Chemical Process Instrumentation

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Lecture – 07

Performance Characteristics of Instruments and Data Analysis - I (Contd.)

Welcome to lecture 7. In our previous lecture, we have started our discussion on performance characteristics of instruments and data analysis-1. So, today we will start our, we will continue our discussion on performance characteristics and data analysis part-I. Specifically, in our previous lecture we have talked about static characteristics and dynamic characteristics; essentially, we introduce the definition of static characteristics and dynamic characteristics. In today's class, we will talk more about static characteristics. Essentially, today's lecture there will be lot of definitions relates to static characteristics of instruments.

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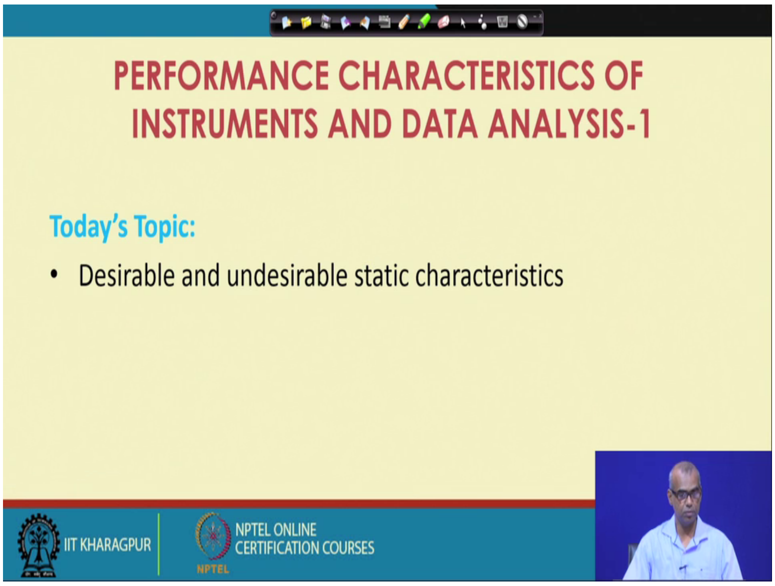

So, this is today's topic; desirable and undesirable static characteristics. There are various static characteristics. So, we will go one by one quickly and define them appropriately.

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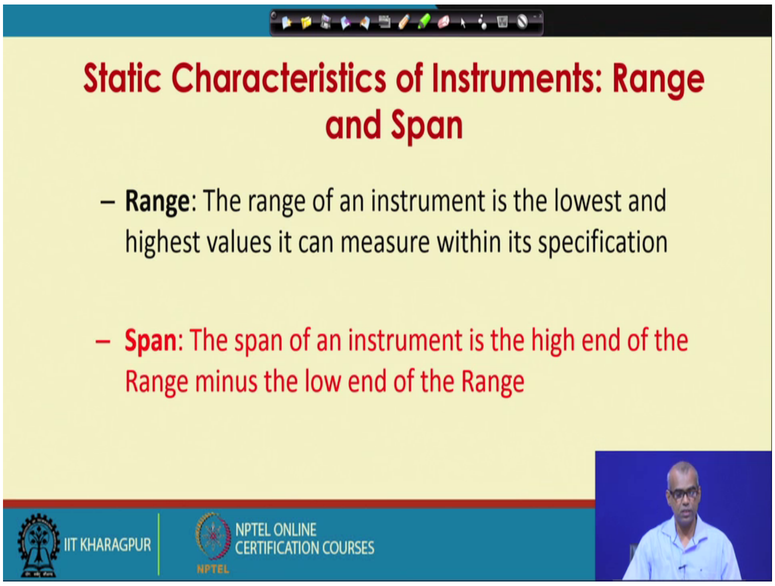

First let us talk about two terms known as range and span of instruments. The range of an instrument is the lowest and highest value it can measure within its specification. So, the range of an instrument is the lowest and highest value it can measure within its specification. The span is the span of an instrument is the high end of the range minus the low end of the range. So, it is the difference between the high end of the range and the low end of the range.

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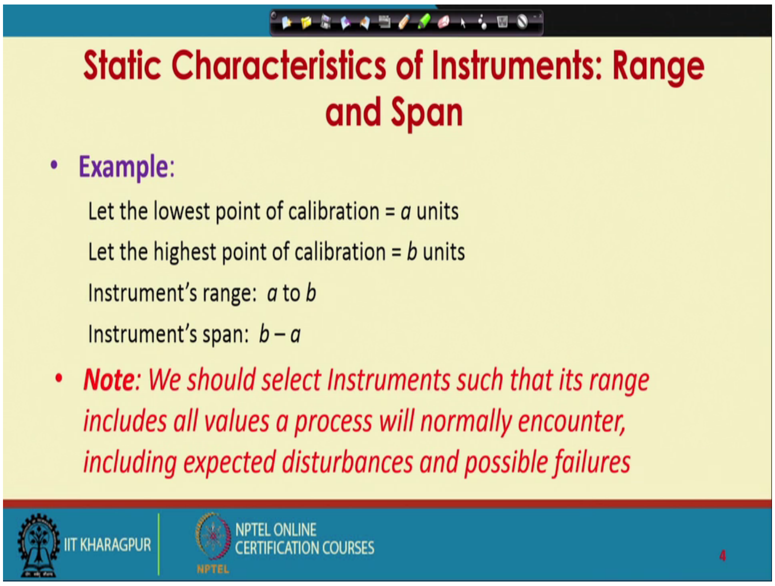

So, let us take a simple example, let the lowest point of calibration be a units and the highest point of calibration be b units; then, you can call or you can say that instruments range is a to b whereas, instruments span is b minus a. So, instruments range will be specified as lower end of the calibration to the higher end of the calibration and the span will be defined as the difference between high end of the calibration and the low end of the calibration. We should select instruments such that its range includes all values a process will normally encounter and it should include the expected disturbances and possible failures during the measurement.

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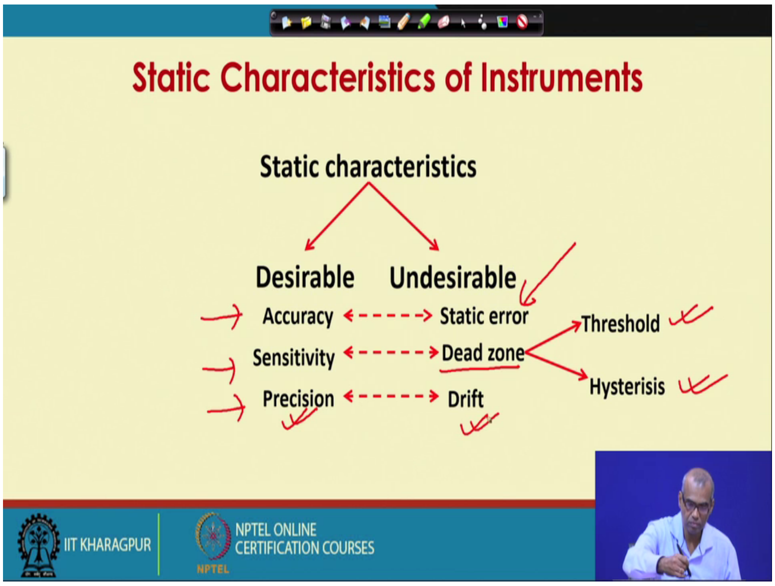

Now, there are certain static characteristics which are desirable that means, we want them to have in our instrument systems and there are static characteristics which are undesirable. So, we do not want them or we want to have them present in as minimum as possible. So, broadly static characteristics can be divided into two categories; a set of desirable characteristics and a set of undesirable characteristics.

So, these are examples; accuracy, sensitivity and precision these are all desirable static characteristics. So, it is obvious that we want our instrument to be accurate, to be sensitive and to be precise. Now, corresponding to accuracy there is an undesirable static characteristic known as static error. So, if the accuracy is high for an instrument the static error has to be low. Similarly, corresponding to sensitivity there is undesirable static characteristics known as dead zone. So, if there is dead zone present in an instrument the sensitivity of the instrument will be low. Dead zone can be divided into two groups; threshold and hysteresis. Similarly, precision is a desirable static characteristics and the corresponding undesirable characteristic is drift. So, if there is drift in instrument the instrument has lost some amount of precision.

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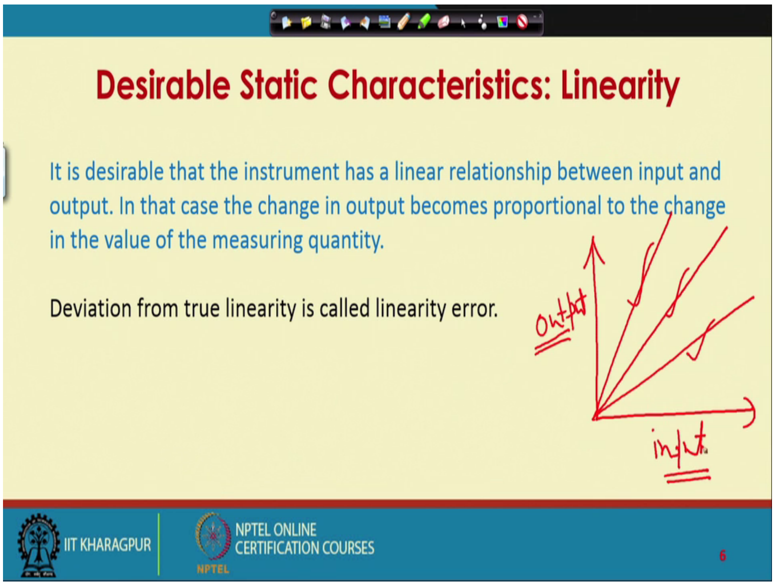

Now, let us talk about another desirable static characteristic known as linearity. A corresponding undesirable static characteristic may be non-linearity. It is desirable that the instrument has a linear relationship between input and output. So, what we mean is, if I have a plot between input or the values of the measuring quantity and correspondingly the output reading from the instrument, if I get a straight line as the relationship between input and output whether these or whether these does not matter, but if I have a linear relationship between input and output then we say that the instrument is linear. In that case, the change in output becomes proportional to the change in the value of the measuring quantity.

So, interpolation extrapolations become much easier. Deviation from true linearity is called linearity error.

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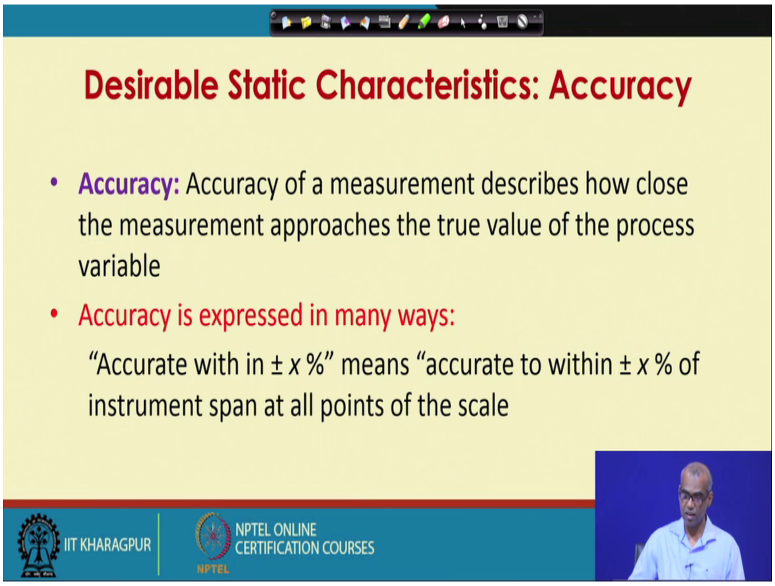

Next, talk about desirable static characteristics accuracy. So, how do we define accuracy? Accuracy of a measurement describes how close the measurement approaches the true value of the process variable. So, if the measured value of the measuring quantity is very close to the true value of the process variable then the accuracy of the instrument is very high. So, here we are assuming that I know the exact two value of the process variable then I can trace the accuracy of an instrument.

Accuracy is expressed in many ways accurate within plus minus x percent will mean accurate to within plus minus x percent of instrument span at all points of the scale.

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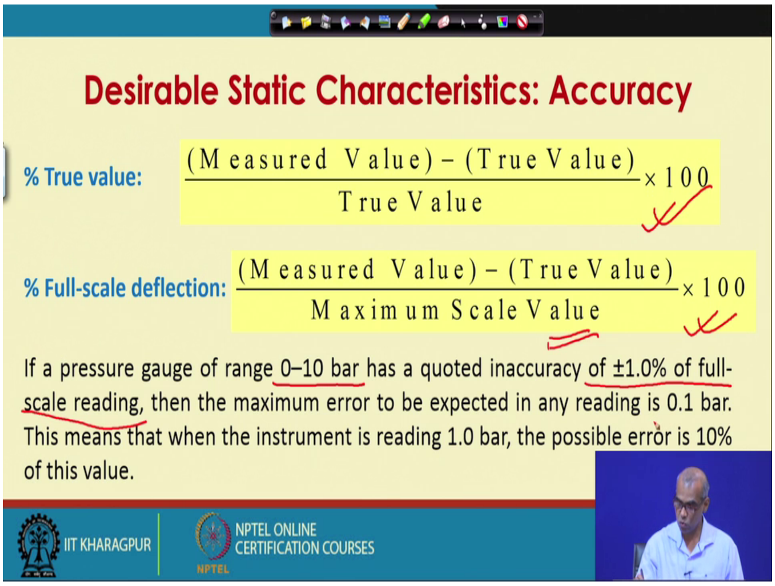

There are other definitions or other ways to express accuracy; it may be expressed as percentage true value. If we expressed as percentage true value it will be measured value minus true value divided by true value multiplied by 100. So, this is how we will express accuracy in terms of true value. Accuracy can also we expressed in terms of full scale deflection then it will be measured value minus true value divided by maximum scale value multiplied by 100.

Let us say a pressure gauge of range 0 to 10 bar, has a quoted inaccuracy of plus minus 1 percent of full scale reading. So, I have a pressure gauge whose range is 0 to 10 bar. So, I can measure up to 10 bar of pressure. The manufacturer has quoted an inaccuracy of plus minus 1 percent of full scale reading then the maximum error to be expected in any reading is 0.1 bar. Why? This is 1 percent of 10 bar; this means, that when the instrument is reading 1 bar the possible error is 10 percent of this value.

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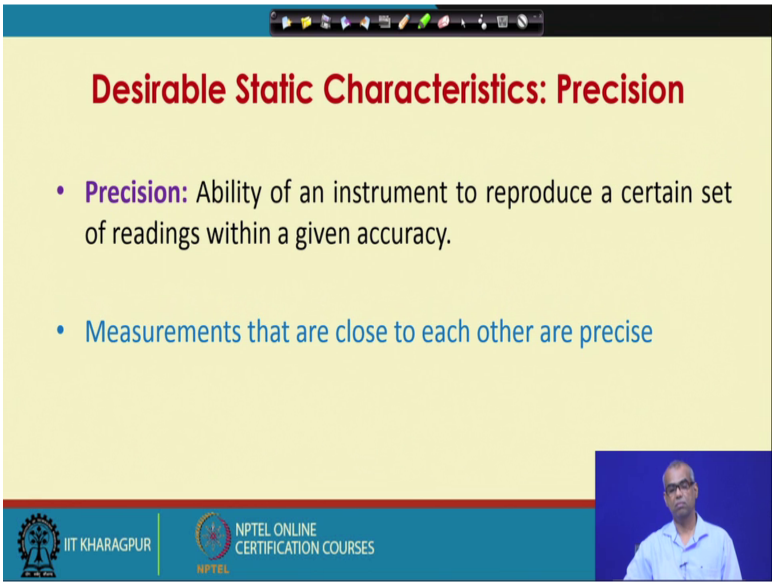

Next, we talk about another desirable static characteristics precision. Precision is the ability of an instrument to reproduce a certain set of readings within a given accuracy. So, precision is the ability of an instrument to reproduce a certain set of readings within a given accuracy. So, within a given accuracy, how close several readings of the same measurement agrees with each other. So, measurements that are close to each other are precise.

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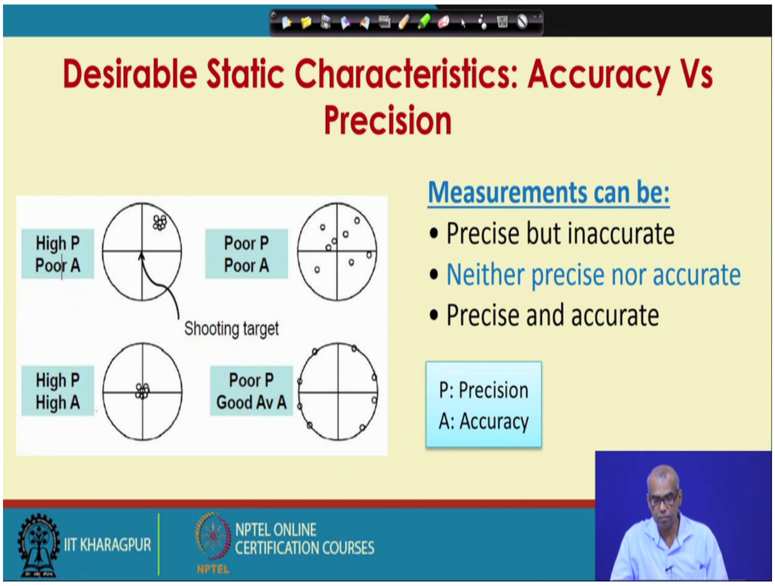

Let us consider an example to understand the difference between accuracy and precision. So, once again we defined accuracy as the closeness of the measured value with the true value whereas, precision is the agreement among the measurement themselves. Now, let us consider that you are doing a shooting exercise. So, you have given some bullets and you have been asked to hit this target. So, you do four sets of exercise.

In the first, you have hit all the bullets here. So, you have missed your target all the time, but, you have hit here all the time; that means, there is agreement among this. This may be away from the target. So, what it means is this is a case of high precision, but poor accuracy, because you have never been able to hit the target exactly. You have always hit away from target. So, accuracy is low, but every time you have hit around the same place, so, precision is very high. So, here accuracy is poor, precision is high. So, high precision does not guarantee high accuracy.

So, let us now look at second set of exercise. So, here what you do is you have hit like here here all scattered throughout. So, you neither have high accuracy nor have high precision. So, it is a case of poor accuracy and poor precision. I am representing P as precision here, A as accuracy here. Let us look at this exercise; you have actually not hit in a scattered manner, you have hit around it on the periphery of this circle. But, there is no agreement between this individual hits, but they are all lying within a radius of a circle, it is here. So, some kind of average accuracy is there, but poor precision.

Finally, this is a case where you have always been able to hit the target. So, we have high accuracy as well as high precision. So, what it shows is that measurement can be precise, but inaccurate, measurement can be neither precise nor accurate, and measurement can be precise as accurate as well.

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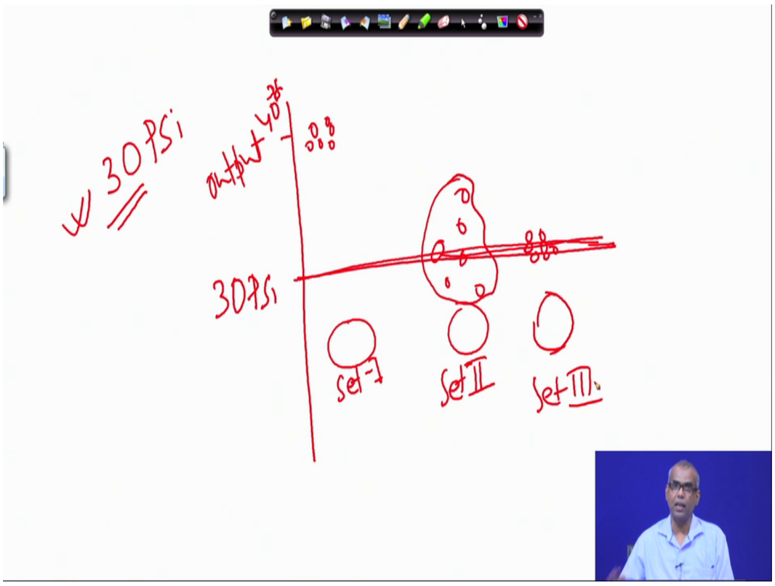

We can also show this by let us say taking another example. let us say I have a pressure gauge and I am measuring a known pressure. let us say I have a 30 psi known pressure source and I have a pressure gauge I am using this pressure gauge to measure this 30 psi psi and I measure it several times. So, ideally I should always get 30 psi pressure.

Let's say this is my output scale and here see each instance of measurements. So, let us say this is 30 psi line. So, I may I performance for set experiments, what it means is I take the pressure gauge and see I measure 6 times this 30 psi pressure. Every time let us say I get here. So, this maybe let us say, 40 psi or 50 psi. So, instrument every time indicating 40 psi, so, its accuracy is low, but precision is high.

Another set of exercise again I measure the same 30 psi pressure with the same pressure gauge with let us say another pressure gauge 6 times and now, let us say I get something like this. So, kind of average accuracy is there, but there is not much agreement among the reading. So, ok type average accuracy or good average accuracy, but precision is low. If I have all the readings here in another set of exercise the pressure gauge is accurate as well as precise. So, high precision does not guarantee high accuracy and measurements can be precise as well as accurate measurement can be precise, but inaccurate.

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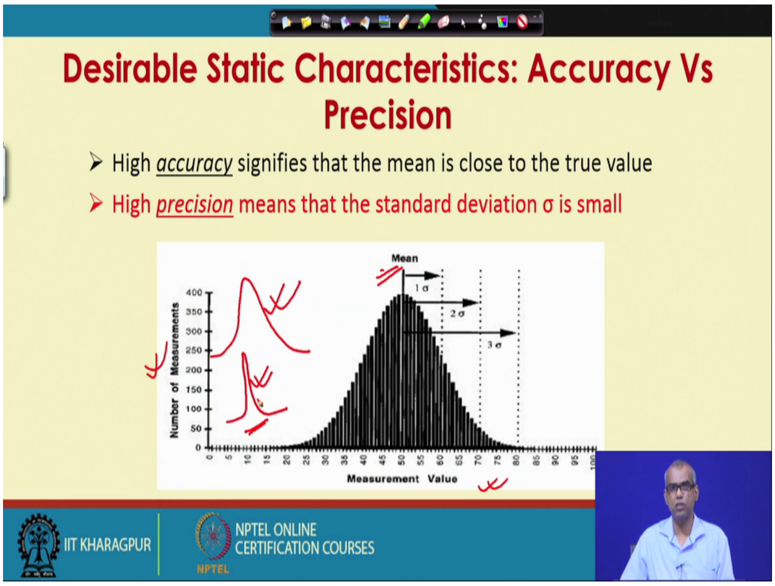

So, high accuracy signifies that the mean is close to the true value. What I mean is, say again I am measuring a known pressure several times using a pressure gauge and, I make a plot of number of measurement versus the measured value. So, I get a distribution. So, I get a distribution like this and this is the mean of the distribution if the mean of the distribution is close to the true value, it signifies that the instruments accuracy is high.

In if the precision of the instrument is low; the spread of the distribution will be less. So, distributions like this and a distribution like this if you compare the precision here is much more than the precision here because the spread of the distribution is low here. So, high accuracy signifies that the mean of the distribution is close to the true value and high precision means is means the spread of the distribution is low or the standard deviation is low. If standard deviation is high it means as the spread of the distribution is high.

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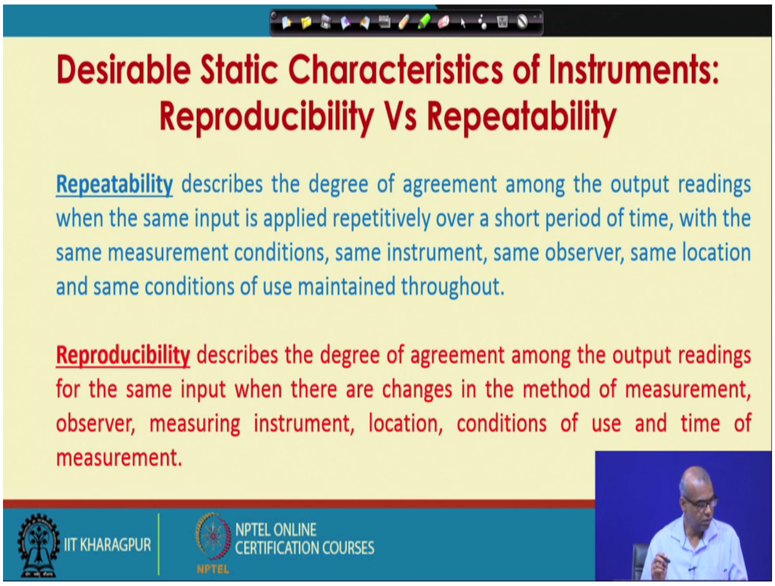

Let us talk about another two terms closely related; reproducibility and repeatability. There is a difference between these two terms and let us try to understand this. Repeatability describes the degree of agreement among the output readings when the same input is applied repetitively over a short period of time within the same measurement conditions, same instrument, same observer, same location and same conditions of use maintained throughout. Whereas, reproducibility describes the degree of agreement among the output readings for the same input when there are changes in the method of measurement, observer, measuring instrument, location, conditions of use and time of measurement.

So, repeatability describes the degree of agreement among the output readings when the same input is applied again and again over a short period of time and the same measurement condition, same instrument, same observer, same location, same conditions of use being maintained throughout, whereas, reproducibility describes the degree of agreement among the output readings for the same input when there are changes in the method of measurement observer measuring instrument location conditions of use and time of measurement.

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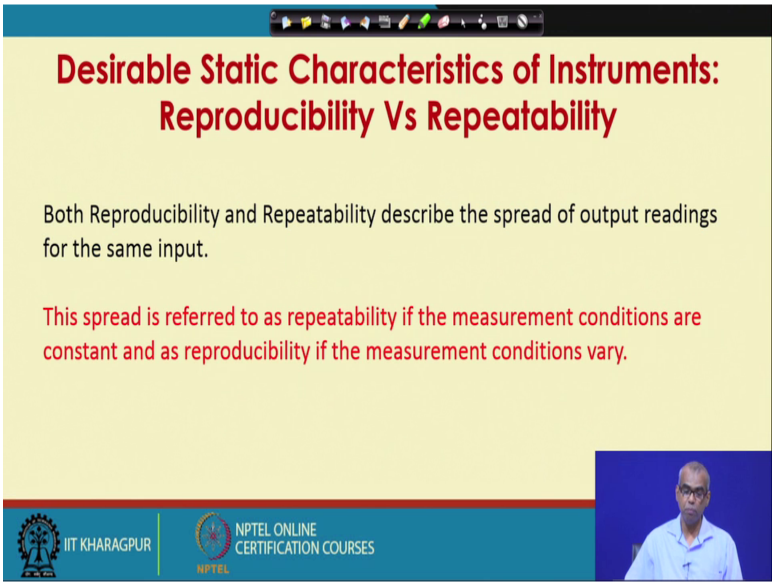

So, both reproducibility and repeatability describe the spread of output readings for the same input, because it describes degree of agreement among readings. Both describe degree of agreement among readings. So, if there is good agreement among readings there will be low spread of distribution. If there is not good agreement among the output readings the spread of the distribution will be large.

So, both reproducibility and repeatability is a measure of spread of output readings for the same input. This spread is referred as repeatability if the measurement conditions are constant and this spread is referred to as reproducibility if the measurement conditions vary. So, this is the difference between reproducibility and repeatability. Repeatability your all the conditions remain constant, in case of reproducibility here the conditions vary. But, both indicate the agreement among the output readings.

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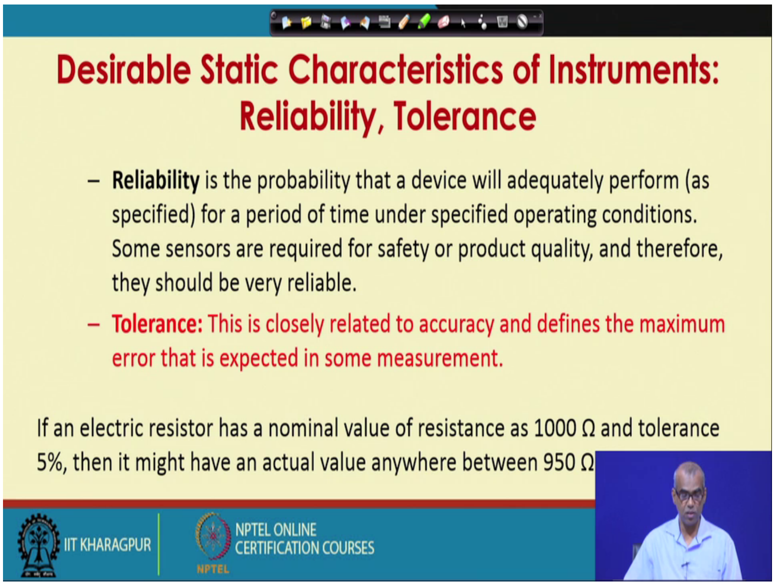

Let us talk about another set of desirable static characteristics, reliability and tolerance. Reliability is the probability that a device will adequately perform as specified for a period of time under specified operating conditions. Some sensors are required for safety or product quality and therefore, they should be very reliable. Tolerance, this is closely related to accuracy and defines the maximum error that is expected in some measurement.

If an electric register has a nominal value of resistance as 1000 ohm and tolerance 5 percent, then it might have an actual value anywhere between 950 ohm and 1050 ohm. Why? It is 5 percent of 1000 is 50. So, the actual value may be anywhere between 1000 ohm plus minus 50 ohm, which means it may be anywhere between 950 ohm and 1050 ohm.

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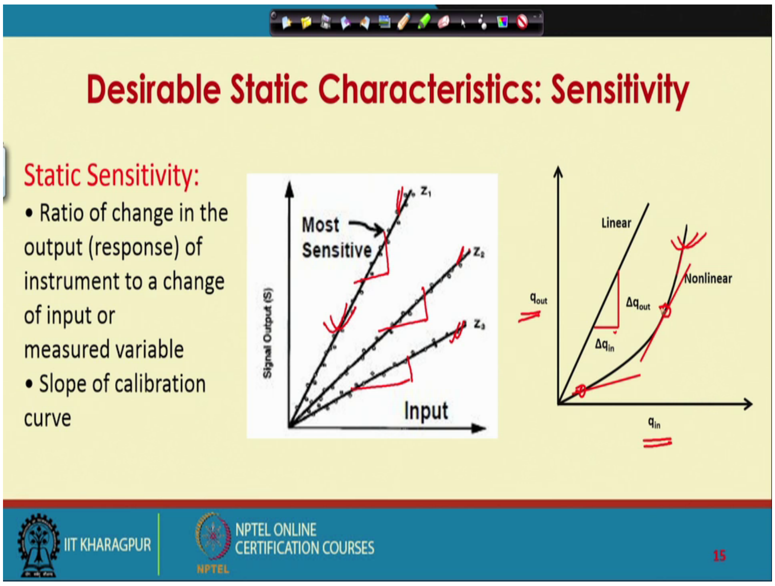

Let us talk about of desirable static characteristics sensitivity. Sensitivity is the ratio of change in the output of the instrument to a change of input or measured variable. So, it is change of output divided by change of input. So, how much output changes by unit change in input, so, that is a measure of sensitivity. So, basically, this is indicated by the slope of calibration curve. So, if the calibration curve is linear. So, this slope will indicate the sensitivity.

So, let us say this is for one instrument, this is for another instrument, this is for another instrument. So, this is calibration curve for one instrument, this is for second instrument, this is for third instrument. The slope here is maximum, so, the sensitivity of this instrument is maximum. This is most sensitive instrument. So, for a linear instrument you can easily indicate by this slope anywhere on the calibration curve because it is linear instrument, so, slope remains constant.

But, if the instrument is non-linear; for example, here it is a example of non-linear calibration curve, non-linear relationship between input and output. So, the slope varies from one point to another. So, sensitivity is different here and here. So, this is also one reason why we prefer linear instruments.

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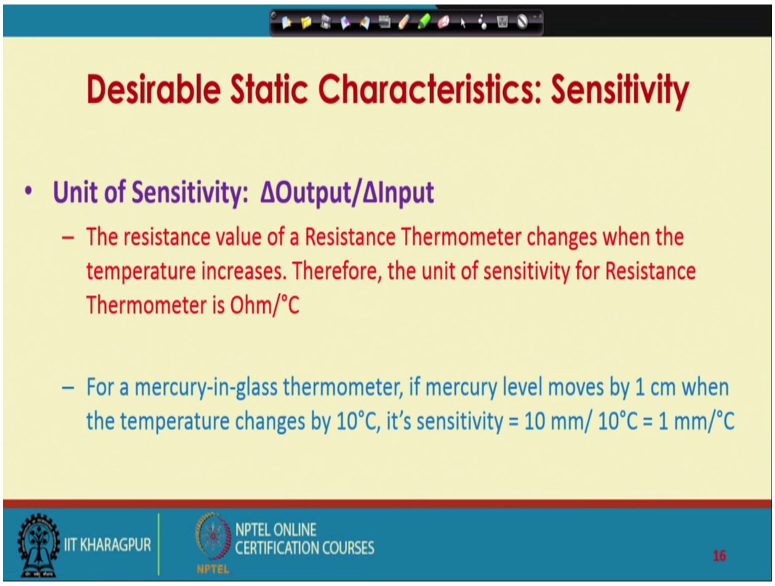

So, what will be the unit of sensitivity? So, this is delta output by delta input accordingly the unit is fixed. The resistance value of a resistance thermometer changes when the temperature increases therefore, the unit of sensitivity for resistance thermometer is ohm per degree Celsius. For a mercury-in-glass thermometer, if the mercury level moves by 1 centimeter when the temperature changes by 10 degree Celsius, its sensitivity is 1 centimeter by 10 degree Celsius which is equal to 10 millimeter by 10 degree Celsius which is equal to 1 millimeter per degree Celsius.

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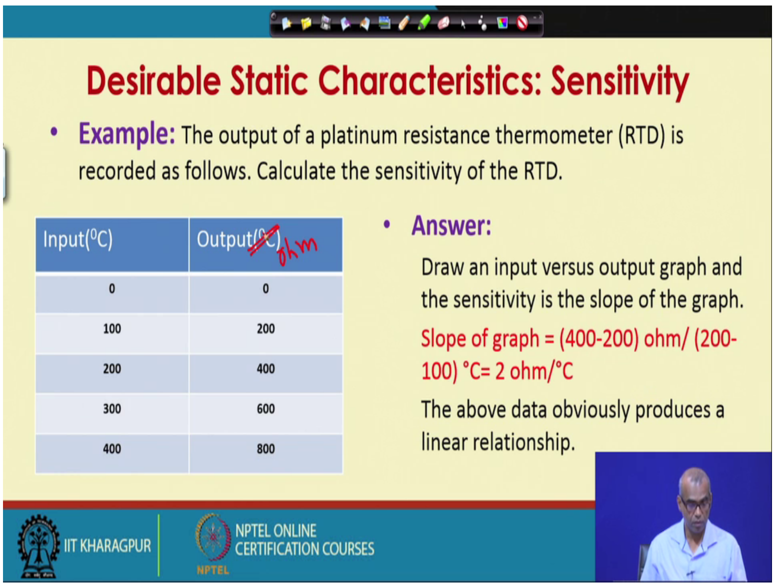

Let us consider this is the output of a platinum resistance thermometer. So, these are the inputs which are temperatures and this is the output. Let us say which is also calibrated in terms of temperature or we can also say that the input to the resistance thermometer, its temperature its output will be let us say here we have it is the output of the resistance thermometer. So, instead of considering at degree Celsius, let us consider the actual output of the resistance thermometer which is the changes in resistance.

So, you can obviously, see that there is a linear relationship between these two. So, when the input there is 0 degree Celsius, there means no temperature input the output, we call it as ohm. So, actual output of the resistance temperature device takes it as ohms not degree Celsius. So, there is a typing error here, when input is 100 degree Celsius, we have 200 ohm as output of the resistance thermometer and so on and so forth.

So, if we make a plot between these and these it is obvious that you are going to get a straight line. So, make a plot between these as input and these is output and the slope of the graph will give you the sensitivity of the resistance temperature device. You can also calculate the slope easily as 2 ohm per degree Celsius.

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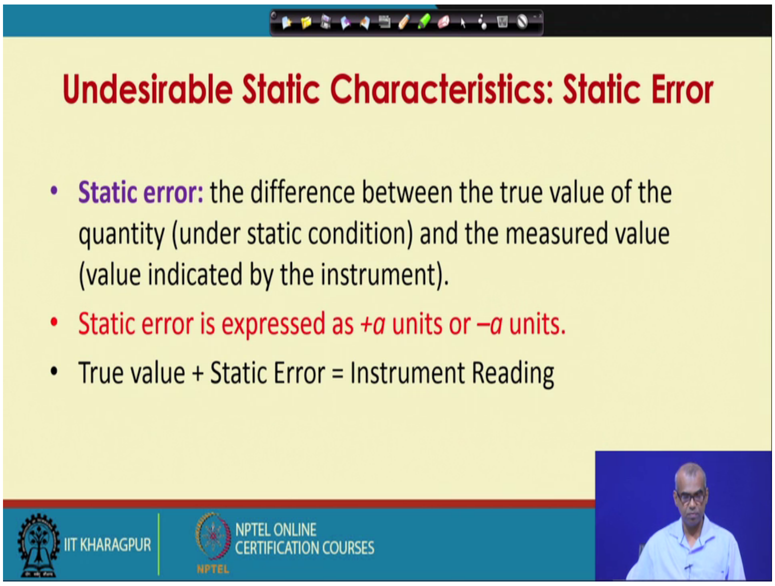

Let us now talk about some undesirable static characteristics; first static error: the difference between the true value of the quantity under static conditions and the measured value that is value indicated by the instrument. So, static error is the difference between the true value and the measured value by the instrument. So, static error is expressed as plus a units or minus a units. So, true value plus static error is actually instruments reading.

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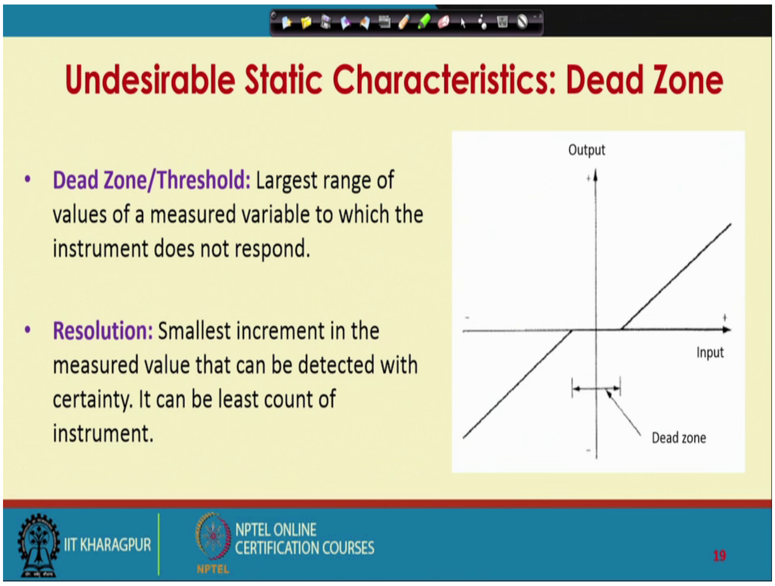

Dead zone is an undesirable static characteristic. Is the largest range of values of a measured variable to which the instrument does not respond. See the instrument does not respond here. So, you have input x is here you have output x is here. So, if we go on increasing the input value up to this, there is no output. From here, the output of the instrument changes linearly with the change in input. Same thing here, in this range there is no output from the instrument. So, this is dead zone.

So, dead zone is the largest range of values of a measured variable to which the instrument does not respond. This is also known as threshold.

Resolution is the smallest increment in the measured value that can be detected with certainty. It can be least count of instrument.

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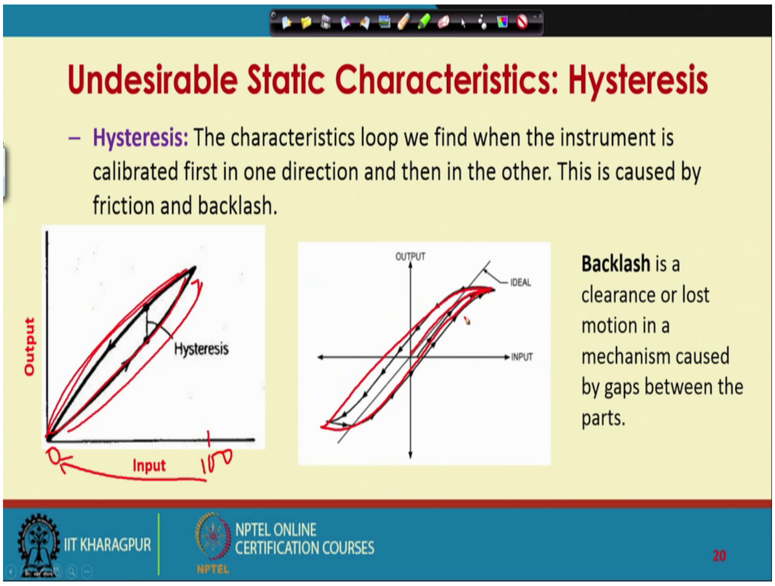

Hysteresis is another undesirable static characteristic. So, this is the characteristic loop we find when the instrument is calibrated first in one direction and then in the other. This is caused by friction and backlash. Backlash is the clearance or lost motion in a mechanism caused by gas between the parts.

So, let us consider again a pressure gauge. So, I am taking a pressure gauge and I am say increasingly changing the pressure show, I am putting an higher and higher pressures. Let us say I am changing the input from 0 psi pressure to 100 psi pressure and I see that I go in this direction. Now, when I decrease the pressure from 100 to 0 degree Celsius 100 psi to 0 psi, I first increase the pressure from 0 psi to 100 psi. Each time I record the output of the reading, make a plot, then I come back from 100 psi to 0 psi I see that I do not come back along this line, but I may come along this line.

So, the characteristic loop that is formed is known as hysteresis. The same thing here, I go on say increasing the value then come back and again then finally, come back like this. So, this characteristic loop which is the non coincidence between the output of the instrument when you are increasing the input values from low end to high end and from and when you are going back from high end to low end. So, the non coincidence between these two signals or two to these two output readings will form a characteristic loop and this is known as hysteresis.

So, this is an undesirable static characteristic.

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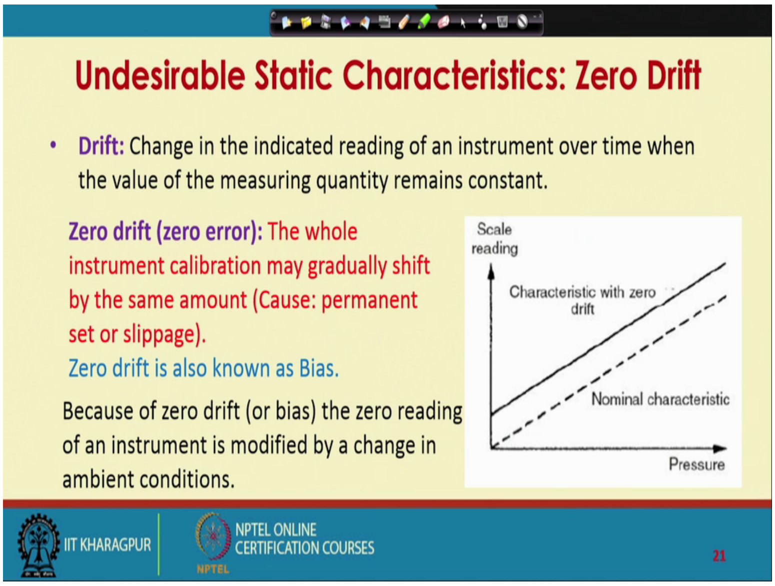

Zero drift is another undesirable static characteristic. You have discussed previously that if drift is more than instrument cannot be very precise. So, drift is the change in the indicated reading of an instrument over time when the value of the measuring quantity remains constant. So, this is the change in the indicated reading of an instrument over time when the value of the measuring quantity remains constant.

There are different types of drifts; zero drift, span drift and a combination of zero drift and span drift. Zero drift or zero error is as follows: the whole instrument calibration may gradually shift by the same amount. This is caused by permanent set or slippage. Zero drift is also known as bias. So, let us say this is the nominal characteristics that mean, this is the calibration curve when the instrument didn't have any zero error.

Now, you see that the current calibration, let us say it is parallel to this, but there is this zero error; that means, when there is no input to the instrument there is an output. So, let us say this is a calibration curve for pressure gauge. So, when there is zero pressure the pressure gauge shows some non zero reading or non zero output, indicating some pressure, but there is no pressure this is because of zero error.

So, the whole instrument calibration has gradually shifted by same amount. So, this is caused by permanent set or slippage zero drift is also known as bias. Because of zero drift or bias the zero reading of an instrument is modified by change in ambient condition.

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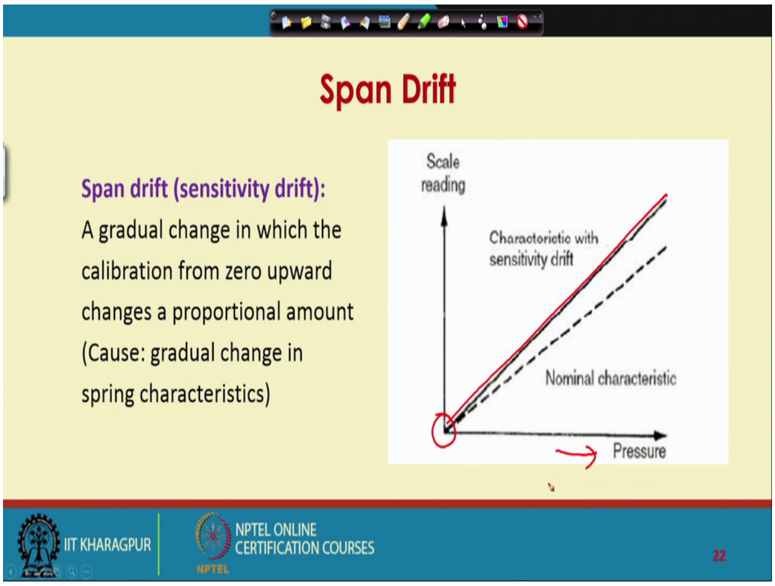

The span drift: a gradual change in which the calibration from zero upward changes a proportional amount. It is caused by gradual change in spring characteristics. Let us consider the same pressure gauge; here there is no zero error. Here, there is no zero error, but see the calibration has gradually changed as we go on increasing the pressure.

So, the calibration from zero upward has changed by a proportional amount. So, this was the nominal characteristics or original calibration when there was no span drift and this is the calibration in presence of span drift, there is no zero error, but the calibration has moved now.

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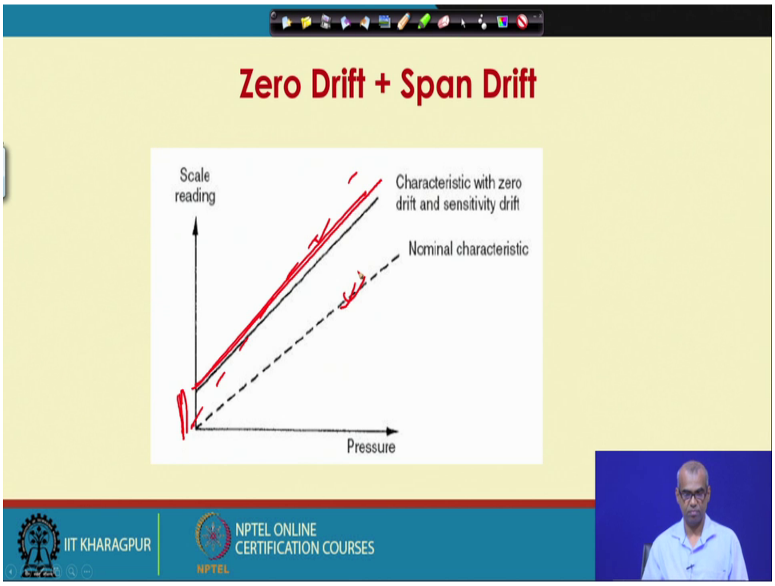

A combination of these two zero error as well as span drift can also be present an instrument and we call this a combination of drift and span drift.

Please note that, if it is only zero drift, then this current calibration will be parallel with the original collaboration without any zero error. If there is only span thrift then there would not be any zero error. So, the new calibration curve will start. So, the current calibration curve will start from here, but then that will not be parallel to this. It would have been something like this. So, combination of this two is this. So, there is a zero error as well as this one is not parallel to this.

So, we will stop here and in the next lecture, we will talk about dynamic characteristics of the instruments.