Industrial Instrumentation

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Lecture - 1
Introduction

Good morning! This is a basic course on industrial instrumentation. As you know, the instrumentation is very important subject in all process industry. As you know, in the industry like steel, petrochemicals, then fertilizers, all this type of, I mean, industry, the instrumentations is a, I mean subject which is a concern for everybody. The reason is there are various sensors in the instrumentation, excuse me and you will find that some of the sensors are ……, especially flow, temperature and all those things you have to measure, then you have to convert it in some convenient domain which can be, I mean signal processed later on and transmit those signal to the control room.

Now, ultimately you know that all these measurements and instrumentation is basically to make your product or quality of the product better. Suppose in the fertilizer plants the quality of the product should be good, urea that means the purity of the urea or in the case of steel industry, percentage of the carbon in the steel all those things are important and in every, I mean step you will find that we have to measure some parameters. What are those parameters? The parameters are pressure, temperature, flow, humidity, viscosity, pH, all those things. The reason that we have given the name of the course as industrial instrumentation instead of instrumentation is that you will see we will always focus on to some process industries. That means what type of measurements they are doing and how that measurement is converted to electrical domain, so that I can get a current of 4 to 20 milliampere and all those things.

Now, today is the first lecture, so obviously I will introduce the different components and I will cover to some extent the static characteristics of the, I will cover full the static characteristics and the dynamic characteristics I will start in the next lesson. The lesson 1, let us look at the contents.

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The lesson 1, it is basically as I told, Introduction. The contents of this lesson is getting started that means basic introduction to the system. Then, I will cover the static characteristics. Now, the static characteristics, it means that the accuracy, linearity, sensitivity, etc., are the parameters of an instrument or sensor and these attributes are collectively known as the static characteristics of an instrument and are given in the data sheet for a particular instrument.

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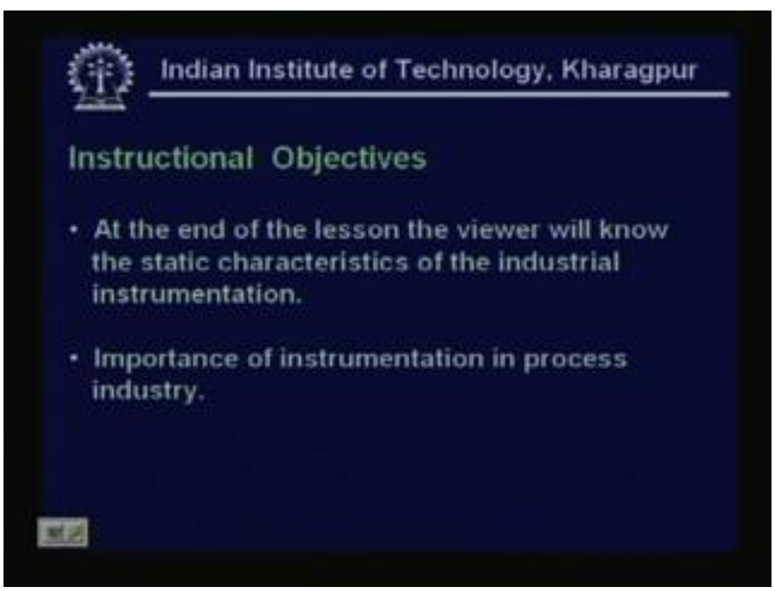

Now, at the end of this lesson, the viewer will know the static characteristics of the industrial instrumentation, the importance of instrumentation in process industry.

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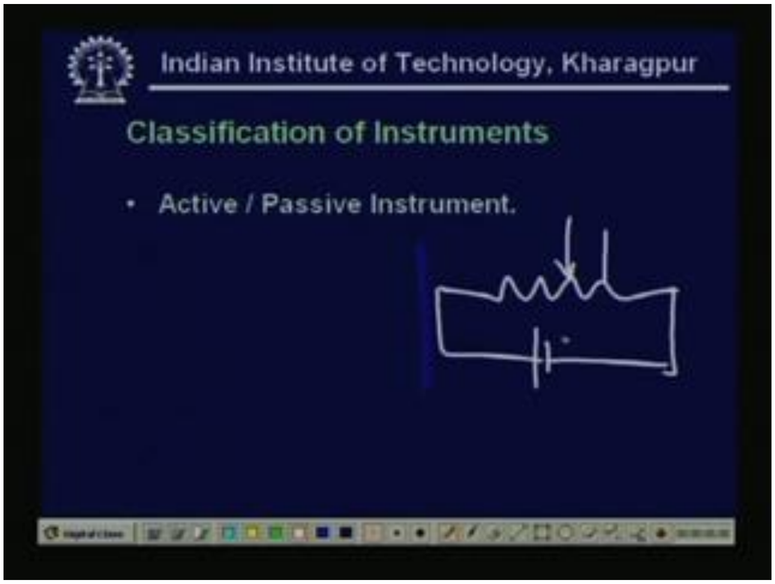

Now, classification of instruments, so they, I mean instrument can be classified in 4 different categories. I mean, it can have active and passive instruments. Then, in the case of active instruments, you know that you have displacement sensors or potentiometer. So, in the case of displacement sensor or I mean you can have in the case of active instruments that means displacement sensor, suppose I have a displacement sensor, it looks like this that I have, sorry, displacement, suppose I have a potentiometer like this and I am giving, energize it by battery and I am taking the output voltage from this one. So, this is the wiper or the jockey of your potentiometer displacement sensors and I am taking the output from these two regions. I am sorry, it should look like this.

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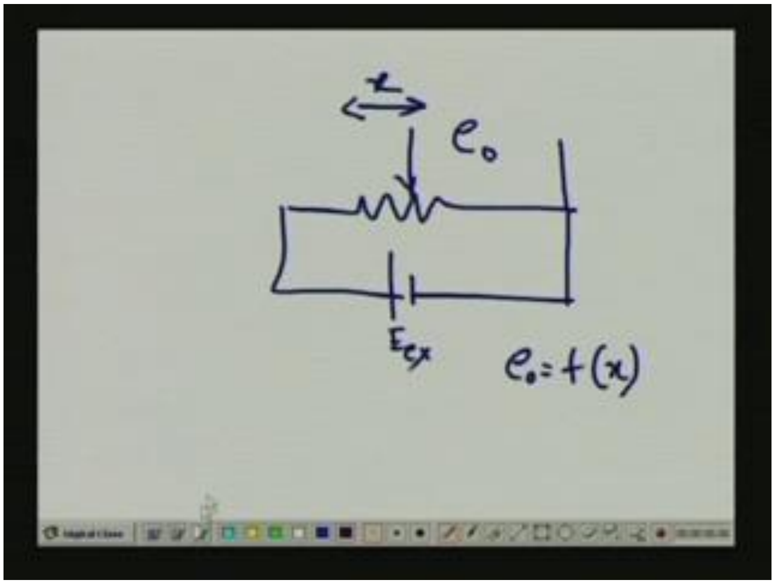

It should be, I mean, I have a displacement sensor, so I am giving a, this is our jockey and I am taking ….. So, suppose this is the voltage e naught, if it supply the ex, excitation voltage and this voltage e naught, obviously you can see that e naught if you displace it in this direction, suppose x, so, that e naught will be a function of x. If the x changes our e naught also will change. So, in this case, you can find that this is a displacement sensor and I need an excitation voltage here. If you do not give the excitation voltage, my potentiometer obviously will not work and I will not get any output voltage there. So, this type of instrument I should call it or we should call it an active instrument or active sensor.

Now, there are some sensors which are passive. Passive in the sense, suppose I have a Bourdon gauge which is used and we will discuss that later on, that Bourdon gauge you know there is a C type of tube, it looks like this.

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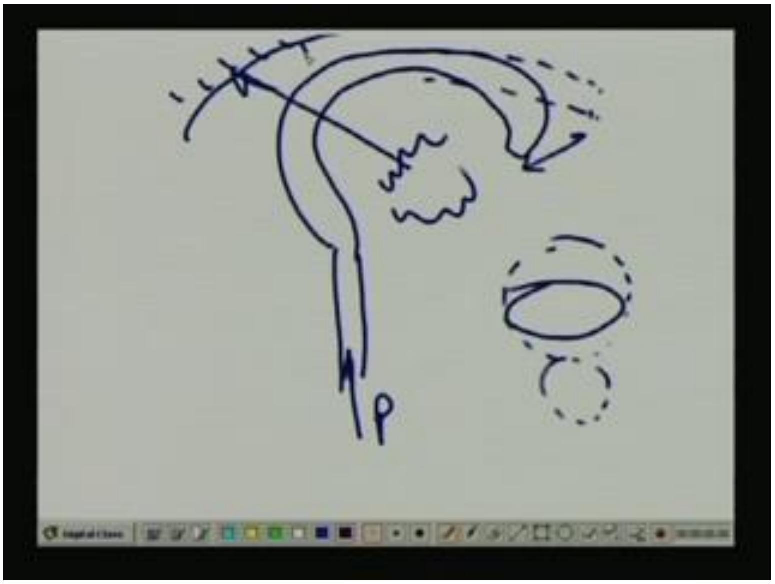

I have a C tube and the area of cross section of the tube is elliptical. Now, if you increase the pressure here, so the tube will try to make in circular form. That means it will have a circular form like this one. So, accordingly this tip of our tube will move in this direction. So, this movement of the tip, this movement of the tip can be utilized to move some pointer on the scale, so that we get some arrangements of a rack and pinion and all those things, you can find that it will move on a scale like this one. So, in this case, that it will work as an, it is a passive instrument, it is not an active instrument.

Moreover, please note that active instrument does not mean it is only electrical. Active instruments can also be pneumatic, because I have told about the active instrument which is only passive, but active instrument is also, it can be pneumatic instruments. It can have also hydraulic instrument, where there is supply, always supply. Now, force balance systems or you can flapper nozzle systems most of them are familiar, we thought we will cover this. I am sorry, you are not familiar with that right now. You will be familiar with the systems after sometime or after few lectures that you will find that this, the flapper nozzle system you need to always have a power supply. I mean it is a pneumatic supply, so without supply, the flapper nozzle systems cannot work. Similarly hydraulic systems also; I need some hydraulic, some liquids like oil or water or kerosene that type of things, so that it will be activated. So, that type of instruments are active instruments and the choice between the active and passive instruments involves carefully balancing the measurement, the resolution. These are the requirements against cost.

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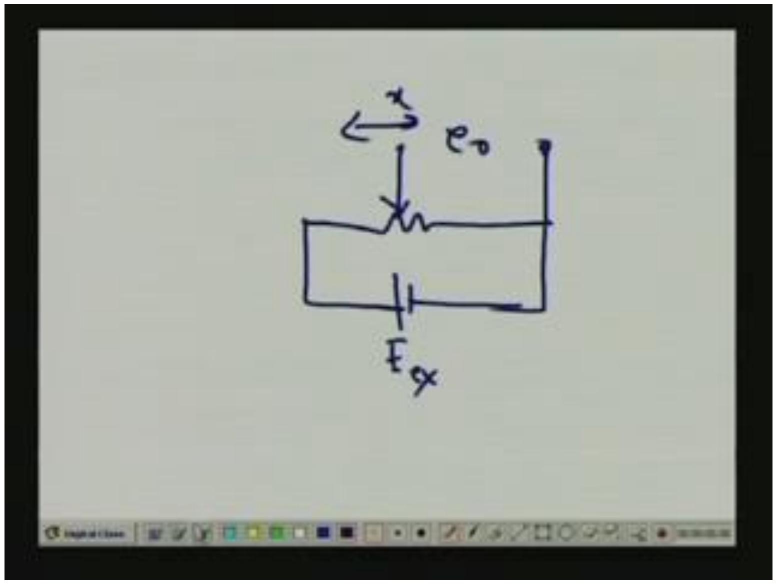

The reason you see that in the case of, I mean just let us go back to again and through this potentiometer you see that when we discussed the potentiometer we have seen that the, we have the potentiometer here, we have a power supply here and we are taking, this is our wiper which moves in this direction, x and I am getting an output voltage e naught. Now, you see that resolution of this potentiometer that is the output voltage can be made better and better, if I, suppose if I increase this supply voltage value, whereas and this is very simple. I mean you just increase the supply voltage ex, excitation voltage and the measurement resolution will increase, right; whereas in the case of the passive instrument, it is not very easy. Suppose as I told you, as I show you both the tube which is used for measurement of, I mean measurement of pressure or suppose one of the, one of the good example is mercury in glass manometers all of you are familiar with. How does it look?

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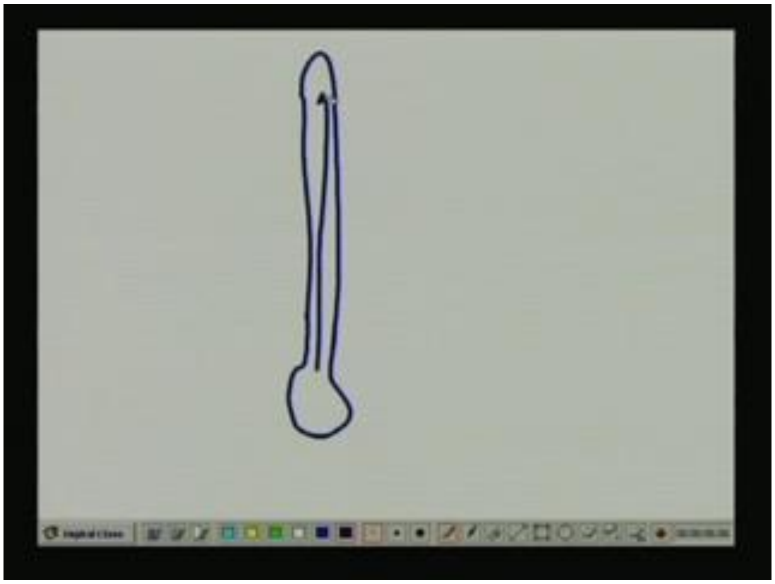

It looks like all of you have seen that we have a tube like this one and there is a mercury column bulb here. So, mercury will heat up, it will go up like this one. So, in this case, the resolution if I want to change, the resolution it is not very easy ….. I mean you have to change the entire constructions of the system. That means the capillary should be more thinner and all those things, so that you will get for a smaller and smaller measurements of temperature. But, that is not necessary in the case of, in the case of electrical instruments or suppose I have, I have some excitations or pneumatic instruments or hydraulic instrument; that we already discussed.

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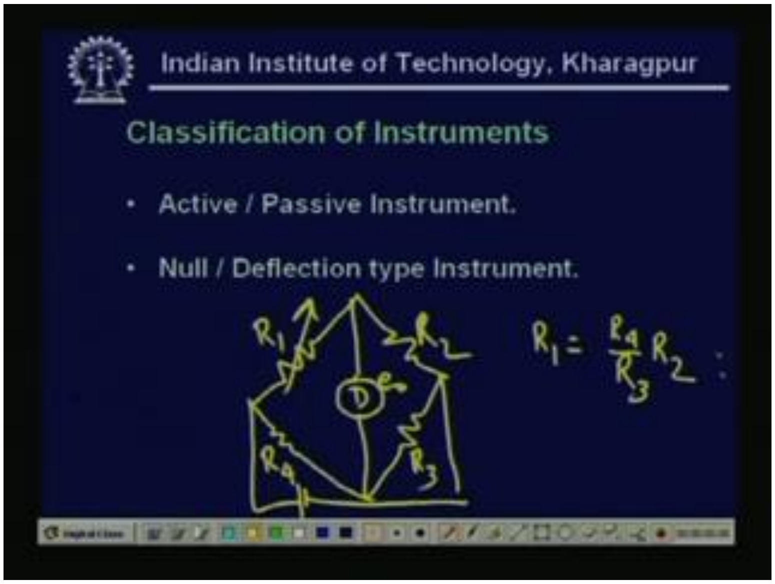

Now, there are null and deflection type of instrument. This is very important, null and deflection type of instruments. You see that if I say here how does it, what is this null deflection type? All of you are familiar with the Wheatstone bridge. How does it look? It looks like this. This is our Wheatstone bridge. I have a power supply here and I am measuring the output voltage here, e naught. Suppose this is R 1, R 2, R 3, R 4; simple, I can write that R 1 is equal to R 4 by R 3 into R 2. Isn't it? At balance I can write like this one, when there is no, I mean no current flowing through the detector, this, suppose this is the detector or voltmeter.

Now, null type means, you see that I can utilize, suppose this R 1 varies; suppose R 1 is a thermistor which is measuring some voltage, some temperatures and this obviously what will happen if the temperature rises? The value of the R 1 will fall. Now, I can utilize either R 4 or R 2 to balance the bridge. See, if I use some resistance R 4 and R 2, suppose R 2 is also varying, so in that case, it is a null type of instrument. Whereas, if I utilize this, suppose whenever there is a, this R 1 initially suppose all the bridge, all are equal, so bridge is balanced.

Now, R 1 since it is a thermistor, as the temperature rises, this resistance will fall. I will get an unbalanced voltage at the detector side. So, this voltage actually will, you can say it is, now the instrument, now our system is a deflection type of system; it is no more a null. I mean I can calibrate this output voltage. That means I calibrate this unbalanced voltage in terms of the temperature or in terms of the resistance R 1, so that is possible. So, this is the difference between null and deflection type of instrument. Sometimes we prefer to have a null type of instrument, sometimes we, I mean prefer to have a deflection type of instrument. Especially in the case of electrical circuits, when we need always some output voltage we should go for the deflection type of instrument. But, in some precisions we need a null, because always whenever if you make the bridge null, obviously it is the most accurate form of measurement.

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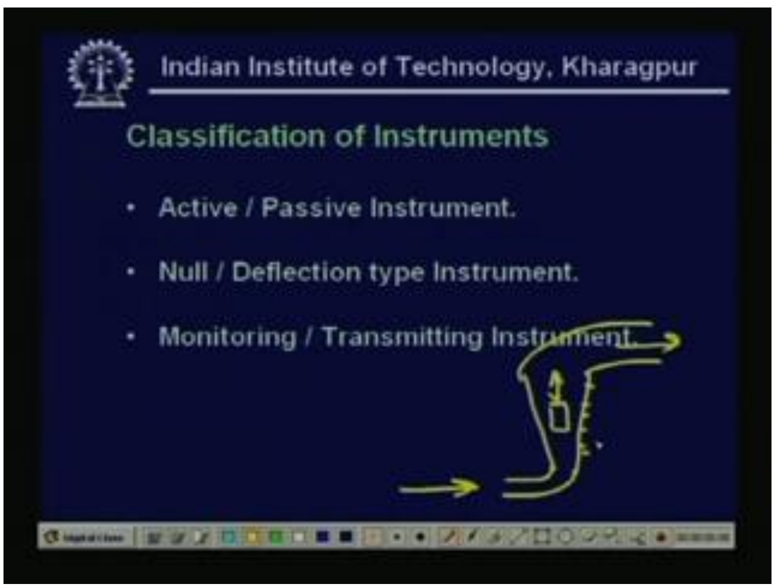

Now, monitoring and transmitting instrument, what does it mean? It means that that mercury in glass manometer, that is a good example of the monitoring instrument. Mercury in glass manometer, as you know, you have seen or suppose a flow meter, suppose a rotometer, it is the common example of the, I mean how does it look is what I will discuss in details later on. So, it has a shape like this one, a vessel and it is, there is a float or bob. So, it will go like this one. So, liquid is flowing through this and going out.

So, this liquid will move up and down, right. The liquid will move up and down and these positions of the bob, position of the bob can be calibrated in terms of the flow, right. So, this type of instrument is only monitoring instrument. You cannot say it is a transmitting instrument, right or mercury in glass manometer that is also a transmitting instrument, because you are reading only the temperature. But suppose, if I use a thermocouple there instead of, I mean instead of mercury in glass manometer if I use a thermocouple, in the case of thermocouple what will happen? You know that you can, you will get a voltage there. Whenever there is a change, difference of temperature between the two junctions of the thermocouple of dissimilar metals, you will get a voltage there. So, that voltage can be calibrated in terms of temperature.

Similarly, in the case of RTD or resistance temperature detectors, which is very accurate form of measurements of temperature you will find also there that if the temperature varies the resistance will vary. So, that change of resistance can be taken, as I have shown in last slide that can be utilized as an unbalanced voltage. So, that unbalanced voltage can be calibrated in terms of the temperature. So, this is also because that signal can be transmitted. Now, one thing you should know that in the industry that usually or you cannot transmit voltage, you have to transmit current.

Even though it is not very relevant whether it is monitoring or transmitting instruments, but I am discussing its importance. Since it is industrial instrumentation, you must know what is the practical aspects of the sensor signal conditioning circuitry. Any signal which is electrical in nature, you are not supposed to, I mean, transmit voltage. Voltage, if you transmit it will be totally corrupted by the noise, you have to transmit current. So, typical standard for industry is 4 to 20 milliampere of current that is for the total range of temperature, pressure, flow, etc. So, this is the difference between monitoring and transmitting sort of instruments.

So, all the instruments, there are some instruments which are both monitoring and transmitting. That means it has monitoring system also. It is monitoring the temperatures. Onboard you will find the, on the panel itself you will find the temperature itself. Also, it has a transmitting capability. If it is has no transmitting capability there is a transmitter which is to be utilized to convert that signal, I mean to the current domain. Transmitter is a very common form. In industry you will find that many a times we are talking about this transmitter. The function of this transmitter is to convert the signal whether it is pneumatic signal, electrical signal, hydraulic signal, to convert to 4 to 20 milliampere of electrical current. This will be converted, I mean transmitted to the control room for packing the control actions which will ultimately activate all the control valve like this one, to control flow or heater, heating to the some heating to the some heater or heating power to the heater and all those things or we can have an analog or digital instrument.

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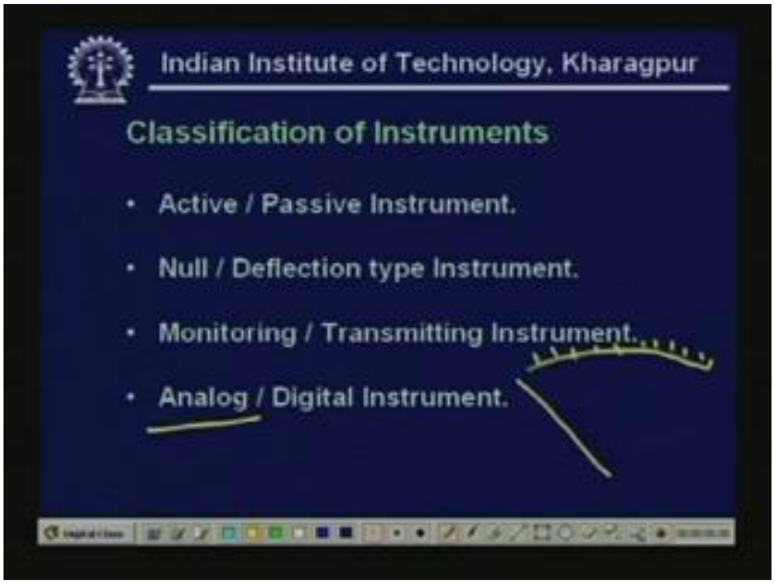

Now, in the case of analog instrument, output varies continuously. It is a, there can be infinite …. positions of the pointer. Suppose I have a simple, if I say that if I have simple voltmeter, suppose I have a voltmeter, if I take a, well I have voltmeter, so voltmeter, what will happen? The pointer will move, isn't it? I have a calibrate scale here in volts, so pointer will move. So, in case of analog instrument, when you talk of analog instrument you will find there is an infinite, infinite position of the pointer. You can have many positions, whereas in the case of digital instruments this is not the case. In the digital instrument, output varies in the discrete forms; it is not continuous. So, in that case, we will consider the digital instrument.

Sometimes when people talk about, I mean talk about suppose a revolution counter whether that is digital, I will not consider that as a digital. Digital instrument is, so far is, I mean today is concerned we talk of the digital instruments where you have some digital circuitry and the output is also digital. Suppose if you have a virtual instrumentation. This is actually I mean digital instrumentation, but you are showing that like a conventional analog meter. It is not necessary it is an analog instrument. So, in that sense I say, if the signal conditioning is there itself inside the system, instrumentation system digital in nature, we call it digital instrument, whereas in the case of analog instruments, it is analog in nature. But please note that in the analog instruments there can be analog meter, there can be many positions of the pointer on the scale, whereas in the case of digital instrument there are finite number of positions of the output. This is all about the digital and analog instrument.

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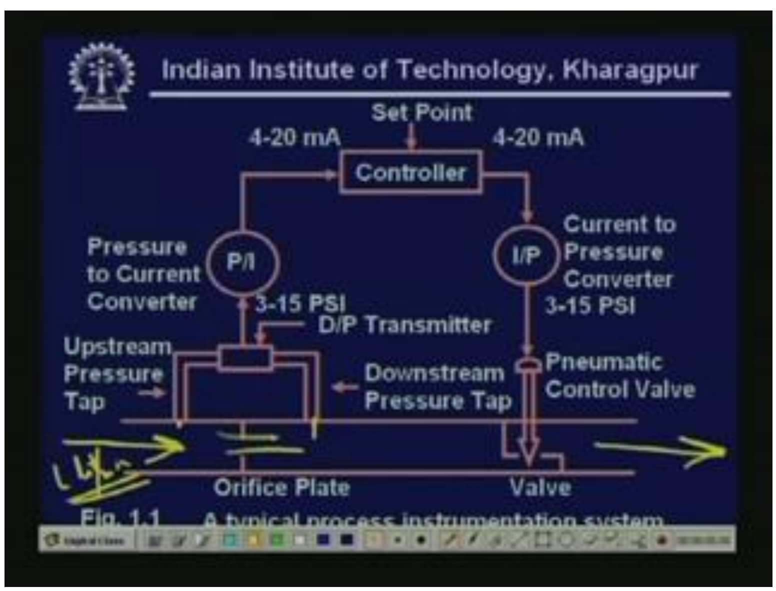

Now, let us look at a process diagram which will show you glimpse, I mean give you some idea of the instrumentation system and why we have given the name of the industrial instrumentation, instead of simple instrumentation, instrumentation devices and all those things. Now, this is a typical process, you look at. This is a typical process. Here, you see that a liquid is flowing through this pipe and it is going out, right and there is an orifice plate. Now, what will happen, you see. There are two tappings here. One is upstream tapping and another is downstream tapping. So, this tapping means that it will, the pressure, the flow, whatever the liquid is flowing through the pipe, our ultimate goal I have a set point that I have a set point, some fixed value of suppose L litre per minute that liquid I have to, I should always or that liquid should always, this rate of the liquid should be maintained through this pipe. That is our ultimate goal.

In many a situation you will find this type of, whether steel, chemical plants, you will find this type of situations. That might be water, might be naphtha and so many things are there, where you have to measure the flow. Now, you see, what will happen is that liquid is flowing. So, there is an upstream tapping and downstream tapping. What is the function? We will see later on. You see that in the case of flow meter, the flow is converted in terms of pressure, because as you know that when the liquid is flowing through this pipe here the flow is, whenever it is flowing through this region the flow is high.

If the flow is high, then what will happen? The pressure will drop. So, there is a high pressure zone and it is a low pressure zone. So, this I will take through a tapping. This is called upstream tapping and downstream tapping and I am giving to a DP transmitter. DP transmitter means it is a differential pressure transmitter. Sometimes back people used to call it a DPDT, differential pressure differential transmitter. But nowadays, more reasonably people call it just DP transmitter or differential pressure transmitter. Why it is differential pressure, because you see, I have to measure, I have to look at, I have to take the tapping both upstream and downstream. So, because this is a restriction, so this we call upstream, this downstream and this differential pressure is going to DP transmitter.

Now, this DP transmitter is, I mean according to flow it is giving a signal, pneumatic signal of 3 to 15 PSI. PSI means pounds per square inch. Even though this is, nowadays as you know it is an SI system, but still in some cases people use, more convenient with the PSI for some reason. Even though while we solve the problem we will find that we are using SI system, but steel industry they use this type of units. It is not a problem. Now, this 3 to 15 PSI of pressure that means varies. That means for almost no flow I will get 3 PSI of pressure. For full, for full flow of the liquid, I will get 15 PSI of pressure.

So, this flow, I mean this will go to the pressure to current convertor. Now, pressure to current convertor, what it will do? It will convert that signal, pneumatic signal to the current domain. As I told you earlier, you see that you have to transmit the pneumatic signal, electrical signal, hydraulic signal to the electrical domain, so 4 to 20 milliampere of current. Now, what is this 4 to 20 milliampere? As you say, it is from for 3 PSI I have a 4 milliampere of current, for 15 PSI I have a 20 milliampere of current. This range you have to maintain. Whatever the range of the flow, it does not matter; accordingly it will …., because this will remain constant. It might be in a huge flow, might be it can be 10 to the power of 5 litre per hour in that type.

Suppose in a power station or water pumping station and all those things, a huge amount of liquid is flowing or in some narrow pipe that might be, it is few, I mean it does not matter. The range will be always, which is converted will be always 3 to 15 PSI for the pneumatic signal and for the, for the current signal it is 4 to 20 milliampere.

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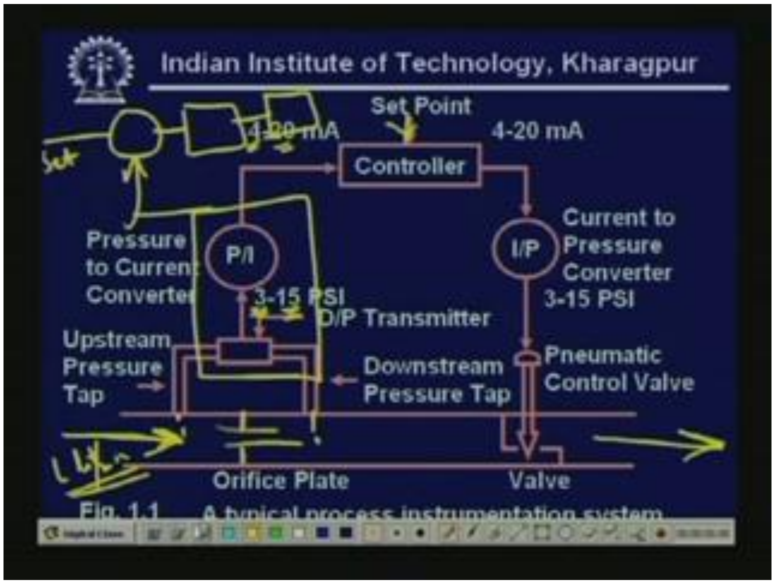

But nowadays, as you know, these, the entire things are incorporated in one DP transmitter, where you will get directly this 4 to 20 milliampere of current. This you do not, you do not need P to I convertor and all those things; everything is incorporated inside. We will see that you will utilize this differential pressure to make a, we will utilize it for a change of positions of a diaphragm plate in the case of capacitive measurement, so that I will get differential of capacitance, we will discuss later on and accordingly I will get a current.

Now, this current is coming to a controller. The controller, the function of the controller is to give a control signal to the pneumatic control valve. I have a set point, because set point, what is set point? Set point will set the value of the flow of the liquid, L litre. Suppose the 1000 litre per minute or that type of very high, 1000 litre per minute or I should say 1000 litre per hour that type of set points we have done. Now, if for some reason or the other this falls, then what will happen? I have to open the valve, so that more liquid will flow or for some reason or the other suppose this, this is, this has increased that means flow has increased, then what you will get? I will get a, I will get a flow. I have to close the valve, right. So, that type of signal you have to, you have to put to the control valve. So, that control, where I will get that signal? I will get the signal, I will subtract this signal, I have a set point and I have a signal. So, these two signals will be subtracted. When you will, in future we will study the control system; we will find all those things in details. That means I have a system here and I have a, this is our set point and this is our error. So, this will be kept and this will come to the controller, okay. This, I have a process, it will take actions or utilize this one, anyway.

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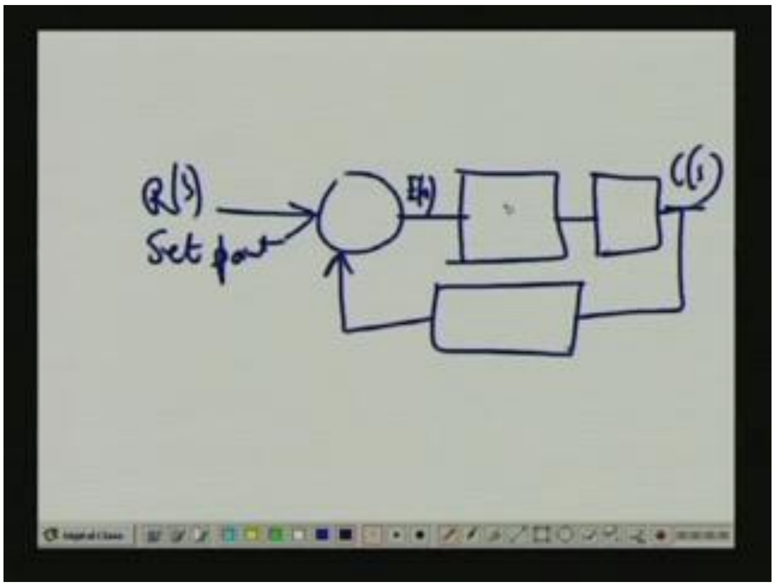

So, I have a, that means I have a controller process. I have a measurement, it is coming like … So, this is our set point, this is our output from the DP transmitter, right. So, this is coming ….. So, our goal is to make this R equal to C. That means these two should remain the same. If there is a difference, I will get an error voltage. So, our controller will take some actions. So, it will send some signal to the control valve and all those things. It will take some action, it will make, so that it will move in such a direction, so that ES will be again zero, right.

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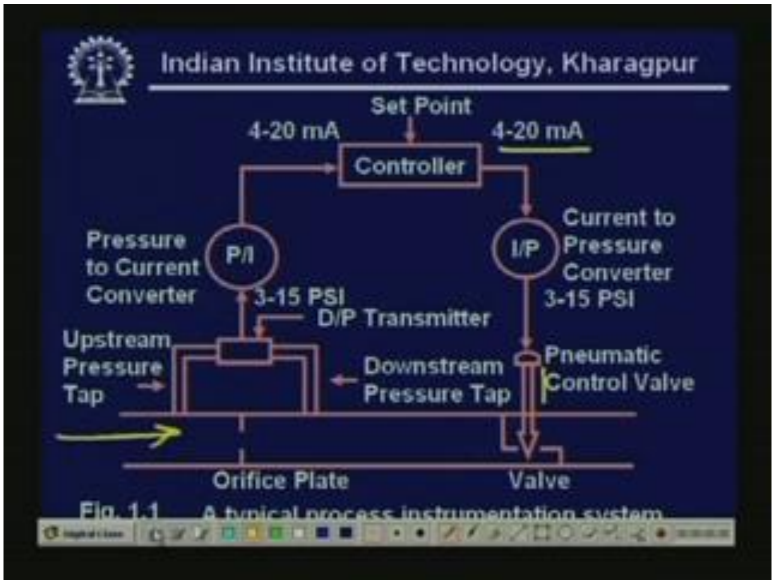

Here also it is same if you see that. What will happen if it increases? If the flow increases, my valve is to be closed, so the flow, if the flow increase this current will also increase. So, there is a, there is a set point. There is an error, so this is an error signal which is coming from there. This error signal also should be 4 to 20 milliampere, because I cannot transmit anything other than 4 to 20 milliampere. So, this will come to the, because this valve is pneumatic. Most of the industrial valve, as you know it is a pneumatic valve, because in many industry like the, especially hydrocarbon industries and all those things, petrochemical industries and all those things, you cannot use our solenoid valve, electrically operated valve, because of the safety reasons, because the operating voltage should be below 50 volt. So, there is a restriction.

So, for a large pipe and all those things, I cannot use there all those small control valves. So, I have to use pneumatic control. But, pneumatic control valve means that signal should be pneumatic to close or open. So, to close or open, I have to give pneumatic signal. So, ultimately what is that? That is very simply, precisely I should say that if I, the flow is increased, so I will get a signal through this transmitter. This will convert to the current domain moving to the controller. I have a set point, so obviously flow has increased. There is a, there is an error voltage, it will come, so the stem of the valve will go down, the flow of the valve will be controlled. This action will take until and unless this error signal will become zero, right or this volt, this current and this set point will remain the same. It is in other way also.

If the flow suppose decreases, then what will happen? The flow decreases, I will again also get some error voltage, but of opposite sign, obviously. So, what will happen? So, I have to take some action, so that the control valve should stem, should go out, so that I will get a flow which is actual to the set points. It will, the action will be taken until unless this error current will become zero, right.

Now, with this, I will go to the instrumentation laboratory of IIT Kharagpur, where you can see some of the instruments or process instruments. You will get the glimpses of how it looks like, how the different flow meter works and what actually the process looks like. We have some small, I mean process, I mean by which you can get the idea of what is the instrumentation system we talk about. We will come back after some time.

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This is a flow and level control system, which is actually the scaled down version of the actual process and what actually it is, the system is doing that it has different sensors.

What I want to mean that you will see the instrumentation is everywhere. You will find that there are several sensors. There are float level sensors, there are flow sensors, there are several control valves. So, the goal of this process is that basically to control the level as well as flow in a particular process. Now, the several sensors will take, I mean will play actually very key role in a system, because, you see everywhere you will find that the sensors output is most important for actual control of the, whatever the control systems you are using that is it is important as well as whatever the sensor output which is coming from the sensors is also important. So, the sensor's calibrations, its accuracy, its resolutions also will control the basic process.

Any process has some output. It has some, suppose if you go to the petrochemical process, it has some desired output or petrol output or kerosene output for any other type of material or if you go to fertilizer plant, you will find that there are different types of fertilizers are coming out, but the quality of the fertilizer or quality of diesel, quality of petrol will typically be decided by, not only by the control elements which you are using in the plant as well by the sensor. If the sensors are not accurate, the instrumentation system is not accurate, then you will find that the entire quality control is out of order. So, this tells that how instrumentation is important in industry.

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Now, I will describe at least two sensors. One of this is, usually this is a rotameter which is a flow meter. It will give the estimate of the flow of the liquid in the entire process. Now, you see, a rotameter is a tapered tube with a very small angle and the liquid is coming in through this pipe and liquid is coming out through that and then, the float, some technical persons they call it bob also. As the liquid flow increases, this bob will move up. Now, the details of these different forces which is acting on the float, we will discuss later on. Now, you can just remember here what will happen that when the float goes up that means the liquid flow also increases here.

Here, you can see here there is one float sensor, it is a pollution free float sensors. Due to the different level of the, you can see that this liquid can move up.

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You can see that this float will go up like this one as the liquid goes up and potentiometer will move and it will give the electrical output. Now, any process or any instrumentation system, one thing we must remember that, which we will discuss later on also, that you cannot transmit voltage, you have to transmit current.

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Now, for that you see here there is a, you have a float level transmitter which will transmit 4 to 20 milliampere of current to the process. This system, this, first it will go through this chord, it will go to the process interface.

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From the process interface, it will come to the digital computer. Now, then the digital computer, there are control algorithms by which you can set the different algorithms. You can tune the controller, it will feedback the system to the process controller, process controller will take the action. Then, the signal will go back through this chord again to this control valve; control valve will make the decision, the flow. Accordingly, you can achieve the particular flow or particular level in this process. This is the miniature versions of the actual process actual process might be large, but whatever the components you can see here, this you will find also in the process.

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In this assembly, you can find several flow meters. There are rotameters, there are optical flow meters, there are hot wire anemometers and there is also a magnetic flow meter. On top of it, you will find there is a weir, it is called V notch weir. As you know, the flow meters are different types. These are, some of them are for the open channel and some of them are for the closed channel. This V notch weir is basically an open channel meter, which will give you the, extensively used for the irrigation purposes, so that how much water is needed in the different fields, to get the estimate of that.

Now, you can see that if you increase the flow here by this, you can have a pump by which you can increase the flow, you see the flow is, I have reduced the flow, so the bob of the flow meter is coming down and this tapered glass is calibrated in terms of centimeter cube per minute. So, it will give you the flow and this height is also calibrated in terms of flow and you can see here, interestingly this is one electro optics flow meter.

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If you go, if I go to the backside, you can see there are four spots and there are lights which are falling on the flow meter and for each complete rotations, I am getting four pulses. So, accordingly, suppose you have 10 rotations, so accordingly I can calculate how much the flow is moving. So, it is a, it has a direct electrical output, wherein you can see here this flow meter has no electrical output. Similarly, hot wire anemometer also has electrical output and this is the hot wire anemometer. You cannot see from there, because it is inside and in the magnetic flow meter also it is electrical output. So, all these flow meters except this rotameter have electrical output.

Now, electrical output has the advantage. If you have in the instrumentation systems electrical output, you can directly convert that signal to the current domain, 4 to 20 milliampere of current domain. Then, you can digitize this if it is necessary, whereas if you have some non-electrical output as a pneumatic output or some mechanical movements that type of things, you have to convert this to the electrical domain by using either pneumo electric convertors sort of things or any other form of devices. So, this will give you the glimpses of the different flow sensors which is used in the industry, in the process. In the flow meters, you will find in any process industry these are thousands in numbers. Unfortunately, here I cannot show you that type of thing, but this will give you the idea of the how the flow is measured in the process.

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If you see here the backside of this flow meter system, even though you cannot see here clearly the hot wire anemometer which is also a resistance based flow meter and electromagnetic flow meter, but you can see here the electro optic flow meter.

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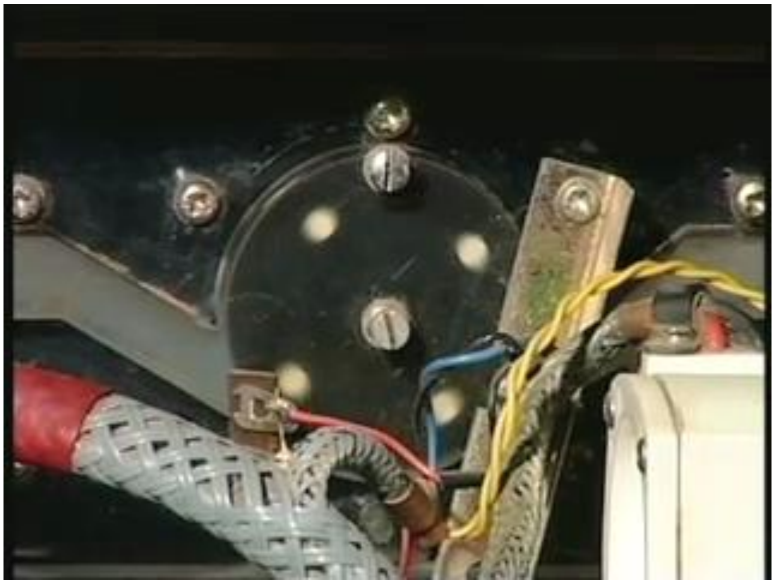

You see, what will happen in this instrumentation system that there is a light source which will be launched and there are four spots in the backside or four white spots in the backside, four white or silver. So, lighting gets reflected from that and there is a receiver on the other side. So, what will happen that when it rotates, for each complete rotation of the system we will get four clock pulses. So, if I can count the number of clock pulses, which obviously you have to, I mean you have to read the single process, we have to make little single processing in the sense that you have to pulse the signal shaper like switch here, we will get output and that can be counted for 60 minutes, so that you can get the flow because if you know the flow by diameters and all those things you can immediately tell that how much is the flow rate in a minute. So, this will give you the direct electrical output, obviously that can be processed, that can be easily interfaced to the computer. So, this will give the glimpses of the different flow sensors in the system and that can be calibrated obviously in this rotameter, which is in the front side, which I have shown at the beginning of this lecture.

Welcome back to the class room. So, we will now study the instrument characteristics.

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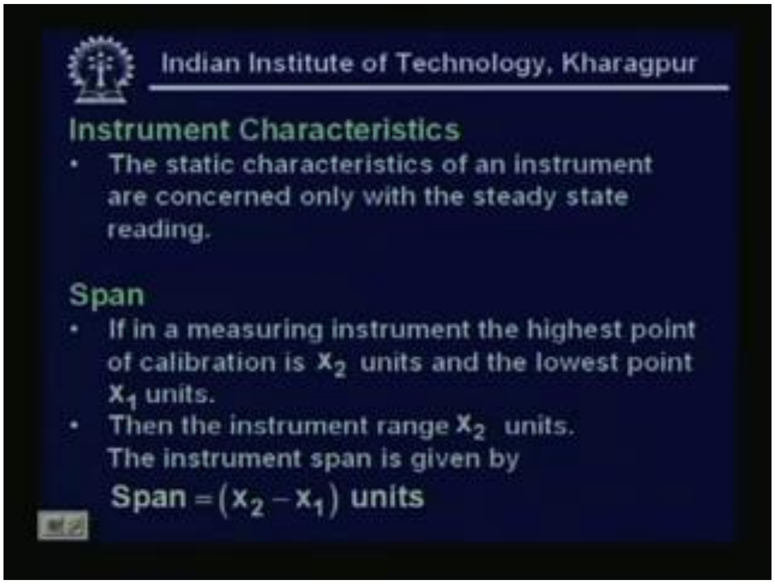

The static characteristics of an instrument are concerned only with the steady state readings. It is not concerned with any transient readings. So, we are concerned only with the steady state readings. So, we will call one by one now, we will read one by one the different steady characteristics. First of all the span; now, if in a measuring instrument the highest point of calibration is X 2 units and the lowest point of calibration is X 1 units, I can tell that then the instrumentation range is X 2 units and the instrument span is X 2 minus X 1 units. It is very simple. That means suppose I have a, if I have a, if I have a total, I mean range, suppose I have an instrument temperature sense which can measure 5 degree centigrade to 200 degree centigrade in that case, range I will call it 200 degree centigrade, span I will call it 195 degree centigrade.

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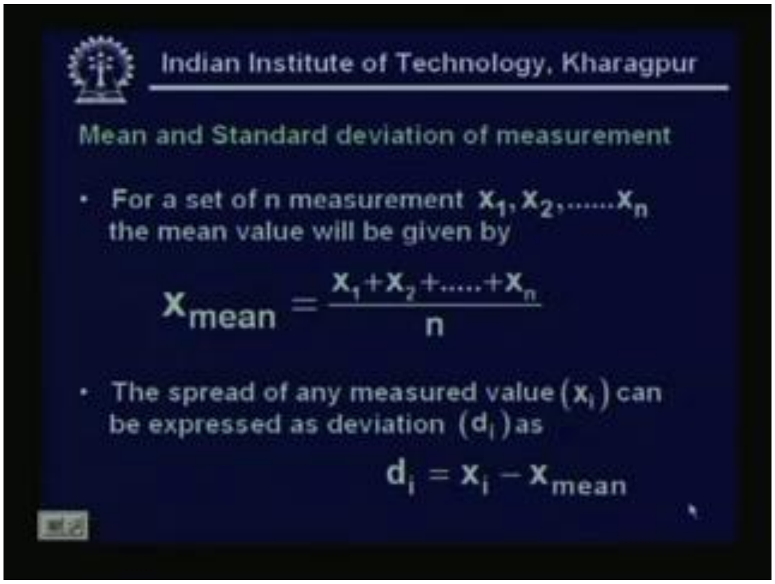

Now, mean and standard deviation of measurement, see we will need this in future. You will find that is the reason we are explaining. Suppose we are making a set of n measurement, X 1, X 2, X n and the mean value will be given by X mean; X 1 plus X 2 plus 1 X n upon n, this is X mean. This is mean of the measurement and the spread of any measured value X i can be expressed as a deviation which can be expressed as, given as d i equal to X i minus X mean.

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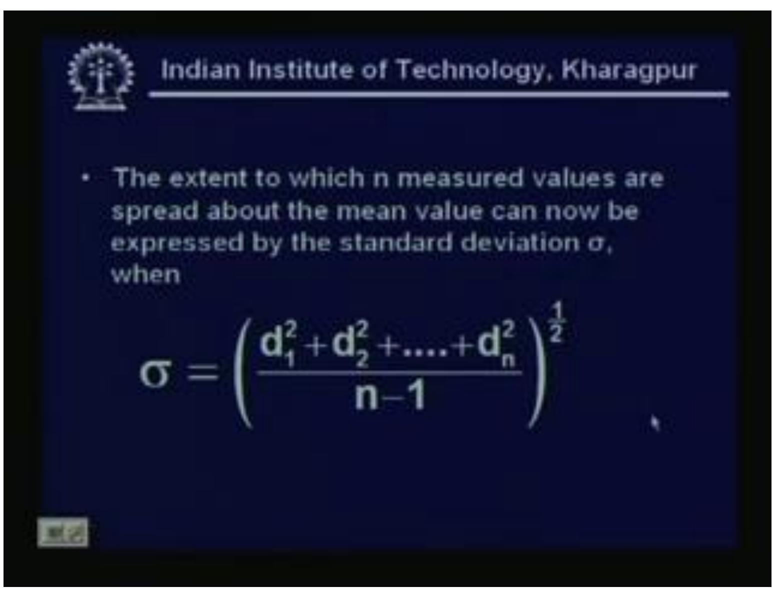

The extent to which the measured values are spread about the mean value are known as, known and now we express as standard deviation sigma, where sigma equal to d 1 square plus d 2 square so on d n square upon n minus 1 whole to the power half, under the square root. So, this is the standard deviations. We need it in future. So, we will find that is the reason we are explaining it here.

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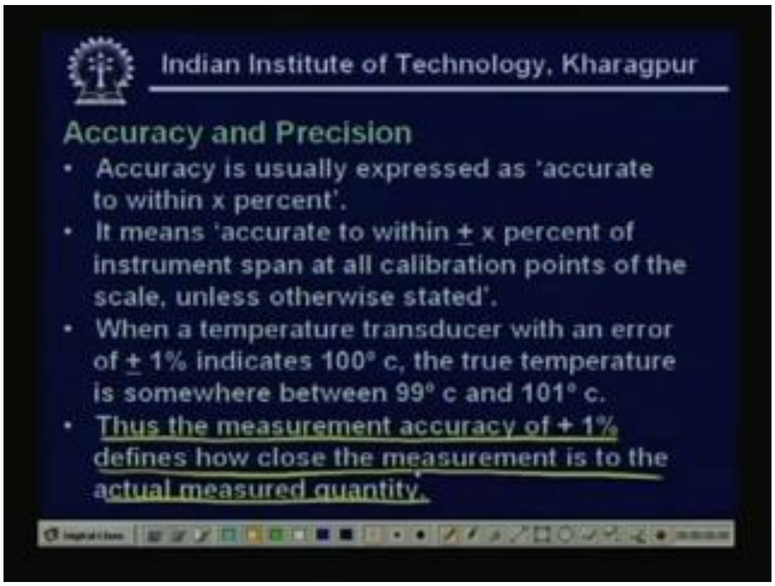

Now, accuracy actually means, accuracy and precisions, accuracy is usually expressed as accurate to within x percent; even though we do not use exactly, use the same, I mean word, so accuracy and accurate, it is slightly different. It is usually, we do not, I mean like that if somebody express the same word, I mean some definition with the, with the implanted in the same word in the definition itself, but these two are different. So, accuracy, we will explain this more. Accuracy is usually expressed as accurate to within x percent. It means accurate to within plus minus x percent of the instrument span at all calibration points of the scale unless otherwise stated.

When a temperature transducer with an error of plus minus 1% indicates a 100 degree centigrade, the true temperature is somewhere between a 99 degree centigrade and 101 degree centigrade. Thus, the measurement accuracy of plus minus 1% defines how close the measurement is to the actual measured quantity. So, this is the main test. Thus the measurement accuracy of plus minus 1% defines how close the measurement is to the actual measured quantities. How much is the deviation? That is actually we talk about the accuracy.

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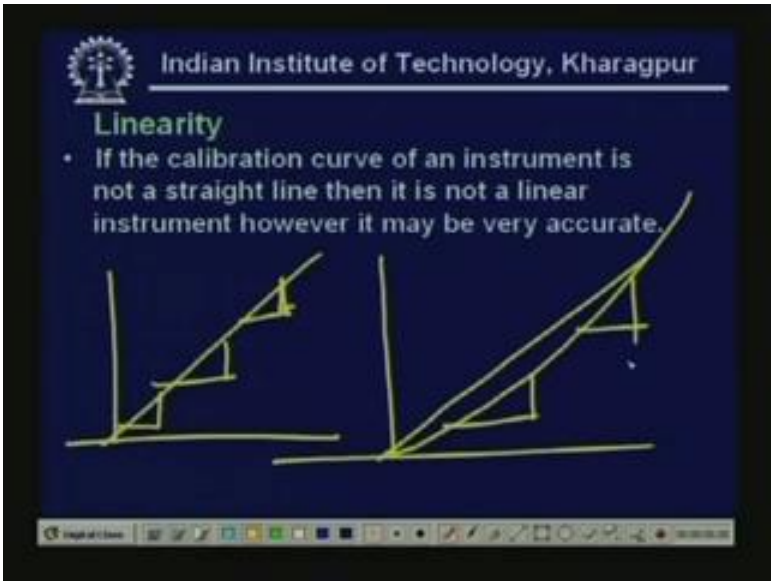

Linearity, if the calibration is very important, because in instrumentation you know always we prefer a linear sensor. There is a lot of problem if you have a, do not have a linear sensor; we will find that. What is mean? Means the input output relation should be linear. Forget about the accuracy, we can have a, I can have a characteristics like this one also. I can say it is a, it is non-linear, but it can be very accurate. But there is a, if the linear ease of calibration will be there that means that if i can calibrate an instrument, if it is linear instrument its calibration is quite simple. Its sensitivity will be same at all positions.

Why? You see here, I have this type of relation. So, it does not matter where I take. The sensitivity, sorry the ……. will remain the same; whereas if you, if you take some other, suppose here in this curve, sensitivity something here and somewhere here, it will be different. So, while you are making the signal conditioning circuitry, it will be very difficult. The task will be very, very hard. That means, I mean your amplifier should also be adaptive. It is a very difficult task. So, always you prefer linear instrument. But, some instruments, some sensor like thermocouple, thermistor, it is non-linear sensor. We cannot do anything, because of its low cost, it is ……, there are so many other positive points we have sacrificed that, sacrificed that it is a non-linear sensor. I mean we want to accommodate it even though it is a non-linear sensor.

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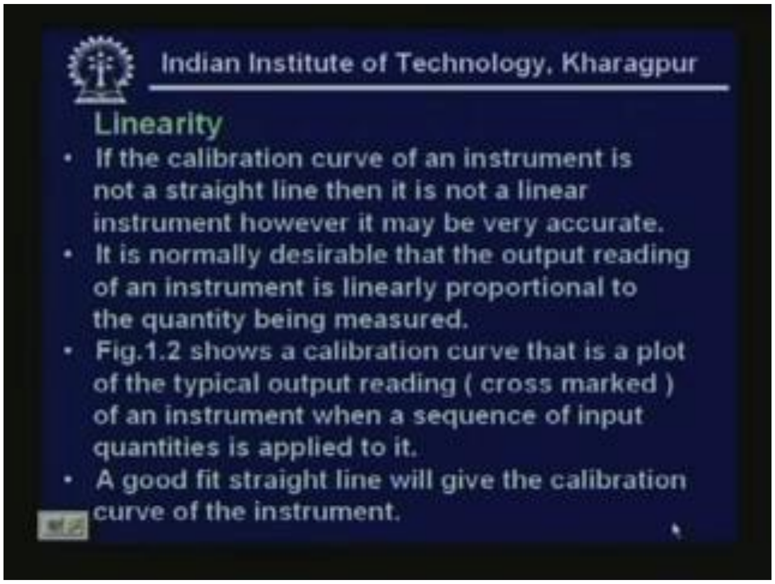

Now, it is normally desirable that the output reading of an instrument is linearly proportional to the quantity being measured. Figure 1.2 shows a calibration curve that is a plot of the typical output reading, cross marked, of an instrument when a sequence of input quantities is applied to it; we will show in the next slide. A good fit straight line will give the calibration curve of the instrument. How does it look?

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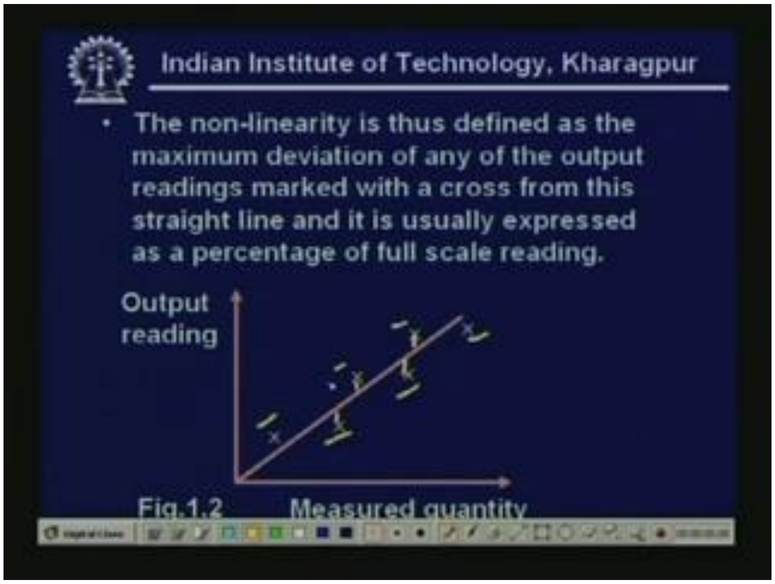

Non-linearity is thus defined as the maximum deviations of any of the output readings marked with a cross from the straight line and it is usually expressed as a percentage of the full scale reading. You see, that is we talked about the Figure 1.2 measured quantity. You see here, that this is our measured quantity. So, you make a best fit curve. There are various softwares available, so by which, least square method is there by which you can make a best fit curve, so that it will be a best fit for all the points which you have given. So, this is our deviations, okay. It is not that this is our deviations, this is our deviations, okay, this is our deviations, this is our deviations. So, this non-linearity is thus defined as the maximum deviations of any of the output readings marked with a cross from this straight line and it is usually expressed as a percentage of full scale reading. Always it should be expressed in percentage of full scale reading.

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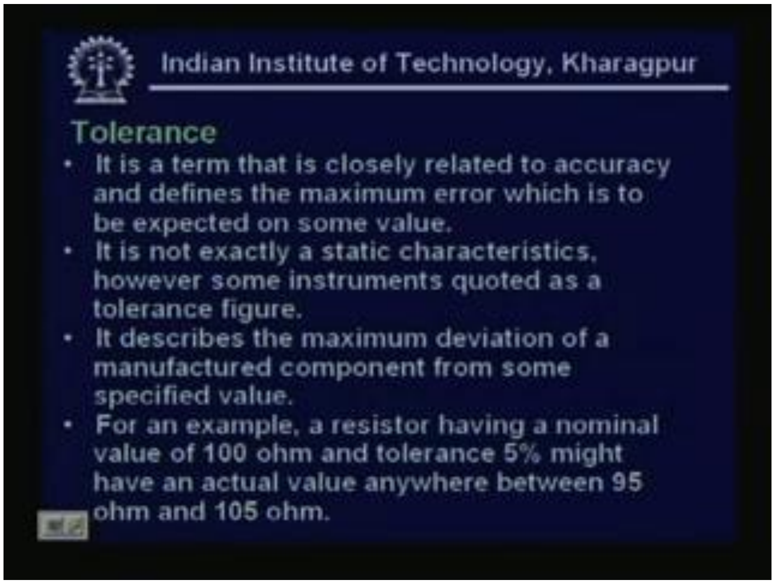

Now, tolerance, it is a term that is closely related to the accuracy and defines the maximum error which is to be expected on some value. It is a not exactly a static characteristics; obviously, you know that. However, some instrument manufacturers usually quote that, I mean quote this tolerance figure. So, you must know what is the tolerance? One of the good examples, those who are not familiar with the instrument tolerance, is the maximum deviation of a manufactured component from some specified value; you are familiar with that.

Why? You see for an example, a resistor having a nominal value of 100 ohm and a tolerance of 5% might be having an actual value anywhere between 95 ohm and 105 ohm. There are resistors available of varying, various tolerance; 1%, 10%, 2% depending on … So, if it is, tolerance band is important, because not always you will find the 0.1% tolerance. If you, with the 5% tolerance, I mean measurement is okay, there is no problem.

Why it is saying I am saying, you see that if my measurement error is 5% that means tolerance band is coming 5%. Ultimately what we will do with this, such a precise measurements? Ultimately the quality of the product, if the quality of the product does not deteriorate, I can amount, I mean I can allow certain amount of tolerances, is not it? If it is not, if the product, ultimately product falls, supposing some, I mean chemical plants you can, you have to be precise. If there is 5 degree centigrade temperature variations, suppose there is a, you are controlling some temperatures of suppose 600 degree centigrade. It hardly matters if the temperature varies to 598 to 602 degree centigrade, whereas in some process suppose in the case of bio process we will find that where the cell grows, in that type of situations with even the difference of temperature of 0.5 degree might be detrimental to the cell, cell will die. So, in that type of situations you cannot allow the temperature to, so this tolerance are there everywhere.

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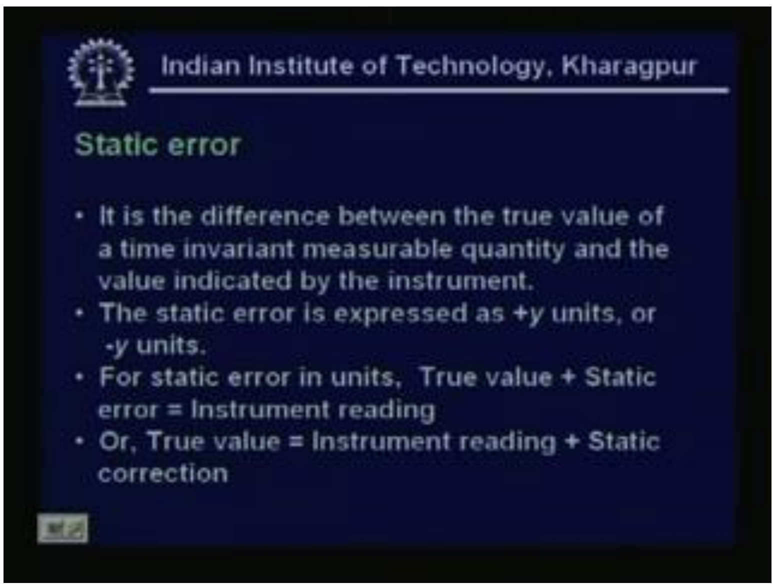

Now, static error it is the difference between the true value of a time invariant measurable quantity and the value indicated by the instrument. The static error is expressed as plus y units or minus y units and for static error in units, true value plus static error is the instrument reading or true value equal to instrument reading plus static correction, quite obviously because it is opposite of that it is the static error.

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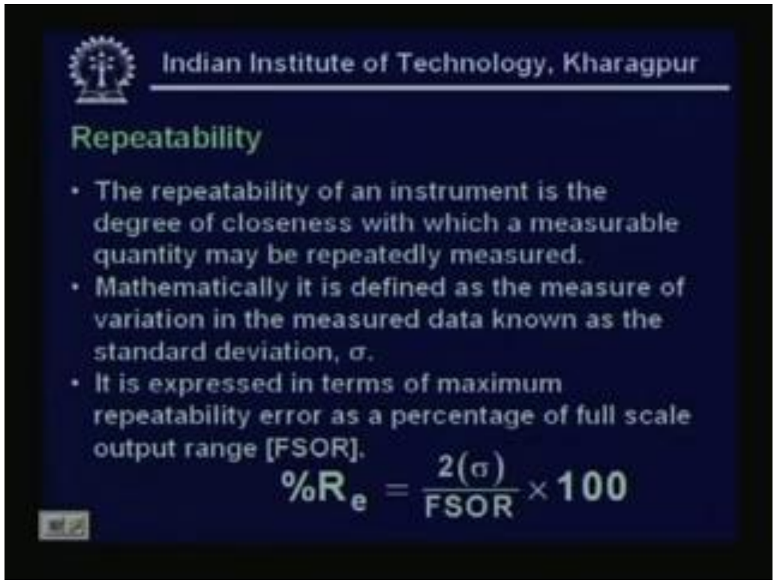

Now, repeatability is very important. Repeatability is, in instrumentation you see that the, I mean if you, there are thousands of instruments in a big plant, thousands of sensors, I mean sub temperature pressure flow, you cannot expect that you will calibrate the instruments every day or every once in 7 days. Usually the typical norm is that there is a routine, maintenance routine, I mean checking of all these calibrations. But if there is a, if the fall of quality of some of the, then you will, for some of the product, we will talk about the instrument calibrations or sensor calibrations, otherwise not. So repeatability, repeatability is defined as the, of an instrument is the degree of closeness with which a measurable quantity may be repeatedly measured.

What does it mean? Suppose I have a voltmeter. So, I am giving a battery voltage. So, battery voltage, suppose a dry cell battery voltage is, voltage is fixed 1.5 volts. If I even measure 1000 times it should always give 1.5 volt by that instrument or voltmeter. I would say that its repeatability is good, because battery voltage is not changing, supposed to. Suppose if it is a dry cell battery, if you are not drawing any current from that, because usually voltmeter doesn't draw much current, so it is, if you take 1000 reading, it should give you the exactly same value 1.5 volt. If it does not, that means that repeatability is poor.

Now, mathematically how will you define this repeatability? Mathematically, it is defined as the measure of the variation in the measured data known as the standard deviation sigma. It is expressed in terms of maximum repeatability error as a percentage of full scale output range, right. So, it is repeatability 2 sigma full scale output range into 100. This is the percentage repeatability.

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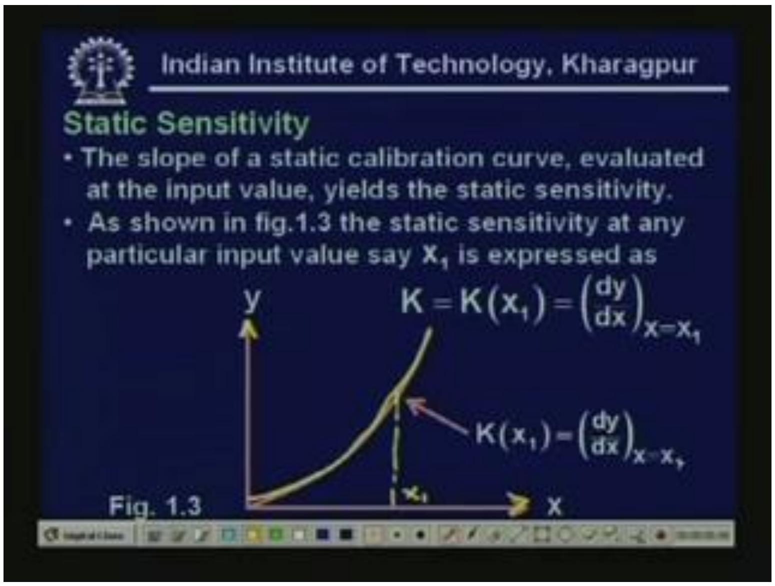

Now, static sensitivity is very important. The slope of a static calibration curve evaluated at the input value is the static sensitivity, right. It means that as shown in Figure 1.3, we will show, it will come, the static sensitivity at any particular input value say X 1 is expressed as this. This is Figure 1. You can see here, so this is a calibration curve, this is my input, sorry, yes, you see here, this is our, this is our calibration curve; this is our calibration curve, right. It is going like this. It is non-linear, it does not matter. So, you see here that this is my input and this is the output reading. The input, say some parameter and output we are getting some reading, excuse me.

The static sensitivity is defined as at X 1 value suppose if I say this is the X 1, at the value X 1 the slope of this, I mean calibration curve, so it is dy by dx at X equal X 1. Interestingly you see this static sensitivity varies. You see, here is some, there is some value, here it is some different value. So, the static sensitivity for the non-linear curve will change. It depends under what point you are measuring, right. You will find this typically true that in the case of thermocouple. Thermocouple you will find that, typically we say something suppose the platinum, platinum rhodium thermocouple, we say that the static, I mean its sensitivity is around 10 to 12 microvolt per degree centigrade. It is non-linear. Suppose in some range you will find 10 microvolt per degree centigrade, some other range you may find 12 microvolt per degree centigrade, some other even less, might be 6 to 7 microvolt per degree centigrade.

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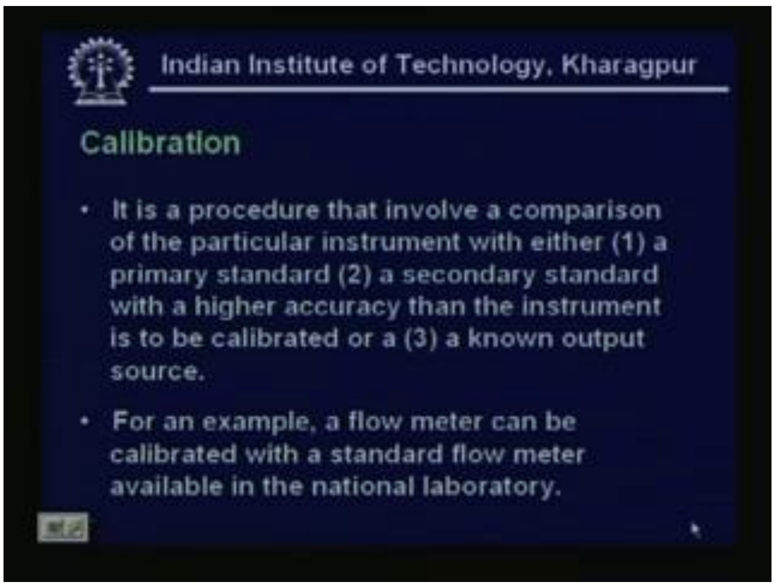

Now calibration, actually it is very important. It is a procedure that involves a comparison of the particular instrument with either a primary standard number 1, a secondary standard with higher accuracy than the instrument which is to be calibrated or a known output source, right. What does it mean? It is a primary standard. That means I can calibrate my instruments with a very accurate instrument by going to some National Laboratory or some other places. I can calibrate that instrument with a secondary standard of higher accuracy. I can use some other instruments which I know they are accurate. So, I can calibrate. Because you see, it is a hardly, in industrial instrumentation you will find that the instruments are of absolute type. That means you do not, it does not need any calibrations. You have to calibrate each and every instrument, so most of the instruments you will find, in that case what will happen that I must calibrate either with some primary standard.

Suppose I have, I mean I have given you a RTD. So, you must calibrate that with some small range, suppose I can calibrate with some standard mercury in glass manometers. So, I can calibrate like that or I can calibrate with some suppose boiling water which is supposed to …. normal pressure and temperature. At normal pressure it should be 100 degree centigrade for the pure water. So, that way we can calibrate, right or I can calibrate with a known output source. What is that, I will show you. For an example, a flow meter can be calibrated with a standard flow meter available in the national laboratory. This is number 1.

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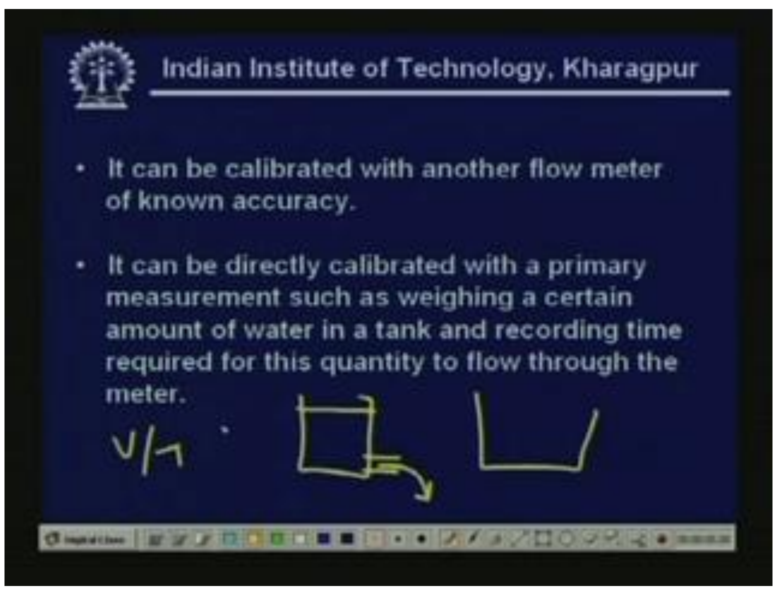

Number 2, it can be calibrated with another flow meter of known accuracy. It can be directly calibrated with a primary measurement such as a, such as weighing a certain amount of water in a tank or a recording time required for this quantity to flow through the meter. How does it look? It looks like this. It looks like, suppose I have a flow meter, I have a vessel. So, I know how much is the height, I know how much is the water flowing out through this one. So, I can tell what is the flow rate, because if I have a stop watch I can tell. So, this is some other form of a calibration. So, I know the quantity of water, I know the time, so I know the volume. So, I can find the volume rate. That means V by time. If I, so I can, litre per minute I can tell that how much is the volume. So, I can calibrate in that way also, right.

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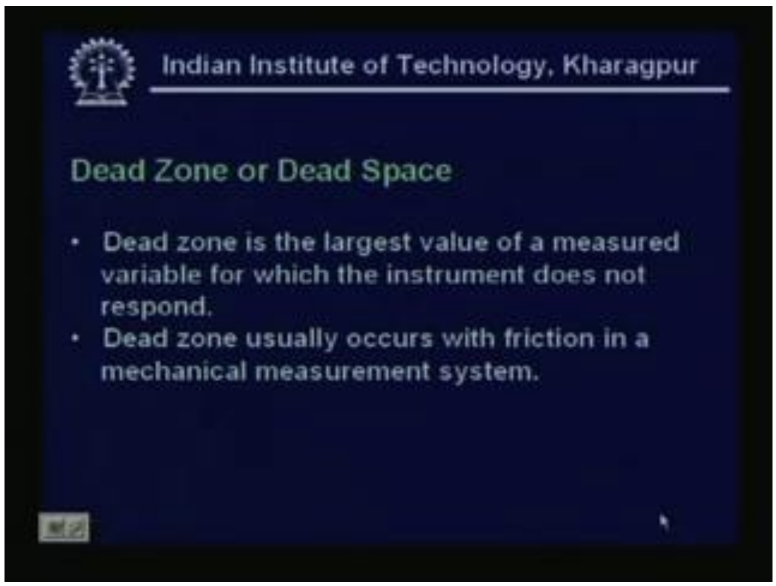

Now, dead zone or dead space is another important factor. Now, in many instrument you will find it has a dead zone. Dead zone is the largest value of a measured variable for which the instrument does not respond, right. What does it mean? Suppose I have a pressure gauge which is measuring a pressure of 10 to the power 5 psi. So, in that type of pressure gauge if you give a 50 psi you will find that there is no movement of the pointer. So, that is the, 50 psi is the dead zone of that type of instrument, right. So, dead zone usually occurs with a friction in a mechanical measurement system.

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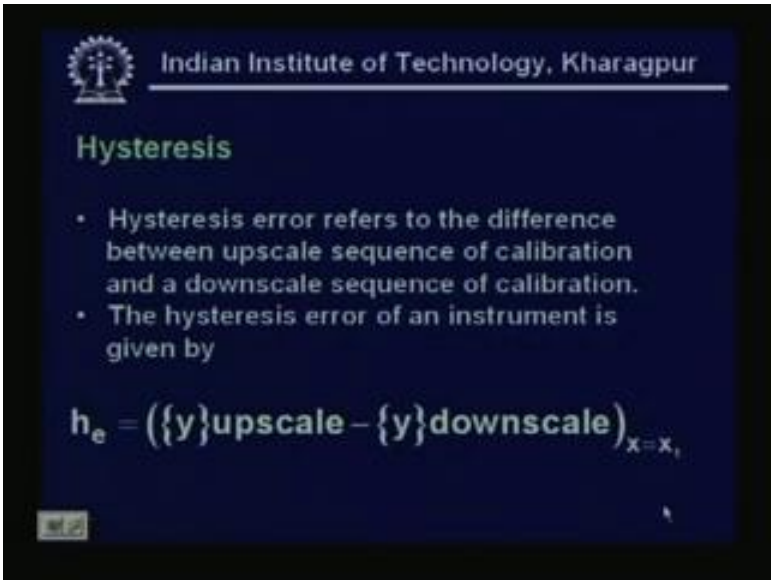

Hysteresis is another important … Hysteresis error refers to the difference between the upscale sequence of calibration and downscale sequence of calibration and the hysteresis error of an instrument is given by y upscale minus y downscale at X equal to X 1. What does it mean? It looks like this.

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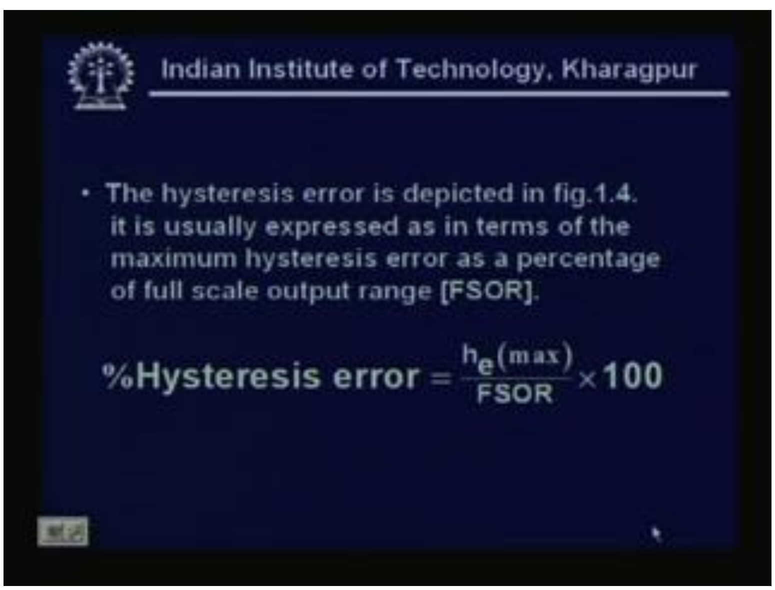

The hysteresis error is depicted in figure and it is usually expressed in terms of the maximum hysteresis error that is the percentage of the full scale output range. Hysteresis error equal to hysteresis, maximum hysteresis error upon full scale output range multiplied by 100. It looks like this.

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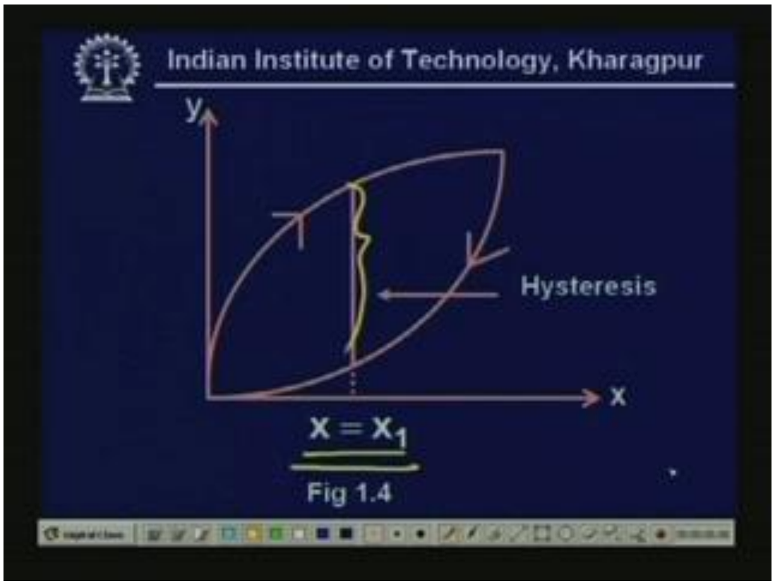

In this figure you can see here. You see, so this is our hysteresis error at X equal to X 1. So, this if you take the full scale output range, so you will get the, I mean total hysteresis is there or I should that it is non-matching of the upscale calibration and downscale calibrations. It may happen in some instrument that it does not match. In that case we will call it hysteresis.

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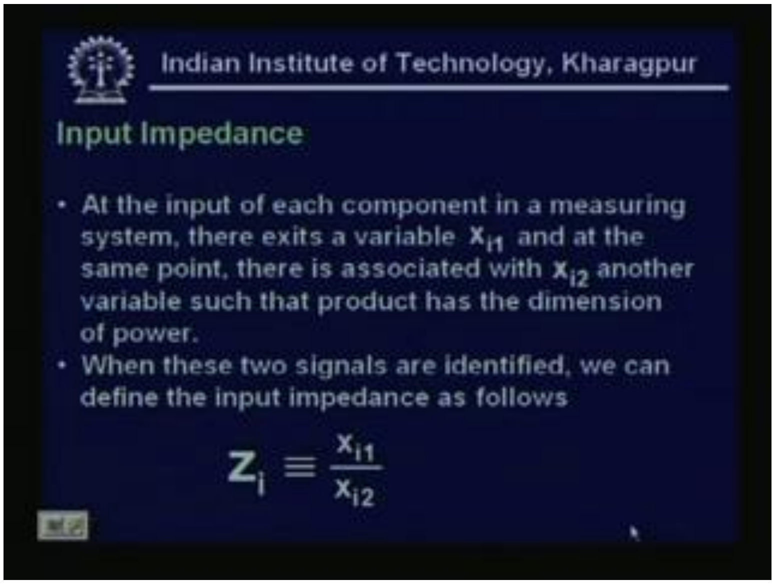

The input impedance at the input of each component in a measuring system there exist a variable X i1 and at the same point there is associated with a X i2 another variable, such that the product has the dimension of power. When these two signals are identified, we can define the input impedance as shown by Z i equal to X i1 upon X i2. This is important because some instrument and the, I mean …

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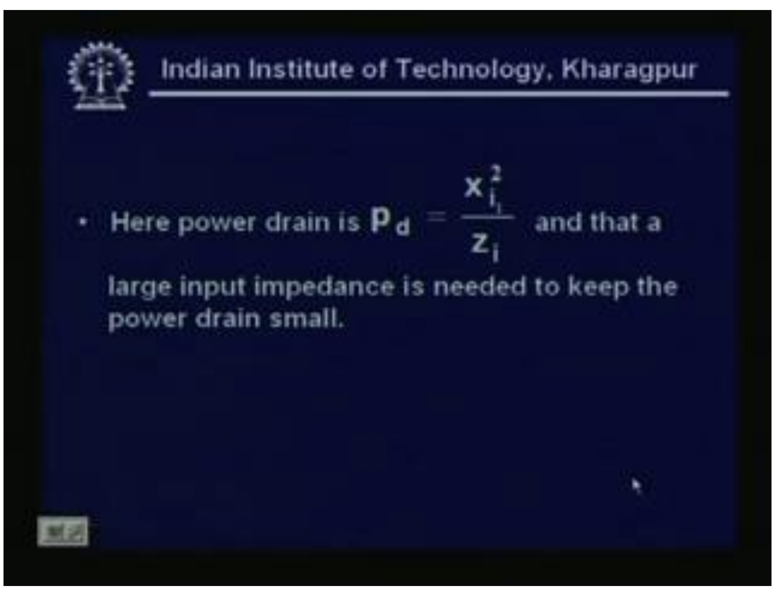

So, here the power drain is P d equal to X i by Z i, X i1 square by Z i and that a large input impedance is needed to keep the power drain small. Because in some instruments, some sensor you will find like a, like a pH meter, all these things need very small, should draw very small current. So, this is very important, because if it draws large current it cannot measure the voltage actually, because it has internal large source impedance, right.

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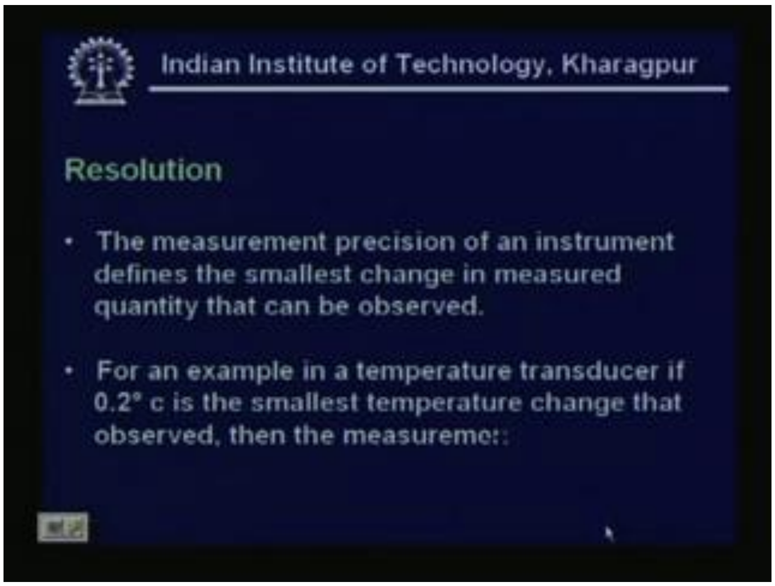

Now, resolution is another important … The measurement precision of an instrument defines the smallest change in measured quantity that can be observed, right. Suppose I have a thermometer, 0.2 degree centigrade. It is the minimum, so it is 10.2 centigrade. For example, it looks like this. It is a temperature transducer. If the 0.2 centigrade is the smallest temperature change observed, then the measurement resolution is 0.2 degree centigrade.

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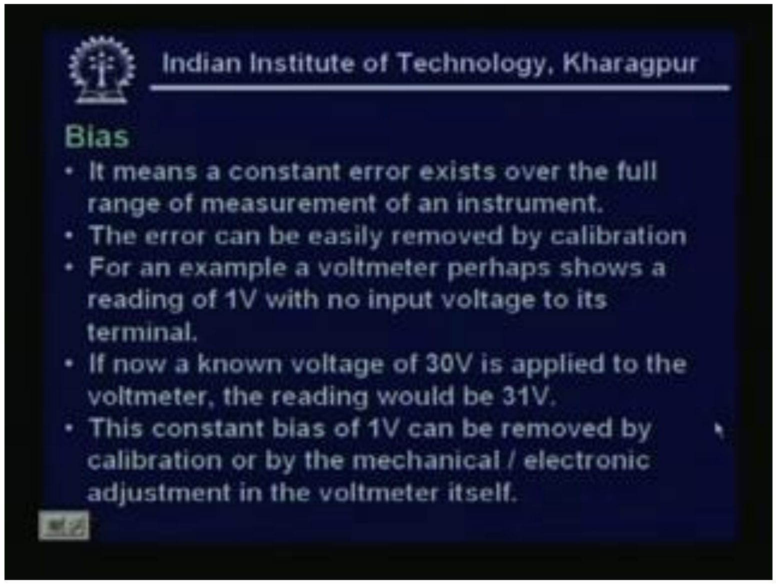

Now, bias is another important … It means a constant error exists over the full range of measurement of an instrument. The error can be easily removed by calibration. For an example, a voltmeter perhaps shows a reading of 1 volt with no input voltage to its terminal. If now a known voltage of 30 volt is applied to the voltmeter, the reading should be 31 volt. So, obviously I can, this constant bias of 1 volt can be removed by calibrations or by simply mechanical electrical means. Suppose by adjusting the needle or in case of …. voltmeter, I mean we should take care, we should charge some capacitors when there is no, I mean input voltage, so that that biased voltage will be charged. Accordingly, it will be subtracted or added to the final value, when you are measuring some voltage.

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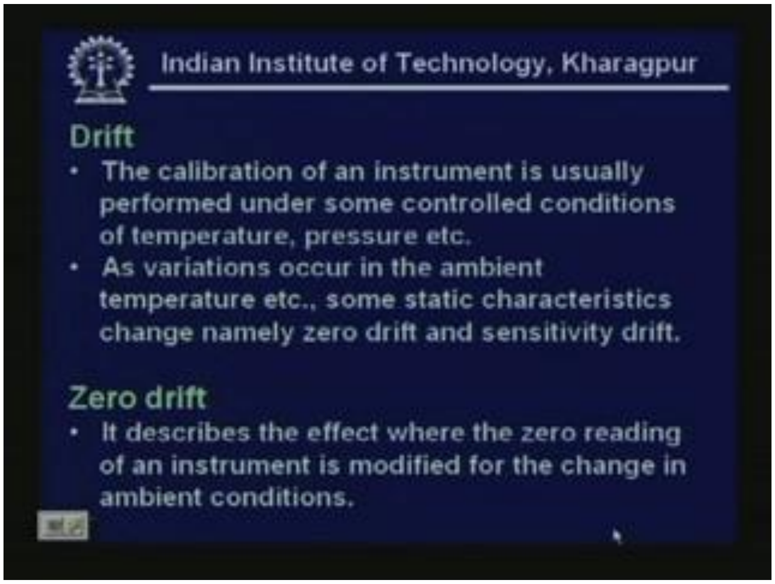

Drift is the calibration of an instrument. It is usually performed under some control conditions of temperature and pressure. Because, not always we have control conditions, so there will be drift in the measurement. As variations occurs in the ambient temperature, some static characteristics change, namely zero drift and the sensitivity; sensitivity may change, zero of the instrument may change. So, zero drift, it is, it describes the effect where the zero reading of an instrument is modified for the change in ambient conditions.

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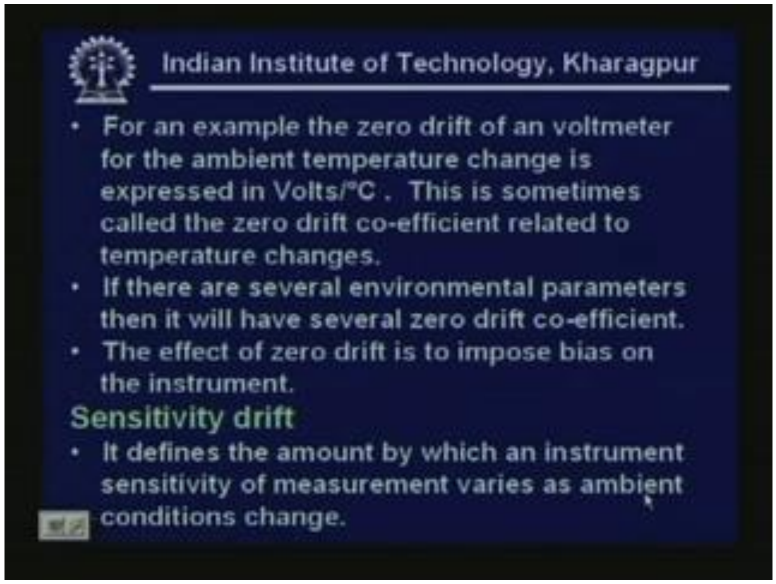

For an example, the zero drift of a voltmeter, zero of voltmeter for the ambient temperature change is expressed in volts per degree centigrade. This is sometimes called the zero drift coefficient related to the temperature changes. If there are several environmental parameters, then it will have several zero drift coefficients. Effect of zero drift is to impose bias on the instrument. Sensitivity drift is another, because sensitivity also will change. The difference, the amount by which an instrument sensitivity, it defines the amount by which an instrument sensitivity of the measurement varies as ambient condition changes, right.

So, this is all about basic introductions of the industrial instrumentations. I will keep the static characteristics in details and you have understood by this time, how the role or what is the role of the instrumentation and how important it is and the responsibility of the instrumentation engineer is to maintain all those sensors, signal conditioning circuitry and all types of things. This ends the lesson 1.