Principles of Mechanical Measurement

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Module - 01
Lecture - 02
Introduction to Measurement

Hello friends. Welcome back to on MOOC course on the topic of Principles of Mechanical Measurement. And today we are into the second lecture of our first module, where we are just setting up the initial concepts about the topic of measurements.

I hope all of you are well and actually I am very much interested to know your feedback about the first lecture, but despite having so many years of teaching experience, I am going to be a bit uncomfortable throughout this course, because simply because I do not have a direct audience in front of me. I am not able to see into your faces and we generally always give me an idea about whether I am going into the correct direction, whether I need to stress a bit more on particular topic or not.

And quite often the questions that keep on coming from your side during a live class or during a normal classroom hours that allows me to go back to some concept explain a bit more find a few more examples may be. Well, here I do not have a live audience whatever I have is only this tablet, where I am doing all this stuff and also the camera and all of you are on the other side of the camera.

So, only thing I have to make this course as much interact I can only thing that I can do is to request you to send your immediate feedback after every lecture. And write to me whatever queries you have immediately after going through a lecture through the portal and I will try my best to answer within the shortest possible time.

And you must have seen the contact details of TA's also the course TAs on the course webpage. You can write anyone of them also. But, all the 3 TA and me personally we shall be checking the portal regularly to get aware about your queries and try to respond to that immediately. So, I request again whatever feedback you have, whatever queries you have please write to me. And also do not hesitate to write your view about how the lectures are going like we have just covered one lecture, you can easily write to me means whether you found it interesting or whether you found it boring or if I need to improve in certain topic or not. Because, then only I can change the direction of my future lectures.

Now, coming back to the course itself yesterday we are in the previous lecture, we primarily talked about the fundamental concepts of measurement system. Like we talked about the very brief definition of measurement, then the need for having a measurement, then you talked about different levels of measurement, different kind of measurement scales that is where we have identified the equal interval scale and the ratio scale of the most commonly used ones for mechanical measurement point of view at least.

And we have also talked about different kind of standards to be used during the measurement, because measurement basically is a process of comparing your measurement quantity and the corresponding standard. So, it is very important to setup or select your standard properly, whenever you are going for some kind of measurement.

And then we ended the lecture by talking about different types of measurement. So, before I start anything let us have a little bit of exercise. As I am not in a live class, again I would like to get the questions from you, but as I am not able to do, I am just guessing what queries you may have and from there, I am trying to form a few exercises.

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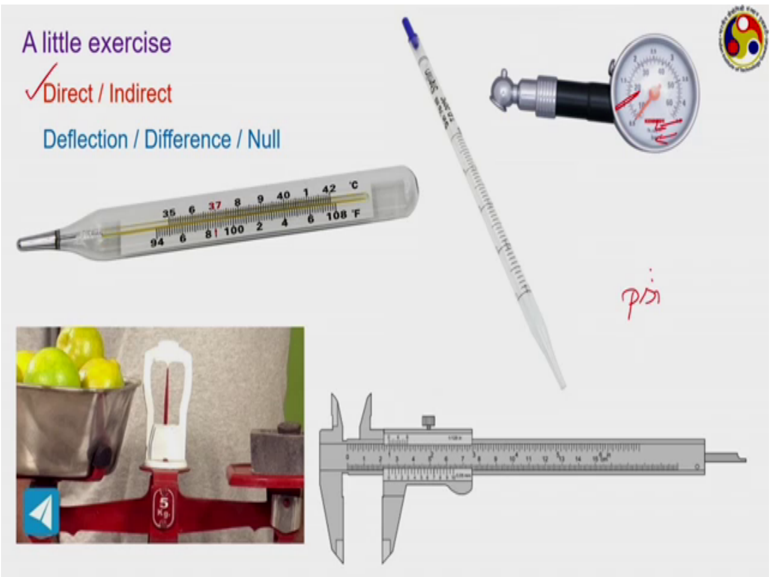

This is something that we shall be trying to do at the beginning of end of every lecture, so that we can either rehearse whatever you have done in the previous lecturer or get the idea about what you are doing in the present lecture. So, this exercise based upon the kinds of the classifications of measurement that we have done in the previous lecture. We have seen that primarily we used two kind of classification; one is direct and indirect type, other deflection difference and null type.

So, let us see a few examples and try to find out from there. See examples of few instruments and try to find out which category they primary fall. So, the first example that I have here is for a very common medical thermometer. So, let us try to classify it, whether it is a direct or indirect type measurement. Of course, we can take the thermometer in contact with the body of the person, where we want to make the measurement so it is definitely something of direct type.

Now, can you tell me it is deflection or difference or null. Actually, this particular example we took yesterday to discuss about this particular classification. So, here the thermometric fluid, which is mercury in common that is able to move through a capillary tube, and the tip of the mercury column will reach exactly the point where from where you are going to get the measurement. So, it is a deflection type instrument.

Let us move to the next one a common balance, another example have discussed yesterday. Here again you have measurement on the one side and standard on the other side. So, they are very close to each other and then it is a direct measurement. The direct comparison between the measure and (Refer Time: 05:44) standard.

But, what about the second category. Here also your having a pointer which is getting deflected, but this pointer itself is not going to show the mass of whatever you have kept here. Rather our objective is to set the pointer or get the pointer to a 0 value to complete the measurement and that means it is a null kind of measurement, where we are try we are putting the measurement on one side and we are adding the amount of or we are adjusting the amount of standard on the other side to ensure that the pointer comes to the null position or 0 position. So, it is the best example of a null type measurement.

Let us move to a third example. This is a common pipette, which we use for means taking some volume of liquid or measuring the volume of liquid, so again it is a direct type. Actually, all the examples that I have here all are direct type in and also we presently have idea would very few instruments. As we go on with the course, and we get idea about several modern instrumentation, then you definitely will be having some more idea about indirect measurement or you will learn more examples of indirect measurement, but presently we are sticking only to direct ones, like I have picked up the examples here from whatever you already know.

So, about talk about the second category. Here again the volume of liquid which is there can directly be observed from the scales that is there that means, you are going to take the measurement as a deflection type instrument or categorize this is deflection type instrument.

Next one what is this is a common vernier scale or a slide caliper. So, here if you want to measure the length or corresponding any other dimension of something, then we put that within this two jaw of this calliper, and get the measurement from the scale which is somewhere here.

Now, what kind of instrument it is definitely a direct kind. And what about the second category either what is our objective final to get a 0 value on the scale or some number directly on the scale, it is not a 0 value. So, it is definitely not a null kind. Whether it is a difference kind difference means, we shall be having some reading on the scale plus a reference the value of the reference we are going to add to the reading on the scale and correspondingly we are going to get the reading or final value of the measurement. Here also we are not having any kind of reference, so it is again coming under the deflection type.

So, let us move to the example number-5. Here this is the example of a common tyre gauge something which used to measure the pressure of vehicle tyres this where were we have a dial and there is a scale on the dial of pressure like in the example that I have you can see there two scale shown. The inner one is pound per square inch, the outer one is in bar. One bar typically corresponds to about 14.7 pound per square inch or commonly we call it psi pound per square inch.

So, one bar commonly corresponds to 14.7 pound per square inch. And so the inner scale where you can see the reading so 10, 20, 30 etcetera corresponds to the psi, and the outer scale that corresponds to bar. You can also see it from the here, the one written on the outside will corresponds to the outer scale, the one written inside will corresponds to the inner scale.

Now, it is again a direct measurement, because we shall be taking the gauge in contact with the or in through the location where we are going to make the measurement, but what kind of measurement it is. Here again you have an indicator that is going to move over the dial. And the final position of the dial is going to indicate the final value is not it. So, should you call it a deflection type then probably not, because commonly the gauge that is going to give you is going to give you only the gauge pressure that means if our interested is to know the gauge pressure, then we can classify this is a deflection type instrument.

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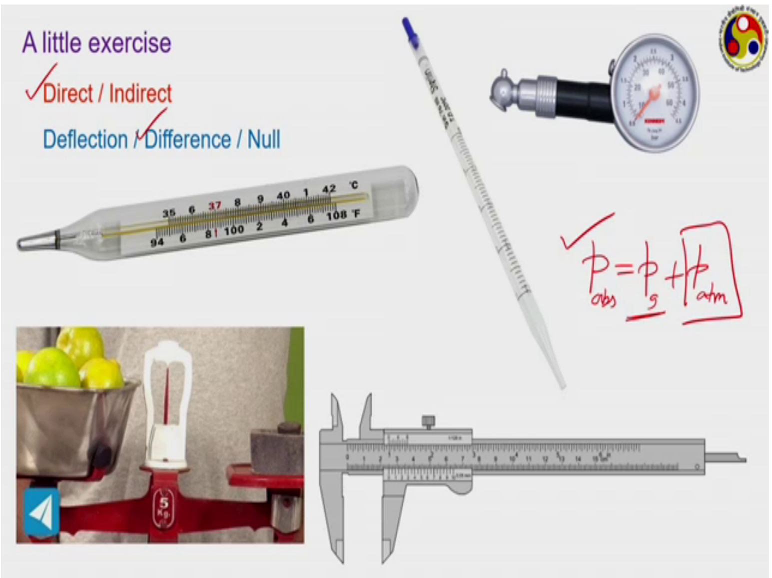

But, if our interest is to know the absolute pressure, then you have to the final pressure value which is the absolute pressure that your looking for that will be the gauge pressure returned by this gauge plus the atmospheric pressure, which you have to collect from some other source (Refer Time: 10:02) something that means, here we do have a reference.

And hence depending on our objective again I repeat. If our objective is to measure only this quantity, then it is a deflection type instrument whatever is objective is to measure the absolute value, then you should classify this one as a difference time instrument, because here we have a reference. And then rest part of that we are measuring with respect to or we using our dial gauge or using our instrument. So, an absolute this one can be considered as an difference type instrument.

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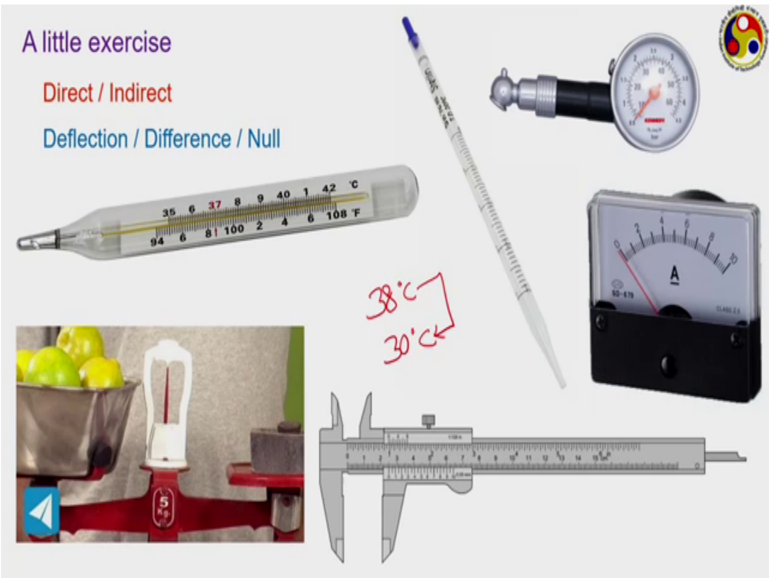

And let us move to the last example that I have that is for an ammeter for measuring the current through some kind of conductor. So, what kind of instrument is this, again a direct type and we can definitely call it a deflection type instrument, because here again the indicator that we have here this particular indicator, this indicator is going to move over the dial in this direction to reach to the final value corresponding to the measurement. So, it is again another deflection type instrument.

So, this we can classify any instruments into either of this three categories and all the six examples that I have here are direct type. But, in near future in the course, you will also be introduced several indirect kind of measurements.

Now before I move to the next slide, I would like to point out to something else. Look at this particular one. Here your objective is to measure the mass of something, and as a standard what you are using again the mass. So, your measurement and standard both are mass. And hence this is directly giving a value of the mass of the of your measurement quantity.

Similar, this one directly give you the length, this one is directly giving the volume of the corresponding measurement. But, now look at the thermometer, in the thermometer our objective is to measure temperature, but actually are you measuring temperature directly here probably not. Because, when we take this bulk which is a pool of mercury in common in contact with human body, then as the human body is in some other temperature, then this then this bulk there will be kind of heat transfer.

Let us say our human body is at a temperature of 38 degree Celsius and the thermometer initially is at 30 degree Celsius. Now, this temperature or the body being higher, definitely it is going to lead to heat transfer from the body to this bulk or to the mercury to at the bulk and because on receiving this heat the temperature of mercury itself will keep on increasing till it attains a thermal equilibrium with the body itself that means, till the temperature of mercury within the capillary attains this 38 degree. So, there is about 8 degree Celsius increasing the temperature of the mercury.

And like any other material with increase in temperature mercury also will expand in volume and that increase in volume will be manifested as a change in the length of the mercury column within this capillary. And actually what we are measuring is the change in the length of mercury column in this capillary tube that means, while you are trying to measure temperature, we are not getting a direct measurement of temperature. Rather we are only measuring the change in the length of the mercury column.

Like, initially at 30 degree the mercury column will be somewhere here. And at the end of the measurement when the mercury attains thermal equilibrium with the body, you are you are column is maybe somewhere here that means, there is this much of increase in the length of the mercury column inside capillary.

And then during the calibration process, we are trying to identify the correspondence between the change in this length and the corresponding change in temperature, change in the length of volume of this mercury with the change in temperature of the mercury, and that gives us a measurement of the temperature of the human body concerned that means, while we are trying to measure temperature, we are measuring it in terms of a change in length.

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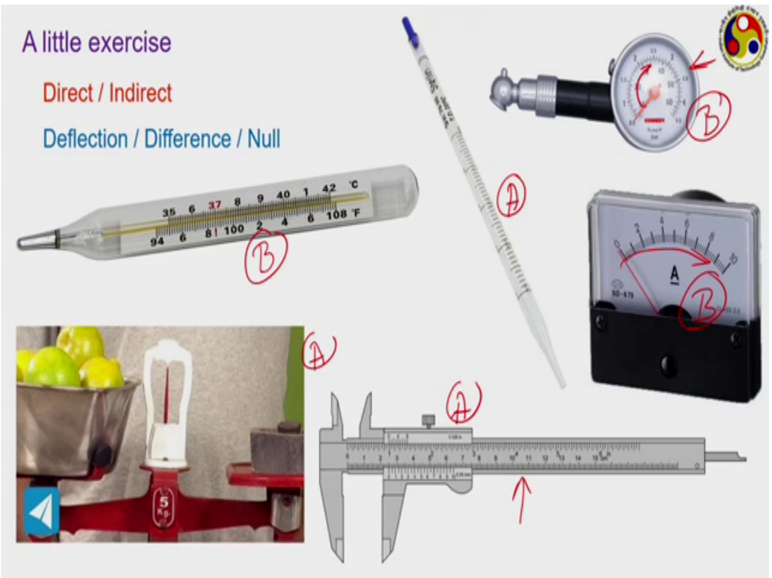

So, while the first three kind of instrument of let us say this one, this one and this one, we call them type A instrument where we are measuring exactly what we want to measure, but this is a type B instrument where we are not measuring, what we are trying to measure rather we are measuring something else and then identifying a correspondence between our objective measurement and this modified one.

The same situation is happening here in this tyre gauge, here we are trying to measure pressure. But, what you are measuring is only the angular deflection this indicator is having over the dial. And then we are trying to identify the correspondence between angular deflection and accordingly we are drawing a pressure scale on this, so this is also a type B instrument.

What is happening in case of an ammeter? Here also depending on their different kinds of ammeter, but in generally most common one we have a permanent magnet type instrument where the current which is being supplied through a conductor leads to a deflection of the conductor in the magnetic field that means, here again will current is actual objective actual measurement, we are converting that to a deflection probably angular deflection over the dial and measuring that angular deflection. And then we are identified the correspondence of this angular deflection with the actual objective, which is current in this case or pressure in this particular case.

So, this is also a type B kind of instrument that means, you can clearly see there are two kinds of instrument possible. One where we directly get the measurement whatever you are trying to measure, we get the output from the instrument in terms of that only. Like in a in a calliper our objective is to measure length and our output is also coming in terms of length. But, in all this type B instruments our output is coming not in terms of the measurement, but in terms of something else.

Like in case of a thermometer our objective is to measure temperature or change in temperature, but the output is coming in terms of change in volume or may be change in the length of mercury column in the capillary. So, there are this type B kind of instruments probably are much more common than type a unless in very simple situations like shown here for measurement of length or volume or mass, we can use this type A kind of instrument but, for most of the measurements, we have to go for this type B instruments.

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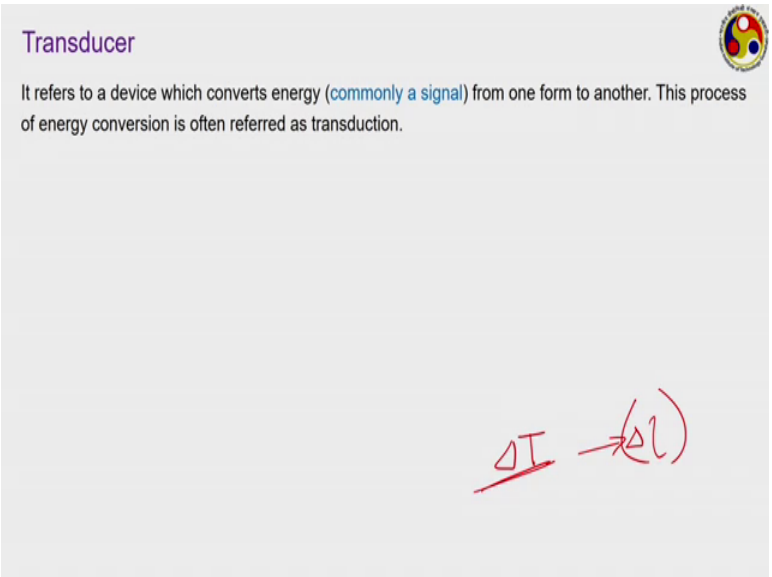

And in that context, I am going to introduce with this particular term transducer. Transducer is a device which converts energy from energy one form to another form. This particular process of energy conversion is often referred as transduction like thing about the thermometer again.

Here our input to the device is some temperature change delta T. Thermometer initially was at 30 degree Celsius and then the mercury receives initial thermometer was at temperature 30 degree. And come in contact with the human body, it is its temperature is increasing to 38 degree. So, we are having 8 degree temperature difference, which is this delta T which is your actual input signal.

But, your output is coming in terms of a change in length of the mercury column in your capillary. So, there is a change in the signal while your input is a thermal signal thermal energy output is coming more like output is getting manifest in terms of a volume or length.

Like in the tyre gauge our input is pressure or maybe force, but output is coming form of deflection. And that the device which does that particular thing is called a transducer. Transducer can be anything like any measuring instrument therefore can be categorised as a transducer, it can be any device depending on the output, we can call it a mechanical transducer like the pressure gauge, where you input is force and then output is coming the deflection which is which is a mechanical kind of output may be in thermometer also we can call them mechanical transducer.

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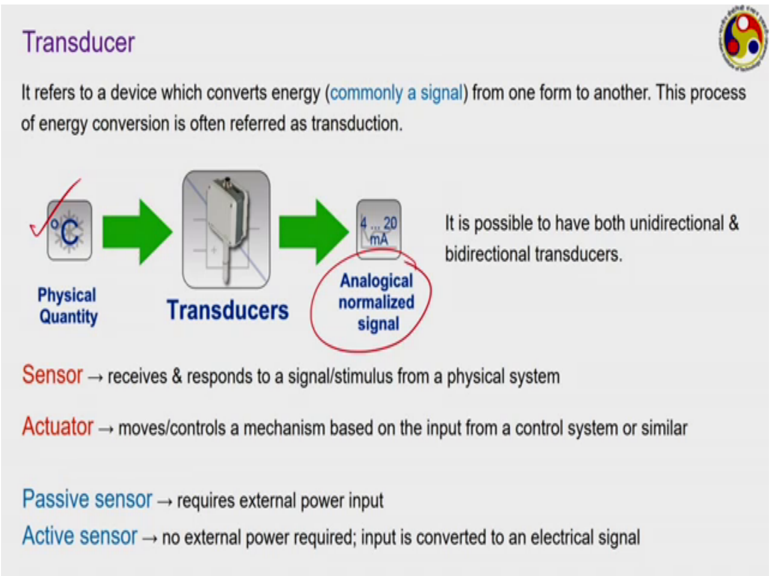

But, this is another example were some physical quantity in a transducer getting converted to an analogues signal, but here also we are measuring temperature. But, your input temperature is temperature sorry input signal is temperature and output signal is some electrical quantity like what happens in case of a thermocouple.

We shall be talking about thermocouple in the concerned module, but the is there here your input has been converted not to a mechanical output like in a common mercury thermometer rather to an electrical quantity. So, we shall be calling this one is a electrical transducer. So, we can have a mechanical or electrical transducers, we can have other types also, but mechanical or electrical's are the once which are commonly used for mechanical measurement.

A transistor can be both unidirectional or bidirectional. Unidirectional means all these examples where the input is being converted to certain another kind of signal or actually transducer can do the other one also, it can take some signal and convert to some output we shall be seeing that examples. So, unidirectional transducer refers to only one direction of this transformation, but there are bidirectional also which can convert your input signal to something some other form, and again convert that some other form back to the form of your input signal like an antenna.

The antenna receives the electromagnetic waves and convert that to some kind of audio, video signal which reaches your device may be the television, but it can do the other thing also. It can take the audio visual audio visual signal from there and convert that to the magnetic electromagnetic waves sending it back to some further destination.

Some similar you can also think about our phones to be similar kind of devices. Like the electromagnetic waves comes to the receiver, where it gets converted to the sound energy. And then when we are talking the sound energy gets converted back to electromagnetic waves, and then that goes to the destination location. So, those are bidirectional kind of transducer.

Now, transducer again we can commonly identify of two types; one is a sensor which receives the signal from some physical system and prepare some according response. Like the one example shown here, it is receiving the signal in form of a change in temperature and converting that to an electrical signal which will be used for further processing.

And the other one is actuator; actuator will take the signal from some processing unit. Sensor generally sends the output to some processing unit commonly, but the actuate will take it from some processing unit of or from some control system and then will perform some kind of mechanical work.

Like in case of that tyre gauge if you think of the pressure signal, which is being supplied to your device has gone through some steps of conversation by some mechanism what is there or we may think about that ammeter that is a much better example probably, where we are supplying current as the input. Now, your transducer is converting the current to a mechanical signal, which leads to the movement of this indicator over all over the dial that is we shall be calling that as an actuator.

So, transducer primarily are of two types sensors and actuators, but we can have other kinds of transducers also. Sensors are primary related to the input of the measurement system, which takes which is in direct count of your contact of your physical system takes the input. And if required converts into some other form, where actuator take the input from the control system, and primary is raised to the output where it gives you the output in the desired formed.

We can also a passive and active sensor. Passive sensors are those, which does not require any external power input, but active sorry passive sensors require an external power input. But, active sensors does not require any external power input, the input itself is converted to an electrical signal like in this case in case of a thermocouple, where despite thermal energy being your input, it gets converted to electrical signal and that electricity itself will be used for further processing, so that is a kind of active sensor for examples of passive sensors we shall be seeing shortly.

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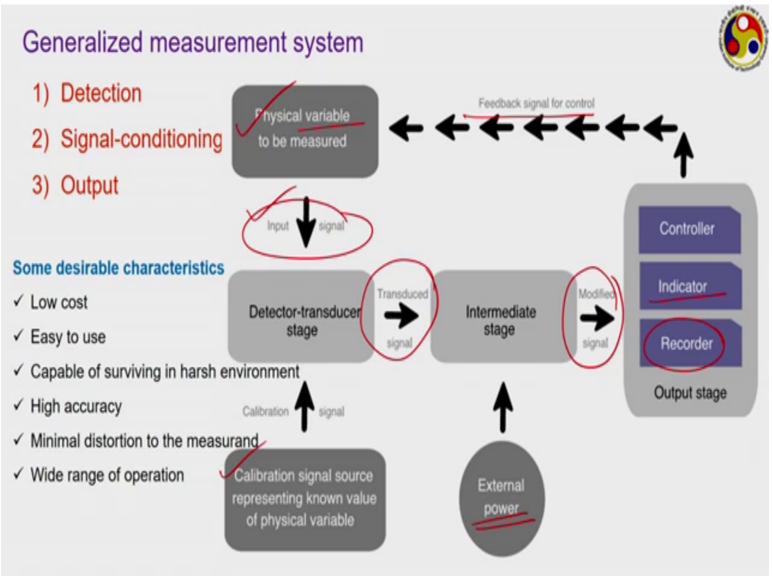

Next move to the general structure of the measurement system. So, in a measurement system all the components whatever simple it may be, whatever complicated it maybe, we can generally identify three different blocks; one detection block or input block, next is the signal-conditioning block and next is the output block.

This can be thought about general structure where our detection transducer stage or the input stage takes the input from your physical variable or physical systems. And if required it can also take the signal from your standard, so this input signal and calibration signal will lead to some kind of transform transduced signal. This transduced signal will go to the intermediate stage over the signal conditioning or processing stage, it may require external power depending on the nature of this weather it is active or passive kind.

And then the transduced signal, we will get converted to some desired form of output here in this intermediate stage. And this output will be going to your output stage whatever form you need whether you need it on some kind of indicator like on excess of dial gauge or whether you want to direct it to some printing device or we want to direct it to for recording to some computer CPU kind of storage, then this output will be recorded there.

And if we are talking about a feedback system like controlling the input itself, then it can also send some feedback signal back to the physical variable itself for changing the value of the physical or I should say changing the value of the input itself, which will be done by the feedback signal if required.

There are several characteristics that we want our measurement systems to have. Like it should be low cost, it should be easy to use do not need any special like a thermometer generally easy and we there is hardly any expertise required to use a thermometer or common clinical thermometer. So, we prefer to measure the temperature of our body using a thermometer despite having a several much more accurate instrument available.

The thermometer or I should say the instrument should be capable of surviving every harsh environment, like there are several situations where we may have to make some measurement in very rough situation. Like think about another temperature measuring gauge, which is measuring the atmospheric temperature. Now, depending on the condition, it may be exposed to very high temperature may be 50 degree Celsius, maybe very low temperature something very close to 0 or in colder countries, it may be well below 0 degree Celsius. It may be exposed to very strong wind, dust particles etcetera, so it should be have should be able to survive that kind of environment.

High accuracy is always desirable, we want the measurement we both reliable and accurate, you probably know the difference between this two terms from our previous lecture. It should cause minimal distortion to the measurement that is very very important, because there are several instruments which draws the energy required for its own operation from the measure and body itself. And if the amount of energy it is drawing is very high, then it may cause a change in the measurement itself.

Like think about the we are going back to the clinical thermometer again to cause the change in the volume or to cause a deflection of the mercury column in the capillary, the mercury itself want some kind of thermal energy. And thermal energy it is being drawn from the body of the concerned human.

Now, if it draws too much amount of thermal energy such that, it causes a change or a reduction in the temperature of the human body itself, then definitely there is something wrong with this. It should draw that much of energy only which will not cause any change in the measurement value or may be insignificant change in the measurement value. And also the range of a operation should be wide and also it should suit whatever target application that we have.

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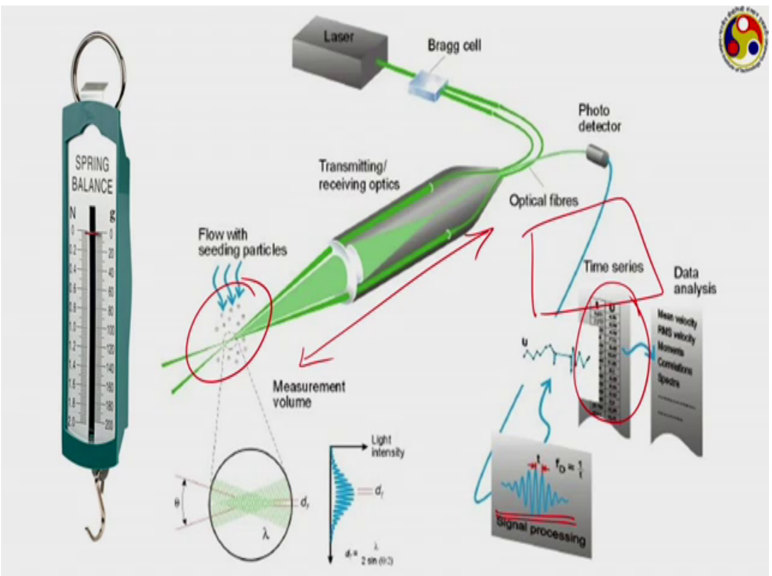

Next we talk about a few examples again. First we have a spring balance; you know spring balance is used to measure the weight of something. So, we put the measure and somewhere here, and that causes that corresponding gravitational force causes a deflection of the spring, which is inside the inside the body and the deflection of the spring causes a change the position of this indicator.

So, from the final position of the indicator, we get the value of the weight in terms of whatever unit we desire, in terms of like the example here shows one Newton on one side and maybe in terms of mass scale the kg mass or kg force or ground force on the other side.

Now, try to identify the three stages here. What is your input stage here, your input stage is this this hook here, which is sensing the gravitational attraction or gravitational pull on this and converting that to some form of again mechanical force maybe on the spring which is inside. Your processing stage here corresponds to the spring that spring take the mechanical pool from this input stage and converts that to again some other kind of mechanical pool of the indicator allowing the indicated to move.

So, this hook itself here is acting as the sensor with sensing the input and converting that to some kind of signal, which will be used by your processing part, which is the spring. And the spring is all acting as a processing unit was also as the actuator, because it is a spring which will make the indicated this indicator move.

So, the indicator the movement of the indicator is going to give you the final read out. So, your indicator is output stage, which will receive the actuator signal from the spring, and accordingly change its position giving you final output. This is a very very simple example, we can have much more complicated examples also just without going to the details of this example of flow measurement using a laser based instrument, where your flow is somewhere here, we have put some fluorescent particles in the flow.

So, the fluorescent particles and also receiving some kind of illumination from light and accordingly your input signal is available forms of light. You imagine that we have some flow of some say some gas like air, the air is carrying some kind of particles which can give some kind of fluorescent image that can glow, when they are subjected to certain frequency of light, that light is the input signal that input signal is received by the process the input assembly here. And that converts that to several series of processing in your processor which may be somewhere here. And then finally, the processor gives you the output, your output can come in different from like a form of signal, like a form of a chart, and several others. So, this can be a very very complicated kind of measurement process.

But, in any measurement process we can always identify the three stages the input of signal detection stage, the processing stage and also the output stage. Think about the thermometer again, we are always going back to the same examples. What is your input sensor? The mercury bulb is the input sensor. What is your the processing signal signal processing stage, again the mercury itself.

And finally, your output stage is the mercury column and its positioning position of the tip of the mercury column on the corresponding scale. So, the same component can also act as multiple stages depending on instruments, which are in simple instruments, we can find some kind of situation. But, in other kind of instruments complicated instruments, we can clearly have three different stages.

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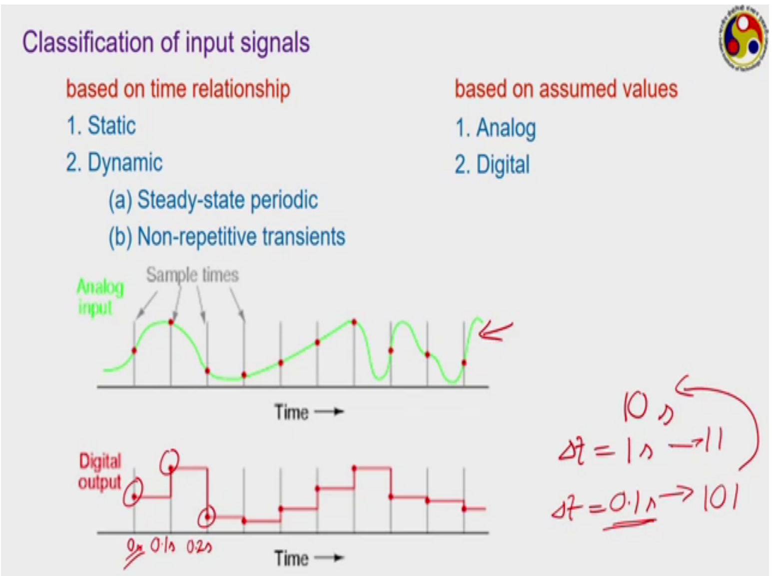

Now, the input signal the input signal can be classified primarily into two categories or we can have primarily two kinds of classification. One based upon the time relationship means, how the input signal is wearing with respect to time. And second is based upon the nature of the magnitude of the input signal. The based on time relationship we can have static or dynamic. Static refers to the input is not changing with time.

Like the when we are measuring mass of something using common balance, the mass of the body is not changing and then is a static signal. When we are measuring the pressure of the vehicle tyres using a tyre gauge, the vehicle tyre pressure that is not changing that is a static signal. But, if the dynamic single refers to when it is it keeps on changing with time that means, suppose we have taken some volume of water put that on an oven and the oven is switched on, so that heat is being added to the volume of water.

Now, it takes some temperature measuring instrument and dip that into that pool of water. As the water receives heat the temperature of water pool also keep on changing, and accordingly the input that is going to a temperature measuring instrument that is also changing that means it is not a static signal any more that is a dynamic kind of signals that is a signal, which is changing with time.

Dynamic signal can be of two types again; o ne is steady-state periodic signal, other is non-repetitive transient signal. Periodic means where as the town suggest we have some kind of periodicity that is a cycle of input gets repeated over a particular interval of time.

The other one when that is there is no such kind of repetitive nature, we have non-repetitive signal. Repetitive signals can be we can think about cycles like the time of day over a 12-hour period the time gets repeated time itself. We can have the high tide and low tide kind of situations, where the level of water in river erosion that keeps on changing with time. And also there are several common large scale instruments also can lead to periodic change.

And non-periodic where we do not have something like the atmospheric temperature general is a non-periodic kind of input, which keeps on changing with time without any kind of repetition of periodicity. Based on as assume value we have the very very common kind of input classification analogue and digital. Analogue means, which keeps on changing with time continuously and for every time instant we can have a value. Whereas, digital means, we are picking out a value only at certain time interval, and instead of having a continuous representation of the input, we have a discrete representation of the input.

Here is an example, the one of the top is shown in green is an analogue input. Here for every value of time, we have some value of the input signal, like here for this time we have value of input, for this time we have value of input, for this time also we have value of input.

So, theoretically speaking we can have infinite number of values for the input signal, it is a continuous representation such kind of continuous representation, we can get in several very common instruments like a thermometer or like a tyre gauge as the temperature keeps on changing, it is also the mercury column or tip of the mercury column also will keep on changing its position, accordingly giving us a continuous representation like the analogue one.

Digital however is we are not going to take the temperature or sorry that is single valued all the time, rather we are going to take it only at certain time intervals. Like, here we identified this is the time this is the time, where we want to take out the value. And so we are getting this particular value.

And next we have decided after a certain time interval apart, we are going to take the second reading which is here. And there we are getting going to get this particular one. And this way after a fixed or changeable time interval apart, we keep on getting the values of corresponding signal like here, another one here, another one here that means we do not have infinite number of values rather we have only finite data set to deal with.

Of course, how many data that we are going to get that will depend upon the length of this time interval. Like say we let us take an examples say, we are going to record the signal of something over a period of 10 second.

Now, we can definitely capture the analogue signal over a period of 10 second and analogue signal will be coming in form of a graph something showing very similar to this. Theoretically, we can get infinite number of data points for any time value, we can get the corresponding signal. But, if we want to digitise this, then we are not going to take the continuous signal rather we are going to take the signal only at certain intervals. And that interval is our choice or generally based upon the instrument that is available with us.

Let us say we have decided to take the interval, after every 1 second. So, your interval length delta t is 1 second that means, at time 0 we get a first signal let us let me draw it here. Say at t equal to 0 second, we take one signal here, which is this value. Then at 1 second, we take another one here, at 2 second we take another one here, this we keep on taking signals and total over a period of 10 seconds starting from 0 upto 10, we are going to get just 11 set of data.

Instead of having a continuous representation or an infinite number of data sets, we are going to have only 11 number of data sets. If our instrument is much more advance instead of taking at once second effort, let us change delta t to 0.1 second that means here our first data will be coming on second apart, the next data will be coming at 0.1 second, next one at 0.2 second. And we keep on continuing this way that means, over one particular second, we can acquire 10 number of total data's. And this way over a period of 10 second, we are going to get total 10 into 10 plus 1 for this particular 0 total 101 number of data set, where it was just 11 in the previous case. So, you have much higher number of data set.

And this way by reducing the time interval, we can keep on increasing the total number of data point that we have. Now, that will depend upon the capability of your instrument and also how much data said that we can handle or we need to handle more number of data set, of course this digital one is approaching the analogue one that is as we keep on increasing the number of data sets or keep on decreasing the time interval the digital signals keeps on approaching the analogue signal, like shown in this particular example.

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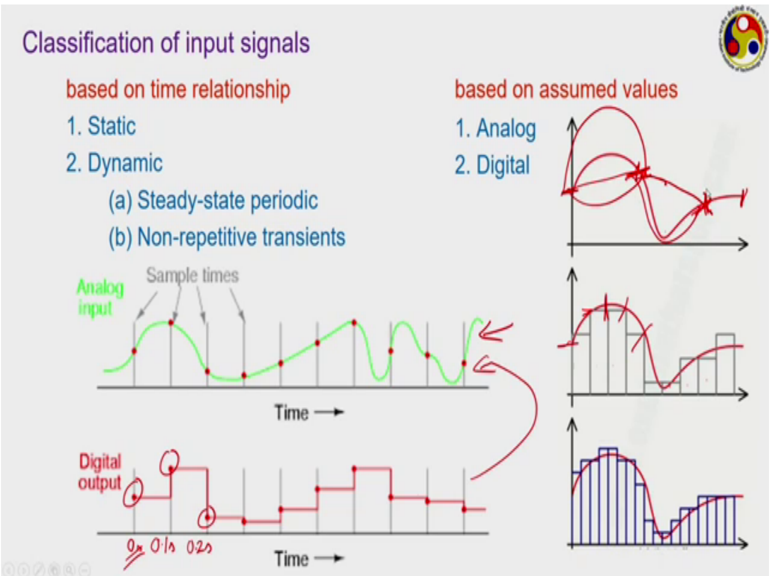

Here we have this analogue signal initially, then we have a digital signal. The over all interval we have into 1, 2, 3, 4, 5, 6, 7, 8, 9 total 9 intervals; that means, instead of having a continuous representation, we are going to get only 10 number of data points or maybe just maybe may be 1 here, then number-2, then number-3 here, number-4, number-5 this way you are going to get 10 data points. And those 10 data points will be representing your final data that means, instead of having a instead of having a continuous curve like this, you are going to get only a set of data. Like one here, another one here, another one here, another one here, another one here and like this and from there we are trying to trace the final curve.

But, if you delta T is too large and number of data is too small that may lead to some trouble to you. Like say you have got one data point somewhere here, next data point here, next data point here and the final one here only for four data. From there can we retrace the original curve that is very very difficult, because you have one point here, another here and ideally you may think about there are infinite possibilities. It can be a line like this, they can be joined by line like this, they can be joined by line like this etcetera.

And from this particular point, we can never come while coming to this particular one, we can never trace the in between portion, because how can we guess that this portion will be not something like this and actual one. It is so we definitely need more number of data to represent.

Like in this particular example while we had only 9 number of data set in the previous case, we have much large number of data sets. So, you have more points to trace back the original curve. So, larger the number of data smaller the time interval, the digital single signals keep on approaching the analogue signal and there is much higher chance of getting a correct measurement.

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Factors	Analog	Digital
Waves	Denoted by Sine waves	Denoted by Square waves
Signal	Continuous signal representing physical measurements	Discrete signal representing discrete time signals generated by digital modulation
Data Transmission	Subject to deterioration by noise	Noise-immune without deterioration
Bandwidth	Consumes less bandwidth	Consumes more bandwidth
Memory	Stored in the form of wave signal	Stored in the form of binary bit
Power	Draws large power	Draws negligible power
Impedance	Low impedance	High order of 100 megaohm
Errors	Analog instruments have considerable observational errors	Digital instruments are free from observational errors

But, still digitisation has his own advantage. Like in case of digital signal, we get a sin wave or basically a time varying signal, whereas in case of in analogue in case of digital we get only square waves. Like in the previous if I go back, here we are having only square signals like this. The continuous representation we get in analogue digital only discrete data points. In analogue there is a big probability of some deterioration from noise as we are acquiring continuously the actual signal and all those interfering signal can also come into picture.

In case of analogue as we are taking at certain point that is highly to the noise. The bandwidth requirement of course can be much more. In case of analogue, we can store in a wave signal, but here we shall be storing more in binary or similar kind of format.

And also the power requirement is also much lesser in digital, and it is much easier to process the digital signal during the signal conditioning stage, and that is why the digital signal has its own advantages. And that is why, they the trained for modern instrumentation is to move towards digital. We shall be discussing more about digital signal and analogue to digital conversion in the 3rd model of our course.

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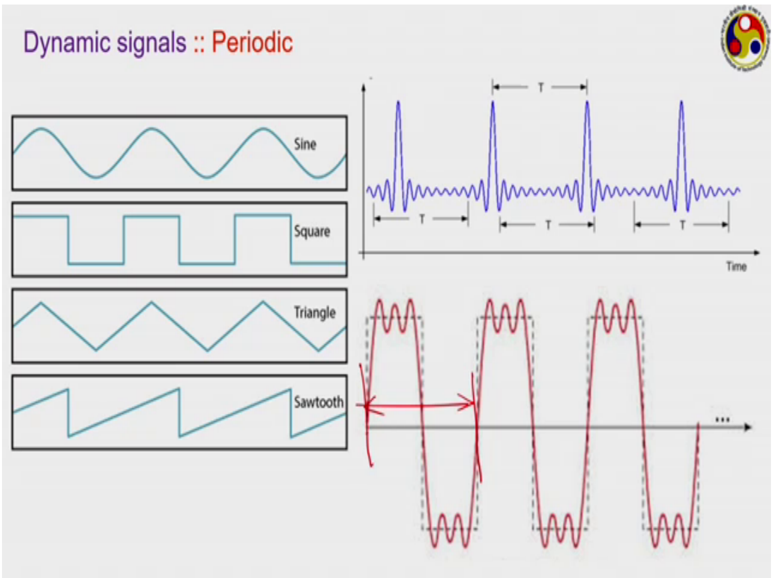

Now, dynamic signal periodic can be something like this, we can have several kind of representation. Once we have some kind of repetitive structure time, we can we shall be calling that periodic signal, we can have very much more complicated shapes also like the one here, it is there is definitely repetitive nature, but the signal itself is very very complicated or another one here. Again repetitive signal, but we have to considered a big time interval like this much to see the repetitive measure. If we are not seeing over a long interval, we shall not be able to capture this repetitive nature.

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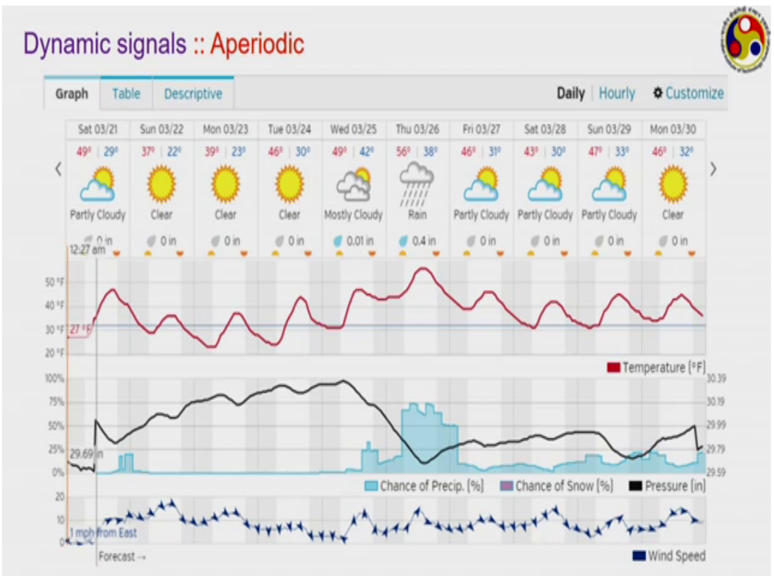

Aperiodic like the variation of temperature over a period of day or over a much longer duration the any kind of whether data that is only the example of a dynamic signal, which is not periodic in nature at all. And in several measurement situations, we face with a period dynamic signals.

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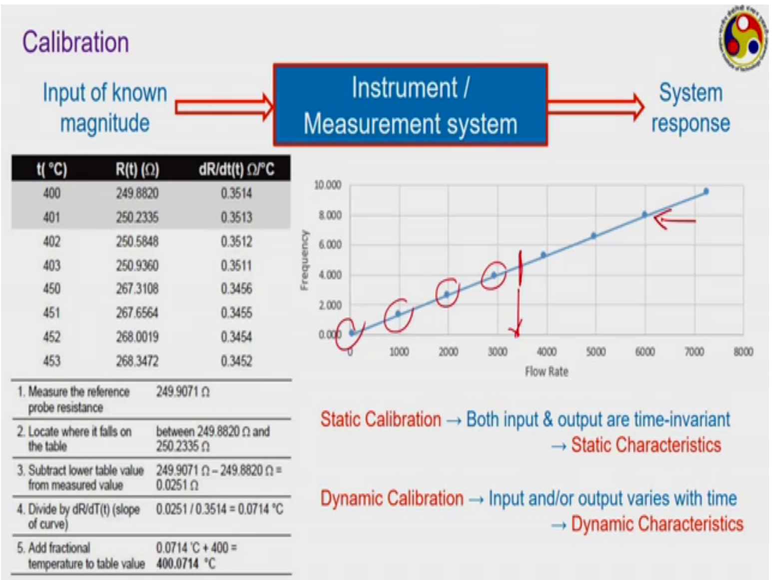

Now, we come to the stage of calibration. Any instrument has to be calibrated to start with and calibration means, the instrument will be subjected to a known magnitude at the input stage and output stage, whatever response we are getting in whatever may be the form we are going to record that and then try to identify the correspondence with your input.

Like shown here, we have a an instrument which is generally known as resistance temperature detector, which I shall be talking the principle of this later on. But, here the idea is corresponding to each temperature, we measure the resistance of a conductor. So, you can see here we have a calibration table, this kind of the chart is called calibration chart. Here corresponding to each temperature we have measure the resistance of a conductor or also corresponding gradient on the curve.

And now if we want to measure some unknown temperature, then we take the probe or take the measuring instrument in contact with that body and corresponding measure corresponding resistance is coming to be this, then we try to identify where it falls in the table. In this particular is it is falling in between these two values, then we perform some kind of interpellation that is subtract the lower value from the measurement and then divide that by the corresponding slope which is 0.3514 in this example. And that is going to give you with the final addition is going to give you the final temperature of the unknown quantity.

So, during any calibration process, we have to find a calibration chart to identify the correspondence this. Even more popular approaches is to get a calibration curve like this, where your input like here the input in this example is fluid, but output is coming terms of frequency of some instrument. So, we these are the points where we have taken the reading some known flow rate corresponding frequency of measured and we have tried to represent them with a straight line or some other suitable curve.

Then when we measure some unknown quantity unknown flow rate see the corresponding frequencies falling here, then easily from the curve we can identify the flow rate this. So, this calibration curve generation is a must for any instrument to start with. Generally the instruments whenever we purchase a new instruments, simple of complicated whatever maybe that comes with a calibration chart provided by the manufacturer, but it may be required to recalibrate the instrument repeatedly after a few periods of operation.

Now, we do this calibration based upon time invariant input and output signal, we call that static calibration. And corresponding curve like this particular curve is called as static characteristic curve or static characteristics. However, when both inputs and outputs are at least one of them are varying with time, we call that a dynamic calibration which is much more complicated and because at every time we can have different nature of the signal. And corresponding characteristic curve or calibration curve is called dynamic characteristics.

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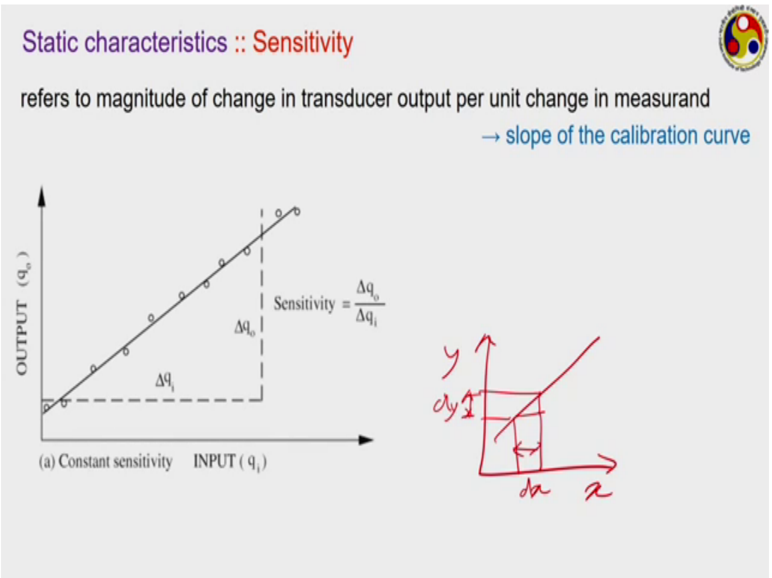

Let us discuss about a few properties of the static the characteristics, which an instrument must have. The first one and the most important probably is sensitivity. Sensitivity refers to the magnitude of change in a transducer output per unit change in the measurand means, it gives you the slope of the calibration curve.

If this is your calibration curve, say x is your input, y is the output that you are getting from your transducer and this is the calibration curve that you have got, then this is going to give you the slope of this curve. Like this much of change in your input dx, whatever change in your output that you are going to get dy that is the sensitivity of the instrument just like this.

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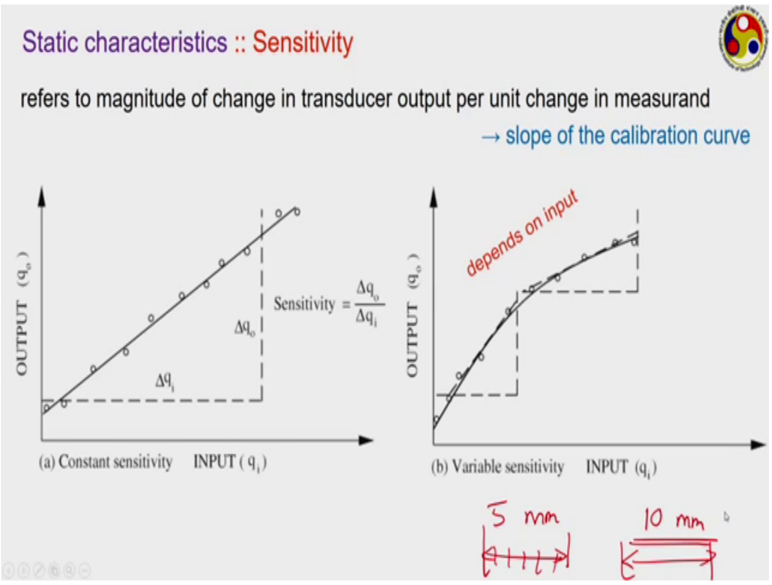

So, this in this particular case the slope does not change with the change in the input, so we call it a static constant sensitivity how we may also face situation, where the sensitive at instrument keeps on changing the input. Then it is a variable sensitivity, because it is depend on the input.

Now, can you tell me, what you want? You want higher sensitivity the instrumental or lower sensitivity. Definitely we always want our system to be more sensitive. Like think about the thermometer example again. We have got a change of 10 degree Celsius temperature. Now, if the 10 degree Celsius change in temperature causes an increase of 5 mm length of this mercury column that is in case one and another case it causes 10 mm length change of the mercury column, then which one is most sensitive? Definitely this one, because here the change in output for the same amount of input is more, so it is a more sensitive instrument. And see the use of use.

Now, here over a distance of 5 mm, we have to plot a we have to draw a temperature scale showing 10 divisions at least to show that to indicate 10; 10 degree change in temperature that means, for every milli meter we have 2 degree change, but here for every milli meter we have 10 degree change. And so much more easy to draw the temperature scale and so we should always go for an instrument with higher sensitivity. But, sensitivity does not need to be confused with accuracy, which we shall be discussing later on.

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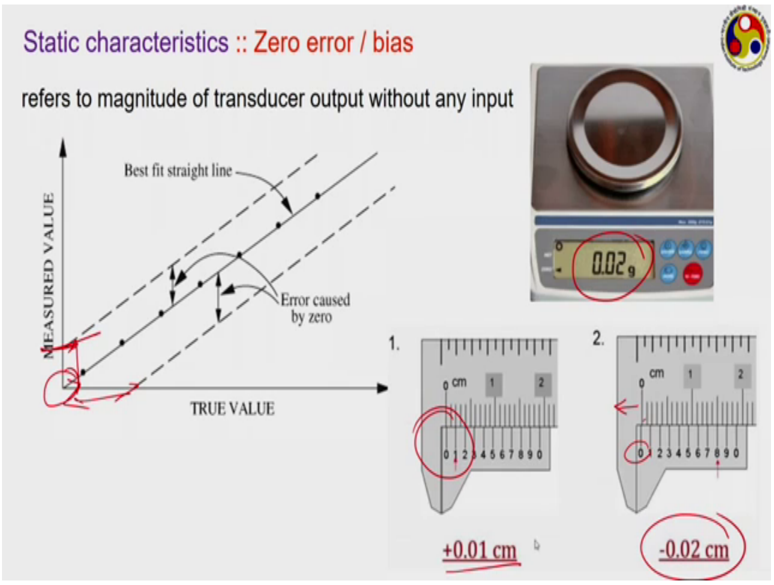

Next is zero bias, it refers to the magnitude of the transducer output when you are not given any input at all. There may be several situation like ideally in case of ratio measurement particularly, we want the output to be 0, when there is no input. But, sometimes your instrument itself, we have some error inside and it starts the reading from some this particular point itself. You must have seen such situations with us weighing scales.

You have not put anything, but it is showing some reading here that this is what we refer to as zero error or zero bias, it can be both on positive side or negative side like in this case. So, we have to be careful of your instruments about this zero bias and you have to ensure that the instrument indicate zero output, when there is no input. And if at all there is any zero bias, which we have to dealt with you need to keep a note of that, because whatever final reading that you are going to get, you have to add that zero bias to get the actual value of the measurement.

Sometimes we can have an error in a scale itself. Like it is an example of Vernier, you can see that the 0 has been shifted here, leading to this much of zero error. Whereas, in this case the 0 of the Vernier is been shifted on the other side leading to this much of error. But, truly speaking both the 0 of the Vernier scale and actual skill should be collinear, which is not happening here as a permanent error in the instrument and we have to be very careful about such kind of zero bias or zero error.

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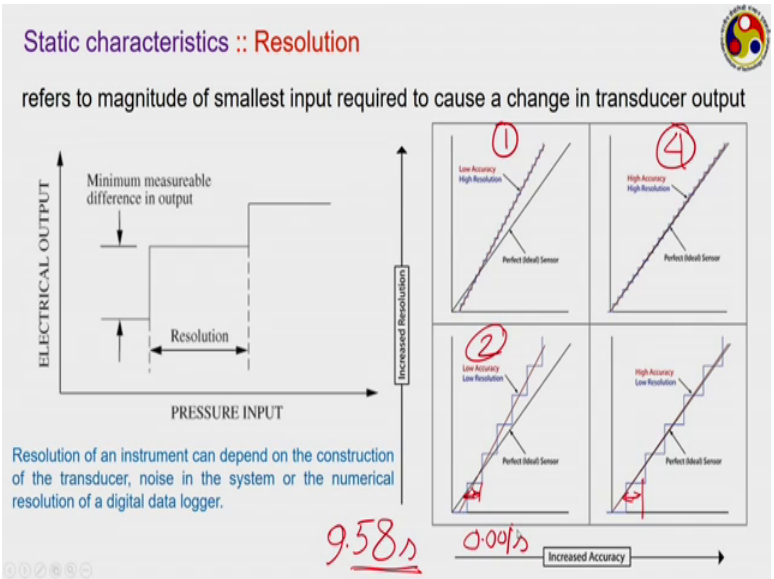

Next is resolution very very important for an instrument. It refers to the smallest input required to cause a change in the transducer output. Smallest change in input required to cause a change in the transducer output, this is different from sensitivity. Here like we are causing initially your system is having a pressure value of this and corresponding output is this.

Now, you are increasing the pressure, but the system is not able to show any output till we reach this particular level that means, over this entire duration or over this entire range of change in input your system is showing the same output value. Only when you reach at this particular point, there is a change in output to this. This is called the resolution of the input, resolution of the instrument, which also gives us an idea about what is the minimum value that we can measure by our instrument.

Resolution of an instrument can depend upon the construction of the transducer can also depend on the noise of the system if anything is present there or numerical resolution of the data Here we have a situation, there are several cases shown. Like this is the continuous line is the perfect representation or perfect output from sensor, which we want.

See from this particular case; case number-1, here your system is having very high resolution, because very very small change in input it is showing a change in output, but actually the value that we are getting that is not matching with the actual curve. So, it is high resolution, but low accuracy.

If you move to this here it is low accuracy, because it is moving away from the actual can also low resolution, because this much of change in input is required to cause any single change in output, so low resolution instrument. Now, this one here we are still at low resolution, because large change in input is required to cause any change in the output, but it is much closer to the actual curves, it is a high accuracy and low resolution.

And this number-4 is the one that is the ideal situation, which is low resolution and high accuracy as well. So, this kind of are always preferred. The resolution of the instrument is not that we always have to go for instruments with having very low resolution, sometimes also use another term call list count. List count also refers to the smallest value the instrument can give. It is not that we always have to measure instruments with very high resolutions like think about measuring time. When your measuring time say, we are presently Guwahati and we want to take a flight to Delhi and when to measure how much time is required during the flight.

Now, the time is coming in the range of something like 2 and a half hours to 3 hours, we can easily measure that to a common wrist watch for similar kind of watch, where the and in wrist watch what is the smallest time interval you can measure maybe a minute, maybe a second, so the smallest value that you can measure is 1 second. If there is any change in time you want to measure, which is less than 1 second your wrist watch will not give that.

But, the example that I am talking about here you do not need at all you, actually do not need any second also minute and hour are sufficient. But, you think about something say how much time Usain bolt takes to finish his 100 meter runs. I think the world record is 9.58 seconds. So, we are talking about measuring at time of 9.58 seconds.

Then can a wrist watch give that definitely cannot, because here we are not only trying to measure second rather we are trying to measure one of hundredth of a second that means, you need an instrument which is going to measure at least 0.1 second point that is the smallest possible value it should be measured with small changes and preferably up to third decimal because, there are several situations where you may have to go for a photo finish.

And there even two decimal points may not be sufficient, we may have to measure even the third decimal point also. So, there we need an instrument with such kind of resolution, but not always that depends upon application and accordingly have to choose the resolution of the instruments. So, resolution and sensitivity probably are the two most important characteristic, static characteristics a system should have.

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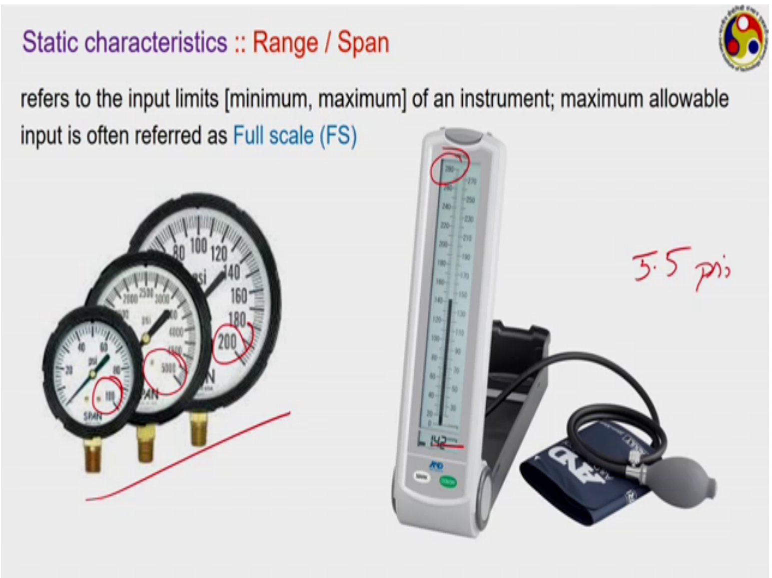

Range and span refers to the range as the suggest what is a range maximum and minimum the instrument can measure to a like the example of the run that I talked about. Here like in a wrist watch we can measure up to 1 hour in one in a dial, whereas when you are trying to measure any instrument or sorry we are trying to measure time with a resolution of 0.01 second, we hardly need to go for such long duration. Your instrument may give just a reading of total 0 to 10 second, 0 to 15 second that will be sufficient for that measurement. So, range will depend on the kind of application.

Like, here we have an example of acupressure gauges. You can see there are three pressure gauges all are giving reading in psi. Like in this case, we are getting reading up to 100 psi, here we are getting up to 200 psi, whereas here we are getting up to 5000 psi. So, there may be different situations accordingly, we shall be choosing the gauge.

Another example the what is this, I am sure you know this. This is the sphygmomanometer, sphygmomanometer which medical practitioners used for measuring the blood pressure. Now, what is the highest value that we have here 280, but

280 what is the reading or sorry what is the unit of this, we have to be careful it is psi, it is bar, none of them, it is milli meter of mercury.

Now, 1 milli meter of mercury corresponds to very small psi or practically one psi corresponds something like 51.7 milli meter of mercury that means, the scale of 280 psi is actually going to give you only approximately 5.5 psi that is a much smaller range compared to any one of the three. But, we do not need to go for a much larger range, when we are measuring the blood pressure. So, this manometer itself is sufficient in this case sphygmomanometer I should say.

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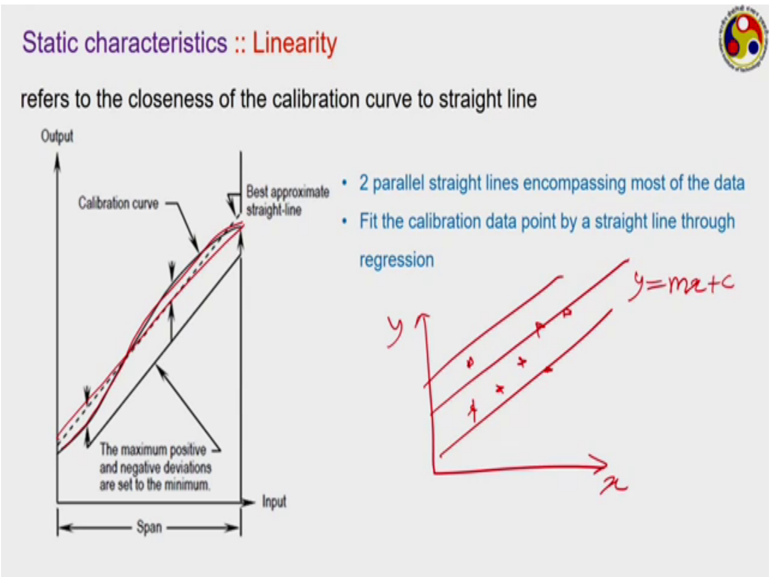

Another characteristic is linearity, we generally prefer to have a linear nature of the calibration curve, like but practically there are several situation we may not get. Like the input output relationship may be like a curve, like shown here. We are not getting a straight line here. If you get a straight line much easier to measure an unknown quantity, so we try to get the best approximate straight line from there.

There are two ways we can do it. One is to put two parallel straight lines like let me see an example. Let us say this is a input x, this is your output y and these are a few data points that we have got from during the calibration. Now, one option is we can put two straight lines, which at encompass at least most of the data and try to get a measure from there. Other is we try to find a calibration straight line something like this using a relation y equal to mx plus c and from use this one identify the value of m and c from this calibration curve used for unknown measurement.

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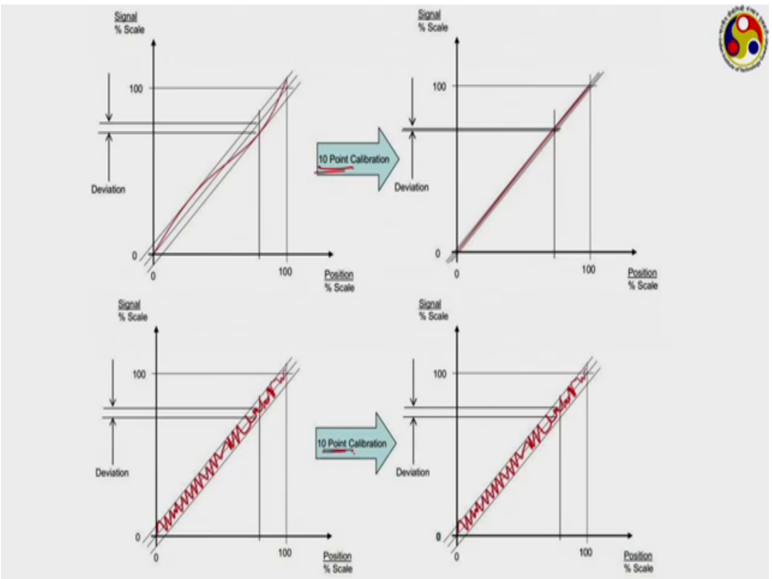

Linearity is a desirable property not always possible to get, but we would like to get the response as a linear one. Like here we have a non-linear response that we are getting by digitalising this what we are doing, we are taking up 10 points from this. And then we can see for such kind of regularise response, we are getting a much linear nature. But when your response is very very non-linear kind of nature or it is a highly time variant nature, then a 10 point scale is of no use.

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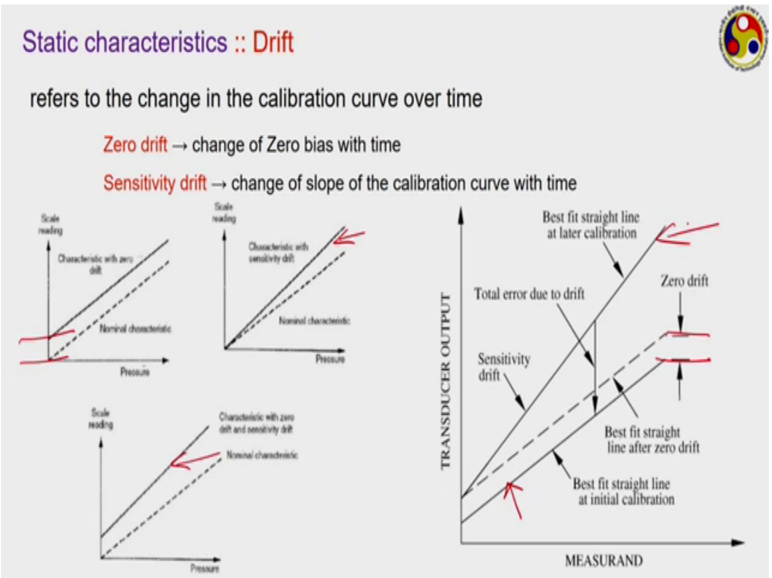

The final characteristic that you would like to talk about, this refers to the change in the calibration curve over a period of time. Now, once you have calibrated the instrument because of different kinds of ageing problem, warranty or certain damage the calibration may get shifted.

We generally have two kinds of drift. One is zero drift, another is sensitivity drift. Zero drift talks about the change in zero bias. Like these dotted one is the original curve, but with time the zero there is zero, but that make get develop that is zero drift. And the second one where the slope of the curve itself is changing that it is the sensitivity drift that in this case, it is a combined curve where both zero and sensitivity drift are present. When that kind of situation is there, we may have to go for recalibration, like in this case this one was the original curve.

Now, we have we can see there is a zero drift that has got developed on also there is a sensitivity drift. And so if you recalibrate this one may emerge as the new calibration curve that this drift, therefore essentializes repeated or periodic calibration of your instrument.

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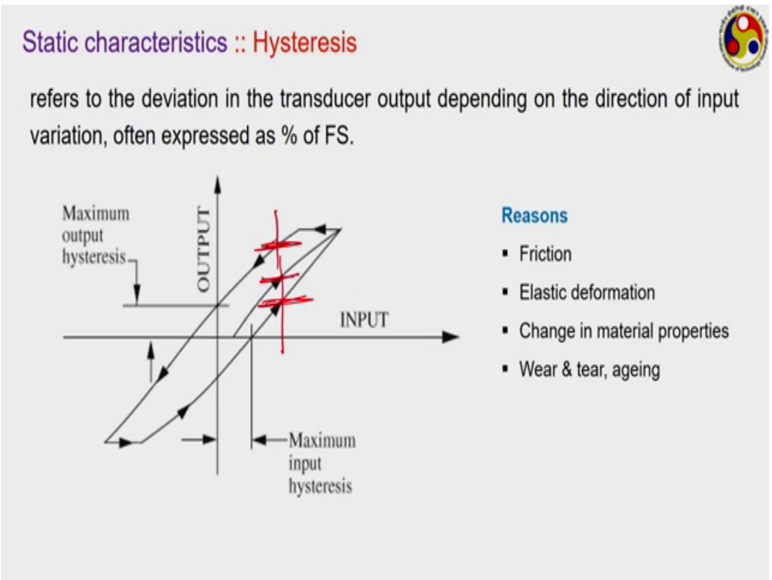

Hysteresis in certain instruments may show the hysteresis behaviour that is the output may depend on the change in input. Like when you are moving in the forward direction for this particular input, you are getting this output. But, when you are coming back for the same input, you may get this as output. And if there is a negative kind of slope while coming back again this is the third input that you are getting. Certain instruments may show a hysteresis depending on the friction, depending on some elastic deformation that may appear warranty or ageing problems, again repeated calibration can lead to some kind of solution to the hysteresis problem.

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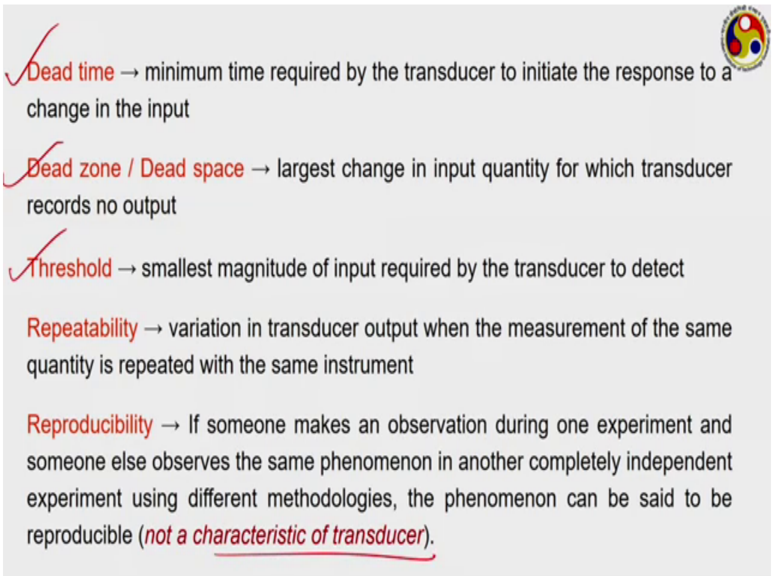

If you lesser is properties dead time refers to the minimum time required by transducer to initiate any response, like in this example itself. As now we changing the input of this period and not getting any kind of output, only after reaching here, we are getting any response from the output device.

Now, that is called dead zone or dead space. And after showing on output corresponding to input when you change the input signal, the transducer may take a certain amount of time maybe in seconds maybe in nanoseconds, but a certain amount of time to represent that on the output side that is referred to as this dead time.

Threshold is the same as the dead zone. The first value of the input for which we get the output is the threshold. Repeatability is we have already talked about this in the previous lecture, we need to repeat the experiment using the same instrument. And if all are coming very close to each other, we consider the instrument to be a reliable one and say that it has a good repeatability.

And reproducibility truly it is not a natural characteristic of a transducer, it is more a characteristic of the phenomenon. Suppose, I have done one experiment in my laboratory using a certain set of instrument and observe something. Someone is far away from the earth does the same experiment using different kind of instruments, and observe the same phenomenon that is called reproducibility. It is an important concept of any research any RND that is the phenomenon or observations that has to be reproducible. And ah, but it is an truly not a characteristic of the transducer itself. So, did this takes us to the end of different characteristics that we have we need to know static characteristics actually about and instruments.

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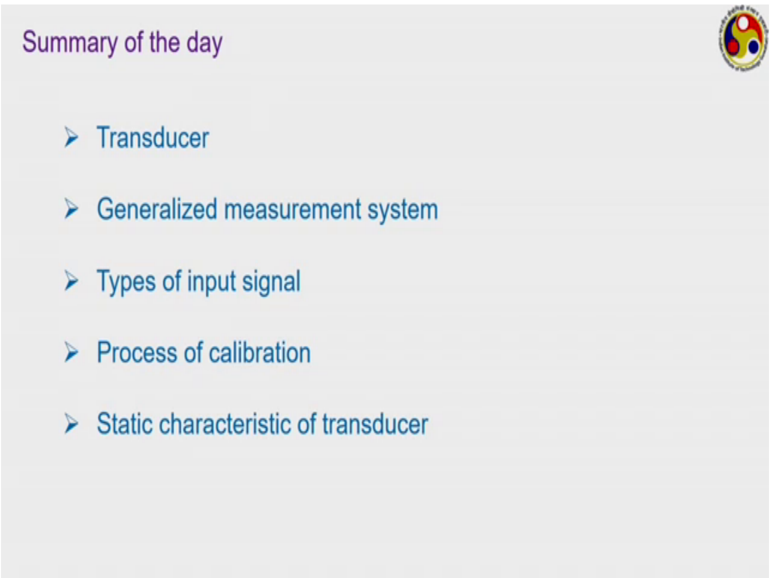

If I summarise the observation or the discussions of the day, we have talked about the transducers, actuators and sensors, then a general measurement system we have seen that. There are three stages an input stage, signal-conditioning stage and an output stage. Then we have talked about different types of input signal digital and analog, time invariant and time variant. And then we have talked about the process of calibration, corresponding static characteristics and dynamic characteristics. And finally, we have different kind of static characteristics a system or a transducer should have.

The most important characteristic for a transducer should is sensitivity and resolution, it should have high sensitivity, it should have a linear kind of nature, resolution will depend on the application and drift should be as low as possible and hysteresis kind of error if those are ideally that should not be present in the instrument.

So, in the we shall be continuing with this module-1 where we shall be discussing about the different kinds of errors that may (Refer Time: 61:02) in your calculation, and how to eradicate those errors and if you other relevant discussions to close up this first module. So, please wait till the next lecture, thanks for your attention for the day.

Thank you.