Industrial Automation and Control
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Lecture - 03
Measurement Systems Characteristics

Welcome to of the course on industrial automation and control, so in this course, in this lesson we are going to start at level 0 of the automation pyramid and in particular we are going to look at measurement systems or sensors. So, before we are going to do, we are going to look at this measurement system for a few lectures to come. So, before we do that, let us first look at a general measurement systems and try to understand its characteristics. So, that is precisely what we are going to do today, so in this lesson we are going to look at measured systems characteristics and the instructional objectives are the following.

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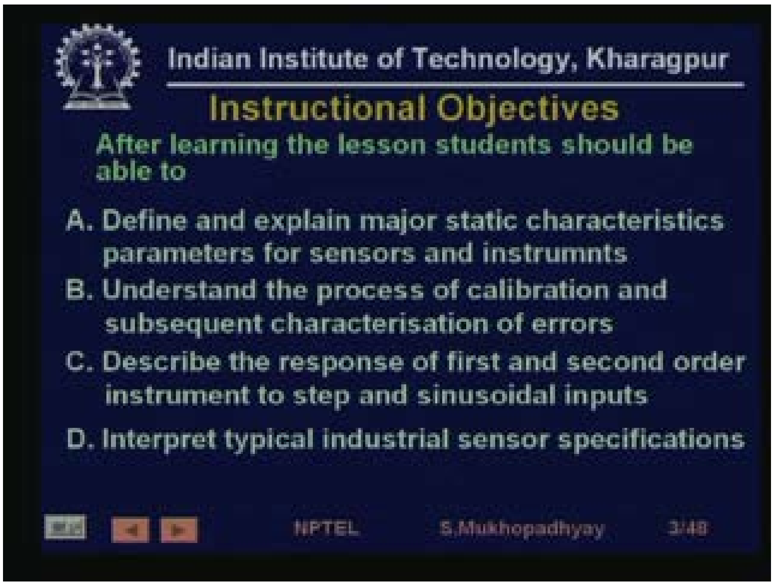

First of all the most important thing is to learn is the, what is known as the static characteristics of sensor and instruments. Then understand what is mean by calibration and what do we how do we characterize errors, describe the response of first and second order sensors to dynamic inputs. So, that is most important for control and finally interpret look at some industrial sensor specifications.

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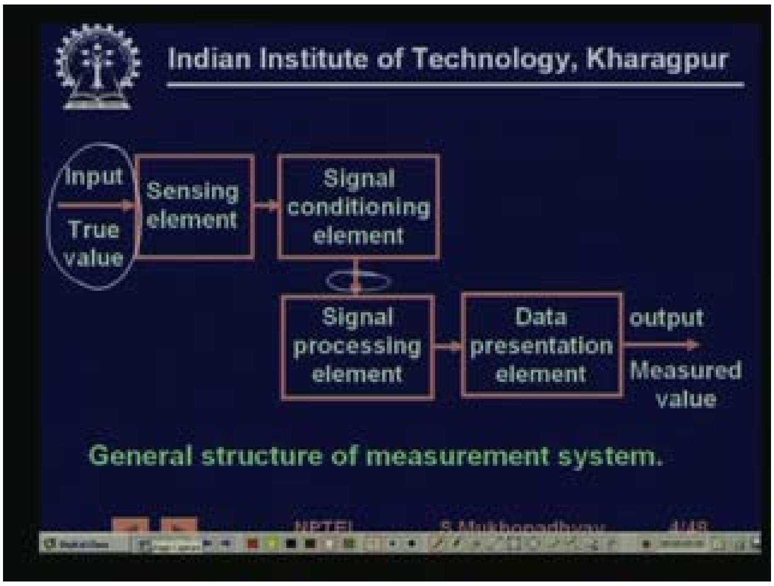

So, let us first look at the general structure of a measured system, so all measurement systems can be thought of being made up of, you know one or more of these blocks. So, here is the, so here we have the actual measurement whatever signal we are trying to measure pressure temperature that is the signal which is effecting the sensing element. So, there is sensing element actually sensing is the, is a process of continuous energy conversion from one form from any form depending on what we are trying to measure.

So, from mechanical form or from thermal form or from optical form to, finally to an electrical form and then the electrical form get finally transmit transformed further to you know digital forms etcetera before their output. So, through these blocks that conversion takes place, so here you have the measurement of the input which is the true value. So, the real pressure or the real temperature with the sensing element which exists at the sensing element there a sensing element does the first round of conversion.

But, brings it generally to some sort of an electric form either in the form of electrical parameters like resistance capacitance changes or in the form of voltages and currents. Which have to be further manipulated by electrical circuits called signal conditioning elements and sometimes you know I mean amplified sometimes the conversion from resistance to voltage?

So, at generally at this level it is in a standard electrical form of voltage, but then some further signal processing goes on to remove noise to make it linear and things like that some of it can be analog some of it can be digital. Then finally it goes to the data presentation element or where the data is utilized it can be presentation or applicational elements. So, it can be a display or it can be a recorder or it can be a controller, so this is the general structure of a measurement system for example if you take an example.

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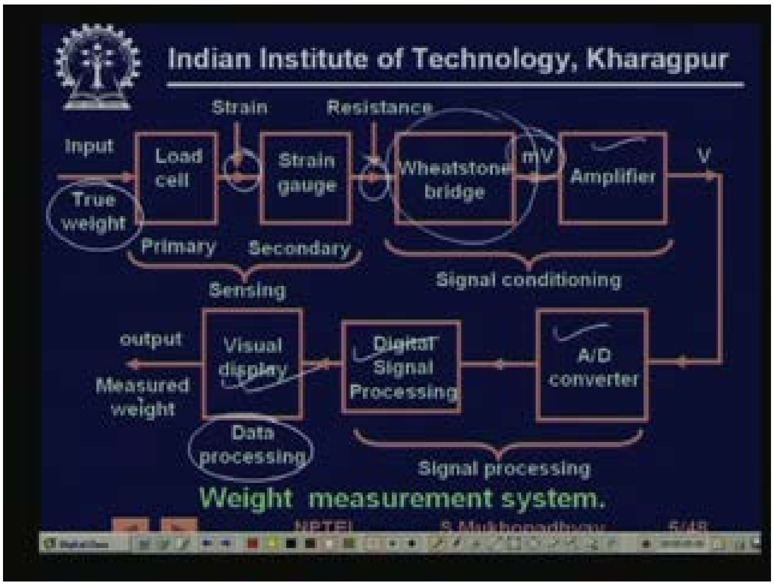

For example, here is weight measurement system, so the input is the true weight, which is sensed by a mechanical member call the load cell, which converts it to strain. That is sensed by a by another member called a strain gauge we will we will see all these all these sensors in our future lessons which converts it to a resistance form. So, you have you see that even, there are two sensing elements the first sensing element converts weight to strain the next one converts strain to resistance. Then we feed it to an electrical circuit called the Wheatstone's bridge, which converts this resistance change to a low level voltage milli volt.

So, this is the, so these are you know signal conditioning elements then it goes to an amplifier which amplify the you know standard voltage ranges like 0 to 10 volts then it goes if we most often it is very convenient to have digital signal processing. So, we may go it make through an A D converter then imported into may be some micro computer and do some digital signal processing.

Then finally send it to a in this case a display, so you get a digital display of the reading along with units, so that is some more data processing. So, this is how real measurement a system looks like, so it has it is basically a cascade of several blocks including the sensor the signal conditioner plus some computing elements like the signal processor.

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So, sensing is actually extremely important in automation from various points of view, firstly in product quality control because the product quality actually accessed by sensor themselves by sensor on instruments in process control. So, if you have a rolling mill and if you want to control the role thickness then and you are feedback almost of all process control is actually. You know a close look feedback control about which we are going to learn in the future lessons, so for that a critical element is the feedback element. So, the variable which is being controlled it may be thickness it may be temperature whatever has to be continuously fade back using a sensor in the sensor of the control system.

The performance of the control system is actually critical to the, adapt this to the sensor, so sensing is a primary importance in control then process monitoring and supervision. So, you know all kinds of you know coordination between machines then fault detection safety measures all this can be done plus proving. You know energy efficient optimal set points for doing all this we need sensors and, finally we also need sensors for you know manufacturing automation.

So, A as will see when will when will see how the, a manufacturing automation systems can be put together using let us a programmable logic controllers. Then you will find that they use various kinds of sensors extensive you sensor like you know a limit switches a pressures switches contact etcetera, so sensing is extremely important in automation.

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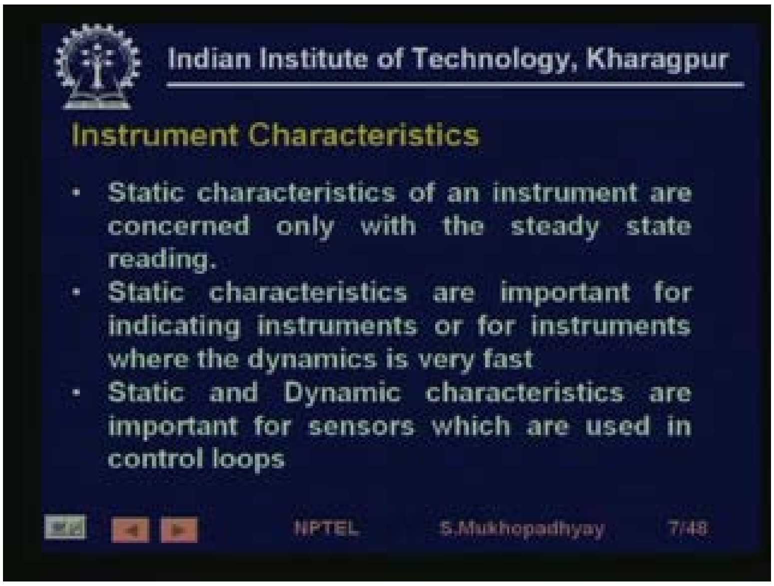

Now, in this lesson we are going to see that if we if we if we look at the sensor as an, as an, as an abstract element which gives you a, which gives you a value, which give you the information about a physical quantity. Then we need to know how to characterize the behavior of this device call the sensor of the instrument. So, we need to understand about instrument characteristics and instrument characteristics can be of two types, the first is the static characteristics static characteristics implies that over instrument or concern only with steady state readings.

So, if you it says that if you apply a one volt signal do you get a 2 volt signal, so we are not we are just saying that if we apply let say we to a temperature sensor. If we apply 100 degree centigrade what is the output voltage, now we are not concern with the fact when we are discussing static characteristic is that how this how the temperature came from whatever was. Let us in the room temperature 200 degrees centigrade, how much time it to what was exactly the way the voltage rows we are not asking about these things. We just want to know that if you apply 100 degree centigrade eventually the temperatures settles at what value, so you know that would be static characteristics.

Now, static characteristics are important for indicating instrument because indicating instruments are generally concerned with steady state values or where for instruments where the dynamics is actually very fast. That is this settling from whatever was the temperature to the 100 degree centigrade temperature is so fast that of, that for all practical purposes we can neglect the way the temperature rows. That is that does not concern in such cases this static characteristics is of importance, while there are cases where dynamic characteristics is also important.

Especially, in control because as we shall see later that the performance is of control loops, for example when you are trying to control the essence for feedback control is that. Suppose you are saying that this temperature should be maintained at 100 degree centigrade. Now, if the temperature sensor has a 2 degree centigrade error by which I mean that suppose when the temperature is 90 degree, 98 degree centigrade. The sensor is telling you, that it is 100 degree centigrade it is giving you wrong information by which is wrong by 2 degrees.

Then the controller has no way of knowing the actual temperature 98, it actually thinks that it is 100 degree centigrade and it tries to maintain it at that temperature while the actual temperature stays at 98 degree centigrade. So, you have steady state error, so you have a real error that is that physical real temperature will be 98 while the controller will think that is 100. So, such errors occur due to due to controller and due to errors in sensors number 1 and number 2 is that, now these errors can sometimes be reduced by you know it designing the gains.

So, it sometimes happens that we need to not only maintain fix temperature sometime we need to track temperatures. So, in such a case if you do not get the readings as they are existing then what happens is that the temperature develops, what is called a phase lag. That is the controller develops a phase lag and it will not be possible to exactly track you know moving commands, so in such cases dynamics of the sensors are actually important.

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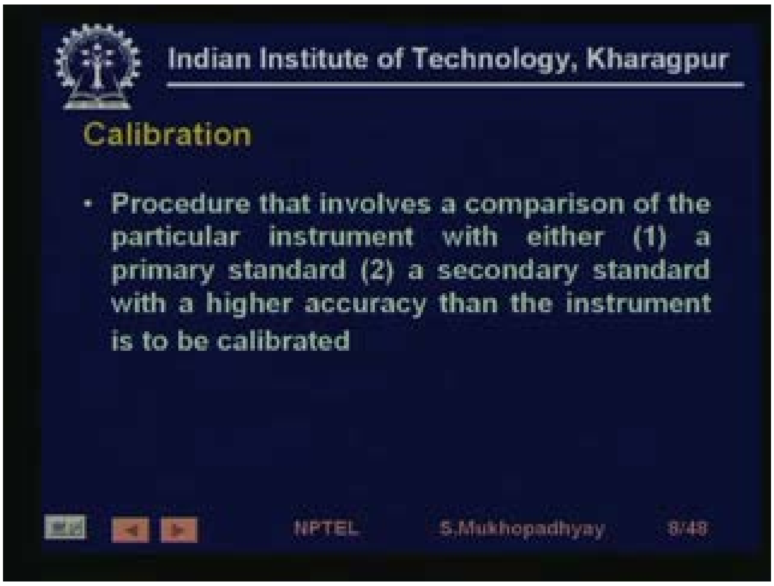

So, we will look both sensor and a both static and dynamic characteristic and before we look at these characteristic we need to understand how there obtains. So, they are actually obtained by a process called calibration, so basically a calibration is you know you are saying that if the true value is. So, what is this, the calibration is basically where you say static when you say characteristics of an instrument what you mean is what is the input output characteristic.

So, if the true value is, so what is the output that is what a, that is what is essential it to be determined, now the point is that the true value can be never be known, so therefore how do you access the true how do get the true value. So, essentially what we have to do is that we have to measure at the true value again using some other instrument which for scientific and technical reasons, we actually believe to be much more accurate. So, it is always calibration is essentially a comparison between the instrument that is being calibrated and another instrument which is assumes to be the true value.

So, such instruments depending on the calibration situation for example if you are calibrating if you are calibrating three is a, there is actually a calibration change in the sense. That when you are calibrating some instrument in the factory it is not possible for all variables there are some very accurate instruments which are maintained in under special conditions in you know, you know national standards laboratories.

But, when somebody is calibrating let saying as in a shop floor it is not possible to possible that every instrument will be calibrated again in the national standard. So, therefore, there are secondary and tertiary standard equipment, so anything we have to be calibrated again such instrument. So, that is what if says that with either a primary standard or a secondary standard with higher accuracy then the instrument is to be calibrated.

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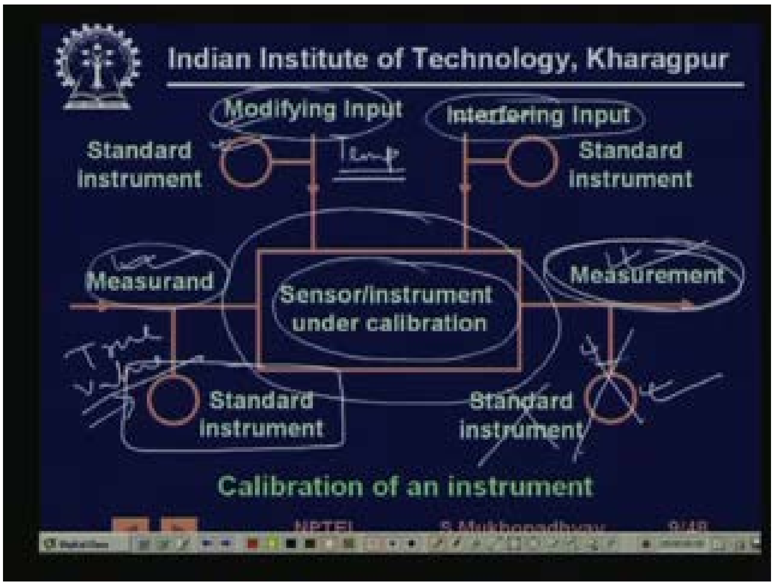

So, this is the essential scenario that you have a, you have a, you have a, this is the sensor instrument which is to be in calibrated. Now, the reading the you are first of all you are look at the fact that this, the measured whose which you are measuring using some standard instrument and you are thinking that this is the true value, this is an assumption. You are also measuring, now here this is not required, I do not know why this is, this connected to this diagram wrong around wrongly.

So, the sensor instrument of the calibration is giving a measurement, now this measurement again, for example suppose it is voltage. Then how many volts it is that again will have to be measured by some instrument, so that may be this instrument, so in that sense is required. So, you have to, you have to measure the measurement if the measurement is for example given in a digital form then you do not need to measure it then you can, so this may be there or not there.

On the other hand, there are, you know this sensor this instrument reading or the measurement is actually a result of not only the measurement it is the result of many other factors. For example, it may be a result of temperature, for example if you take the, if you take the way in weight measurement is. Then the strain gauge resistance change is not only a function of the weight you put, it is also a function of the temperature because every resistance has some temperature co efficiency.

So, if the temperature varies then the resistance is going to change, similarly there are various kinds of interfering inputs like. For example, there may be some noise there may be some noise induce from a, from a, from a power supply or from some power line. Especially, in the, in the, in the industrial environment there are plenty of noise sources and these sources these signals can also effect the sensor measurements. So, generally when you to the extent possible when you are trying to calibrate an instrument you will have to also note what are the, for example what is the temperature.

So, if would, so that you can actually apply the corresponding corrections and you can characterize when you are trying to characterize the instrument you will also have to characterize its response with respective these kind of inputs. So, I mean in some cases it may not be possible to possible to measure these kind of interfering inputs and in such cases we try to ensure that these interfering inputs are not present. So, we do shielding we actually do take it to a different setting and actually try to try to see what the sensor is doing.

So, essentially we try to measure the measured, we try to send we try into also measure the output of the instrument and we try to measure modifying inputs like temperature and then we establish the characteristics of the instrument. So, since the instrument must have constructed to be you know relatively unaffected by modifying input. So, with I means generally what is, what is of much more importance of primary importance is to see how the instrument characteristics are dependent on the measured, so that is what we are going to look at mainly now.

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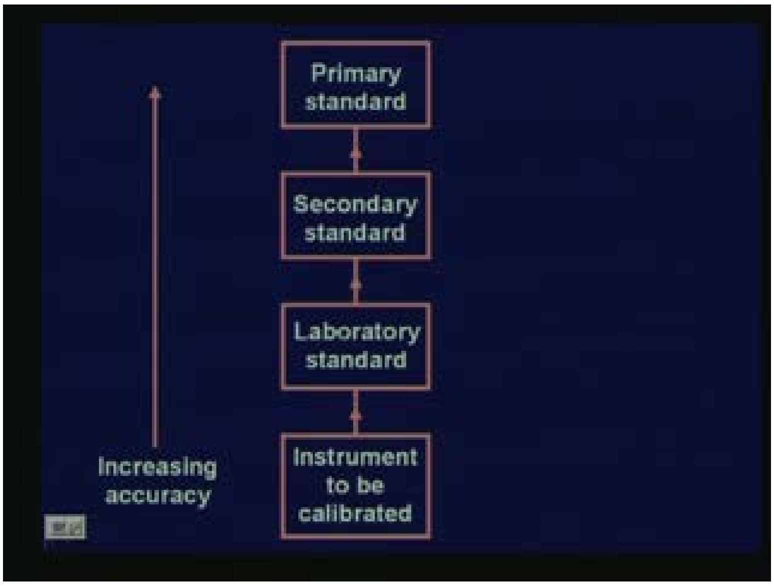

So, this is what it says that this is what I was talking about that there are different standards of instruments, so the instrument to be calibrate it can we calibrated against a laboratory standard. Now, the laboratory standard instrument also has to be from time to time calibrated against you know, other standard like. You know secondary standards which are which are which are, which are special instruments which can be you know existing in some test houses and then. So, use from time to time you have to send these instruments to be test houses and get them calibrated.

On the other hand, these test house instruments again have to be calibrated against in some very accurate national standards. So, in this way you have, we know what is the, what is called a chain of standards of increasing accuracy and at different levels. You always calibrate according to a with respect to an instrument which is at the high at the next level according to the chain these static characteristics.

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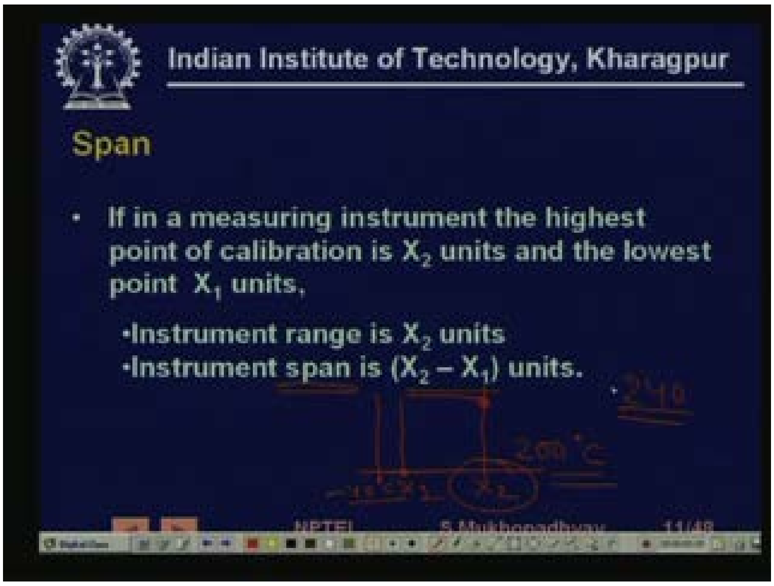

So, we begin with span, so it says that if in a measuring instrument the highest point of calibration is X 2 units and the lowest point is X 1 units. So, what we are trying to say is that the instrument has been used between 2 points, so the instrument has been calibrated to work between 2 points and this is. So, this is X 2 and this is X 1 then the instrument range is X 2 it is the, it is the highest, so it can work up to that value and the span is X 2 minus X 1. So, if this is 200 degree centigrade and if this is minus 40 centigrade then the range is 200 and the span is 240, so that is very obvious, so we have to remember these two details.

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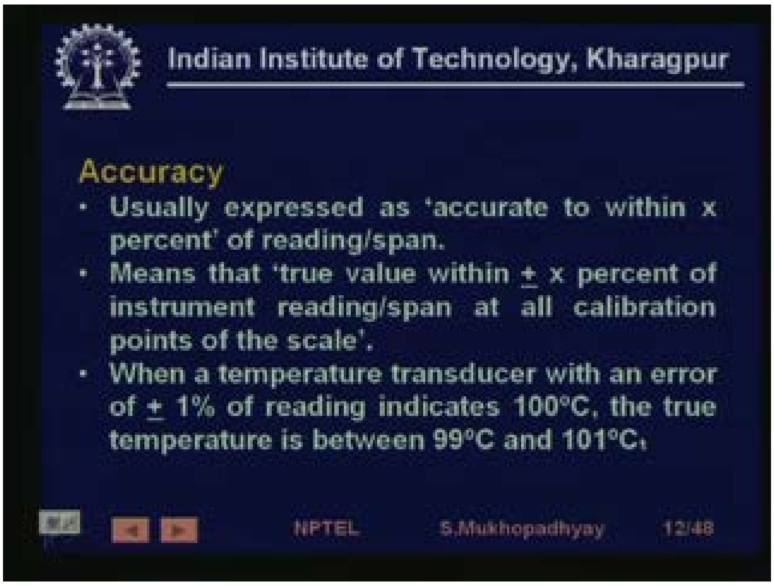

Next, let us talk about one of the most, one of the most important parameter called accuracy. So, accuracy if you see instrument classification there will be there will be generally written as accurate to within X percent of either reading or span. You know sometimes they say reading sometimes this is span, in fact sometimes they also mention constant values that is have that is accurate within plus minus 1 degree centigrade. So, if when this constant value then since the span is a constant quantity, so you can always express as a percentage of span also.

So, if the span is 100 degree centigrade then an error is of plus minus 1 degree centigrade can be expressed as 1 percent of the span. So, it is either a constant value it may be express of the percent of span or it is a percent of the reading, so what it means that if there if a reading is 100 and if has plus minus 1 percent of let say span accuracy. Then the reading is somewhere within, let us say 99 and then the true temperature will be between 99 and 101 degree centigrade and this.

So, it at all point, so whatever reading you get you can always basically these are needed because the because the user of the instrument needs to know there in within what value. So, gets a reading, but within what is the guarantee that the true value will be staying within certain limits. So, that limit is stated by accuracy, but then again the true value is unknowable and it is actually what stated is that with respect to the calibration, so then the next point is linearity you know we generally want.

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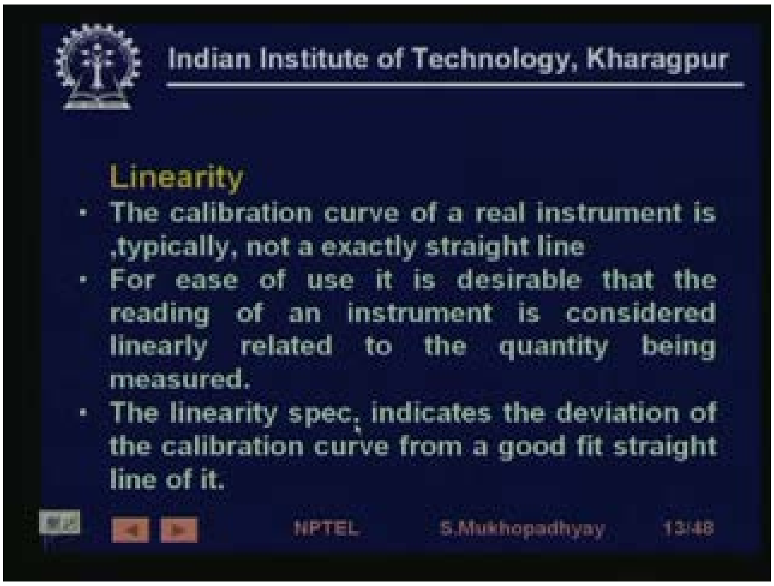

Although, instrument calibrations will not strictly follow a linear curve, but still it is very useful to imagine the system as a linear one. So, you know if you have a, so there you can very easily interpret the true value, so if you have an instrument sensitivity of let us say 10 milli volts per degree centigrade. Then if it gives a 25 milli volt signal then you know that it is, that the temperature is 2.5 degree centigrade, so you can get just by dividing by a number or sometimes adding another number to it.

So, it is, it is from that point of you, from the point of usability it is very attractive to express a, the characteristic of the linear one, but then it is not linear. So, therefore while you mention a line which can be, which can be used for reducing the true value from a reading? You also have to give some bonds within which the true value will remain because it is not exactly going to because instrument does not actually follow that line characteristic the line is only an approximation.

So, when you, when you are telling the user to use the approximate model of the line for simplicity you also have to tell him what is the kind of error that he or she can expect if she uses that uses the a linear model of the instrument. So, that is given by the measure of linearity, so the linearity specification indicates the deviation of the calibration curve from a good feed straight line. So, now how do, how do you obtain the straight line we can obtain the straight line in various ways.

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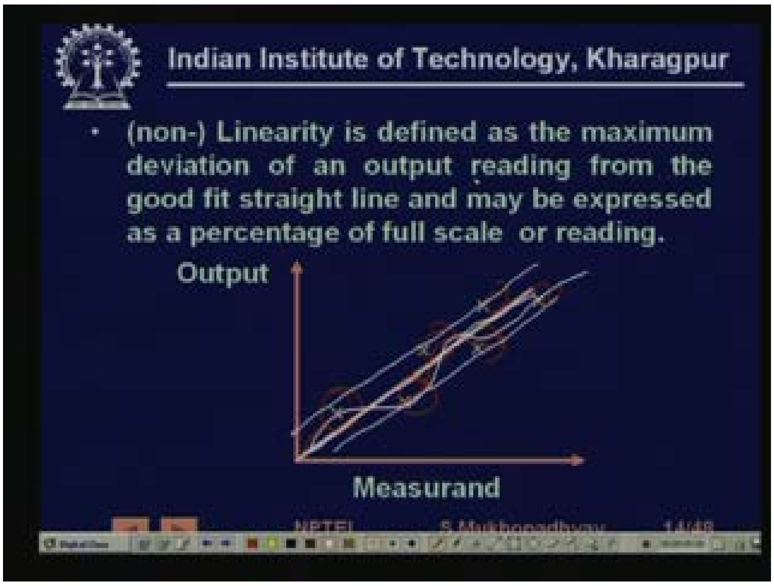

So, one way would be this that we actually perform some calibration experiment, so you got these data points, so you got these data points these are experimentally obtained. So, for all you know the true characteristic of the instrument let me use of white color that will be good. So, for all you know the true characteristic of the instrument may be like this and you are approximating it by the straight line. So, you have to also say that why while if you use the straight line characteristics then the true value is going to be within which limit.

So, that is why when you say linearity actually the linearity specification is actually and non-linearity specification the sense that it indicated deviation from linearity. So, it is defined as a maximum deviation of an output reading from a good feed straight line, so obviously you want that. So, obviously you want that the straight line, that the, that the, you will know linearity specification is small. So, that you are telling that if your use that straight line characteristic you are not going to have much error that is what you are telling to the user.

So, that it is the smallest possible you have to actually take all the data and make up make up make up best feed straight line such that the sum of square of errors is the least or something like that. So, that is that is linearity reduce the deviation of the calibration data from some good straight line which you have obtain either by data fitting or in some cases it may be obtained also in a different way.

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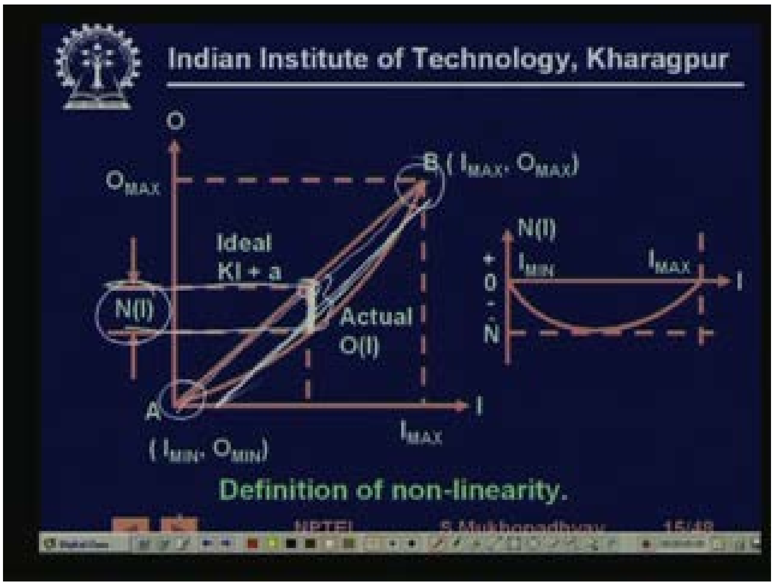

So, for example, in this case you can also obtain it that that is that is simpler way by taking the reading at the least value and the maximum value. Then simply assuming that the characteristic is going to be like this, now this is not the feed line probably for this curve the best feed line would have been like this. However, in some in some cases you can perhaps use this line that is actually simple thing if he does not matter. So, basically non linearity whatever is the line, once you have fix the line the non linearity is actually this deviation, so it has the maximum deviation. So, the non linearity is spec or which is I mean some we actually referred to as a linearity spec is actually deviation from that line.

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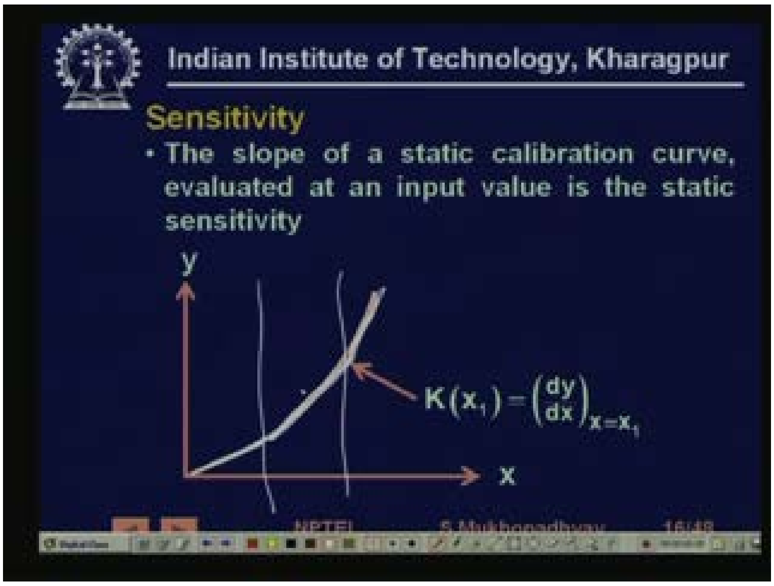

So, next we are interested in sensitivity, so sensitivity is actually the slope of the line, so if you have a calibration curve and then. So, that that will be the sensitivity and if you to, if you have calibration curve and then get a get a get a straight line. In case you have, you have a linear characteristic, it will have one single sensitivity, if it is very non linear then sometimes you may also express it as. So, you can take you do actually it do various things you can express say let us say 3 sensitivity figures.

So, one sensitivity figure will apply in this range the other sensitivity figure which is the, which is the average slope of the line in this range and then another sensitivity figure which will apply in this range or you can. So, basically sensitivity is the slope of the characteristics, so depending on the non linearity you have you can use multiple slopes on multiple ranges sometimes instruments do that.

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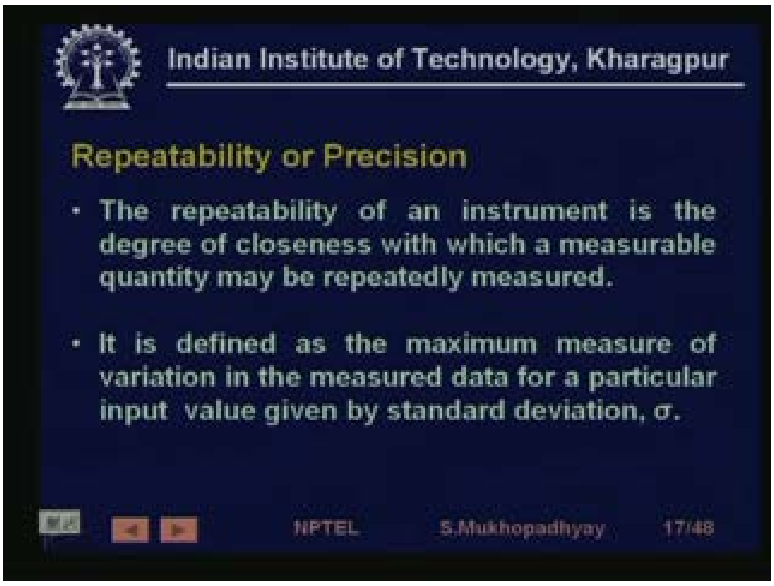

Similarly, we are also interested in what is called repeatability or you know precision in the sense that we want, we do not want that, today we make a measurement of the temperature of the boiling water. So, it is giving me some reading, tomorrow if I take that reading should be, should be nearly same it may not be exactly same, but it, but it should be nearly same. So, when it is very close when you if you take multiple readings if they are very close then the, then the instrument is said to be repeatable or precise. So, the repeatability of an instrument is a degree of closeness with which a measurable quantity may be repeatedly measured, so we go to the next one.

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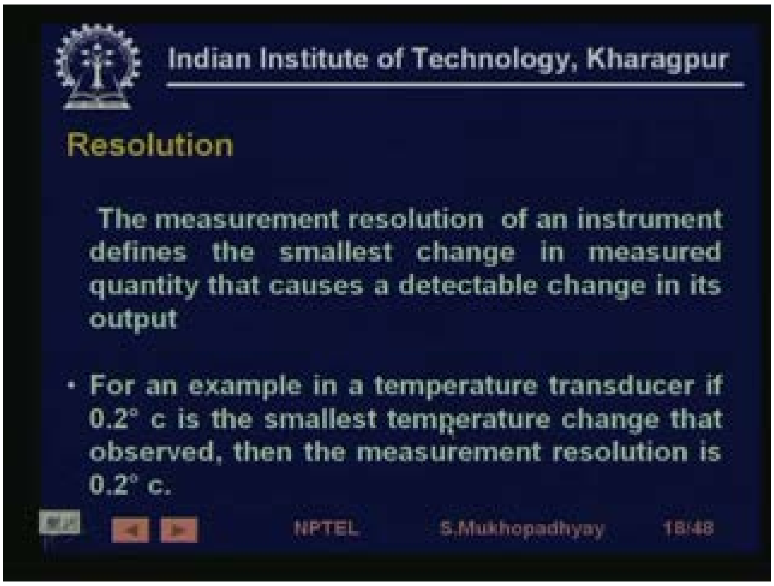

Which is resolution is also very it says that how much of change in input will actually cause a detectable change in the output, so what is the smallest change in the input. So, if, so can we detect a change of 0.1 degree centigrade or can be detected change in 0.01 centigrade, for example if you have a clinical thermometer. Then you cannot possibly detect a change of 0.01 degree centigrade or 0.01 degree Fahrenheit, generally they are calibrated in terms of Fahrenheit. So, that is resolution if a temperature transducer is resolution is 0.2 degree centigrade, there is a smallest temperature change that can be observed.

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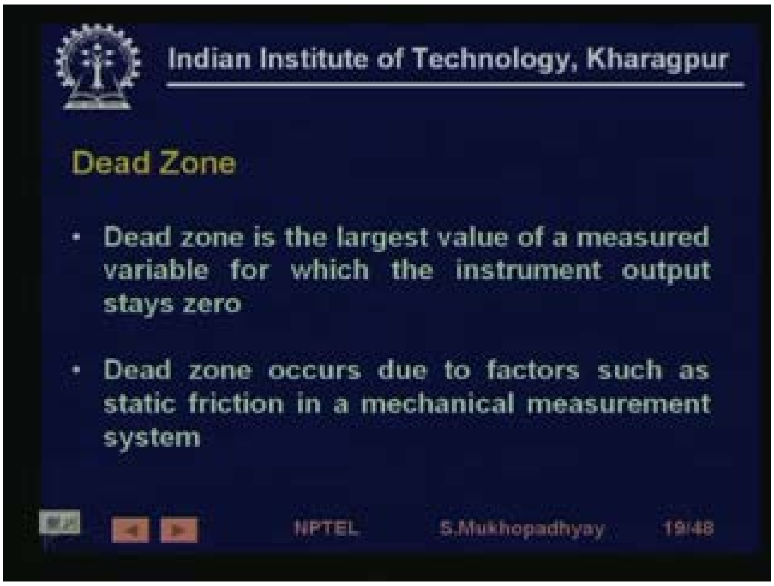

Similarly, we have similar to the concept of dead zone sometimes you know sensor system you will have dead zones, for example we often find that you know these electrical meter. Sometime, they will stick you know any mechanical arrangement tends to develop something like a static friction which also develop depends on many things like temperature time humidity and another things. So, what happens is that till they say if you have ammeters then till you send a certain amount of current the torch is not enough to overcome static friction.

So, the needle does not move, so it is, so that is on largest value of measured variable for which the instrument output stays 0. So, from 0 to that value there is going to be no deflection, no reading nothing, so that is called the dead zone. So, what is the different between the dead zone on the resolution dead zone is the, is actually the resolution from

0 while resolution is, resolution can be resolution from 24.24 to 24.1, 24.1 to 24.2 while generally dead zone is referred to from 0, so it occurs due to factors at a static friction.

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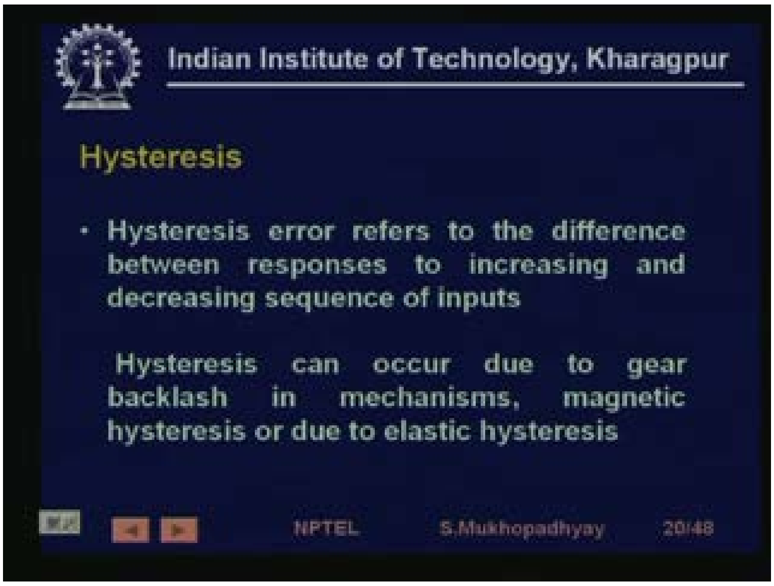

Similarly, sometimes we have we have hysteresis in instruments, so that if we have an increasing sequence of input value. If you are increasing the input from let us say 0, 10 degree centigrade, 20 degree centigrade, 30 degree centigrade they are increasing sequence of values. Then we get one set of reading while if we have a decreasing set of values then we get another set of readings and these readings are distinctly different.

So, in that case we say that the instrument has an, has a hysteresis it can occur due to various factors like you know gears backlash or it can occur due to. You know magnetic components or sometimes by due to you know hysteresis which occurs due to elasticity, so did you such things the hysteresis can be there, so what is…

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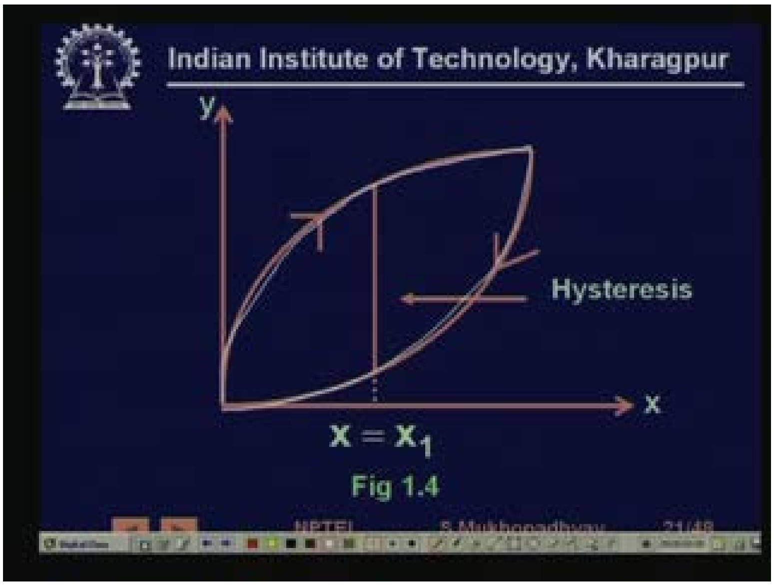

So, this is the figure that we are saying that the, if X is increasing then the, then the, then the readings at we obtain follow this curve while if X is decreasing. Then actually forward, distinctly different curve, so if such behavior is demonstrated by instrument it is called it is said to have hysteresis.

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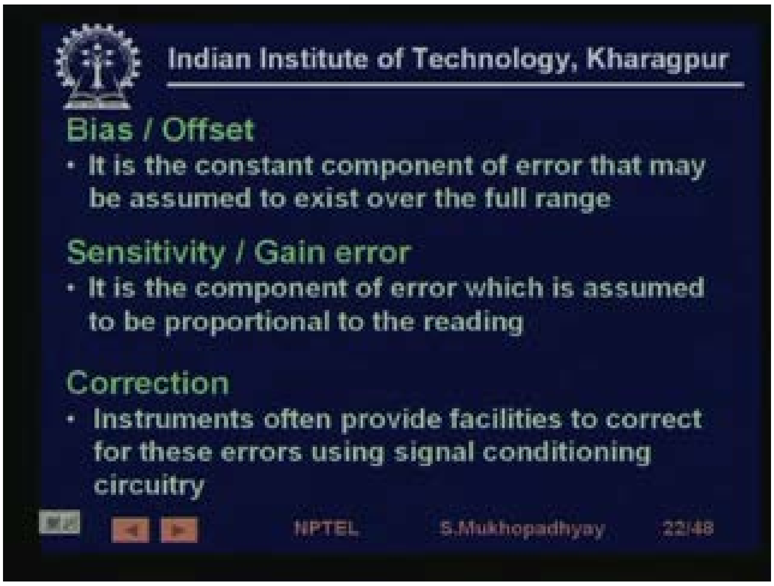

So, next, now the errors that we have you know the, so we have actually typically an instrument is suppose to have a, suppose to have calibration curve. But, the reading that it has may not exactly match with the calibration curve it is if you, if you, if you read out an ammeter then it has some scale fixed. But, if you send exactly one ampere current then the, then the needle may not stand at one ampere, so this is the error. Now, the error is typically you know characterize as in into two different kinds, so since the instrument is actually assume to be linear instrument.

So, it is assume that the error can be of two types the first type is called bias of offset which is a constant error, which is, which is going to stay throughout the range. So, may be at half at when you have a reading of when you have an actual current of 2 amperes you reading shows 2.5. When you have 3 ampere it showed 3.5, when you have 10 ampere it shows 10.5, so you have a 0.5 ampere of bias. If you see ammeters normal ammeters you will find that such biases can be corrected by you know screwdrivers there are, there are, there are sometimes zero adjusts.

Similarly, there can be see there can be again error, so you have a sensitivity while we have a nominal sensitivity which is indicated by the scale and your actual instrument sensitivity may actually deviate from that and then you have a sensitivity or gain error. The error in reading due to this gain error is going to be proportional to the ready, so if you have if you have measuring 10 degree centigrade.

Then the error due to gain error is going to be half of if what you measure due to 20 degree when you when you measure 20 degree centigrade. So, we assume the errors are of two kinds and these typically in typical sensors and instruments very often they can be corrected by electronic signal conditioning means.

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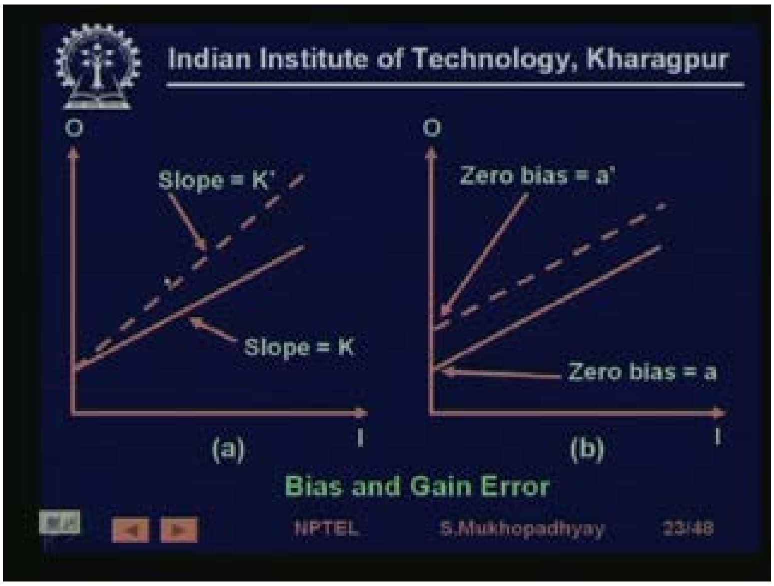

So, that is why it is depicted that if you have as 0 error, so that is of bias and if you have slope error that is your gain error.

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Next is drift, so sometimes what happens is that even if you correct even if you correct at any at some point of time during calibration even if you correct for the bias of the gain error you have drifts in the bias on the gain. So, again such bias and gain errors can develop due to you know variations in temperature variations in time or some other conditions. So, the rate at which it these will develop are characterize by a performance characteristic called drift, so typically drift is characterized for temperature and time.

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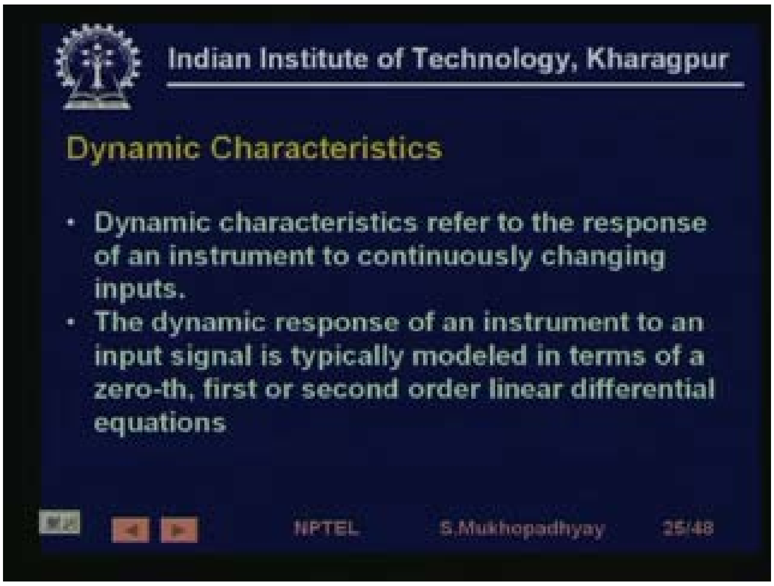

Now, we come to, so this more or less completes all static characteristics, so generally talks about and input output curve right that is the calibration curve. So, there is no time here if you given input you will get an output in the steady state and we are only talking about this, the characteristic between this input and this steady state output value. But, we have to talk about dynamic characteristic of the instrument when the input is not steady, 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 are signal, if the, 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 concern with the steady state new steady state values of the output signal will a achieve, but we are also concern with how it how it is going achieve that overtime. So, when we talk about such characteristics we talk about the dynamic characteristics of instruments.

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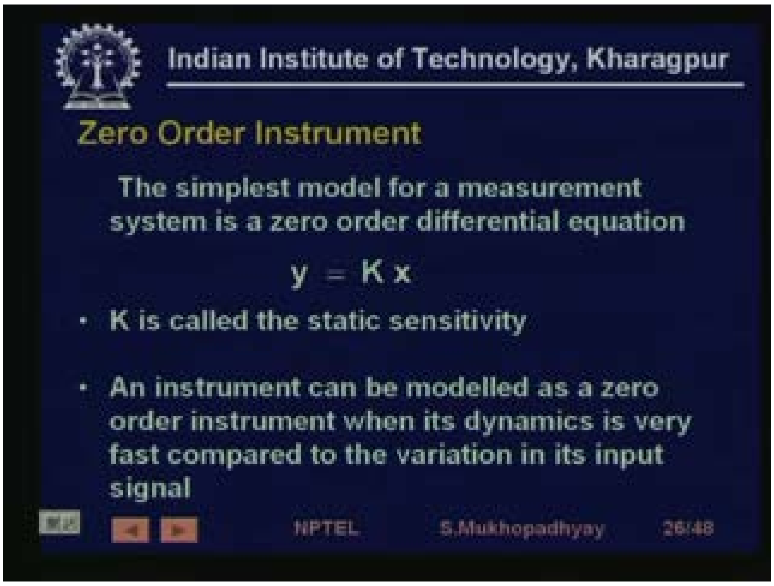

So, accordingly we have various kinds of instrument, so we call we start with simplest which is the zero order instrument whose characteristic is given by y equal to K x. So, it is assumed that is for the kind of inputs that are relevant to that sensor the output is instantaneously equal to the input. So, it is like a resistance you know you just apply a voltage you immediately get a current. So, the input output ration is linear and this linearity exists from instant to instant, so it is a, so for such instruments there is no dynamics. This static characteristic is the only characteristic that you need to see, so such instruments are called zero order instruments, for example typically.

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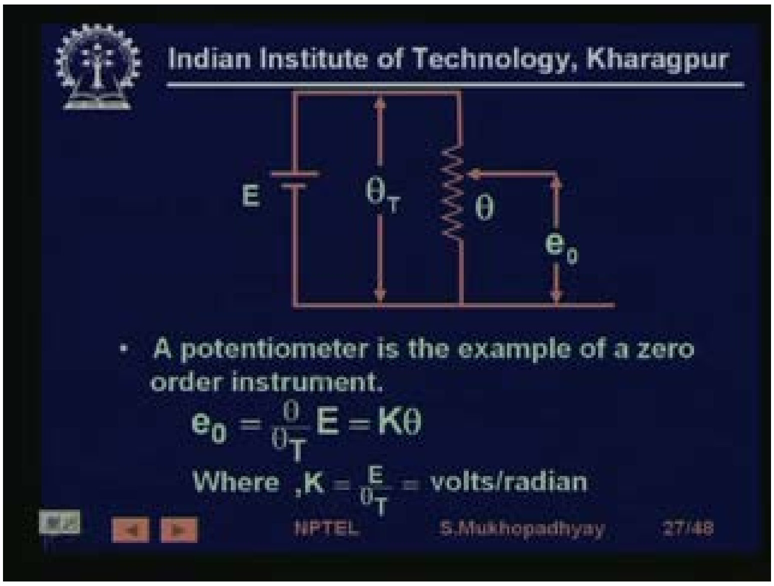

For example, a potentiometer I mean, I was talking about a resistance, so a potentiometer is nothing but a resistance. So, for a potentiometer the position signals potentiometers typically major position which, so the potentiometer will be connected to this variable points. So, as the variable point moves the voltage that you will get will be directly proportional to the, to the position. So, in this case there will be instant to instant and, since the position is a 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 compare 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 ordered characteristics. So, the output voltage will be directly proportional to the displacement theta that is an angular displacement in this case if potentiometer is can be angular as well as linear, so there is, so there is sensitivity called of the potentiometer is volts per radian.

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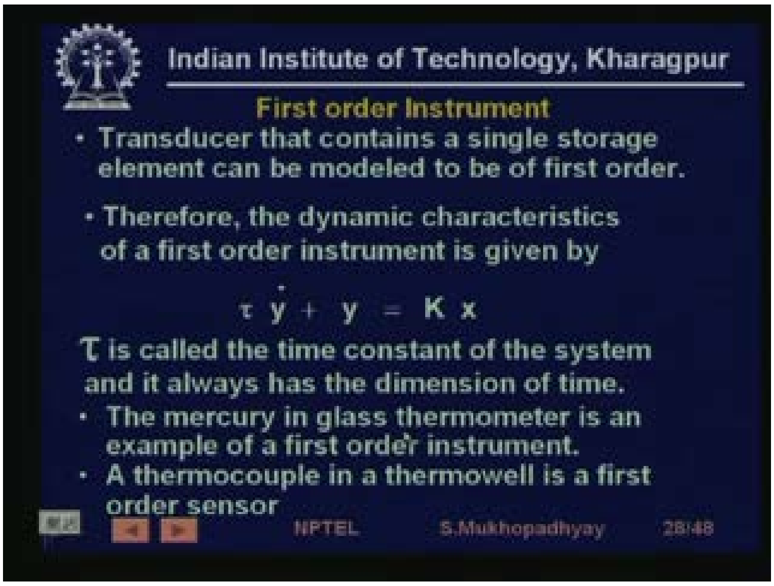

On the other hand, there are some kinds of instruments where the where if the input changes suddenly the output cannot change suddenly the output takes some time to rise. For example, let say it let a temperature measuring instrument, for example thermocouple actually thermocouple is typically as will see it is not wherever it is making the measurement of the temperature.

May be it steam then the pair thermocouple is actually not inserted into the steam because that will that may that that will damage the sensor it will 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 thermo well, so it is a tube inside that you have the thermocouple. So, even if you are 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 thermo well into the thermocouple junction before a before an E M F 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 a steam the temperature of the junction will not junction of the thermocouple will not instantaneously be equal to the temperature base steam, but it will slowly rise.

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. So, typically first order instruments are transducer that contain a single storage element and can be modeled of first order. So, in for such cases the output value actually obese some kind of 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, 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 two various kinds of changing inputs. So the first, so these are two examples mercury in glass thermometer and thermocouple in a thermo well.

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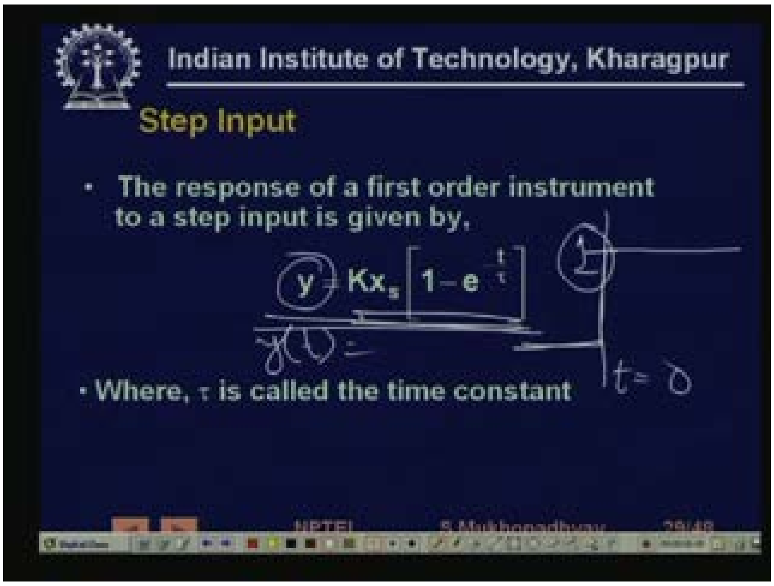

So, if you have a step input, so the first kind of input that we consider is a step input, so step input means it is a it is a 0 and then suddenly it rises, so at t is equal to 0 the input is 1 suppose. So, then you, we actually we can we can compute that the time response or y t is going to be such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

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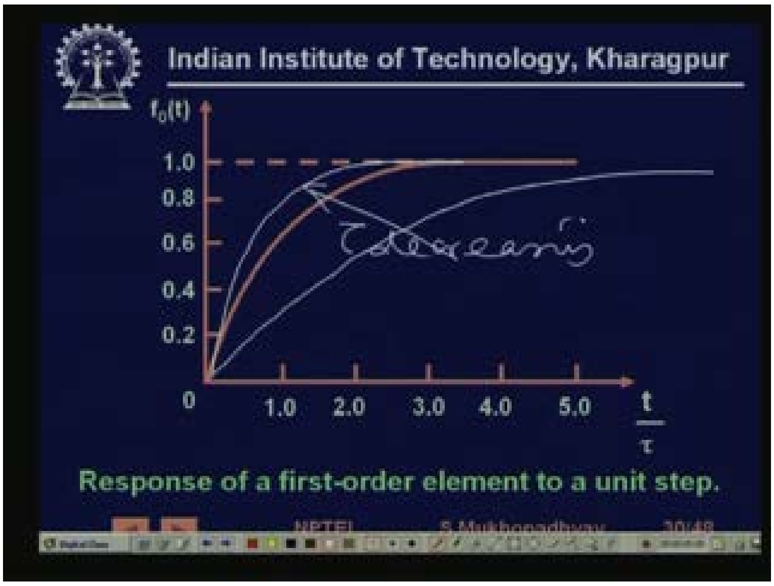

So, you see that it will gradually rise and then it will become 1, so if you have a, if you have a large curve tau, if you have a large tau it will rise slowly, if you have small tau it will rise fast, so this is tau decreasing.

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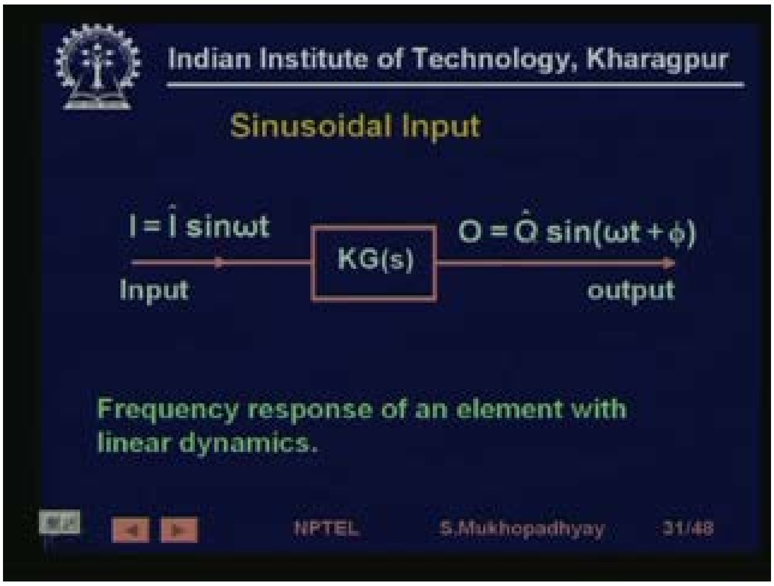

On the other hand, you know as we all know I mean the response to a dynamic a sensor to arbitrary inputs is of interest because if we if we such a sensor is actually put in a control loop all kinds of it is not going to be regularize as a step input. So, we sometimes, since we know that any arbitrary wave form most arbitrary wave forms can be thought of as a some 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.

So, this is called frequency response and this is very important for an instrument, so if we have a sinusoid. So, we this is, this is, this is my instrument I am applying, sine omega t typically what will happen is that if the instrument is suppose to be linear. Then you will get as, output also you will get 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.

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 ration 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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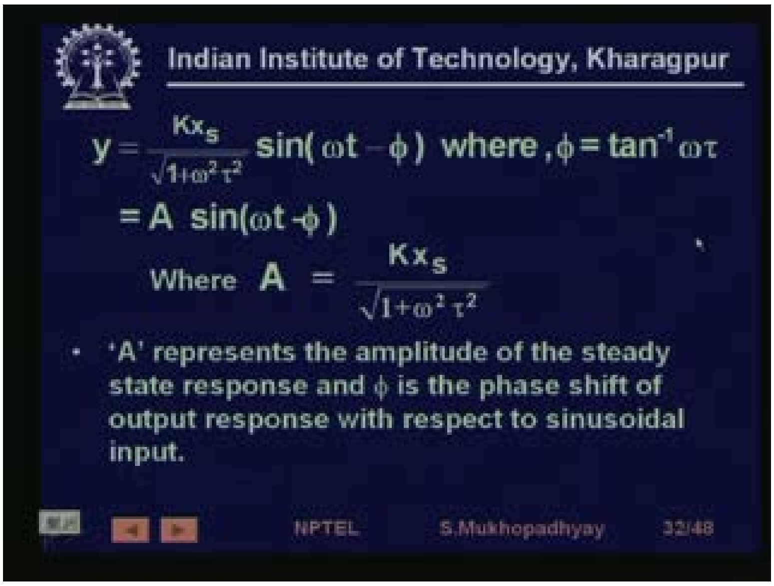

So, you know this is a this is a mathematical solution we did not do that.

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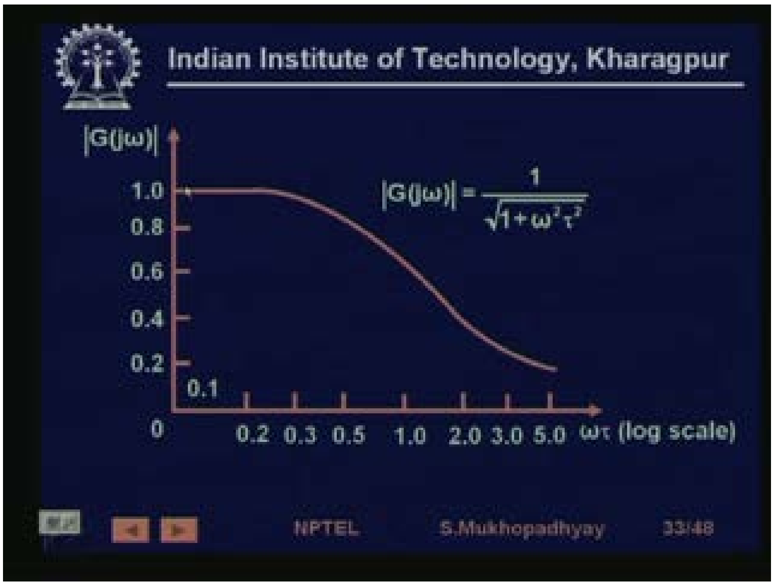

So, for example the gain over different values of frequency actually varies like this, so you can understand that if the, if the frequency is too low then the then the gain of that is one because. So, the frequency is too low means you are giving a slow sinusoid which means that the instrument can always 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 really rise the input changes. So, the output of the instrument can never rise enough and, therefore the gain falls, so this is the, you know frequency characteristic of an instrument.

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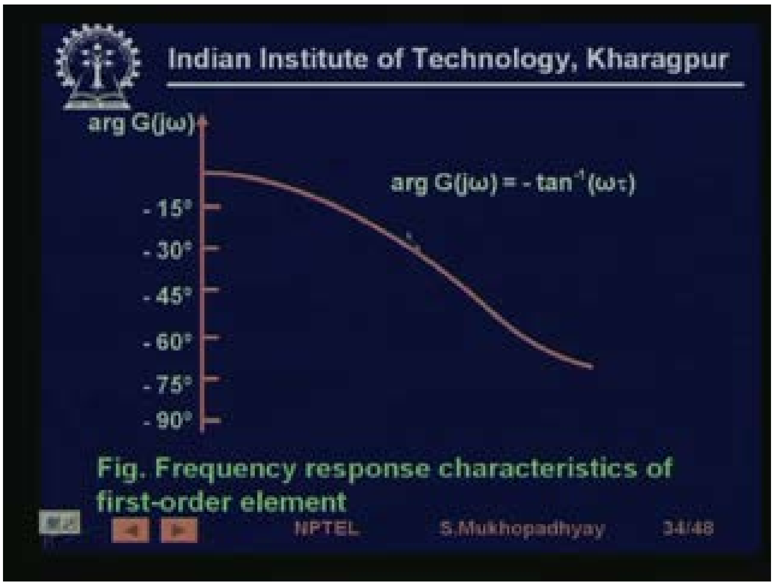

Similarly, you know you if you have a, if you have a phase plot then it turns out that as you go for higher and higher frequency is the phase lag increases. On the maximum phase lag possible for a first order system can be 90 degrees, so it will gradually approach 90 degree.

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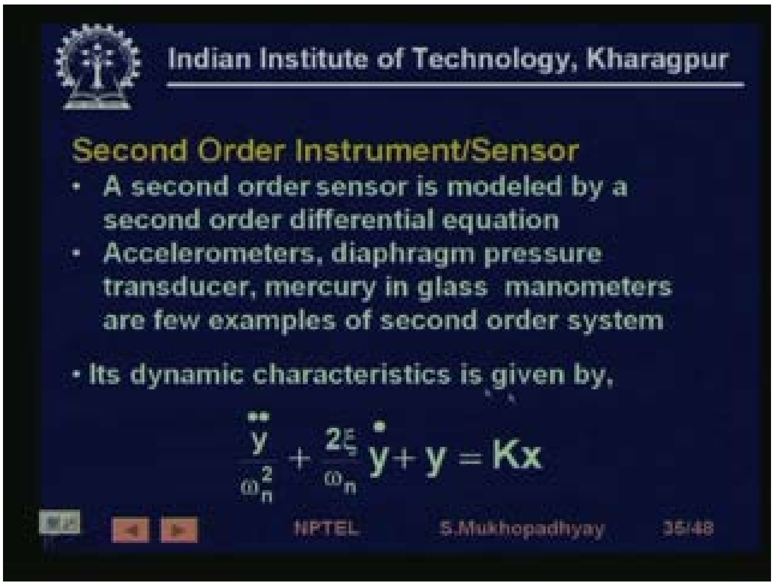

Now, sometimes we also have to model the systems as second order instrument or sensor this choice can actually depend on you know we which kind of module you will use that may depend on physical reason. So, it may depend on the kind of response that you actually get from the instrument, so some instruments are a larger assumes to be governing by a second order differential equation.

For example, accelerometer anything, which has you know mass spring damper kind of representation and will have will have second order dynamics. So, its dynamic its input output dynamics she 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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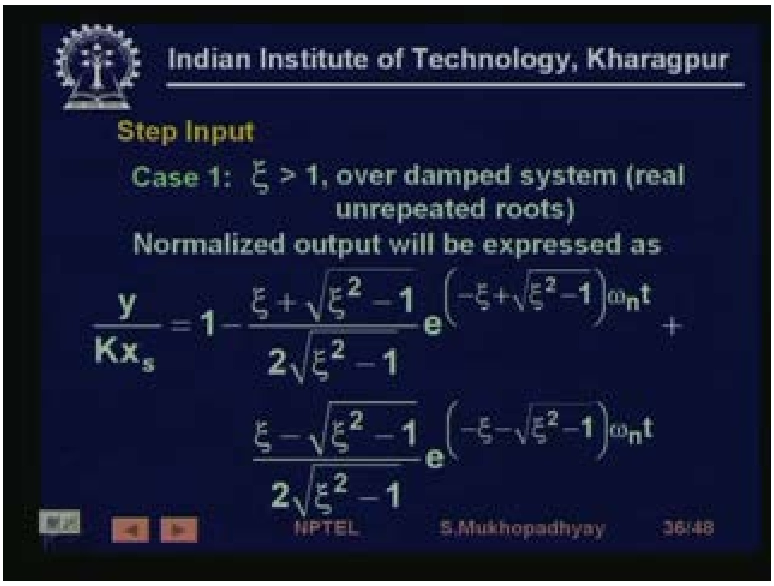

So, again it response to the step input in this case we have 3 kinds of cases depending on what is the damping factor. So, one case is when the damping factor is zeta is greater than one in which case we call it an over damped system and this is the expression for the output time function.

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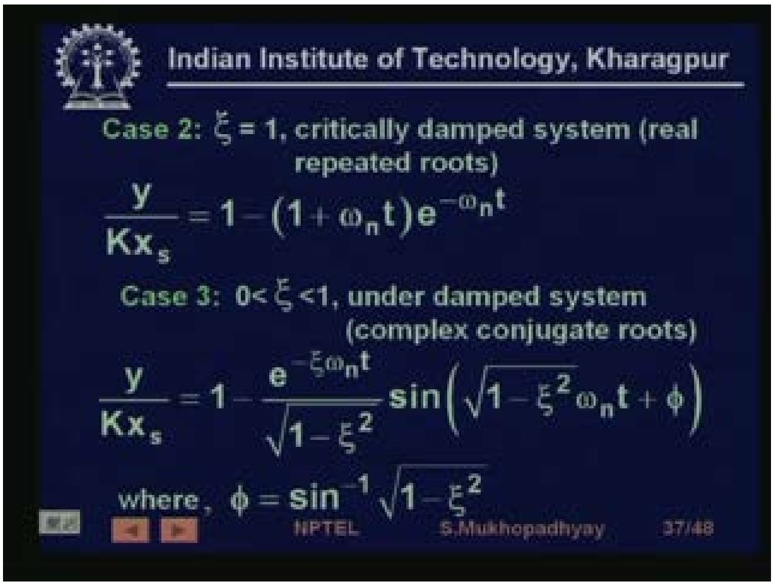

We will just see the cases and then will see the plots, so and then we have a case when xi is equal to one zeta equal to 1 which is called the critically damped case. Here, we and is the last case is when we have psi is less that between 1 and 0, so that is called the under damped case.

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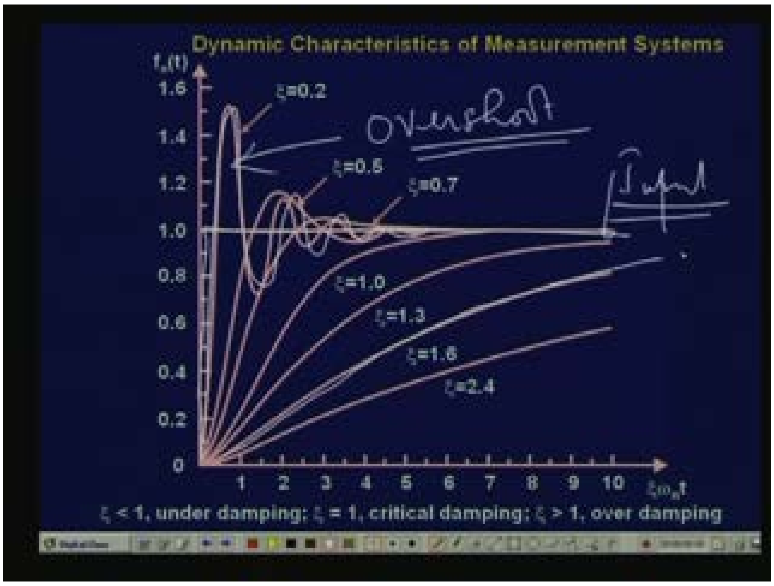

So, the plot actually looks like this, so this is of interest to us, so you see that this is a step response, so the input apply it is this is the input. Now, for different values of zeta for example if as zeta goes to lower and lower values you can see that you get an oscillator it is heavier. So, there is an over shoot is called an overshoot, so for under damped sensor you will you are go to get an overshoot. On the other hand, for over damped systems you there is no overshoot and slowly rises just almost like a first order system.

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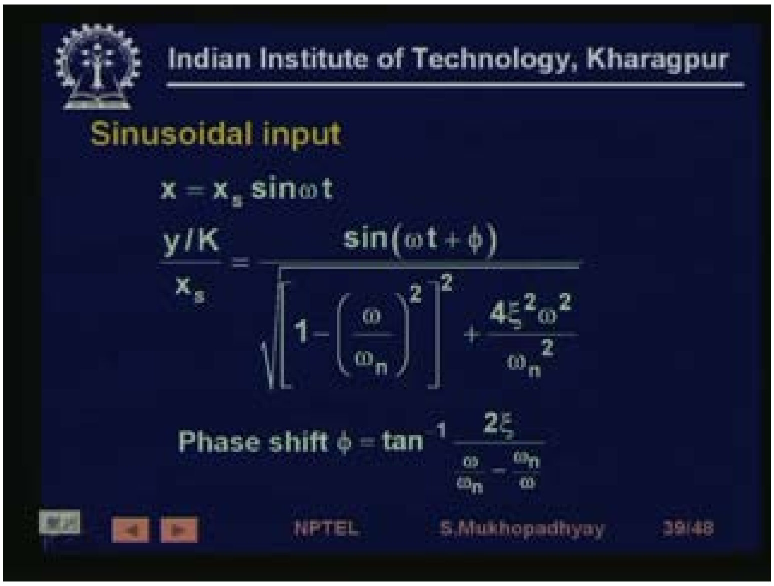

Similarly, if you its response to a sinusoidal input again you will find that this is these are the expressions, so you get again and you get a phase shift.

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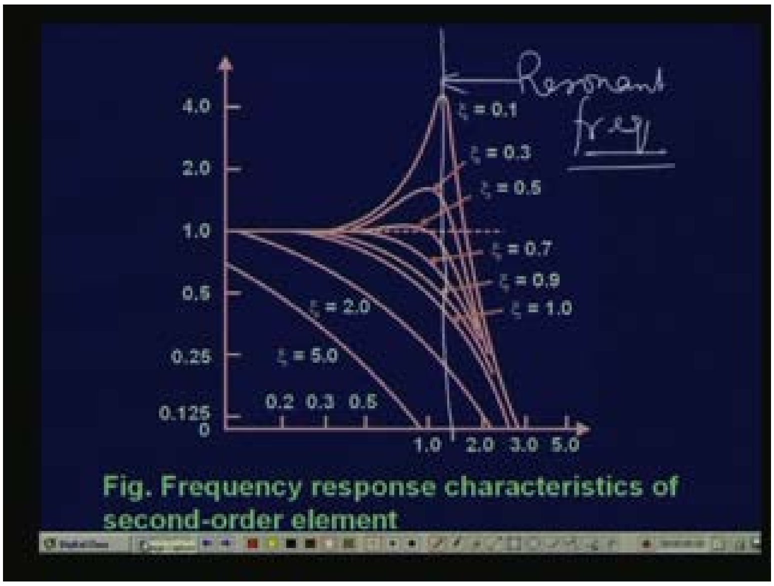

This is the expression for this is the plot for gain, so you see that the gain actually changes with frequency and for under damped systems the system tends to be tends to resonate. So this is the resonant frequency, so if you give a sinusoid close to the resonant frequency then you get a huge output.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

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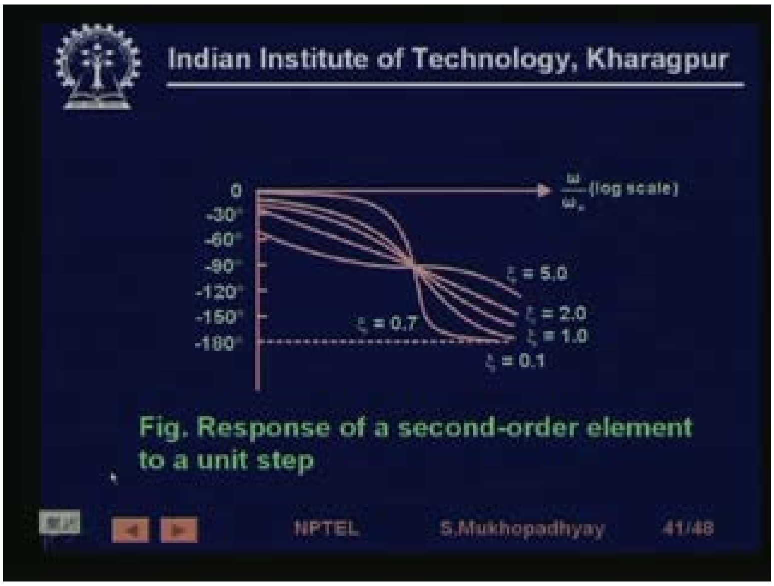

The phase plot looks like this again with frequency, so towards low frequency the phase is phase tends to stay small and as frequency increases, so this maximum phase that can occur is 180 degree, so these are the phase lags.

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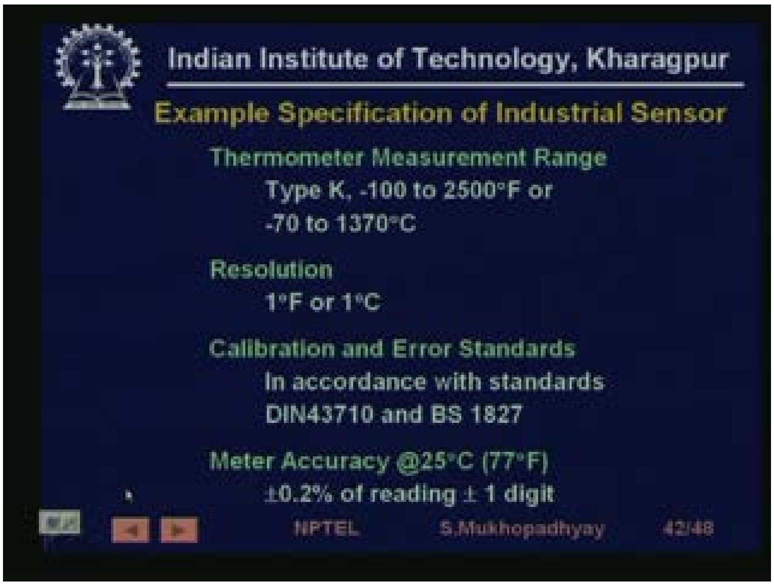

So, we have seen the static and dynamic characteristics of industry of sensors, now let us see some example specifications, so this is, for example, and industrial thermometer, so see what is says what all are stated. So, first of all it is it is based on thermocouple, therefore the type of the thermocouple is stated we will see what the type of thermocouple is.

But, interestingly the range is given, so you see this is 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 1 degree Fahrenheit or 1 degree centigrade and etcetera what, so whatever specifications are given or valid within this range. So, in this case range is 1370 and span is 1440, the resolution is 1 degree Fahrenheit or 1 degree centigrade.

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 this scale that you choose you can have different kind of electronics. So, the resolution also varies, so it says that is the resolution say, here it is stated as one degree centigrade, so it is. So, the minimum change that can be observed which can be detected by the sensor is actually 1 degree centigrade calibration error standards. So, all these specifications are actually with respective a certain this D I N is the actual the German standard B S is the British standard.

So, similarly it says that the that the that the meter accuracy at 25 degree centigrade there is when the ambient temperature is 25 degree centigrade is 0.2 percent of reading plus minus 1 digit. This plus minus 1 digit comes because you are have got to have digital display, so we see that in digital displays there has to be a there is a, there is effect called quantization. Therefore, this plus minus 1 digit error comes, so basic accuracy is 0.2 percent of reading in this case it is stated as in terms of V D.

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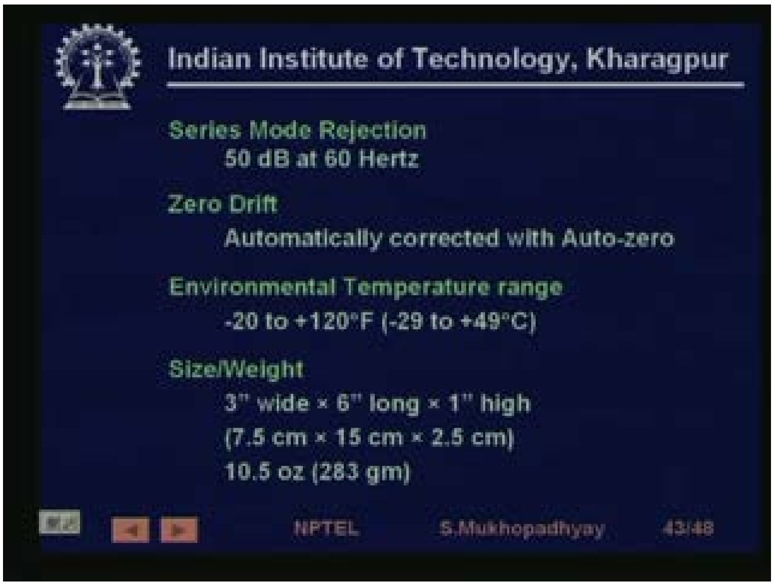

There is some other, there apart from these kinds of specification they are typically if you read see and example industrial specification. You will find some other things like which are which are specific to the, which are, which are specific to the particular sensor that you are using. Now, since thermocouples use long wires, so there is a series mode rejection series mode rejection means that typically when thermocouples are drawn from long wires. So, they typically tend to catch series mode interference especially at the power frequency because there may be power lines and the, and they will they will they will add power frequency interference as a series voltage.

So, it says that the sensor is, so constructed that it can actually reject that 60 hertz such interfere a, such voltage is which are induced. Similarly, 0 drift it says that even if the 0 drifts the every time possibly this instrument will have button, or may be every time this instrument is you know commanded to take a reading it will first automatically make it zero. So, it will it, so there is an auto zeroing facility, the environmental temperature range is, so there are all these specifications are to be to this sensor is to be used in such a range and the psi and weights.

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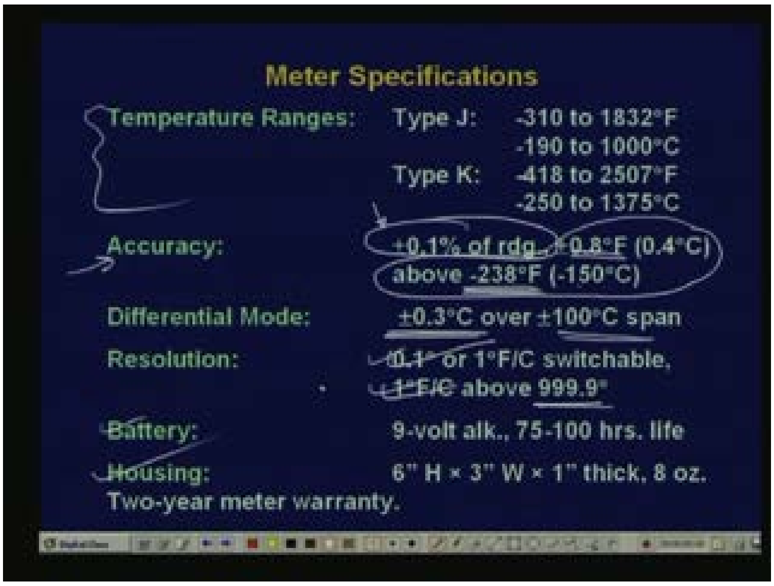

Similarly, another thermometer that another temperatures thermometer again based on thermocouple again it has some ranges. So, we have already seen it look at its accuracy it says that below 230, you see that below 230 degree Fahrenheit above minus 2. Then 200 and minus 150 degree centigrade, this is its accuracy statement while below that is, this is the 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 plus minus 0.3 degree centigrade over a plus minus 100 degree centigrade span. So, you can see that typical thermo typically such industrial instrument specifications will include this kind of parameters. For example resolution is 0.1 degree and above 999.9 degree it is 1 degree, the other things are you know battery housing these are specifically battery is important especially when you have a portable instrument.

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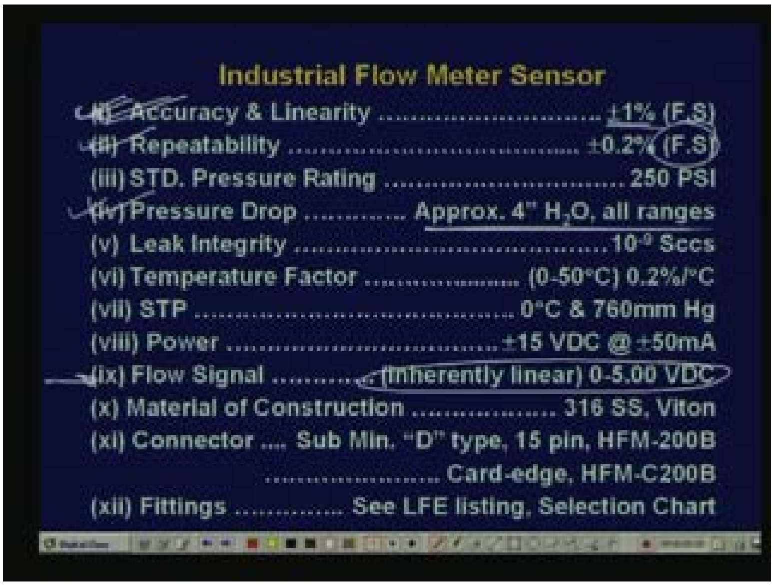

So, let us look at another sensor which is flow meter and there are, so many specifications the important one such say accuracy and linearity is 1 plus minus 1 percent full scale. Here, you see accuracy and linearity are both plus minus one percent possibly the instrument is inherently linear. So, therefore they are stated together see repeatability is stated as plus minus 0.2 percent of full scale. That mean if in, if you make 100 readings of the same flow, the readings will not differ by more than plus minus 0.2 percent of full scale.

Similarly, you have say inherently linear flow signal is inherently linear, therefore accuracy and linearity are specs both are same actually if it is not inherently linear then accuracy and linearity specs with will actually vary. So, then there are some you know special other specification which are specific to a flow center. For example pressure drop is very important because the pressure drop in the flow sensor is actually in energy loss, so it should be low. So, it says that approximately 4 inch H 2 O, so the other factors we will not understand so much unless we really know what is sort of a flow meter it is, so this brings us to the end of the lessons.

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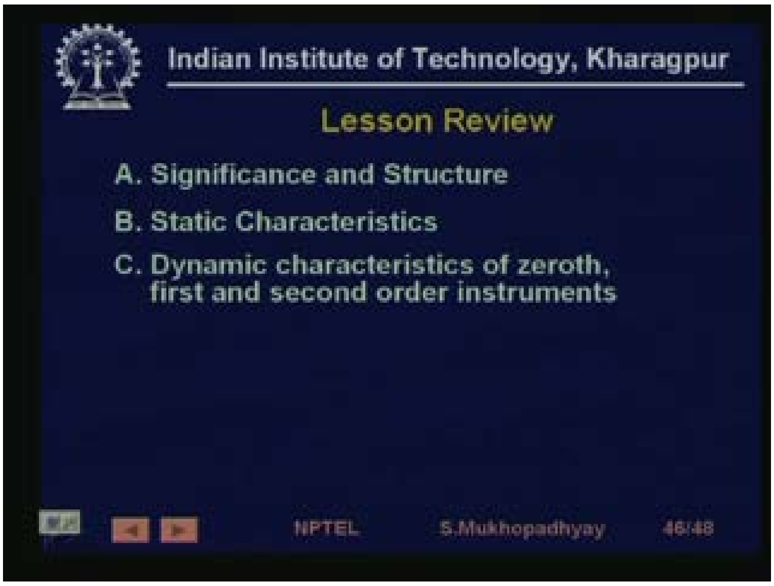

So, what we have done in this lesson is that we have seen why sensors are, so important we have also seen them, they are, they are, they are generally structure. We have looked at the static characteristic main static characteristic parameters and like sensitivity linearity accuracy resolutions span etcetera. We have also looked at the dynamic characteristic of 0-th, first and second order instruments and we have seen that the exhibit phenomena like an 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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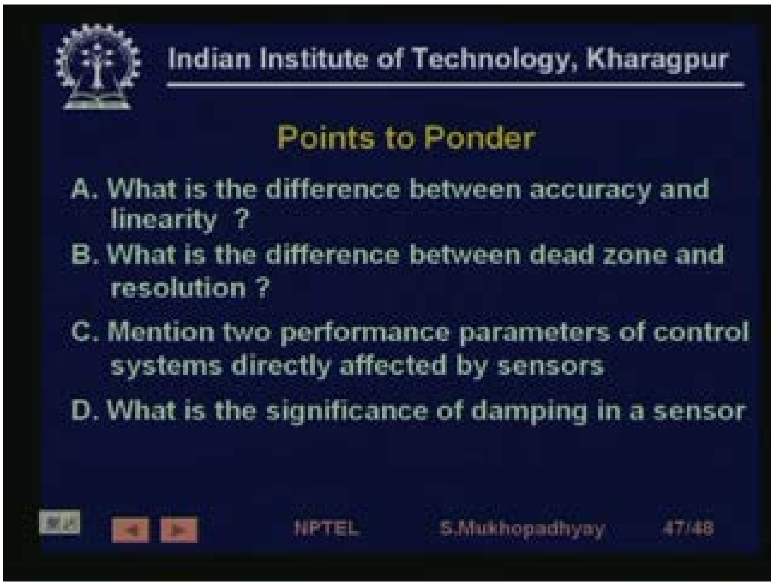

So, before closing would like to have some points to ponder, so for example what is the difference between accuracy and linearity? So, when are the same and when are the different and why, what is the difference between dead zone and resolution which is likely to be more dead one or resolution. Then mention two performance parameters of control systems that are directly affected by sensors 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 damping level for a let say feedback sensor, so think about these and that is all for today.

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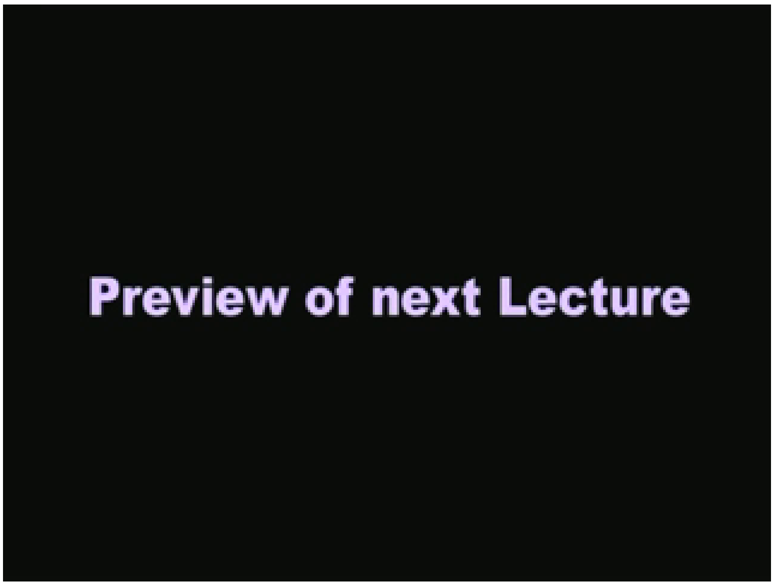

Today, we are going to look at temperature measurement temperature is a very important quantity, especially in the process industries all big process plants like you know chemical plants steel plants. They for them monitoring of the temperature is very important, so we will see how these measurements are done both in the online and the offline case.

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Looking at the instruction objectives the first one is of course that there are various principles of operation of the different temperature sensors. So, thus student will be familiar with that, here she would all will be able to describe the various you know signal conditioning aspects as we have already discussed. That measurement involves transformation from one variable to another till the measured or the variable of interest comes in to an electrical form that can be used very easily.

So, for that you need signal conditioning and processing and they are specific to the kind of sensor that are used, so the student will be used to describe the signal conditioning aspects. Then of course nickel and copper are much cheaper than platinum, so therefore except in critical applications when you really need to know the temperature accurately you do not use platinum. For example, in most of the air conditioning applications you know this building air conditioning applications people generally use Nickel R T D’s because of the fact that is the cheapest. Anyway, the application is not, so critical it does not demand a very high level of accuracy.