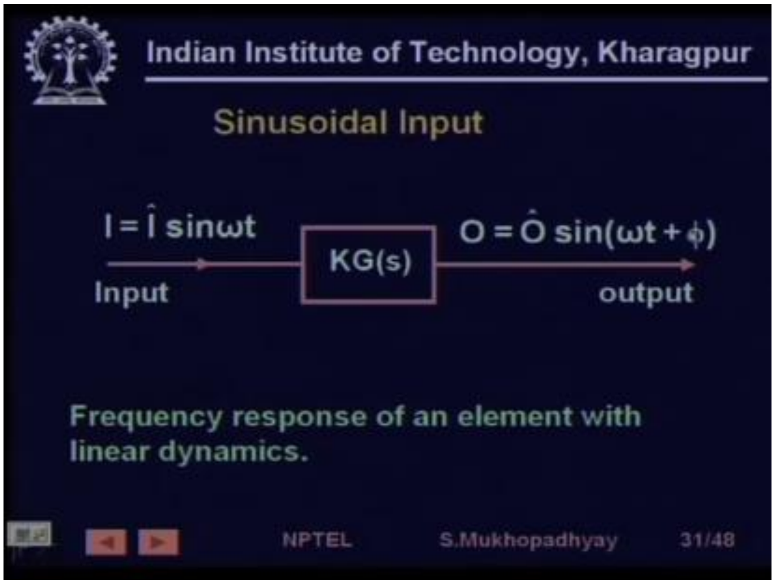


So if we have a sinusoid so we this is this is this is my instrument I am applying an I sin ωt typically what will happen is that is if the instrument is supposed to be linear then you will get as output also you will get a sine wave but that sine wave magnitude will be higher will be different from the magnitude of the input wave and it will also have develop a phase lag.

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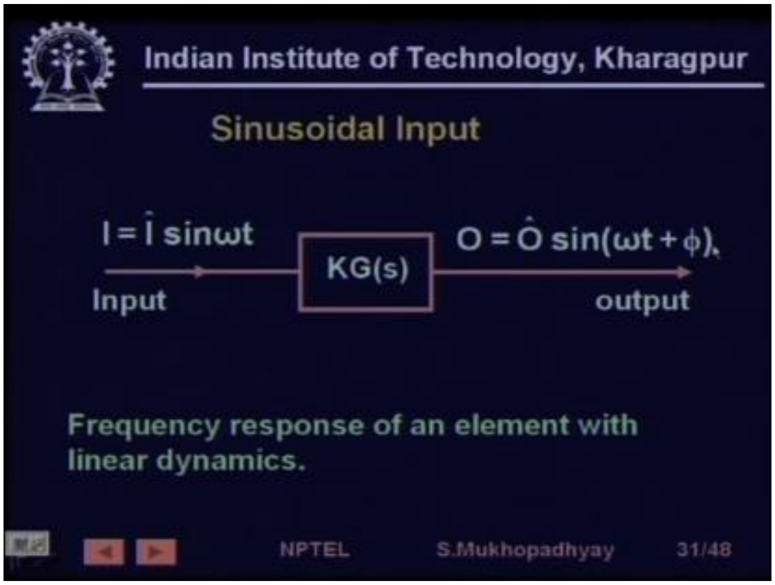


So it is this so we actually try to study two things since the frequency is going to remain constant so the frequency need not be studied it is the input frequency itself but the ratio between the input between the output magnitude and the input magnitude which we call the gain and the phase lag these are the two things that we typically characterize.

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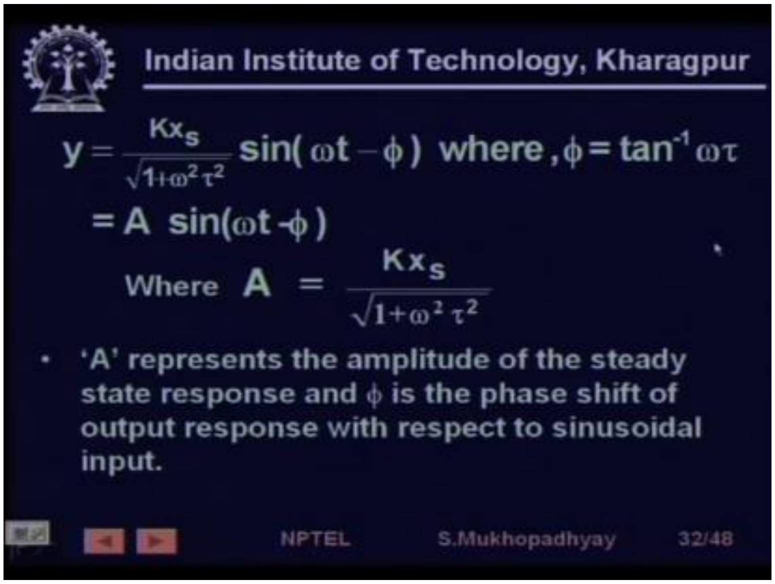


So you know this is a this is a mathematical solution.

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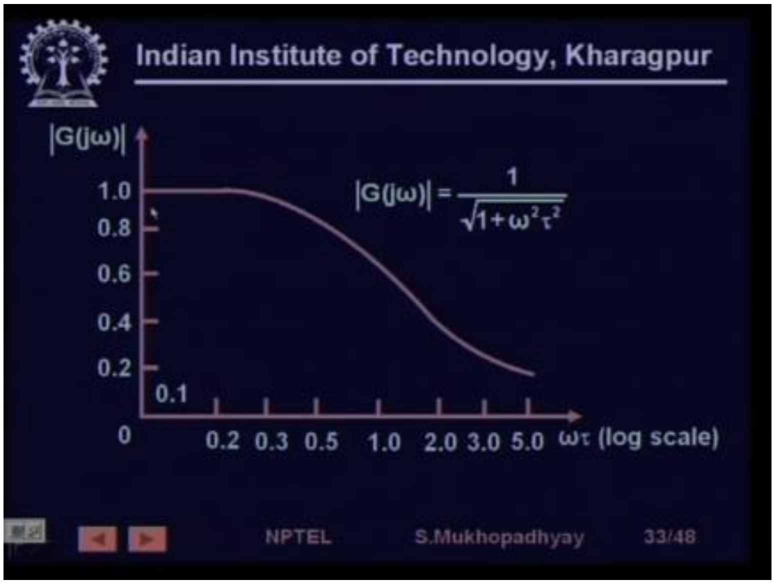


Which will so for example the gain over different values of frequency actually varies like this, so you can understand that if the if the frequency is too low then the then the gain of that is one because so the frequency is too low means you are giving a slow sinusoid which means that the instrument can always come to steady state and it can it can get the value of the input on the other hand as the input frequency increases so before the, before the output of the instrument can rise the input changes. So the output of the instrument can never rise enough and therefore the gain falls.

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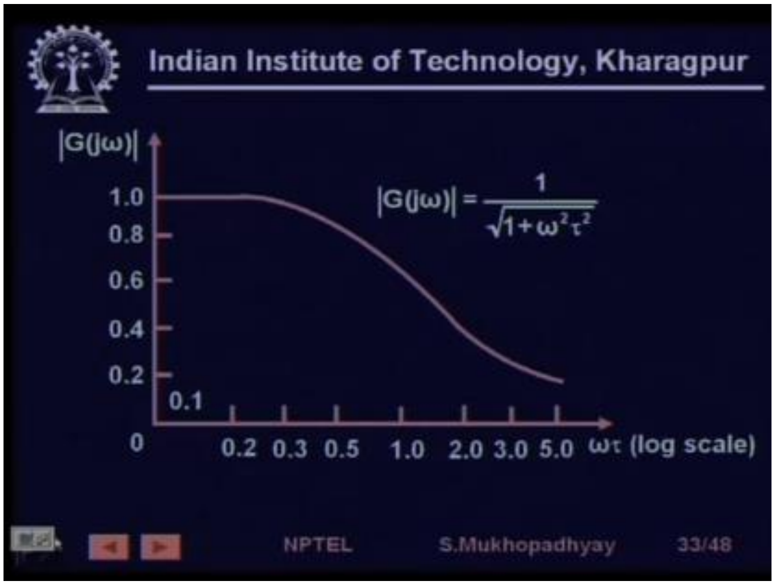


So this is a you know frequency characteristic of an instrument.

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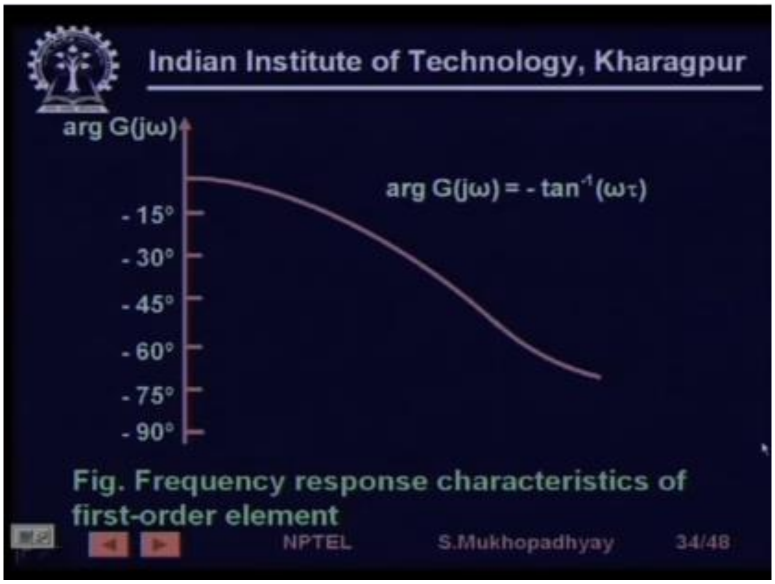


Similarly you know if you have a if you have a phase plot then it turns out that as you go for higher and higher frequencies the phase lag increases and the maximum phase lag possible for a first order system can be 90 degrees so it will gradually approach 90 degree.

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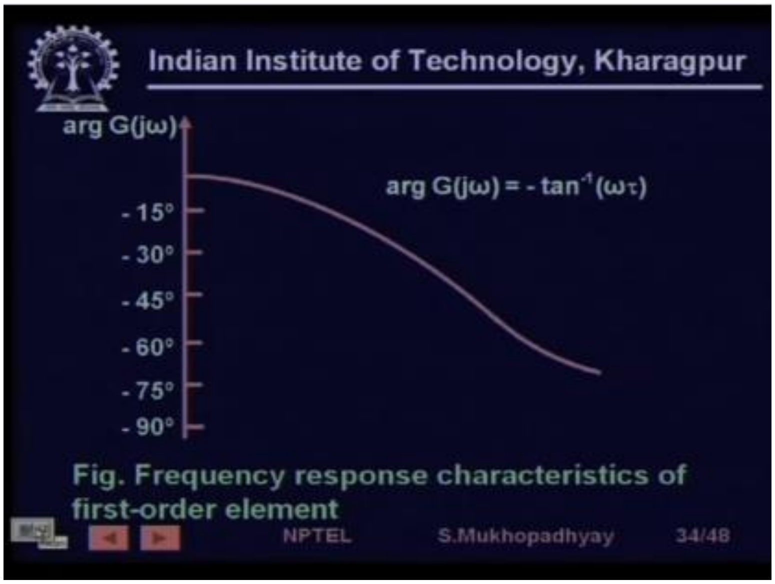

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Now sometimes we also have to model the systems as a second order instrumental or sensor this choice can actually depend on you know which kind of model you will use that may depend on physical reasons so it may depend on the kind of response that you actually get from the instrument, so some instruments are rather I assumed to be governed.

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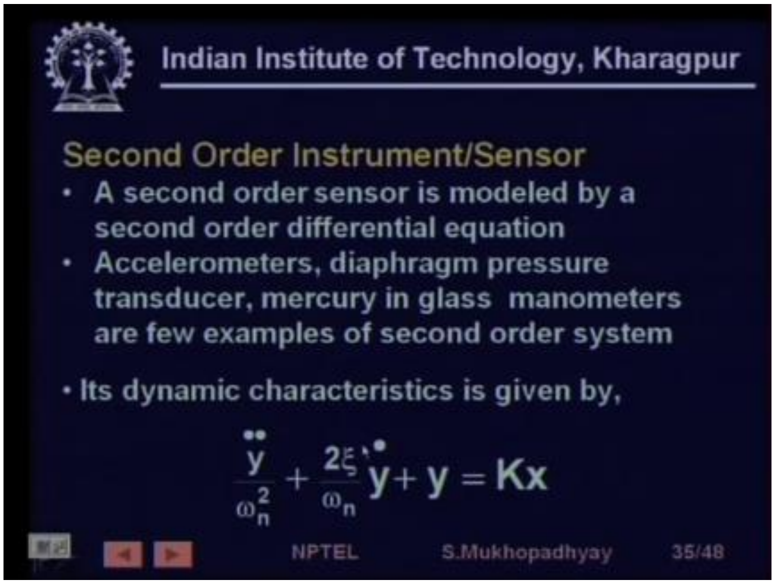


By a second order differential equation for example accelerometer that anything which has you know mass spring damper kind of representation and we will have will have second order dynamics, so this so its dynamics its input output dynamics is given by a second order differential equation as shown in which there are two parameters one is called a natural frequency another is called a damping factor.

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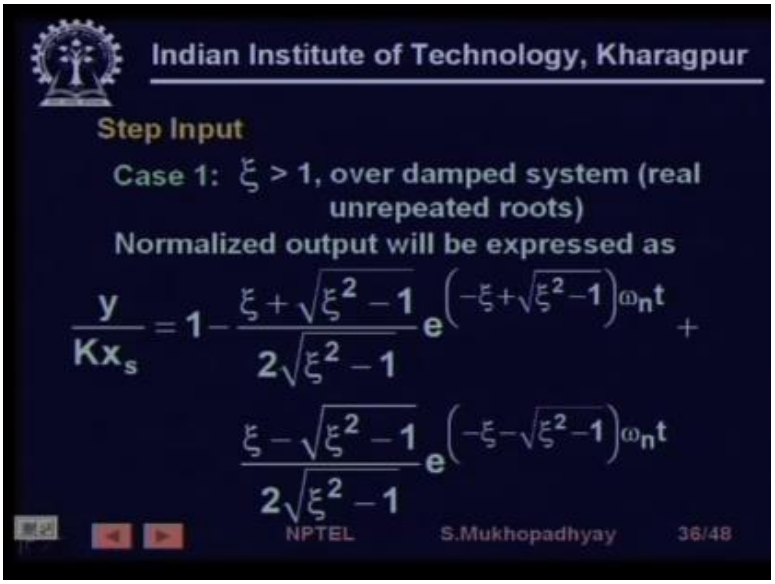


So again it is response to the step input in this case we have three kinds of cases depending on what is the damping factor so one case is when the damping that is zeta is greater than one in which case we call it an over damped system and this is the expression for the output time function.

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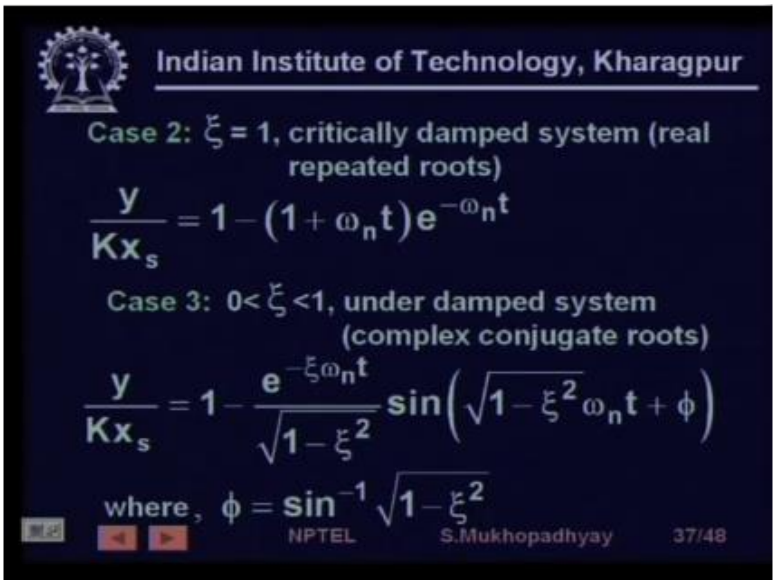


We will just see the case and then we will see the plots so and then we have a case when $\xi = 1$, $\xi = 1$ which is called the critically damped case here we and the last case is when we have $\xi$ is less than between 1 and 0, so that is called the under damped case.

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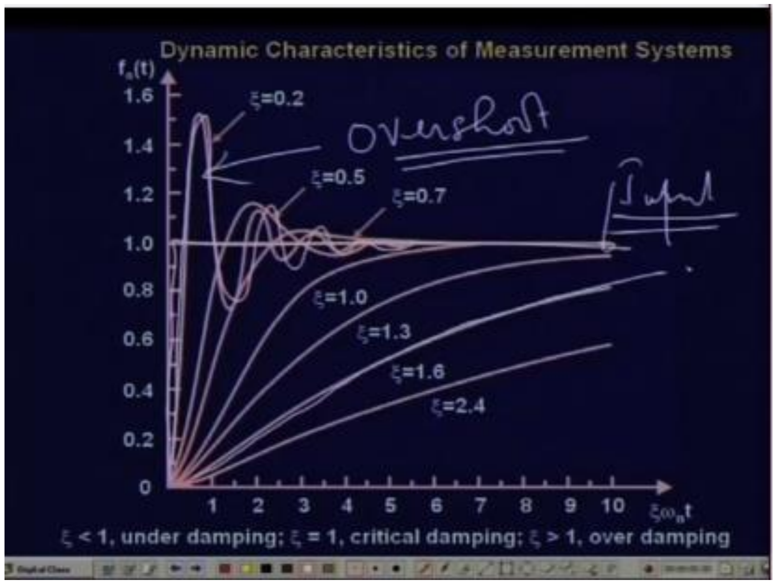


So the plot actually looks like this so this is of interest to us so you see that this is the step response so the you so the input applied is this, this is the input now for different values of Zeta for example if as Zeta goes to lower and lower values you can see that you get an oscillatory behavior so there is an overshoot this is called an overshoot, so for under damped sensors you are going to get an overshoot.

On the other hand for over damped systems you there is no overshoot and slowly rise is just almost like a first order system.

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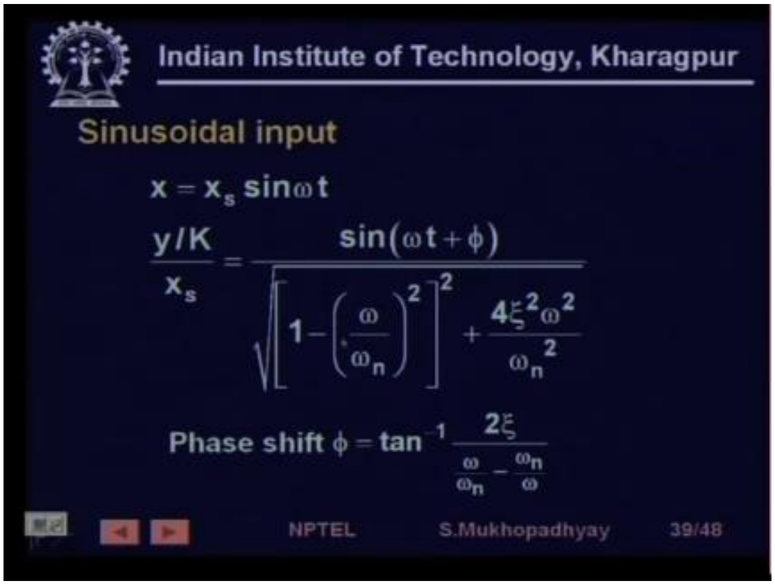


Similarly if you see its response to a sinusoidal input again you will find that this is these are the expressions so you get again and you get a phase shift.

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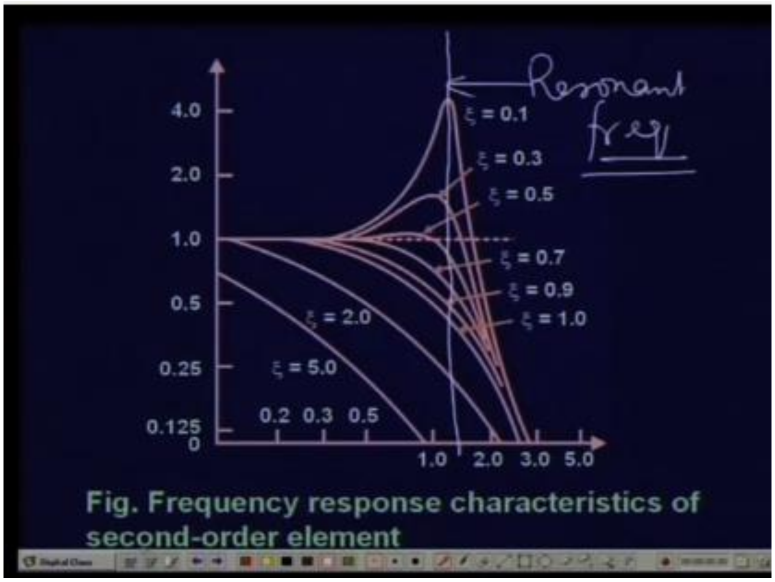


And this is the expression for this is the plot for gain so you see that the gain actually changes with frequency right and for under damped systems the system tends to be tends to resonate so this is the resonant frequency so if you give a sinusoid close to the resonant frequency then you get a huge output right on the other hand for over damped system there is there is there is no such resonance.

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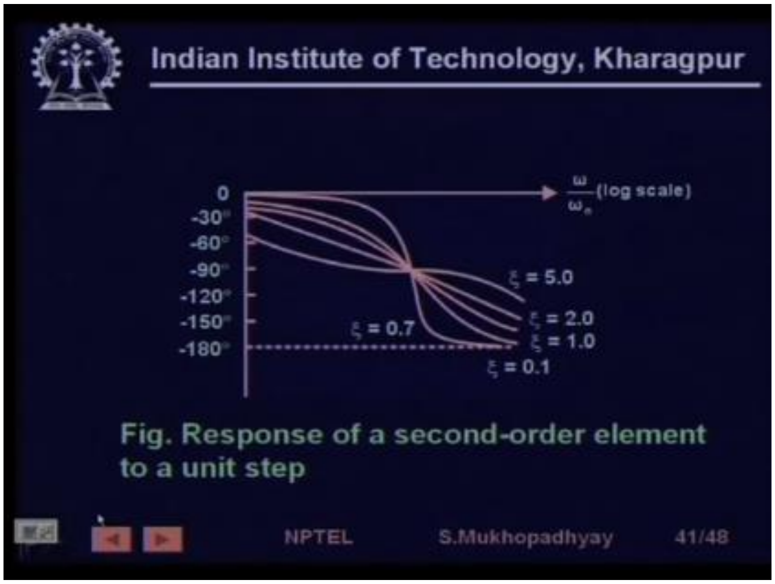


So you have similarly the phase if you see the phase the phase plot looks like this again with frequency so towards low frequency the phase is phase tends to stay small and as freaked as frequency increases so this maximum phase that can occur is for is 180 degree, so these are the phase lags.

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So we have seen the static and the dynamic characteristics of in the sensors, now let us see some example specifications.

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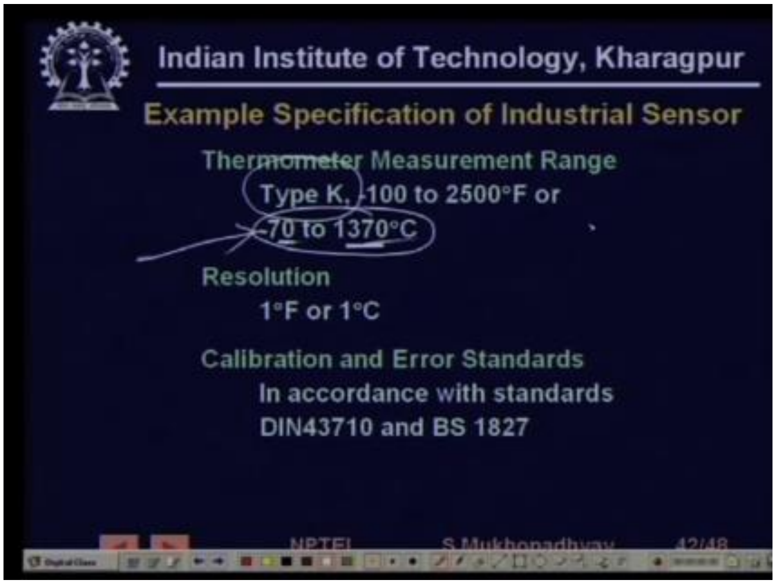


So this is for example an industrial thermometer, so see what it says what all are stated so first of all it is it is based on a thermocouple therefore the type of the thermocouple is stated we will see what the type of thermocouple is but interestingly the range is given so you see this is that the minimum and the maximum values in which this thermometer can be used with these given specifications.

So if you use it within this range then you will get a resolution of one degree Fahrenheit or one degree centigrade.

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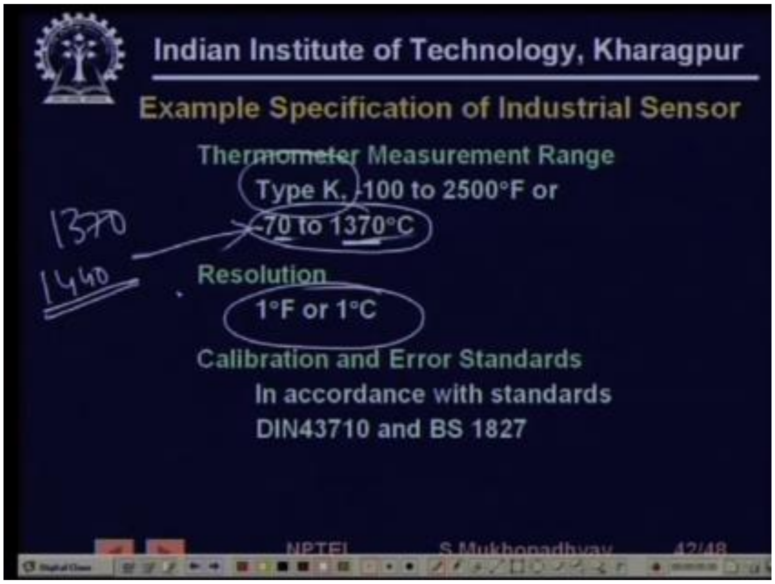


And etc, etc what so whatever specifications are given or valid within this range so in so in this case range is 1370 and span is 1440, the resolution is one degree F or one degree C actually it is whichever is whichever scale you use because actually the resolution of the basic sensor is the same while the actually it is depending on the scale that you choose you can have different kind of electronics so these so the resolution also varies. So it says that this dilution so here it is stated as one degree centigrade.

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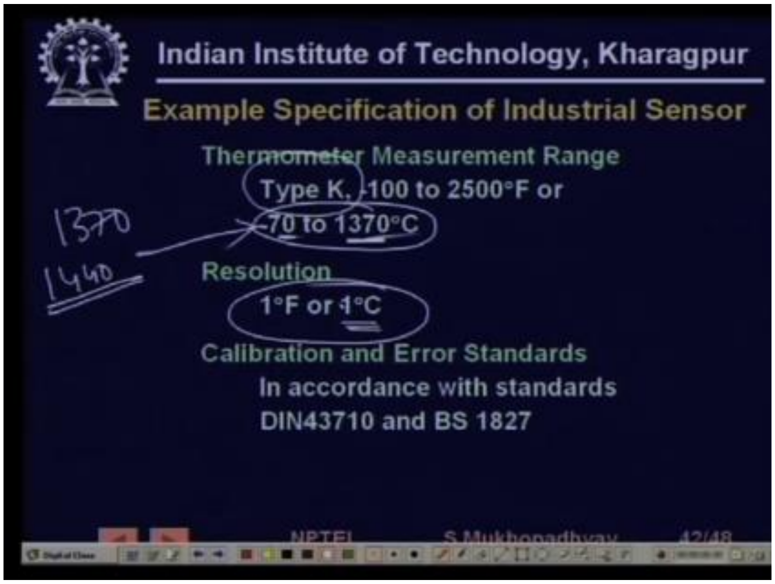


So it is so the minimum change that can be observed change which can be detected by the sensor is actually one degree centigrade.

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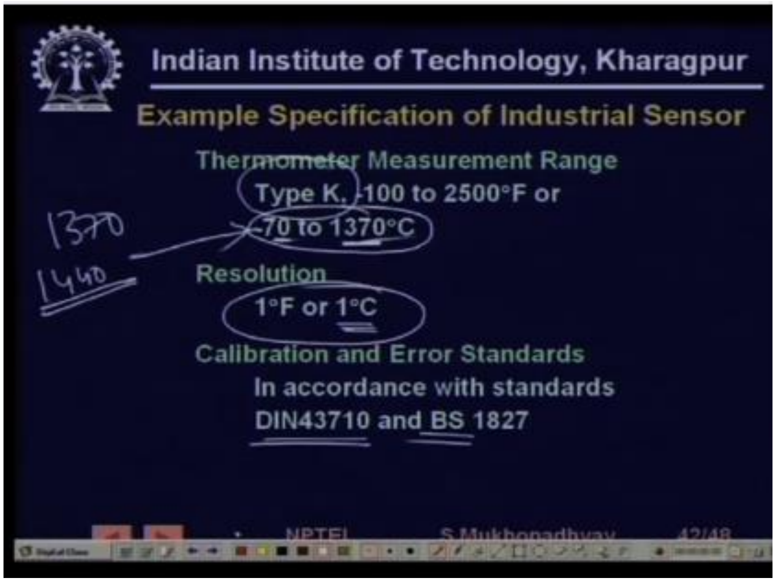


Calibration error standard so all these specifications are actually with respect to a certain you know this Dean is the actually the German standard BS is the British standard.

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So similarly it says that the that the meter accuracy at 25 degree centigrade hat is when the ambient temperature is 25 degree centigrade is 0.2% of reading ± one digit this ± one digit comes because you are going to have a digital display, so we see that in digital displays there has to be a there is a there is an effect called quantization.

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And therefore this ± one digit error comes, so basic accuracy is 0.2% of reading in this case it is stated as interms of reading.

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There are some other there apart from these kind of specification they are typically if you read see an example industrial specification you will find some other things like which are which are specific to the which are which are specific to the particular sensor that you are using.

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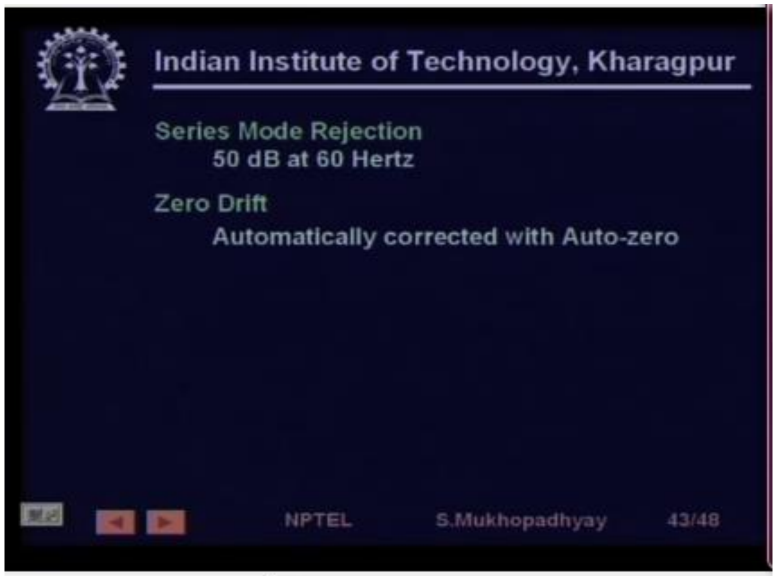


Now since thermocouples use long wires so there is a series mode rejection since mode rejection means that typically with thermocouples are drawn from long wires so they typically tend to catch series mode interference especially at the power frequency so because there may be power lines and they will they will add power frequency interference as a series voltage.

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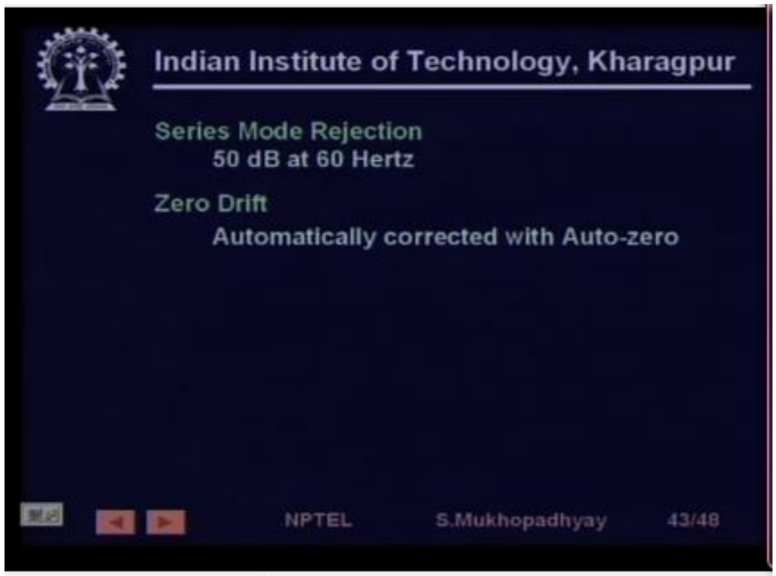


So it says that the sensor is so constructed that it can actually reject that 60Hertz such interfere such voltages which are induced.

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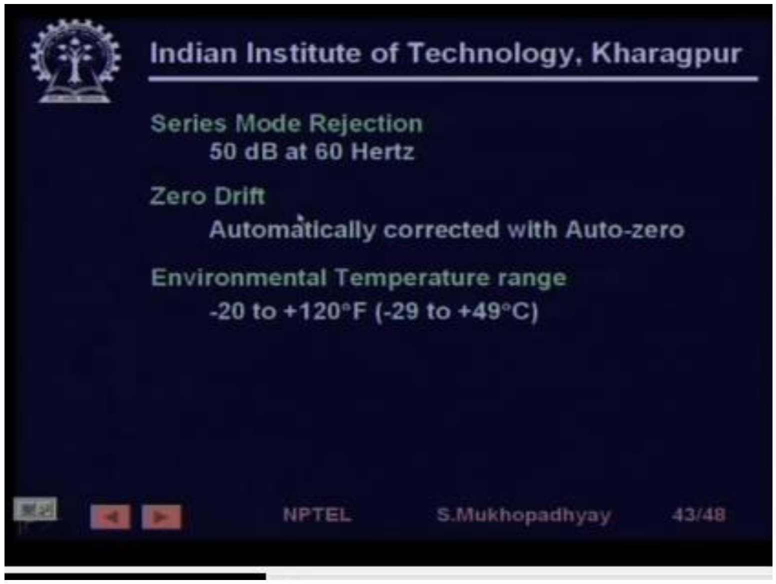


Similarly 0 drift it says that even if the zero drifts every time possibly this instrument will have a button and or maybe every time this instrument is you know commanded to take a reading it will first automatically make it 0, so the so there is an auto zeroing facility the environmental temperature range is.

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So there are all these specifications are to be this sensor is to be used in such a range and the size and weights okay.

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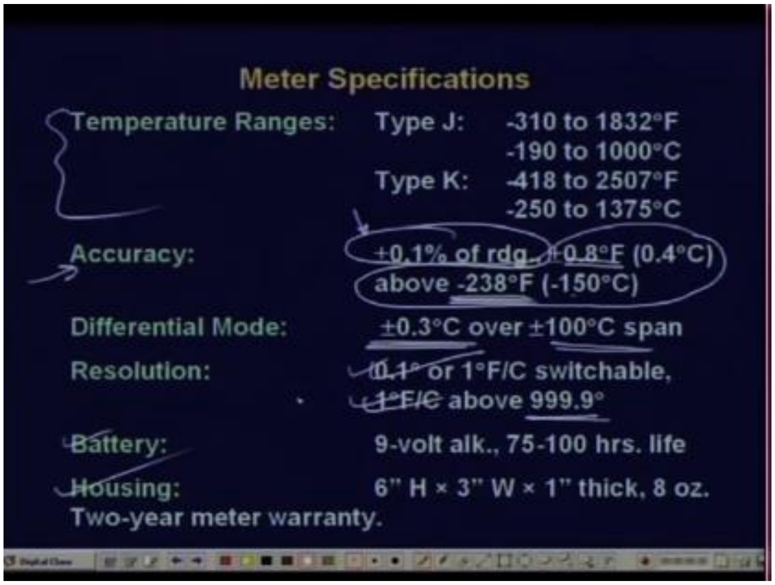


Similarly another thermometer that another temperatures thermo meter again based on thermocouple again it has some ranges so we have already seen it look at its accuracy reading it says that below two thirds so you see that below 230 degree Fahrenheit above minus -238 (-150) degree centigrade this is its accuracy statement, while below that is this is this statement so here it is stating it in terms of reading here it is stating in terms of a constant or a percent of span.

Similarly it says that in some other mode called a called a differential mode this is the this is the kind of accuracy ± 0.3 degree centigrade over a ± 100 degree centigrade span so you can see that typical thermal typical such inertial instrument specifications will include this kind of parameters for example resolution is 0.1 degree and above 99.91 degree it is one degree. The other things you know battery housing these are specifically battery is important especially when you have a portable instrument.

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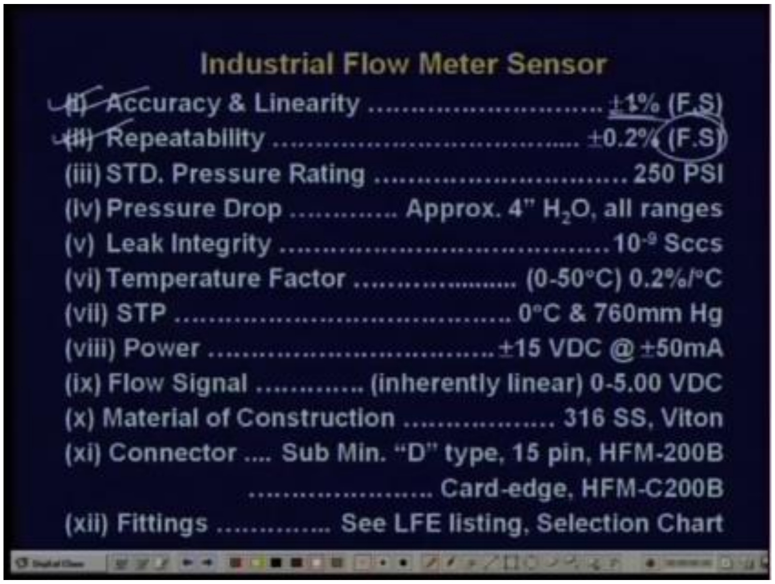


So let us look at another sensor which is a flow meter, now there are so many specifications the important one such accuracy and linearity is one ± 1% full-scale here you see accuracy and linearity are both ± 1% possibly the instrument is inherently linear, so therefore they are stated together see repeatability is stated as ± 0.2% of full-scale that means even if you make 100 readings of the same flow.

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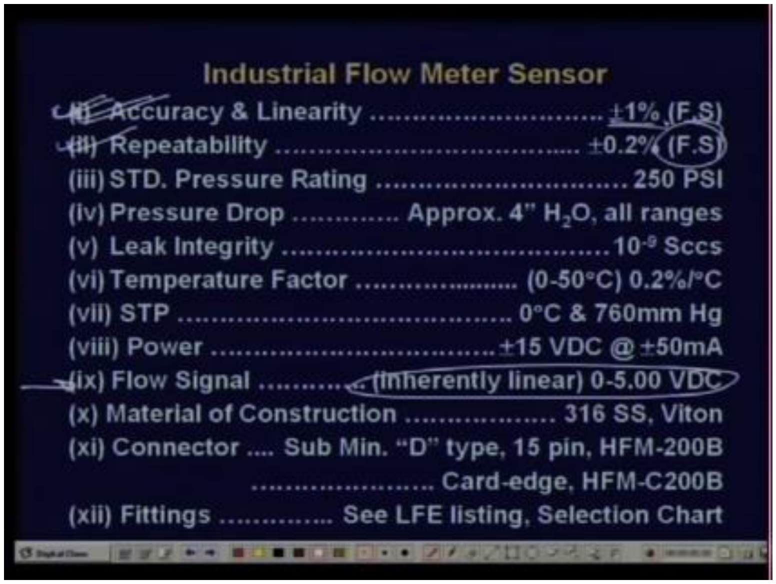


The readings will not differ by more than ± 0.2 % of full-scale, similarly you have see inherently linear flow signal is inherently linear, therefore accuracy and linearity are space both are same actually if it is not inherently linear then accuracy and linearity specs we will actually vary. So then there are some you know special other specifications which is specific to a flow sensor.

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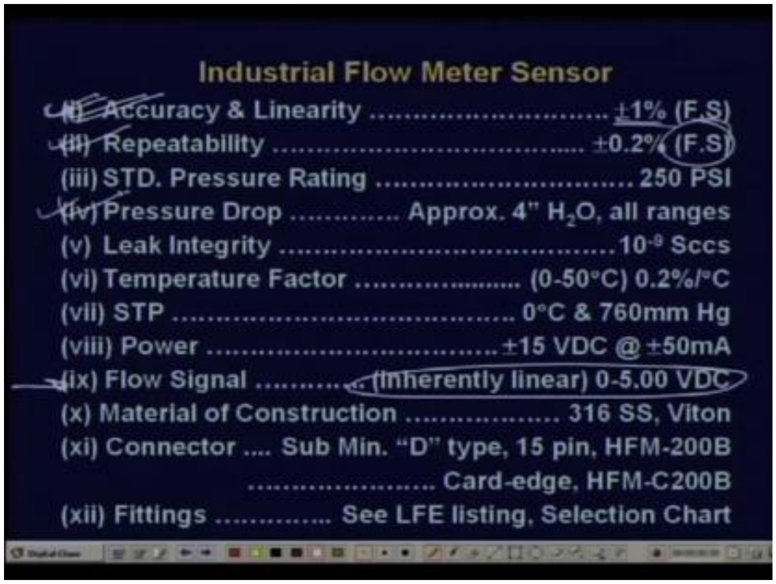


For example pressure and drop is very important because the pressure drop in the flow sensor is actually an energy loss so it should be low so it says that approximately 4 inch $H_2O$ so the other factors we will not understand so much unless we really know what sort of a flow meter it is.

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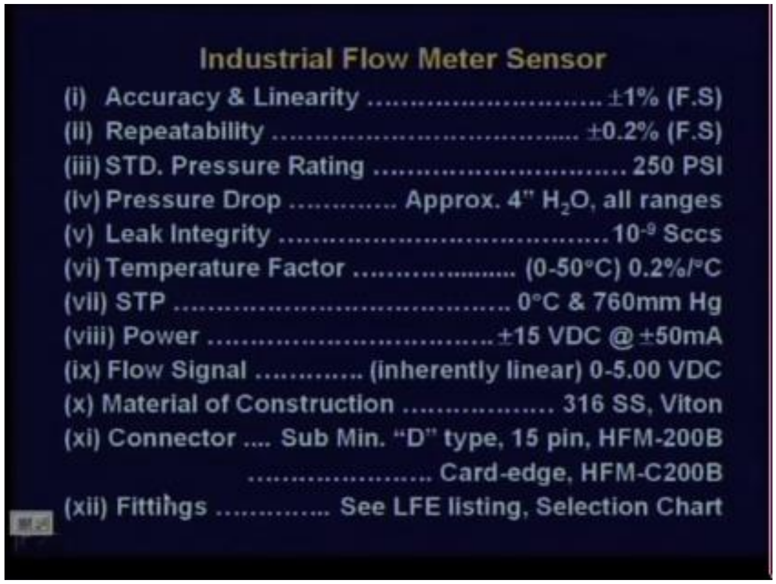

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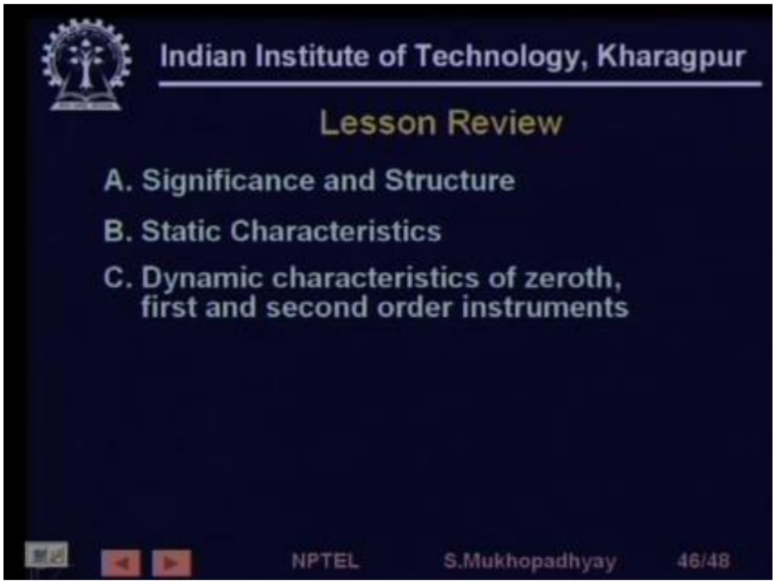


So this brings us to the end of the lesson so what we have done in this lesson is, that we have seen why sensors are so important we have also seen there they general structure we have looked at the static characteristic main static characteristic parameters and like your sensitivity, linearity, accuracy, resolution, spam etc.

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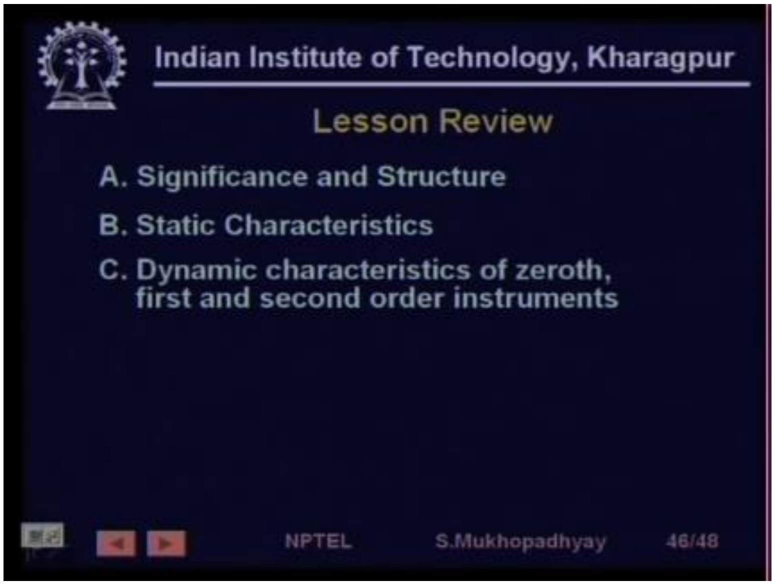


We have also looked at the dynamic characteristic of zeroth first and second order instruments and we have seen that they exhibit phenomena like oscillations overshoot they have time constants and all the sensor all these characteristics are very important especially when these devices are used as feedback devices in control ,we have also seen some industrial specifications.

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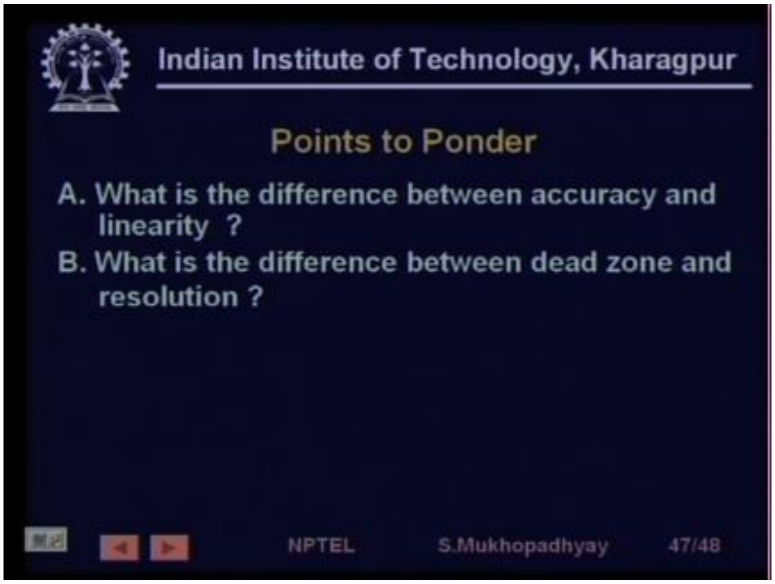


So before closing we would like to have some points to ponder so for example what is the difference between accuracy and linearity so when are the same and where are they different at why, what is the difference between dead zone and resolution, which is likely to be more dead zone or resolution.

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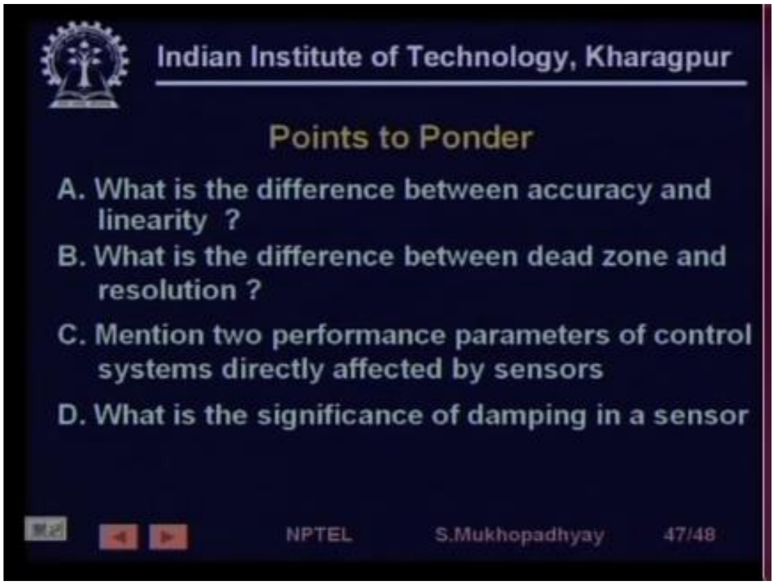


Then mention to performance parameters of control systems that are directly affected by sensors so and finally what is the significance of damping in a sensor so if you have good damping what kind of sensor should have what kind of damping for example what should be the damping of an indicating instrument and what should be then what should be the damping level let us say for a recorder or what should be the dampening level for a let us say a feedback sensor so think about these and that is all for today bye, bye.