Process Control and Instrumentation
Prof. D. Sarkar
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 35
Instrumentation: General Principles of Measurement Systems

In this module of process control and instrumentation, we will now learned about instrumentation specifically we will discuss about measuring instruments core sensors that at used in process industry to measure common process variables such as temperature pressure flow rate of a fluid or liquid level. Science of measurement is very old and well advanced now. So, it is for us not possible to teach you every details of call the instruments that are available and for as it is not required also, but the purpose of this course or purpose of the module of this course is to give you a basic introduction to the instruments, that are used in industry for measurements of common process variables for process monitoring process control and safe profitable operation.

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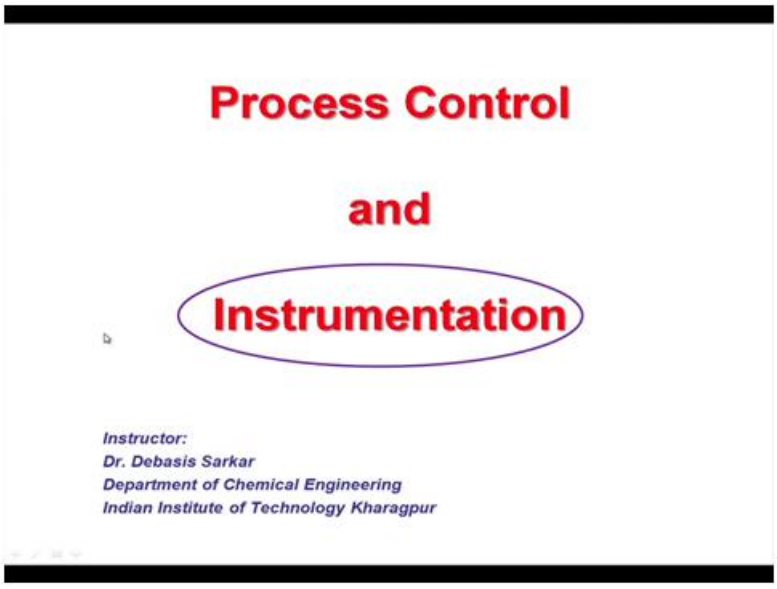

So, I will talk about the instrumentation part of process control and instrumentation we are now familiar with this block diagram which is a feedback control block diagram for feedback control system process control has been the topic of discussion so far. So, we can recognize very well all the blocks of this block diagram.

What we intend to do here is we have a process which is influence by some disturbance which we cannot manipulate the process is also influenced by flow of energy and our material which we can manipulate we want to control the process meaning we define a desired state for the process and the control variable has to be kept at that desired state. So, how does this feedback control work the first thing that is done is we need to measure the control variable and we do that using a sensor or measuring element. So, the sensor or measuring element measures information about the controlled variable and the information goes to controller where this value is compare with the desired value of the control variable that is set point and then here error signal generated.

Depending on this error signal the controller decides what action to be taken. So, that this control variable is the went to the desired value of control variable. So, controller take thus decision and directs final control element to manipulate this input energy and material which we can manipulate such that control variable is driven to the desired state. You can write such block diagram for any control system such that you can think of the control of temperature in this water bath by manipulating the flow rate of steam. So, you measure the bath temperature then information goes to the controller and the controller decides what should be the opening of the control valve.

Similarly, you can also talk about the level control in this tank very use a level indicator which is nothing, but level measuring instrument which measure the level of the liquid determines whether these are desired state or not then information goes to controller the controller decides what is to be done and accordingly changes the opening of this valve. So, you see that every control every feedback control system will have at least one measuring sensor or measuring instrument feedback system is widely use for control of temperature pressures flow rates liquid levels in process industry. So, it is a at most important that we learned about this sensor or the measuring elements.

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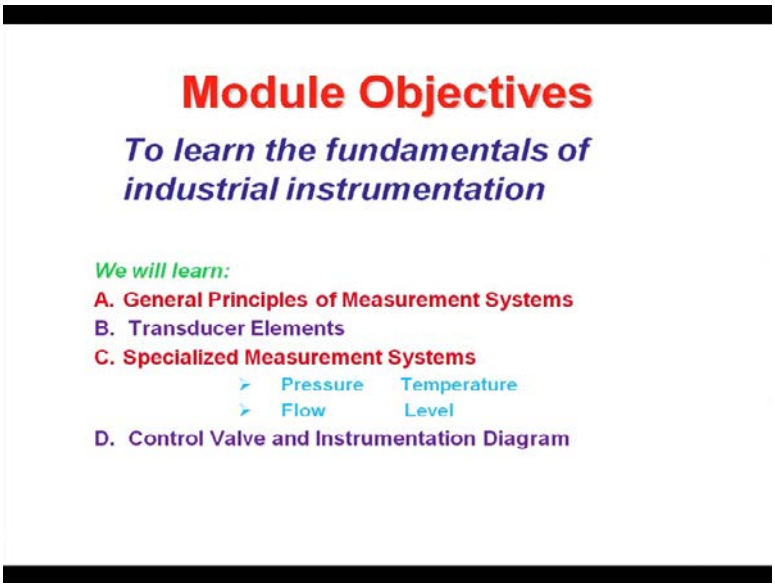

So, this is the objective of the module we we intend to learn the fundamentals of industrial instrumentation as we as I told you in the beginning that it is for as not possible to learn every details of all the instruments that are available, because there are numerous instruments for measurement of various process variables. So, what will do is we will learn general principles of measurement systems this will be done without any reference to in a specific hardware then you'll talk about transducer elements.

Transducer elements are those elements which changes the energy from one from to another let us say a pressure signal is converted to an electrical signal a displacement signal is converted to an electrical signal. So, transducer elements are useful in process instrumentation although by transducer elements are those elements which converts the energy from one form to another typically by transducer we mean those elements which converts the energy in one form to an electrical signal, Then specialize measurement systems that will be the body of this course will learn about various pressure measuring elements various temperature measuring elements various flow measuring instruments and various level measuring instruments and finally, the control valve and instrumentation diagram.

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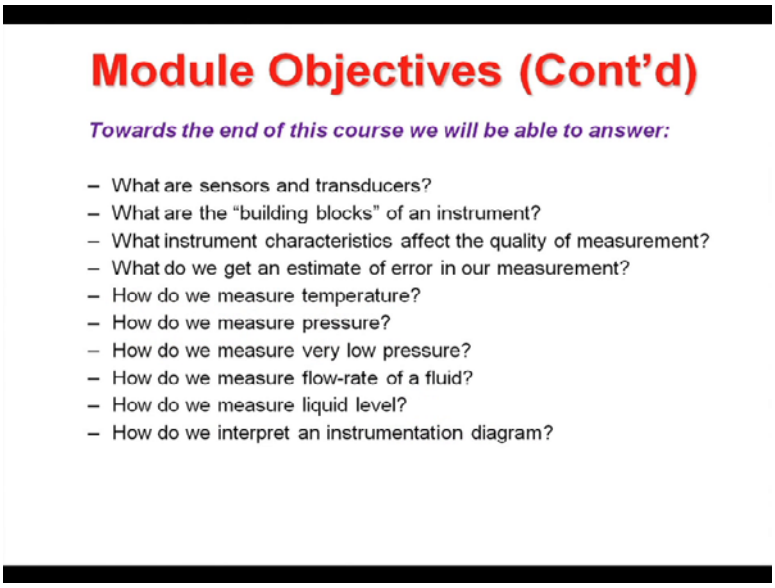

So, towards the end of this course we will be able to answer the following questions what are sensors and transducers what are the building blocks of an instrument; that means, can I break down an instrument in to various building blocks and describe the operation of an instrument what instrument characteristics affect the quality of measurement. What do we get an how do we an estimate of error in our measurement since every measurement is in error, we should be able to get an estimate of how much of error is there in my measurement how do we measure temperature how do we measure pressure how do we measure very low pressure or high vacuum how do we measure flow rate of a fluid say in a process flow rate of a process fluid in a pipe, how do we measure liquid level let us say how do we measure liquid level in the storage tank how do we interpret an instrumentation diagram, what what are the what are the meaning of the symbols that are present in an instrumentation diagram.

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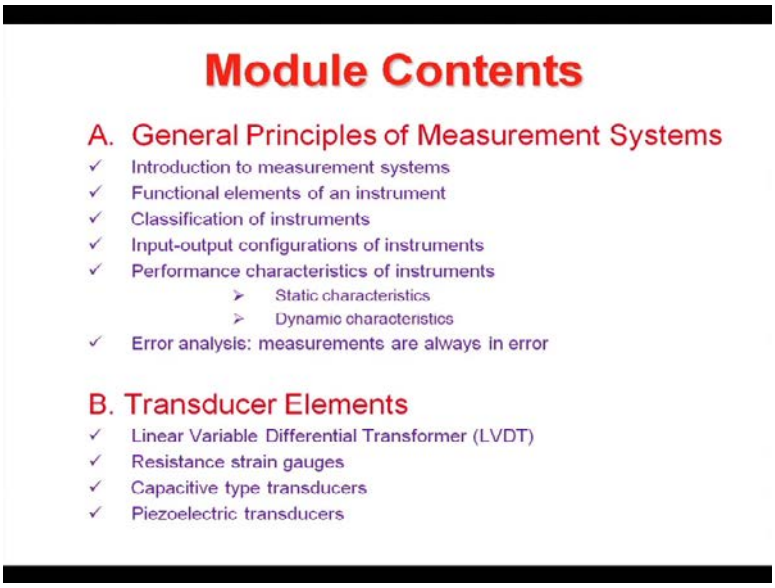

So, towards the end of this course we should be able to answer these questions here is the details of model module contents is divided into four parts in part a we talk about general principles of measurement systems we will start with an introduction to measurement systems and today will discuss that we will talk about what do you mean by measurement why should you measure what is the purpose of measurement what is direct measurement what is indirect measurement what are the various types of application of measurement then will talk about functional elements of instrument this is an important concept which which helps us to describe the operation of instrument in a very generalized manner. So, we will try to break down an instrument into various functional elements and try to see how the instrument works

Then classification of instruments then instruments can be classified in various ways. So, we will see some of the some of the ways how we classify the instruments we will talk about input output configurations of instruments then will go to performance characteristics of instruments what are the various performance characteristics that affect the quality of measurement broadly we talk about two different types of characteristics one is call static characteristics another is dynamic characteristics as the name sagest static characteristics a those characteristics which we must consider on the instrument is being use to measure the value of a condition which is not changing with tile and dynamic characteristics such the name sagest a those characteristics which we must

consider when the instrument is being used to measure a condition which is changing with time.

Them will aim part a with brief discussion on error analysis since every measurements are in error we should have an estimate of error in our measurements in third b we will talk about transducer elements we just discuss the transducers transducer elements are those elements which converts energy in one form to another and practically we mean those elements which converts energy in one form to electrical energy

We'll talk about four different types of transducer elements linear variable differential transformer or l v d t which is the displacement displacement transducer it converts displacement signal one electrical signal then resistance strain gauges resistance strain gauge if strained it resistance changes. So, it converts the strain to an electrical signal capacitive type displacement capacity type transducer which is again a displacement type transducer and piezoelectric transducers which is like if a crystalline material like quartz is distorted a charge is produced. So, we will talk about piezoelectric transducers in detail also

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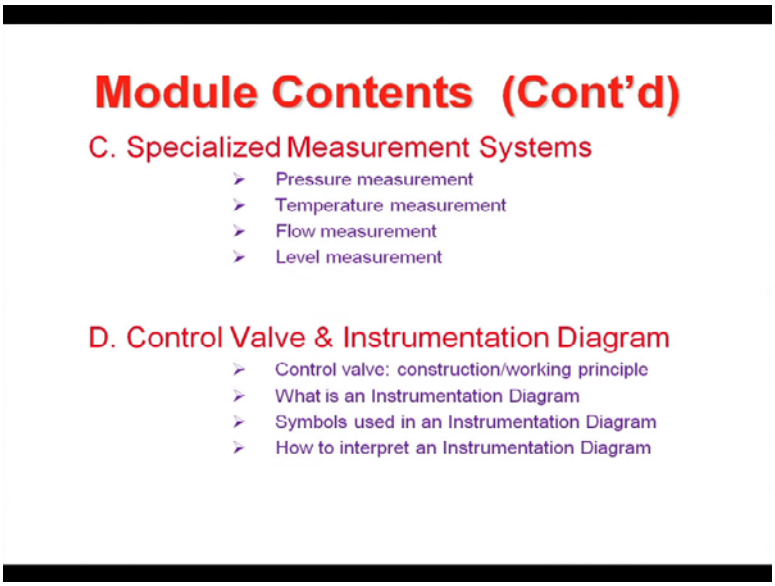

Part c will be the main body of this module here we will talk about various process variable measuring instruments in detail we start with various pressure measuring instruments we will see how we classify the various pressure measuring instruments

what are the various pressure measuring instruments available what are the are working principle what are the ranges of this instruments and so on and so for.

Similarly, we will treat various temperature measuring instruments various flow measuring instruments and various level measuring instruments mainly we will focus on liquid level measuring instruments. Then in part d we will talk about control valve and instrumentation diagram the contains will be the construction and working principle of a control valve how does a control valve work then we will see what do you mean by instrumentation diagram what is it what are the symbols used in an instrumentation diagram how do we interpret an instrumentation diagram.

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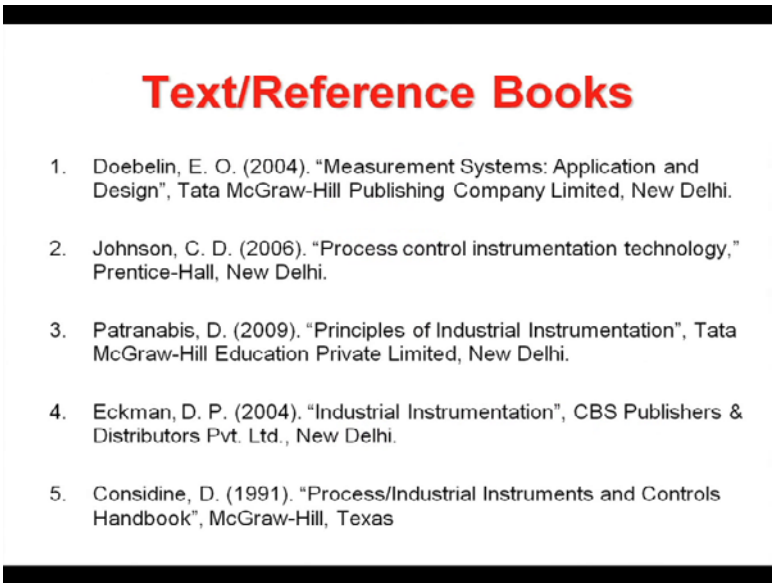

This is the list of text books or reference books number one measurement system application and design by dulblein number two process control instrumentation technology by johnson number three principles of industrial instrumentation by patranabis number four industrial instrumentation by eckman, and finally process industrial instruments and controls handbook by considine.

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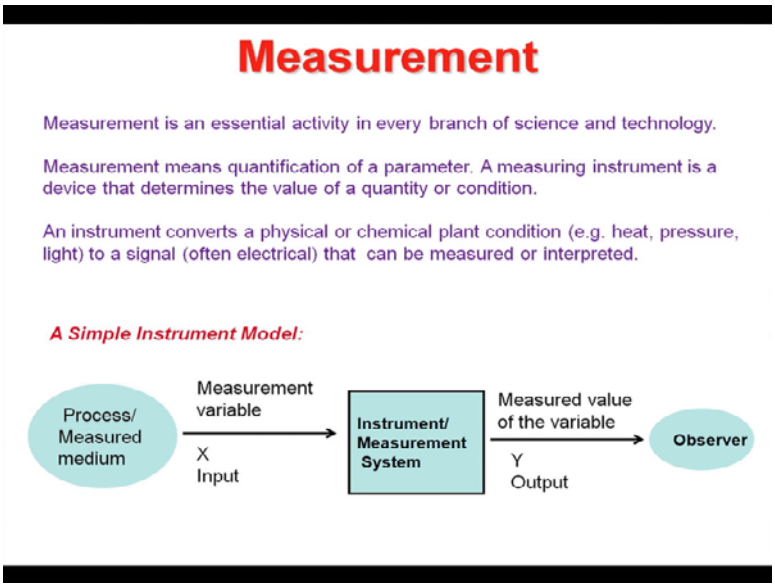

So, let us start part a with a definition of measurement measurement is an essential activity in every branch of science and technology measurement means quantification of a parameter or quantification of a quantity or condition a measuring instrument is thus a device the determines the value of a quantity or condition an instrument converts a physical or chemical plant condition for example, heat pressure or light to a signal which is often electrical, but not necessarily. So, that can be measured or interpreted

So, simple instrument model may be as follows we have a process or measured medium let us say you are interested in measuring the temperature of a liquid in a tank. So, this is the process or measured medium for you then I take a temperature measuring instrument this temperature measuring instrument interacts with this process, and produces an output which is in some sense related to this input and this output should be in a form which can which can be interpreted by the observer.

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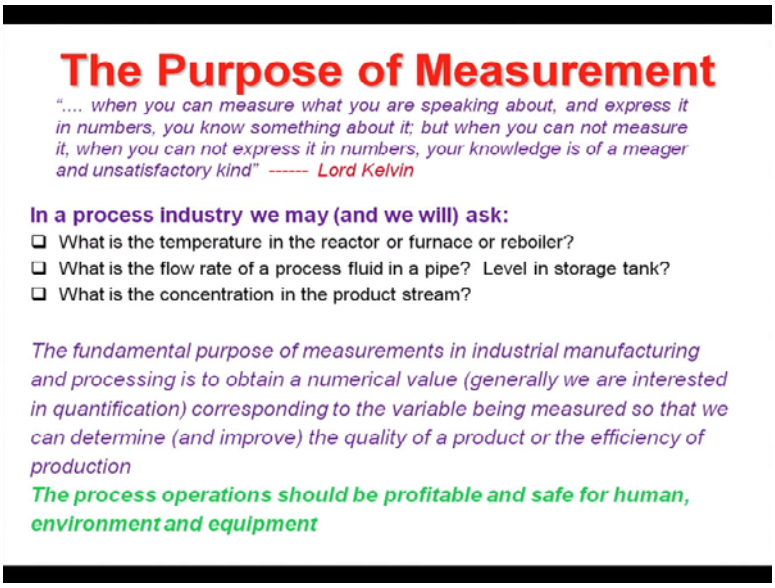

So, why should we measure what is the purpose of measurement lord kelvin said when you can measure, but you are speaking about and express it in numbers you know something about it, but when you cannot measure it when you cannot express it in numbers you knowledge is of a meager and unsatisfactory kind within court and un court that defines the purpose of instrument the purpose of measurement very nicely in a process industry if you visit even you work for a process industry you for a sell frequently us or we will want to know what is the temperature in reactor what is the temperature in furnace or in the reboiler what is the flow rate of a process fluid in a pipe or what is the level of liquid in the storage tank or what is the consultation of a product in the product steam.

So, to go to an answer to these questions we definitely need to take help of various instruments. So, the fundamental purpose of measurements in industrial manufacturing and processing is to obtain a numerical value because generally we are interested in quantification corresponding to the variable being measured. So, that we can determine and improve the quality of a product or the efficiency of production. The fundamental purpose of measurements in industrial manufacturing and processing is to obtain a numerical value corresponding to the variable being measured. So, that you can determine and improve the quality of a product or the efficiency of the production by efficiency of production you mean the process operations should be profitable and safe for human environment as well as equipment.

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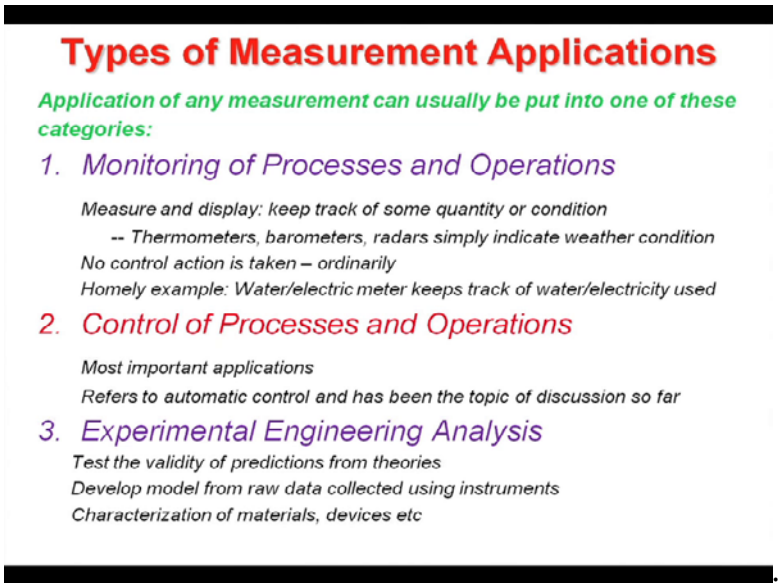

Now, let us come to types of measurement applications the measurements can be done for various reasons we have various process variables to measure we have various instruments to measure those variables. So, there can be various types of measurements there can be various types of measurement applications fortunately the application of any measurement can usually be put into any of the following three categories a monitoring of process operations b control of processes and operations and three experimental engineering analysis.

What do you mean by monitoring of process and operations by monitoring of process and operations we mean the instruments simply measures and display what it is measure usually control action is not taken. So, it basically keeps track of some quantity or condition for example, let us talk about weather monitoring thermometers barometers radars simply indicate weather condition it does not take any control action.

So, thermometers barometers radars they all indicate the weather condition and weather condition can be monitor that way a homely example is a water meter or electric meter which keeps track of how much of water or how much of electricity has been used. So, monitoring of processes and operations where the instruments simply measures and display what it has measure it is essentially for keeping track of some quantity or condition and usually no control action is taken a homely example is water meter or electric meter which tells us how much of water or electricity is used.

Two control of processes and operations perhaps is the most important applications of measurements and we basically refer to automatic control we are briefly talked about a feedback control system in the beginning of today's discussion and also it has been the topic of this discussion. So far Say you know that every feedback control system has at least one measuring instrument involve and this is this is definitely one of the most important application of measurements.

And number three experimental engineering analysis, we can measure variables or some quantity or condition to test the validity of predictions from theories we can perform measurements to develop model from raw data that you collect using instruments we can also perform carryout measurements for characterization of materials devices etcetera. So, application of any measurement can generally we put into one of these three categories process monitoring and operations where instruments simply measures and display no control action taken number two control of processes and operations well control action is actually taken and the control in a feedback control system control action has to be taken on the basis of the measurement of the control variable and number three is for experimental engineering analysis when you use it for testing the validity of predictions from theories or you build up a model using the data that you collect using instruments.

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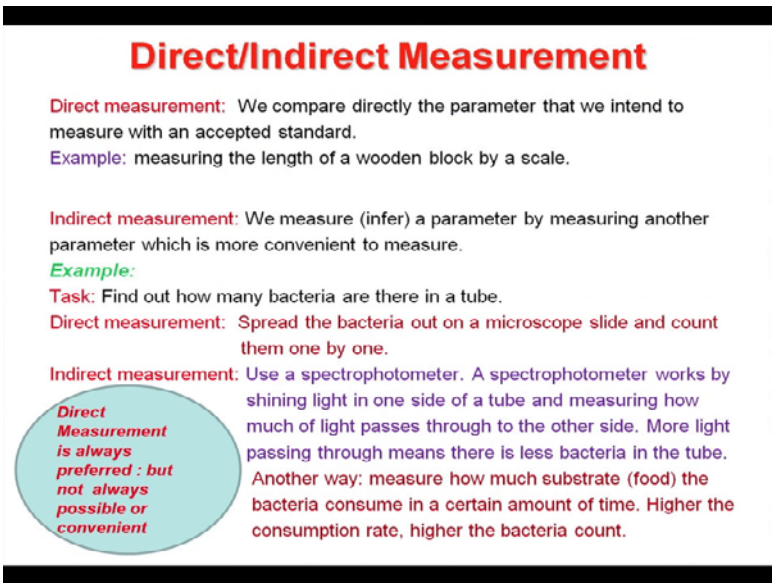

The measurements can broadly classified into two categories direct measurement and indirect measurement direct measurements what do you mean by direct measurements in direct measurements we compare directly the parameter that we intend to measure with an accepted standard for example, measuring the length of a wooden block by a scale if i have an accepted standard accepted standard I can directly measure the length of wooden block using that accepted standard for example, you measure the length of this class room using a tape which can be consider as an accepted standard.

Indirect measurement as the name sagest we measure a parameter by measuring another parameter which is more convenient to measure. So, essentially we infer here we do not measure directly the parameter that we intend to measure, but you measure some other parameter which is more convenient to measure and infer the value of the other parameter

Let us take an example to clarify this i have task at an find out how many bacteria are there in a tube. So, we have a tube and there are some bacteria in the tube i want to find out how many bacteria are present in the tube what can be the direct measurement here a direct measurement can be you spread the bacteria out on microscope slide and directly count under the microscope.

So, you take a microscope slide spread out the bacteria put it under microscope and count it that will that will of course, be a direct measurement, but you understand is going to be very inconvenient and cumbersome. So, what can be indirect measurement use a spectrophotometer use an instrument call spectrophotometer a spectrophotometer works by signing light in one side of a tube and measuring how much of light passes through a passes through to the other side if more light passes it means there is less bacteria in the tube.

Say you can bac calcular and can measure how many bacteria are present in the test tube there can be another way of measuring the bacteria count indirectly we give some substrate or food to the bacteria to it engrow. So, the bacteria will consume the substrate and grow unless measure this consumption rate higher the consumption rate higher the bacteria count. So, this will be another way of measuring the bacteria count indirectly of course, the direct measurement always preferred, but as I notice here there it is not

always possible to go for direct measurement it may not always be possible or even if it is possible it may be very inconvenient.

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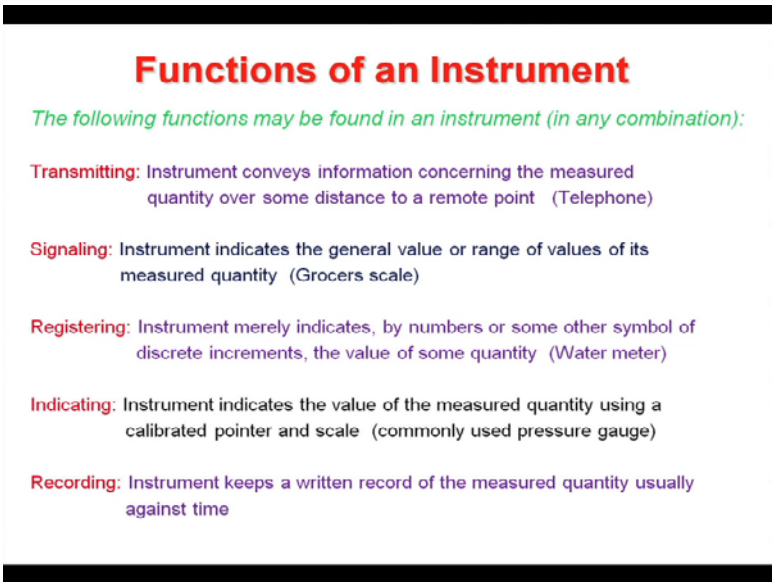

Well the instrument measures the value of a condition the following functions may be performed by an instrument transmitting signaling registering indicating and recording accordingly, you can say transmitting instrument signaling type of instrument registering instrument indicating type instrument and recording instrument.

What do you mean by transmitting or transmitting type of instrument here the instrument conveys information concerning the measured quantity over some distance to a remote point. So, the instrument will measure the quantity and convey the information from one place to another a homely example is telephone signaling type of instruments here the instrument indicates the general value or range of values of its measured quantity some grosses scale indicates the general value of what it has measured.

Registering type of instruments the instruments merely indicates by numbers or some other symbols of discrete increments the value of some quantity for example, a water meter which uses discrete numbers to indicate how much of water has been consume indicating type of instruments the instrument indicates, the value of the measured quantity using a calibrated pointer and scale you have seeing this type of instruments in laboratory say commonly use for pressure gauge which uses a pointer n scale to indicate the value of the measured quantity which is pressure in case of pressure gauge.

And recording type the instrument keeps a written record of measured quantity and usually it is recorded against time. So, all these functions transmitting signaling registering indicating recording all the functions may be found in a instrument in any combination.

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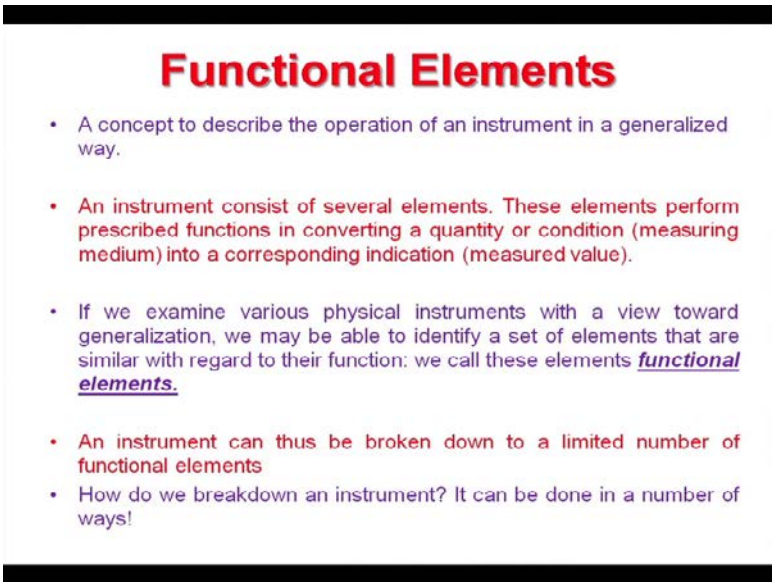

Now, let us come to an important concept called functional elements is a very useful concept to describe the operation of an instrument in a generalized way an instrument consist of several elements these elements perform a prescribed functions in converting a quantity or condition which is measuring medium into a corresponding indication which we called measured value.

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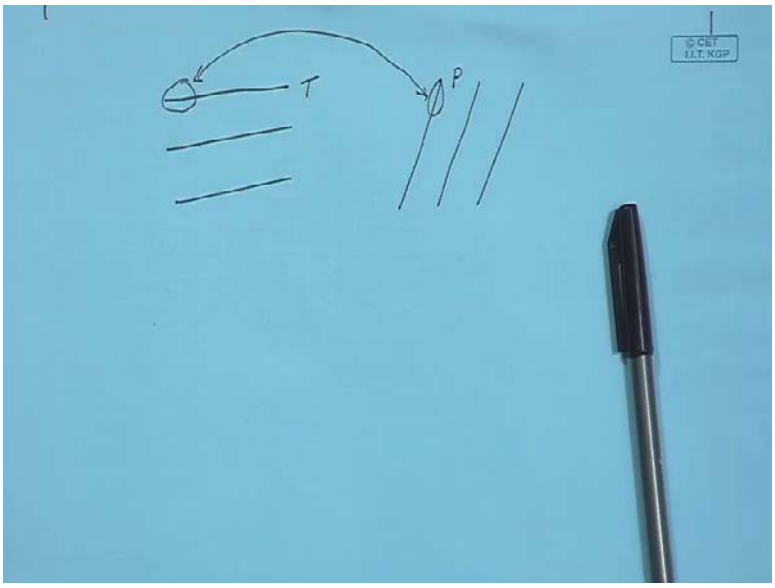

If you examine various physical instruments with a view to a generalization we may be a able to identify a set of elements that are similar with regard to their function we call these elements functional elements. So, what you mean is we have various instruments let us say we have various temperature measuring instruments we have various pressure measuring instruments.

Now, if we examine all these instruments and several other instruments very closely with a view towards generalization we may be able to identify a set of elements that are similar with regard to their function what you mean is if I take let us say this is a temperature measuring instrument and this is the pressure measuring instruments perhaps i may able to see an element here and similar element here which does similar job.

So, in terms of function they are similar we call these elements functional elements. So, we will define functional elements as if we examine various physical instruments with a view toward generalization, we may be able to identify a set of elements that are similar with regard to their function we call these elements as functional elements.

An instrument thus can be broken down to a limited number of functional elements and this gives us a way to treat the operation of an instrument in a generalized way, but the question now is how do we break down an instrument into its building blocks or various functional elements it can be done in a number of ways and looks like there is nothing

like universally accepted generalized scheme. So, there are different schemes propose in different looks and you'll see here at least two of them.

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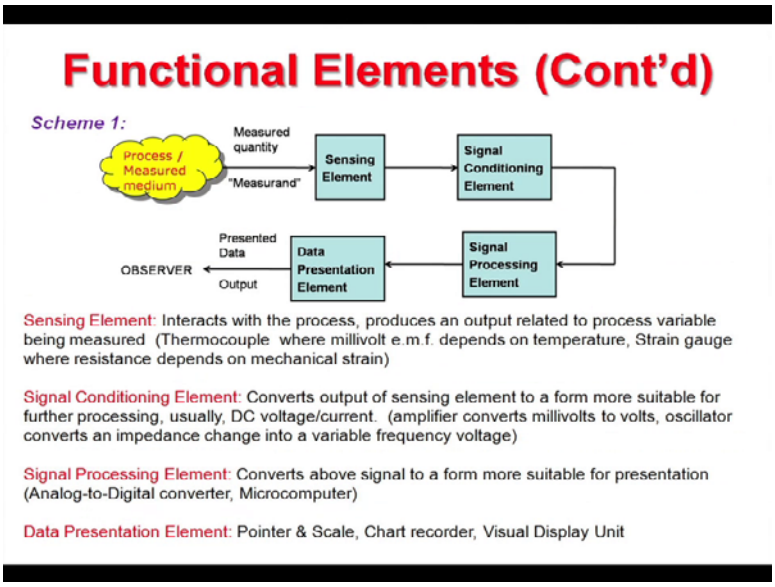

Let us look at this scheme which describes how you break down an instrument into various functional elements you have a process or measured medium which i am interested in measuring having a instrument in contact with this the instrument interact with this measure medium and presents may what it has measured.

Now, if I examine the instrument how it works or if I if I able to breakdown instruments into various parts which performs different functions I can identify these elements the first element is sensing element sensing element the sensing element interacts with the process first it produces an output which is related to process variable being measured. So, this is the element which first interacts with the measured medium a receive signal from the measured medium which we call measuring and produces a signal which is related to the process variable that is being measured.

And example can be a thermocouple you know which a thermocouple measure temperature a thermocouple has two junctions one is call measuring junction another is call cold junction we will talk about thermometer in detail later. So, the hot junction or the measuring junction is brought in contact to the medium whose temperature i am going to measure. So, depending on the temperature or the temperature difference that

exist between the measuring medium and the cold junction thermocouple produces an e m f as output.

So, thermocouple is produces e m f which is in the range of millivolt depends on temperature. So, the output signals of the sensing element is related to the process variable that is being measured or thermocouple is temperature here is millivolt here similarly strain gauge where it resistance depends on the mechanical strain. So, if a resistance strain gauge is strain differently is resistance will change differently.

The next element in line is signal conditioning element the signal conditioning element will convert the output signal of the sensing element to a form or to a signal which is more suitable for further processing. So, it conditions the signal that comes out of sensing element So, it converts the output signal of the sensing element to another signal which is more suitable for further processing it may be a d c voltage or current it is require when output signal of the sensing element is not in the form which is more suitable which is suitable for further processing say the output of the primary signal is a displacement signal anyone may be interested in converting into a electrical signal which can be processed much more easily. So, you need a signal conditioning element which will converts the displacement signal when electrical signal.

Examples may be amplifier which will converts millivolts to volts and oscillator which converts an impedance change into a variable frequency voltage the output of the signal conditioning element goes to signal processing element a signal processing element converts the output signal from the signal conditioning element to a form which is more suitable for presentation for presentation to the observer it may be a analog to digital converter.

An analog to an analog to digital converter will convert voltage signal into a digital form for input to a computer it can also be a micro computer which calculates measured value of the of the variable from incoming digital data and finally, we have data presentation element the data presentation element presents the data to the observer and it has to be in a form which the observer can recognize. So, the data presentation element presents data to the observer in a recognizable form examples are pointer and scale a chart recorder or a visual display unit.

So, in this thing we identify four functional elements firs is sensing element which firs receives information about the measured medium and produces an output which is somewhere related to the variable we are going to measure second in the line is signal conditioning element which will changes the output signal of the sensing element to a form which is more suitable for processing next is signal processing element which will convert the output signal of the signal conditioning element to a signal which is more suitable for the purpose of presentation and the data presentation element will present this signal to the observer in a recognizable form.

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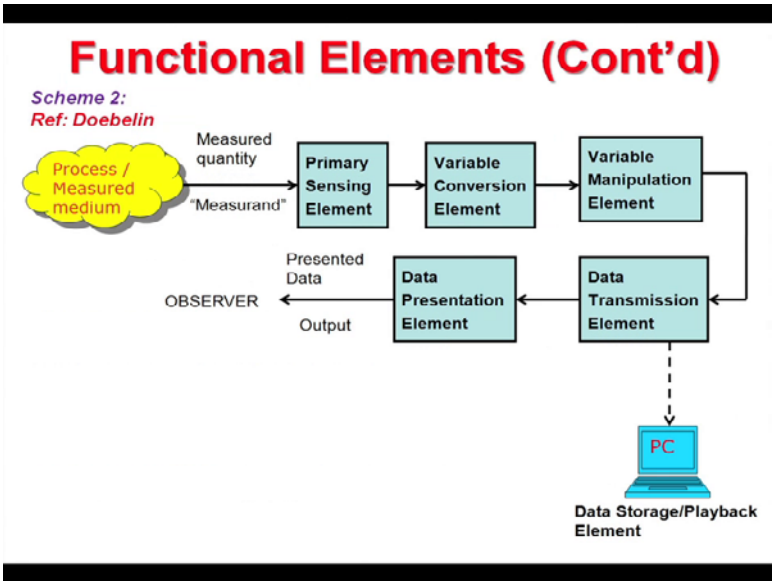

Let us discuss another scheme as proposed by doebelin we have a process or measure medium as before again consider it is liquid whose temperature I am going to measure. So, I bring a temperature measurement measuring instrument in contact with this measure medium and analyze how the instrument works I mean able to identify these functional elements.

The firs lock is primary sensing element the primary sensing element the primary sensing element is that which first receives energy from the measured medium and produces an output depending in some way on the measured quantity. So, this is same as what you saw in the scheme one we called sensing element there that is called primary sensing element here because you can have if you have more than if you have more than two

sensing elements in the one interacts with the system first may be called primary sensing element.

So, this is the element which first receives information from the measured media and and produces an output depending on some way on the measured quantity if you if you take the temperature measurement as an example the primary sensing element will first extract some amount of thermal energy from the measuring medium. So, immediately we know that we are disturbing the system that we are going to measure because it is it is extracting some amount of thermal energy from the system and that is necessary for the act of measurement which makes perfect measurements extremely difficult or theoretically impossible this is call loading effect the amount of energy that is necessary for the purpose of measurement is called loading effect. So, will good instrument will receive very minimum energy from the measuring media for the purpose of measurement. So, good instrument will have minimum loading effect.

So, the next is variable conversion element the output signal of the primary sensing element is some physical variable such as displacement or voltage say if you are using thermocouple as a temperature measuring instrument the output signal of the primary sensing element will be a millivolt signal for the instrument to perform the desired function it may be necessary to convert this variable into another more suitable variable while preserving the information content of the original signal and variable conversion element will do this function.

So, the variable conversion element will convert the physical nature of the signal that comes out of the primary sensing element to another signal which is more suitable for the purpose of measurement. It may be noted here that all instruments may not have variable conversion element some instrument may have more than one variable conversion element next in the line is variable manipulation element in performing the measurement and instrument may require the signal represented by some physical variable the manipulated some way that is we may be interested in changing the numerical value of the signal while preserving the physical nature of the variable for example, an electronic amplifier excepts a small voltage signal as input and produces an output signal that is also voltage, but it some constant times the input.

So, variable manipulation element will manipulate the signal that comes out of variable conversion element by manipulation we essentially mean changing the magnitude of the signal unlike variable conversion element it will not change the physical signal of the nature for example, an amplifier will change the mini hold signal to voltage signal. It may also be noted here there is not necessary that variable manipulation element will always follow the variable conversion element it may be present before this block or it may present elsewhere in the diagram or in may not be present at all.

Next is data transmission element as the name sagest data transmission element transmits the data when functional elements are actually physically separated then it becomes necessary to transmit the data from one place to another and the data transmission element will transmits the data from one place to another the data transmission element may be as simple as a shaft and bearing assembling or it may be as complicated as a telemetry system for transmitting signals from satellites to ground equipment by radio.

And finally, we have data presentation element the data presentation element communicates information about the measured quantity to the observer for monitoring or control purpose and as we have said earlier the data must be communicated such that it is recognizable by human sense solvent the common examples are pointer moving on scale is a data presentation element recording using a pain moving over a chair is another data presentation element.

Finally we may also have a data storage or playback element which will stored data which can be restore later whenever it is require examples may be a computer a magnetic tape recorder etcetera. So, this block diagram tells us all possible functional elements that you can present in an instrument.

I repeat again that it is not necessary the functional elements will be present strictly in thus in this order in any instrument and also it is not necessary the there will be only one variable conversion element or there will be one variable manipulation element. So, there may be more than one variable conversion element or there will be there may be more than one variable manipulation element at that may they may be present anywhere in the chain, but we can describe the operation of any instrument in terms of these functional element.

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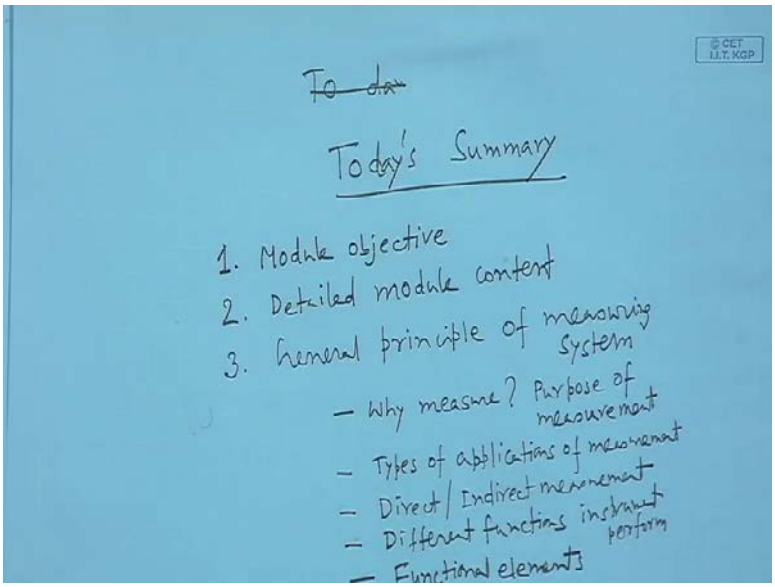

So, let us summarize what we did today define the module objective detail module content then is started with general principles of measuring systems where we give a brief discussion on why we measure purpose of measurement types of application of measurement we talked about direct indirect measurement we stares that direct measurement is always preferred, but we may not be possible always.

Then we talked about different functions that instrument perform, and finally we talked about functional elements where we define what functional elements are and what are various schemes available which will allow us break down an instrument in to various functional elements in the next class we will take an example and try to identify the functional elements that are present in that instrument.