Automation in Manufacturing
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Week - 03
Selection and fabrication
Lecture – 02
Terms related to performance of electro-mechanical systems

Hello everyone, I welcome you all to the course on Automation in Manufacturing. We are starting the lecture 2 of week 3. In week 3, we are studying the Selection and fabrication techniques that are required to develop an automated system. In this lecture, we will be studying various terms related to the performance of a typical electromechanical system. Electromechanical system in general will be considered; but in particular, the terms related to the sensor technology are discussed.

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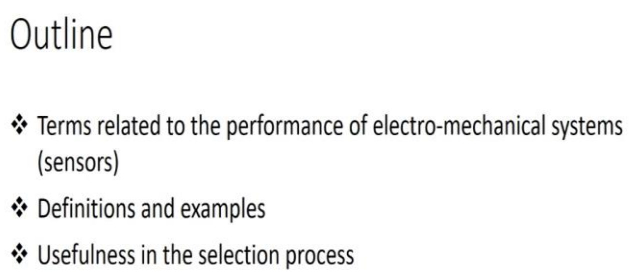

The outline of this lecture is as follows. We will be studying the terms related to the performance. We will learn the definitions and look at various examples related to these terms. At the end, we will discuss the usefulness of all these terms in the selection of the variety of electromechanical systems.

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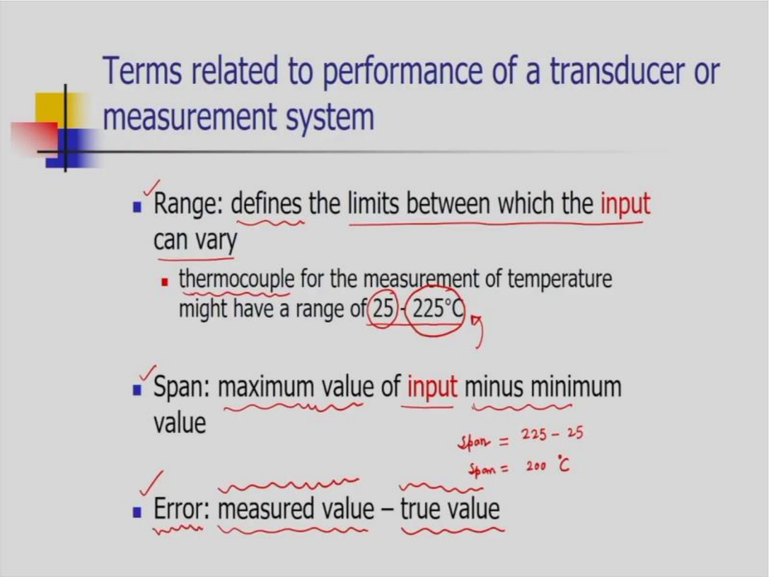

We are dealing with many sensors in our applications domain. But when we try to procure them or when we try to purchase them, we have to look at their characteristics; we have to choose or select a particular sensor or a transducer for our application. So, during this selection process, we have to look at certain characteristics of these sensors. These performance characteristics of the sensors or the terms related to the performance of the sensors or transducers that we will see one by one.

The first term is range. Range is defining the limits between the input that can vary by that sensor. If a thermocouple is considered, which is used to measure the temperature and when we say that the range of the thermocouple is from 25 to 225°C, it means that, the minimum amount of temperature that sensor can measure is 25 °C and the maximum amount of temperature that sensor can sense is 225 °C. So, the range is 25 to 225, the limits between which the input can vary.

The next term is span. Span is nothing but the difference between the maximum value of input and the minimum value of the input. If we take the example of the above mentioned range, then the span of this thermocouple is its maximum input value that is 225 minus 25. So, here we can say the span is 200 °C.

The third term is the error. Error is nothing but the difference between the measured value and the true value. The sensors are designed and manufactured in laboratory and are calibrated. Based on the calibration, the true values are determined or the expected values are determined for a set of input parameters.

When the same sensors are used in the in actual practice, they may not give the exact or the desired result. The value which is measured in environment or during the application will be different than the true value or the expected value or the desired value. The difference between the measured value and true value, it is called as the error. If the sensor is giving the less error, it is more accurate.

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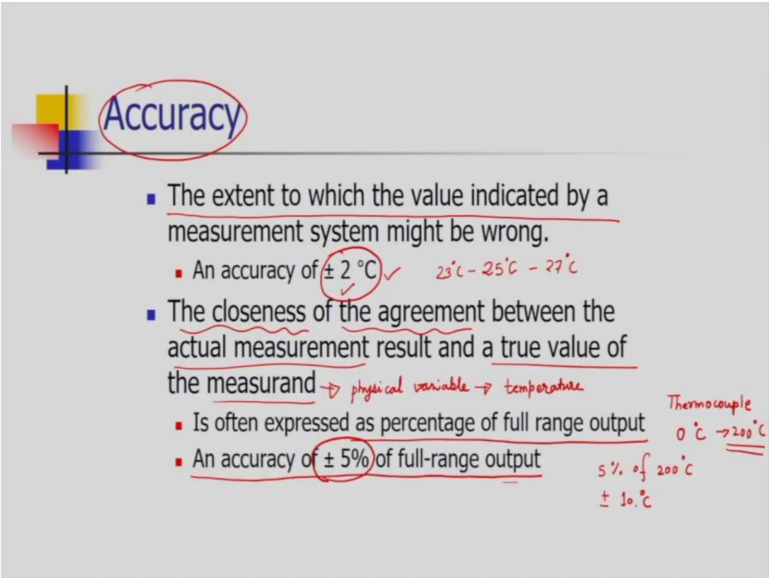

The next term of the performance of a sensor is the accuracy, which is widely used. The accuracy of a sensor can be defined as the extent to which the value may go wrong than the expected value. If it is said that the accuracy is ± 2 °C in a thermocouple, it means that if a thermocouple is giving me a temperature of say 25 °C; this 25 °C is having an accuracy of ± 2 °C.

Meaning is that these value may have an error of up to ± 2 °C. The exact value may be 27 °C or may be 23 °C. There is another definition of accuracy. The closeness of the agreement between actual measurement result and true value of the measurand. So, measurand is nothing but the physical variable. In this case, it is the temperature.

Often the accuracies are expressed as a percentage of full range output. For example, if it is expressed as an accuracy of ± 5 % of full range output. What is the meaning of that?

Let us consider an example of a thermocouple which is having a range of 0 °C to 200 °C. Here, maximum output is 200 °C. The accuracy of ±5 % of the full range output is nothing but 5 % of 200 °C. Thus, the accuracy of this thermocouple sensor is 10 °C. Whatever the values the thermocouple is sensing, it may have ± 10 °C deviation from the target value or the true value.

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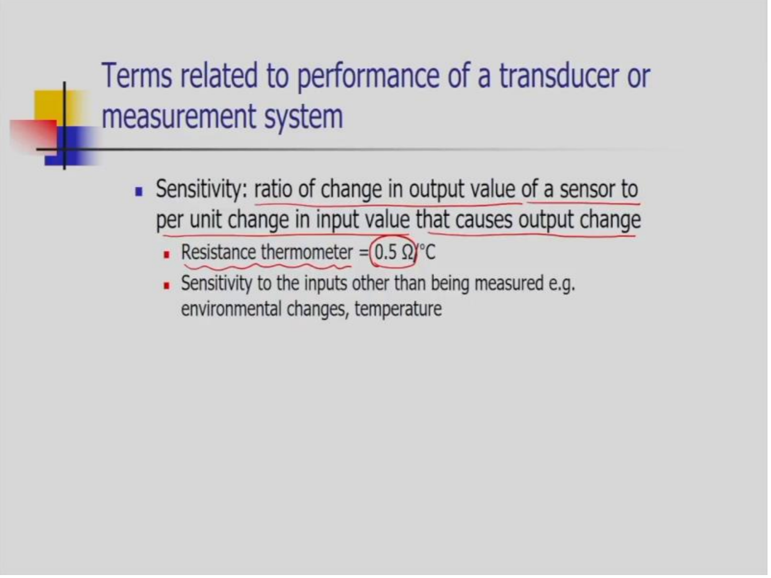

The next performance related term of a transducer is the sensitivity. It is defined as the ratio of change in output value of a sensor to per unit change in input value that causes output change. Considering the example of a resistance thermometer, if there is a change in 1 °C in the environment, then the instrument is reading or the instrument is giving an output of 0.5 ohm. That is called as the sensitivity.

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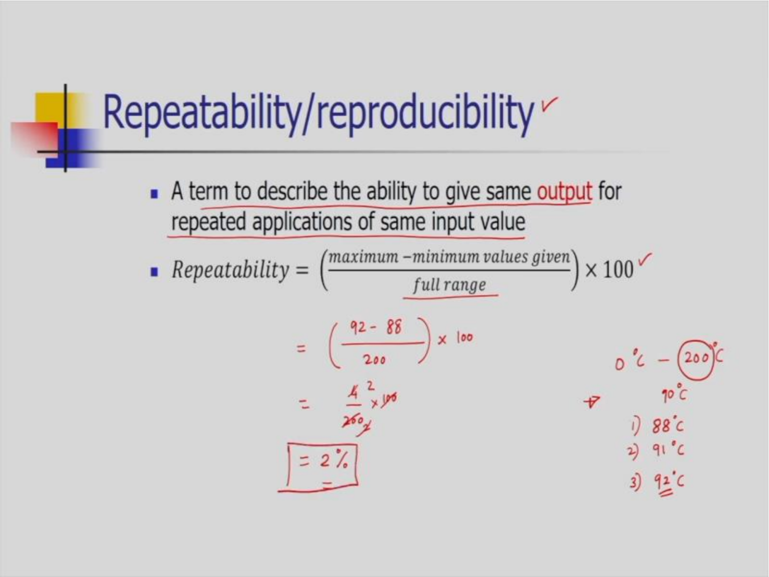

Next term or next performance related term is the repeatability or reproducibility. It is defined as the term to describe the ability to give same output for repeated applications of same input value.

When these sensors are used for multiple number of times and during these operations, it is expected that the sensor should give the same answer for the similar input that are given. But it may not be actually achieved. There may be many reasons for that.

It can be computed as:

$$Repeatability = \left(\frac{maximum - minimum\, given\, values}{full\ range} \right) \times 100$$

For a sensor whose range is 0 °C to 200 °C, let us consider the sensor is used for a operation and in that operation, the temperature to be measured is 90 °C. During the experiments it is found that the temperature in first case, it was 88 °C, second trial, it was 91 °C and the third trial, it was 92 °C. Here, the repeatability in this case can be computed as:

$$Repeatability = \left(\frac{92 - 88}{200} \right) \times 100$$

$$= 2\%$$

Thus, the repeatability is 2 %. The sensor is having repeatability of 2 % which is quite high.

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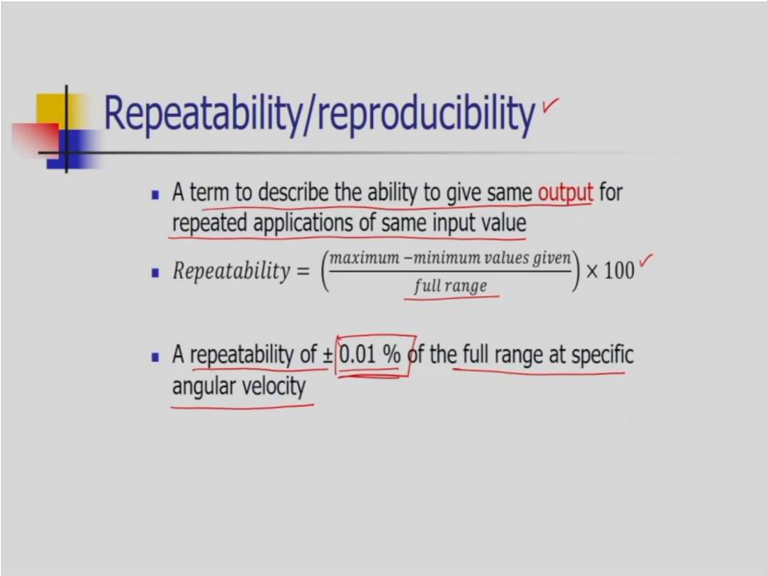

Let us consider one more example. A repeatability of ± 0.01 % of the full range at specific angular velocity. Here we can consider the repeatability is very stringent; its very high 0.01 %, the system is very accurate.

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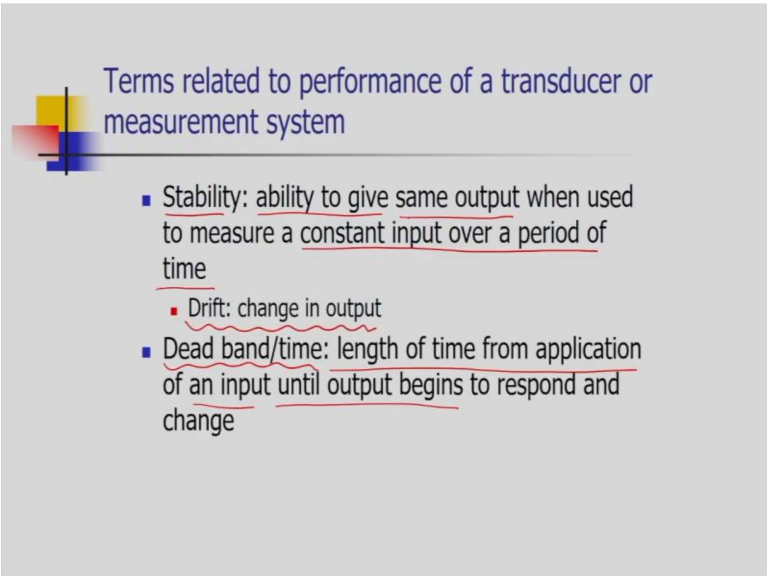

Stability is defined as the ability to give the same output when used to measure a constant input over a period of time. Let us consider an example of a furnace where the continuous heating is carried out at a constant voltage induction furnace.

We are we are applying electrical field continuously and the input is also fixed. The furnace should give a same output for a long period of time. But when that is not achieved, that system is called as the unstable systems. Although we are providing a uniform same input, but the system is providing different output. That is called as the system stability.

The change in output is measured in terms of a parameter called as drift. Although, we are giving a same input to the system, the output is not same; it is varying, it is diverting from its target or the change from its target, it is called as the drifting of the output value.

The input is applied to the system, but the system will not respond to that. To get the initial signal or the first signal from the system, some time will get consumed. That initial response time to get the first signal from the system, it is called as the dead band or dead time.

Length of the time from application of an input until the output begins to respond and change is nothing but the dead. Many times when mechanical systems are being used, to get the threshold value during the rotation; for example, in bearing, we are providing angular velocity to the shafts. But to measure that angular velocity, the system should come to a level; it should achieve the threshold value. And that threshold value, we have to compute or we have to measure angular velocity. To reach that threshold value, it will take some time. So, that time is called as the dead band or the dead time.

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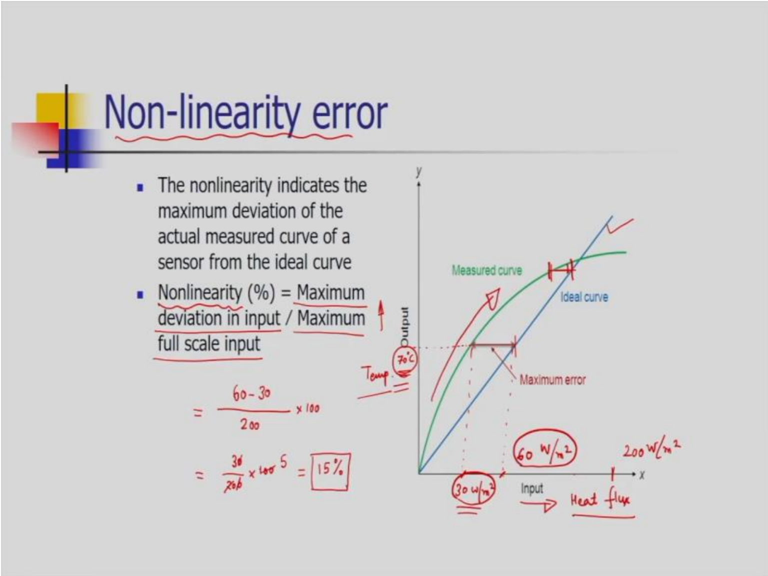

The next term is the non-linearity error. The non-linearity error indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. As mentioned earlier, the sensors are designed and manufactured in laboratories and the designers are expecting an ideal behavior from the sensor. But when these sensors are used at the shop floor in real life conditions, it is entirely different, the handling is different. There may be the setting errors which are which are borne by the human beings; there maybe environmental errors or there may be errors which are induced due to the environment or the condition in which the sensors are used. Due to that, the desired result may not be obtained; the sensor may give us the non-linearity, they it will give the different results than the exact results.

Let us take a simple example, we can take an input; say a heat flux and an output say temperature. As the heat flux is increased, there is an increase in temperature. A sensor is designed and ideally it is found that the sensor should give a linear relationship. The heat flux is having a linear relationship with the temperature.

This is the ideal curve, based on that the sensor is designed. However, in reality, when the sensor is used, we are getting a non-linear curve. There is no linear curve that we got. There is a difference in the input value for which we are getting the desired output value. Ideally, it is designed that when we apply a heat flux of say 60 W/m^2, then the output of the system is giving us a temperature say around 70 °C. But in reality, it was noted that this 70 °C was achieved when the input value was 320 W/m^2 only.

That means, the system is providing the desired output at the different input value. We are getting the desired output value at the non expected input value. The expected input value say 60 W/m^2; but for 30 itself it is giving us the 70 °C. The non-linearity error is the maximum difference between the input values which are producing the desired output value. That is nothing but the non-linearity error.

$$Nonlinearity\,(\%) = \frac{Maximum\,deviation\,in\,input}{Maximumf\;\;full\,scale\,input}$$

So, for the given example, non-linearity error is given by:

$$Nonlinearity\,(\%) = \frac{60-30}{200} \times 100$$

$$=15\%$$

So, 15 % nonlinearity is error is there of that system.

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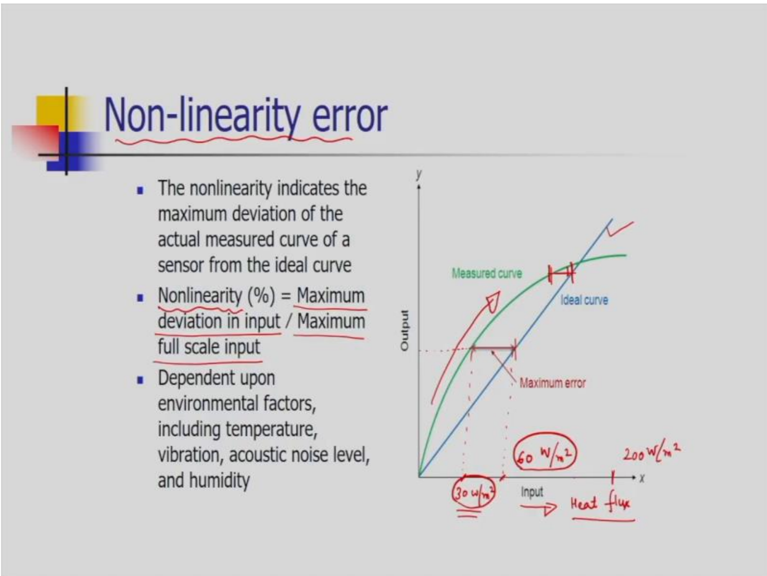

What are the reasons due to which we are getting the non-linearity error? These non-linearity errors are due to the environmental factors such as temperature, vibration, acoustic noise level and the humidity.

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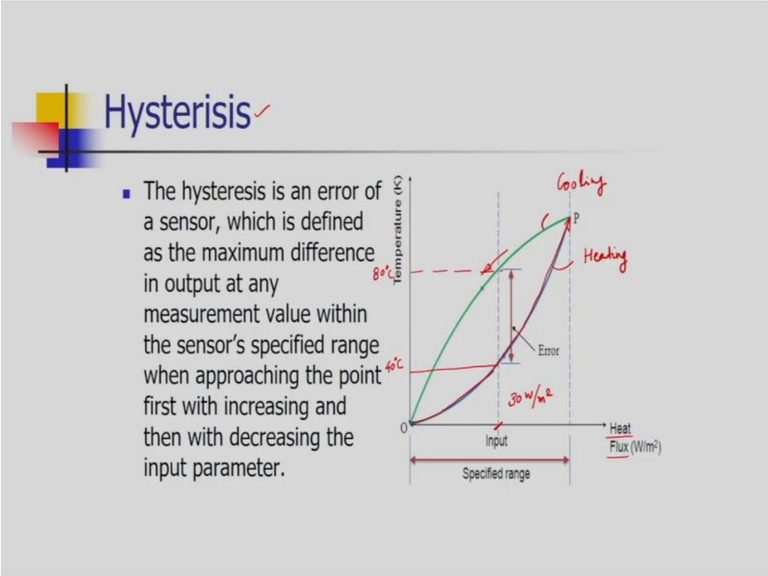

The next performance related term is hysteresis. The hysteresis is an error of a sensor which is defined as the maximum difference in output at any measured value within the sensors specified range when approaching the point first with increasing and then, with the decreasing the input parameter. We are using certain sensor for increasing trend of the field variable to measure the response when the field variable is having increasing trend.

Let us consider the temperature itself. A sensor is used to measure the increase in temperature, say from 10 °C to 80 °. When we are measuring for the increasing trend, we are getting a graph. Let us consider the previous graph, a system which is showing an increasing trend when we apply a heat flux from O to P.

But when we decrease the heat flux value, the temperature which was measured by the system is following a different pattern a different way or a different path. That path is shown by the green color over there. This unusual behavior is called as the hysteresis. Here we can see for the same input of 30 W/m^2, the temperature was measured around 40 °C. When the sensor was used in increasing trend, it was 40 °C. During heating, we achieved 40 °C for 30 W/m^2; during cooling operation, the system is showing 80 °C the error of the output for same input value. There is the difference in the output for the same input value when the paths are different; so, increasing trend and the decreasing trend. This error in the output value it is called as the hysteresis error.

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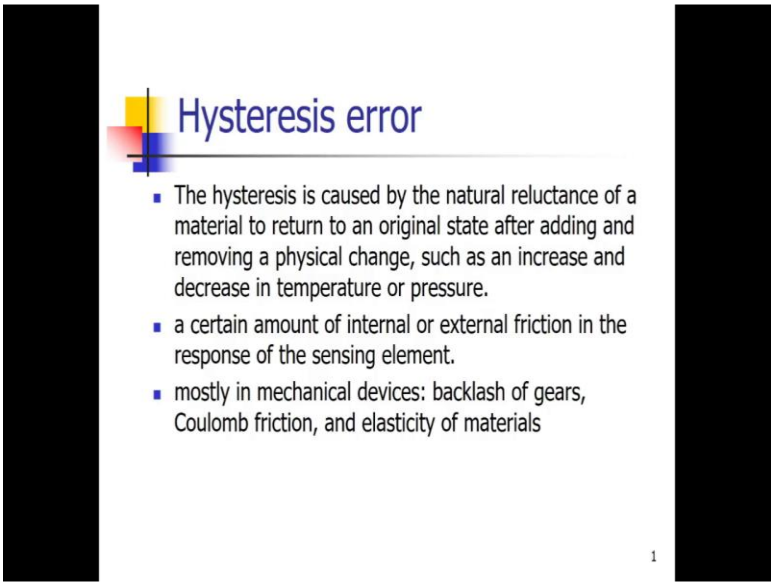

Now, let us see why this hysteresis error is generated. The cause of the hysteresis error is due to the natural reluctance of a material to return to an original state after adding or removing a physical change.

If we are adding or if we are increasing the temperature or if we are putting up a pressure or we are applying a pressure and then, we are removing or we are releasing the pressure, then it is expected that the system will respond the way in which it was responding when we are putting it up, when we are increasing the pressure. But due to its natural reluctance, we do not get it. That is called as the hysteresis.

It is the natural reluctance, natural tendency of the material that is giving this hysteresis error. In addition to this natural reluctance, a certain amount of internal and external friction is also causing the hysteresis effect in the sensors and transducers. The hysteresis mainly occurs in mechanical devices; there are certain phenomena such as backlash of gears, Coulomb friction and elasticity of materials are also contributing to the generation of hysteresis error.

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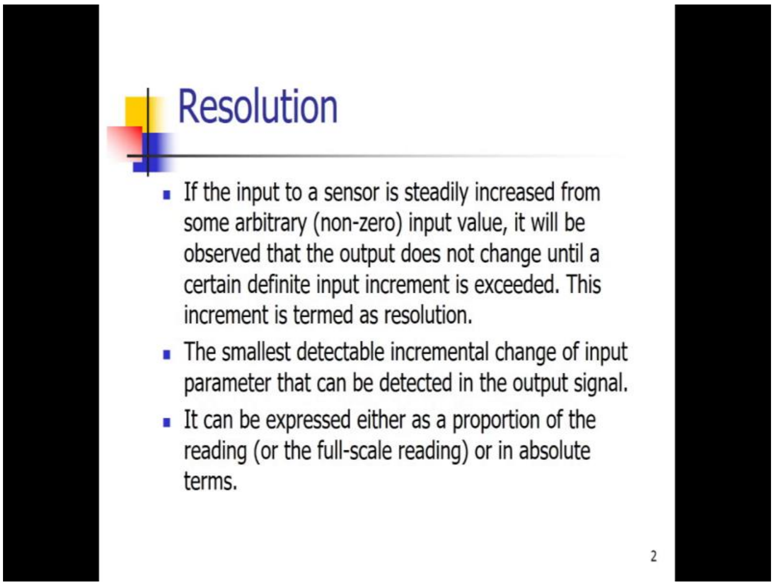

The next term associated with the performance of a sensor is the resolution. It is defined as if the input to a sensor is steadily increased from some arbitrary input value, it will be observed that the output does not change until a definite input increment is exceeded. This increment is called as the resolution.

We are applying the input steadily and when there is a change in the output is observed, the amount of input which is generating the change in the output, it is called as the resolution of the system or in other terms, we can say the smallest detectable incremental change of input parameter that can be detected in the output signal. This term resolution is also expressed either as a proportion of the reading with the full scale or in absolute terms.

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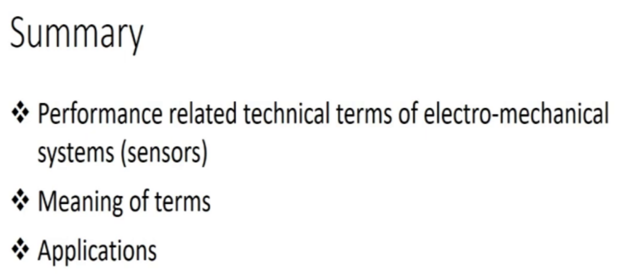

Well, my friends let us summarize the lecture. In this lecture, we have seen the various performance related technical terms of sensors, we have seen their usefulness or application in selection of the sensors or transducers for our desired purpose that is the development of automated system.

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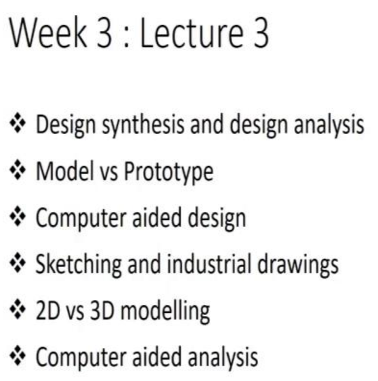

In the next lecture that is lecture 3 of week 3, we will study the design synthesis and design analysis phenomena, the difference between modeling and prototyping. We will look at comprehensively the utilization of computers in the designing of the prototypes, the difference between sketching and industrial drawings. We will also learn what is the meaning of 2-dimensional modeling and 3-dimensional geometrical modeling. At the end, we will have a short discussion on the computer aided analysis.

Thank you.