Experimental Methods in Fluid Mechanics
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Lecture – 1
Basic concepts, Caliberation.

I welcome you all to this course on Experimental Methods in Fluid Mechanics. This is my first lecture on this course. In this course, I will be focusing on several techniques used in measuring flow parameters like velocity, pressure, temperature, et cetera. In particular, I will be focusing on, rather I will be discussing several challenges involved with the measurement techniques and as a consequence, what are the precautions we need to take into account while using any device for measuring any flow parameter, essentially for the better prediction.

So, I will discuss several topics included in the course through different lectures. But before I go to discuss those topics, I would like to discuss about basic concepts and this basic concept, why these are very important we should know. Basic concepts are very much important to know because whenever we are using any device to measure any quantity, it may be velocity, it may be pressure or temperature, then how we can use that particular device in a system? On the top of that whenever using the device to measure any quantity for prediction or correct results or accurate result, these basic concepts are very much important. Not only that these basic concepts are also important to analyze the data captured through different experimental methods using different device.

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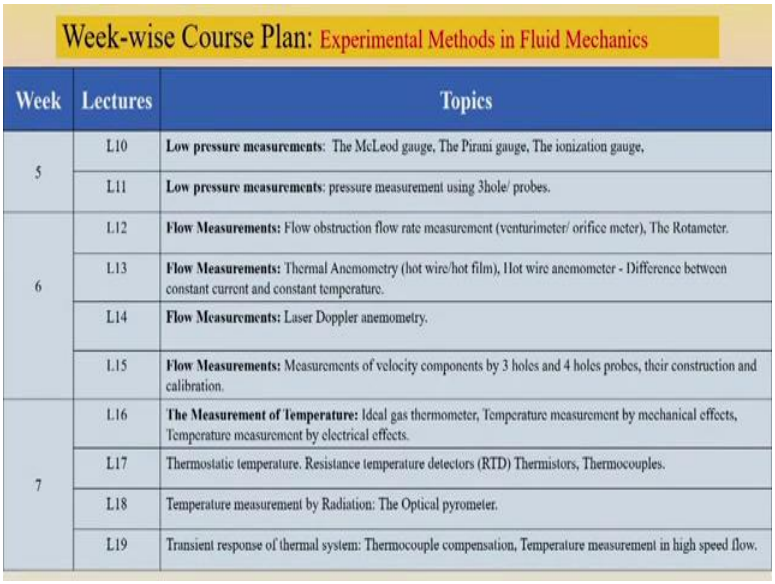
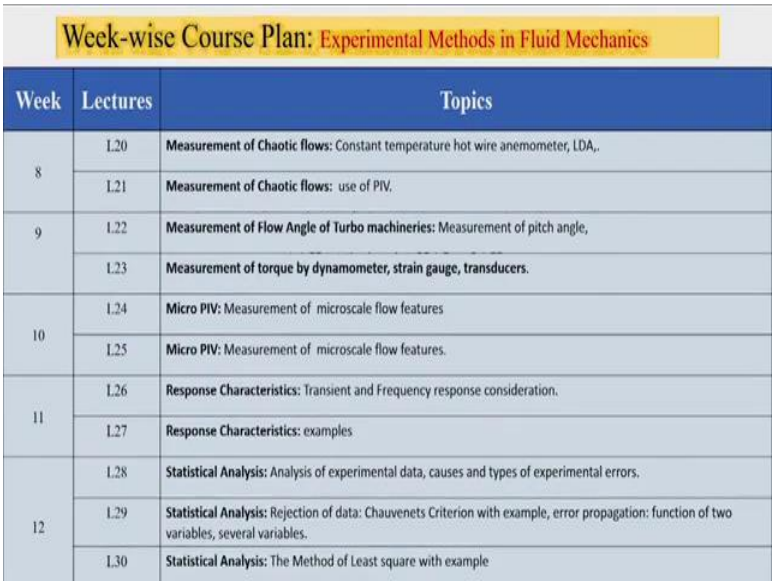
Week-wise Course Plan: Experimental Methods in Fluid Mechanics

Week	Lectures	Topics
1	L1	**Introduction to Experimental Methods:** Basic concepts, Calibration.
	L2	**Introduction to Experimental Methods:** Dimensions, Units, Standards, Systems of dimensions, System of units, Unit conversion table.
2	L3	**Measurement System:** Basic concept of dynamic measurements
	L4	**Measurement System:** System response and distortion, Impedance matching.
3	L5	**Displacement and Area Measurement:** Dimensional measurement Gauge blocks, The pneumatic displacement gauge.
	L6	**Displacement and Area Measurement:** Area measurements, The polar Planimeter.
4	L7	**Pressure Measurements:** Definition of absolute and gauge pressure, Dynamic response considerations: measurement of total and static pressure,
	L8	**Pressure Measurements:** Mechanical pressure measurement devices, U-tube manometer, The incline well type manometer.
	L9	**Pressure Measurements:** The aneroid barometer, Diaphragm and Bellows Gauges



Week-wise Course Plan: Experimental Methods in Fluid Mechanics

Week	Lectures	Topics
5	L10	**Low pressure measurements**: The McLeod gauge, The Pirani gauge, The ionization gauge,
	L11	**Low pressure measurements**: pressure measurement using 3hole/ probes.
6	L12	**Flow Measurements:** Flow obstruction flow rate measurement (venturimeter/ orifice meter), The Rotameter.
	L13	**Flow Measurements:** Thermal Anemometry (hot wire/hot film), Hot wire anemometer - Difference between constant current and constant temperature.
	L14	**Flow Measurements:** Laser Doppler anemometry.
	L15	**Flow Measurements:** Measurements of velocity components by 3 holes and 4 holes probes, their construction and calibration.
7	L16	**The Measurement of Temperature:** Ideal gas thermometer, Temperature measurement by mechanical effects, Temperature measurement by electrical effects.
	L17	Thermostatic temperature. Resistance temperature detectors (RTD) Thermistors, Thermocouples.
	L18	Temperature measurement by Radiation: The Optical pyrometer.
	L19	Transient response of thermal system: Thermocouple compensation, Temperature measurement in high speed flow.



Week-wise Course Plan: Experimental Methods in Fluid Mechanics

Week	Lectures	Topics
8	L20	**Measurement of Chaotic flows:** Constant temperature hot wire anemometer, LDA,.
	L21	**Measurement of Chaotic flows:** use of PIV.
9	L22	**Measurement of Flow Angle of Turbo machineries:** Measurement of pitch angle,
	L23	**Measurement of torque by dynamometer, strain gauge, transducers.**
10	L24	**Micro PIV:** Measurement of microscale flow features
	L25	**Micro PIV:** Measurement of microscale flow features.
11	L26	**Response Characteristics:** Transient and Frequency response consideration.
	L27	**Response Characteristics:** examples
12	L28	**Statistical Analysis:** Analysis of experimental data, causes and types of experimental errors.
	L29	**Statistical Analysis:** Rejection of data: Chauvenets Criterion with example, error propagation: function of two variables, several variables.
	L30	**Statistical Analysis:** The Method of Least square with example

So, these are the different sub-modules I will be focusing through this course. I have divided several modules, I mean lecture wise several modules and I will recover at least 30 lectures to complete the course.

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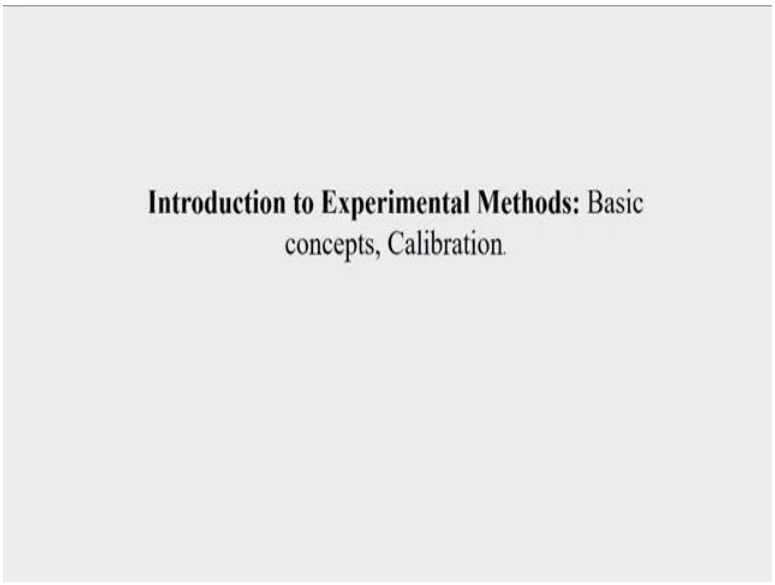

In a first lecture as I said that I will be focusing on the basic concepts, and then I will be focusing another important aspects of experimental techniques, experimental methods. In particular, I mean, since, I will be focusing on experimental methods in fluid mechanics, so these concepts I will be discussing today.

And to discuss all those concepts, I will be defining those parameter first and then I will discuss why those terms or parameters are very much important, and why we should know about these parameters to, before we go to learn about several measurement techniques. So, basically I will today define a few parameters which are closely related to almost all the experimental methods and all the techniques used in measuring different parameters.

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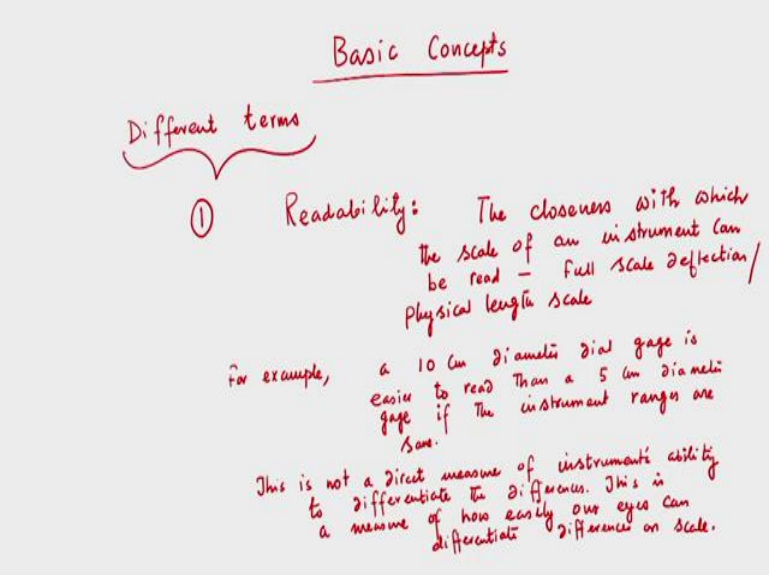

So, today I will discuss about basic concept. Through this basic concept, let us see what are the different parameters because experimental methods, there are two parts of this. We need to know the theory. Then if you would like to apply the theory to measure any parameter using any device, we have to apply our understanding whatever you have from our theoretical background.

So, I will be first discussing about say different terms. Different terms, so as a first one, I will discuss about what do mean by readability. So, is very important; readability. What is the definition of this particular term and why it is so important, rather why we need to know this, to know several methods while measuring any particular parameter? So, I am, I will be writing the actual definition of this. The definition of this is the closeness with which, the closeness with which the scale of, the scale of an instrument can be read.

For example, it may be a full scale deflection or a physical length scale. We have talked about the scale, the closeness with which the scale of an instrument can be read. So, basically this is the definition of the readability, how close we can read the scale of an instrument. The scale may be full scale deflection or the physical length scale. We will discuss this term again taking an example. Say, for example, say 10 centimeter diameter dial gage is easier to read than a 5 centimeter diameter gage.

If, so this is an example, a 10 centimeter diameter dial gage is easier to read than a 5 centimeter diameter gage if the instrument ranges are the same, if the instrument ranges are same. So, this is a measure of how easily our eyes can differentiate, differentiate on the scale

and it is not a direct measure of the instrument's ability to differentiate the differences. So, we have understood what do we mean by readability?

How closeness of a scale, of a reading can be read with a, the scale I mean of instrument. So, basically the closeness which I can read or we can read the scale of an instrument. And we have given an example, if the scale is 10 centimeter dial gage, diameter dial gage is 10 centimeter, which is easier to read of course, than a 5 centimeter dial gage, of course, if the instrument ranges are same.

And basically again I am writing, it is not the direct measure of instrument's ability to differentiate differences. So, this readability, this is not a direct measure of instrument's ability to differentiate the differences, to differentiate the differences. Rather this is a measure of how easily our eyes can differentiate differences on the scale. So, this is a measure of how easily our eyes can differentiate differences on scale.

So, this is the important concept, rather the abstract of this definition is that: This is not the direct measure of instrument's ability to differentiate the differences, rather this is a measure of how easily our eyes can differentiate differences on scale. Next, we will discuss about another important term which is very important to know and the experimentalist who is using any device to measure any flow parameter, any other parameter, he or she should must, he or she must know about this parameter. That is, least count.

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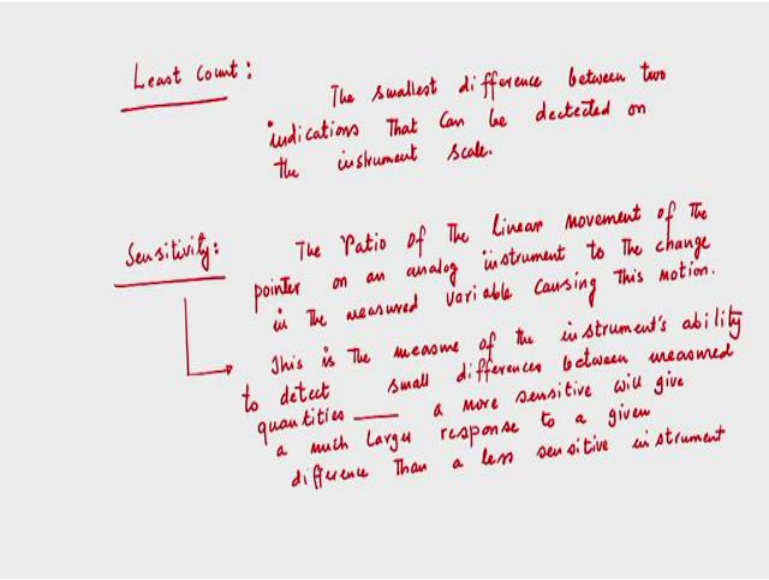

So, another important parameter is least count. So, this is another important parameter. So, what is the definition of that? We should know. The definition is that - The smallest difference between two indications that can be detected on a instrument scale. So, I am writing again the definition. So, the definition of least count is that – The smallest difference, the smallest difference between two indications, between two indications that can be detected on the instrument scale; that can be detected on the instrument scale.

So, we should know about this, information about this before we start taking reading using any device in any environment. So, the smallest difference between two indications that can be detected on the instrument scale that is the least count. So, we should know that. Similarly, if we go to define next term or next important parameter, that is the sensitivity. This is sensitivity. We should know about this and also we should know why do we need to know about this term and why it is so important while measuring any parameter using any experimental technique.

So, again I will write the definition here – Sensitivity is the ratio of the linear movement of the pointer on an analog instrument to the change in the measured variable, the measured variable causing this motion. So, the ratio of the linear movement of a pointer on an analog instrument to the change in the measured variable causing this motion. Now, what do we mean by this? So, this is a measure of the instrument's ability to detect small difference between measured quantities.

Whenever we are measuring any quantity, so the smallest difference that an instrument can detect, the ability of an instrument to detect the small difference, to detect a small difference between measured quantities is essentially the sensitivity. So, that means this sensitivity, I can write this is the measure of the instrument's ability. That means whenever we are telling this instrument is, sensitivity of this instrument is like this, so what do we mean by that?

That means the ability of instrument, what is the ability of the instrument to detect the smallest difference of the measured quantities. So, this is the measure of instrument's ability to detect a small difference or I can say small differences, small differences between measured quantities. That indicates a more sensitive instrument, a more sensitive equipment or more sensitive instrument will give a much larger response, this is very important, to a given difference than a less sensitive instrument.

So, we have discussed about the definition of this term. What is the final, what is the actual meaning of this? Basically, this is a measure of instrument's ability to detect small difference between or small differences between two, between measured quantities. That means a more sensitive, many a times we call or rather we say that this instrument is having this much sensitivity. So, a more sensitive, again we should know, we should have a indicator by which we can say that this instrument is higher sensitive and this instrument is lesser sensitive.

So, a more sensitive will, a more sensitive instrument that means, that instrument will give much larger response to a given difference. So, whenever we are perturbing any things or whenever we are disturbing, say if I take an example of flow through a pipe, if I would like to measure the pressure, then if I give small disturbance, then of course, pressure might change within the fluid pathways of fluidic pathways. Then for a given disturbance whether it is small or large that is not important, for a given disturbance the larger response is given by a more sensitive instrument while the response is less for a less sensitive instrument.

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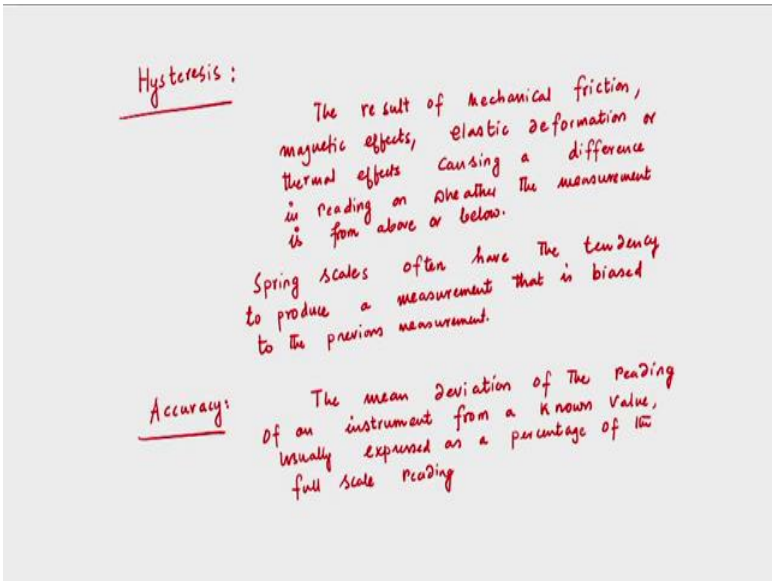

Next, we will, so we have discussed about a few terms. Another, we have to discuss another few terms. So, another one is known as hysteresis. Another one is hysteresis. What is the definition of this term and again why you need to know about this? Hysteresis essentially a dissipative kind of thing like mechanical friction if it is mechanically actuated device or instrument. Sometimes we use magnetic action to detect anything. We magnetize to detect something zone or device, to detect something.

Or sometimes we put load to measure the deformation. From that deformation we can calculate our desired output or desired signal. So, if it is elastic material then what is the elastic deformation? Or sometimes if we need to pass current or if we need to pass, we need to supply heat from outside, then the thermal effects. So, whenever we are supplying these kinds of external agitation, external disturbances, so then this disturbances, this perturbation supplied externally and those disturbances are very much important to measure the desired quantity through a particular device, through a particular instrument.

And while we are disturbing, while we are perturbing, these perturbations leads to a difference in reading depending upon whether the measurement is from above or below. So, I will write again, what is then hysteresis? So, since we are discussing about many terms, to recapitulate our basic concepts, and these terms will be very much important throughout this course because whenever we will be measuring any particular flow meter, either we will discuss about the theoretical aspect of that instrument and then we will discuss about the measurement procedure.

Then we have to rely on that device, we have to rely on that instrument. So, we should know about these terms because these terms essentially are important, since, these are very helpful to predict the data, to capture the data, moreover, to analyze the data captured through the experimental procedure. So, the result of mechanical friction, mechanical friction magnetic effect dissipative in nature, mechanical friction magnetic effects, then elastic deformation or thermal effects causing a difference in reading, we will discuss this again taking an example, causing a difference in reading on whether the measurement is from above or below.

Now, we will discuss this again. Take an example, spring scale, spring scales, to have a clear understanding on this, we will discuss this example. Spring scale often, spring scales often have the tendency to produce a measurement. Whenever we use spring scale, of course, to measure something, we all know why we use spring scale. Now, whenever you spring scale to measure a weight, that those, rather those scales always rather very often have the tendency to produce a measurement, which is or that is biased to the previous measurement.

So, this is hysteresis effect. So, basically it causing a difference in the ring whether the measurement is above or below. Whenever we use spring scale to measure weight, it always have a tendency, even if it is not always, very often have a tendency to produce a measurement that is biased with the previous measurement, that is below. So, with this we

have understood about the what do, about this term, that means what do we mean by hysteresis.

Another few terms we need to know and again those terms are very much important in the context of the experimental methods or experimental techniques used either in measuring flow parameters, either in measuring any other things in different other fields. So, next is, next term is accuracy. Accuracy is very important to know, we know that we many a times we say this device or this instrument is very accurate. What do we mean by that?

We have to compare the device, we have to compare that instrument with some other standard instrument, then only you can say this is much accurate than the other or this is accurate. Accurate is subjective, how much accurate it is, I mean we have to compare that. So before that, we need to know what do we mean by accuracy, what is the definition of this term. So accuracy is, I am writing the definition, the mean deviation of the reading of an instrument from a known value, from a known value, usually expressed as a percentage of the full scale reading.

So whenever we use any device, any instrument to measure any quantity, the mean deviation of the reading, I mean we are getting reading from the measurement, so there is a deviation or the mean deviation of the reading of an instrument from a known value. If we know the known value, what the known value would be? And I mean if we know, we know the measured value and if I know the known value, then the mean deviation of the reading of the measured value from the known value is the accuracy and usually expressed as a percentage of the full scale reading.

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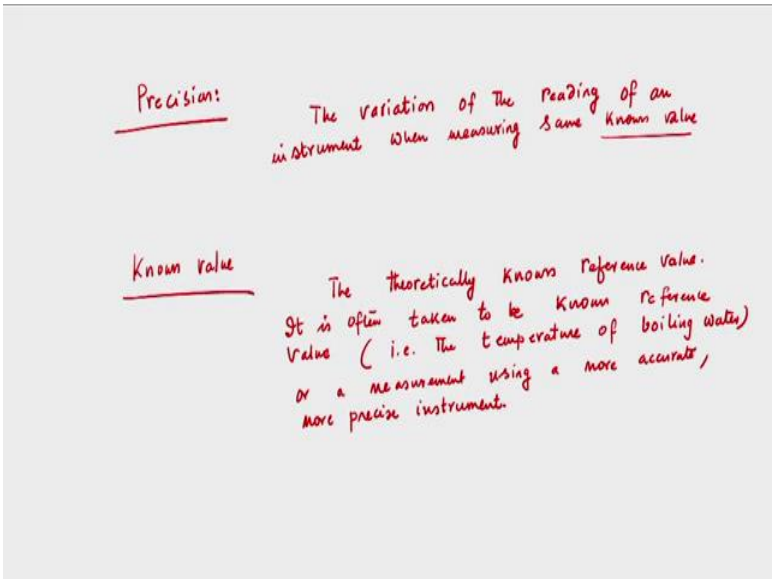

Next, I will discuss about another important term which is precision that is precision. The definition is many a times we need to do, we need to repeat the experiments, we need to repeat the measurements. The same measurements we repeat, I mean to recall from, to check whether the value we are getting from each and every measurements are same or not. So, and it is seen that if we measure the same thing repeatedly, it is unlikely that we will get same reading every time.

So, the variation of the reading, that means the readings, the number of times we measure any particular thing, any particular parameter using a device, we will get many number of, many numbers of data and all time we may or may not get the same value. It is quite common that at every measurement we will get different data, different value. So, the variation of the reading, so say if I measure length of a particular say of a given, if you would like to measure the length of a tube or diameter of a tube, say diameter of a tube I am measuring, and if I measure n times, we will get n measurements.

And if I try to see and if we tabulate the data the n times we have measured, the diameter of a tube we will get n different value. So, n different values are not, I mean, equal with each other; of course, they are different. So, the variation of the reading of an instrument, of a instrument when measuring same known value. That means if I know the diameter of a tube a priori, now knowing the diameter of a tube if I would to measure to calibrate that particular instrument.

I mean, maybe it is I am trying to calibrate that device and instrument to check whether it is performing well or not. It is likely that if I measure n times using that device or that instrument, the diameter of the tube, the diameter which I know a priori, we will get always different results than the known value. So, the variation of the reading of an instrument when measuring same known value, so that is the precision.

Now, I have used the word 'known value', so what do you mean by known value? So, if the difference is very less, say I am measuring n times, I am getting n different measurements but I know the known value, so now if I calculate say and I have five or six instruments, similar type of instrument and I am using all those, I mean all the instruments to measure the diameter of the tube, I know the diameter before start reading the value.

So, now I can say similar type of instruments, so the instrument which is giving very close value to the known value, that is the precision of that instrument is very high. So, now I am trying to discuss what do we mean by known value? Known value – It is very important because the word I have used calibration. Many a times we need to calibrate and it is always advisable to calibrate a device or instrument to perform, to check its performance before we use that to measure any parameter.

So, while we are trying to calibrate any device, any instrument, we need to calibrate that device with any other standard device or with any other known value because I need to know whether the device, which I would like to calibrate, whether that device predicting the value which is close to the known value or not. So, known value is a reference value. So, this is the theoretically known reference value. It is often taken to be known reference value. Say, for example, that is, the temperature of boiling water or a measurement using a more accurate, more precise instrument.

So, we have discussed about the accuracy, then precision, then I have come to this word 'known value'. So this is theoretically known reference value. So, this is theoretically known reference value. It is often taken to be the known reference value, I know, we all know temperature of the boiling water or a measurement using a more accurate, more precise instrument. Say, while we have discussed about the term 'precision', we have discussed about this, if we, if I know, rather if I measure the diameter of a tube using a more accurate or precise instrument, then that is a known value because the value which I got using the equipment that is more precise, more accurate.

So, I can consider that reading as a reference one, so that is the known value. So, the definition of this parameter, we have understood that whenever we are taking any data from experimental investigations, we have to rely on that instrument. Many a times it is possible that instrument may not functioning well or whenever we are recording data, it is highly possible that we are, because of some reason we may not capture the correct data.

So, all the data we are capturing from experiment when that we are collecting data from experiments, it is very common that the measured value, measured data may not be correct at each and every run. So that problem, the sources of, there might be different sources for which the measured value, measured data may not be correct. So, what I mean to say, there is a possibility that the measured value or measured data may not be always correct.

And we need to know if this is not the correct, we need to know even, as I said, that if I take any particular measurement n times, we will get n different values and all the values will differ from the known value that is the reference value. So, we need to know what is the difference between the measured value and the known value or the reference value that is the error?

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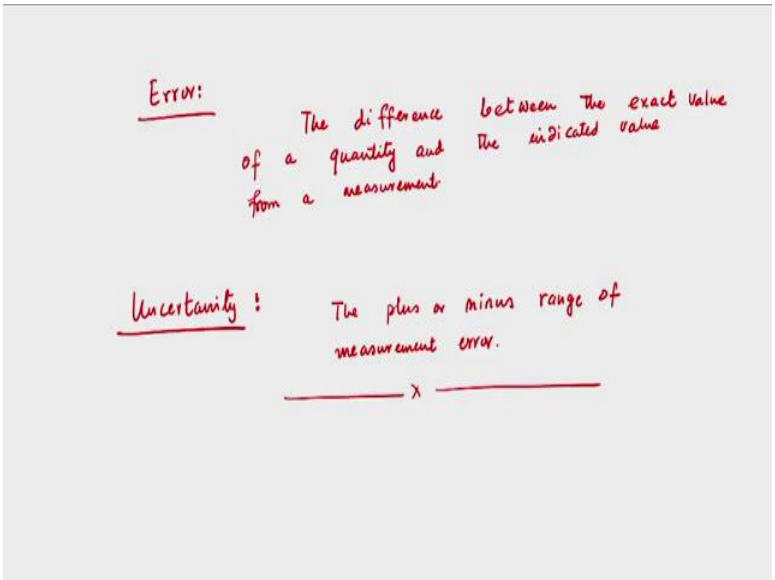

So, we need to know what do we mean by error. So, this is another important parameter. The definition of the error is the difference between the exact value of a quantity and the indicated value from a measurement. That mean, it indicates that if we, I know the known value, if I measure the same thing n times, rather through n measurements, n number of measurements, I will get n different values.

So, if I now calculate the difference between the exact value of a quantity, say a pipe diameter, if I know the known value, if I try to measure the diameter of a pipe using any instrument, using any particular instrument, then if I measure n times, I will get n different values. So, the difference between the exact value of a quantity, say diameter and the indicated value, that is the value we have measured using the device, instrument, this is the error.

So, that is very much important to know for the experimental analysis. And we should be discussing about this aspect 'error' and another important term through statistical analysis. And that part I will discuss towards the end of this course. And last important term is 'uncertainty'. So, this is uncertainty. What do we mean by that? The plus or minus range of measurement error. The definition is – Plus or minus range of measurement error. That means whenever we are measuring, again I am taking this example, diameter, n times I measure the diameter, I will get n different values.

So whether the value, sometimes it may so happen, rather it is happening, rather it will happen that the diameter will be higher than the known value or the diameter which you are measuring it may be lesser than the known value. The number of times, n times we have measured out of n measurements, say m measurements are giving diameter reading which is higher than the known value and n minus m times we are getting diameter, the measured value which is less than the known value. So, the plus minus range of measurement error that is the uncertainty and we need to fix that, what is the percentage or how much percentage of uncertainty we will consider of a measured value using any particular device.

So, with this I stop my discussion today and next class, we will be discussing about the another important term, another important concept, that is known as calibration. We need to know about this because we will be, whenever we are using any experiments, mostly you are relying on the equipment, instrument. So the instrument, equipment we are using to measure any quantity, we need to know whether that instrument or device is calibrate, calibrated with a standard instrument or equipment or not before we use that.

This is essential to check the performance of the device or instrument I am going to use. So with this I stop here and we will continue our discussion in the next class. Thank you very much.