Mechanical Measurements and Metrology
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**Module - 4**
Lecture - 50
Case Studies

This will be lecture 50 in Mechanical Measurements. It will also be the last lecture in this series and the second lecture in module 5. In lecture 49, we gave a few general remarks on measurement of quantities, and specifically we considered the gathering of data using electronic circuitry.

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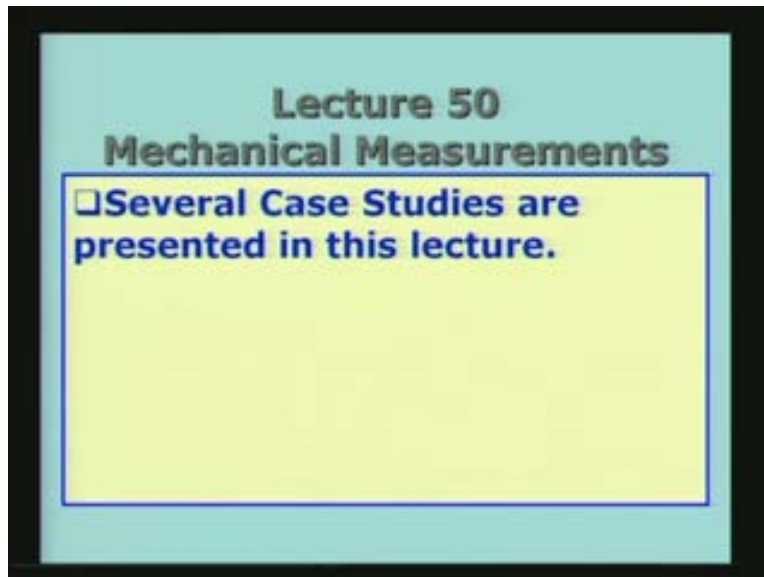
In the present lecture, we will look at a few cases, and then see how we can go about making the measurements, and also choosing the right kind of instruments for making the measurements. So the first example is with respect to calibration of a thermocouple. Let us see how it can be done when data logger is available to us. To some extent we already know the principle of calibration, the need for calibration is to make a particular instrument come into agreement with a standard instrument.

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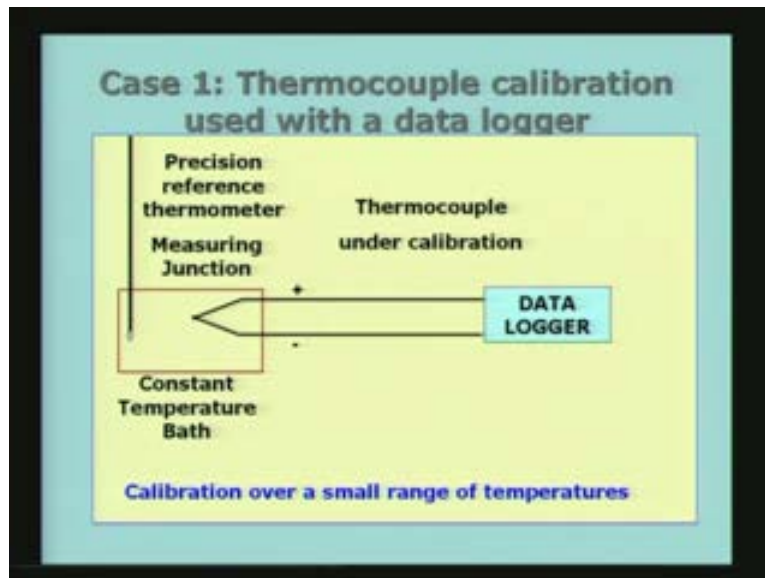
So in this case, if I have a thermocouple of a particular type, I would like to see whether it is in agreement with the thermocouple which is standardized or calibrated in a standard laboratory, or by a third party who is not involved in your particular activity. So, an independent check on the instrument is required so that, we can rely on the measured values. One way of doing it is, to compare it with another thermocouple of the same type, but which has been calibrated in another laboratory which is acceptable to every one.

What I will do is, instead of comparing the thermo couple with another thermocouple which is standardized, I will compare the thermocouple output directly without worrying about the nature of thermocouple, it's type and so on. We will try to compare it with a secondary thermometer, another thermometer which I will call as the precision reference thermometer.

If I look at the sketch here, this is the precision reference thermometer which is accepted as standard, as far as this particular calibration is concerned. So, I will take as a truth whatever value of the temperature is indicated by the precision reference thermometer, which itself may be calibrated or certified by a standard laboratory. That is the way we are going to go about. I will subject the thermocouple which I want to use in my experiment. I will expose it to the same temperature as the precision reference thermometer, by putting the two together in close proximity within a constant temperature bath.

So, in principle, whatever temperature is indicated by the precision reference thermometer must correspond to a certain voltage developed by the thermocouple under calibration, and I am using it in a form without the reference temperature being at the ice point. That means that, this calibration is valid as long as the temperature of the data logger is at a uniform value which is not going to vary with respect to time. However, the data logger is going to be exposed to different temperatures, because the laboratory temperature varies over a period of time so this calibration will not be totally correct. That will we be a secondary issue.

Here what I am going to look at is only without having a reference junction. Or ,another way of doing it would be to have cold junction compensation within the data logger, because many of the data loggers do come with such arrangements so that I can use that signal to correct for any variation in the room temperature. I am going to just look at the data logger as a black box. I am not comparing but calibrating the thermocouple by just equating or assigning a temperature on the precision reference thermometer to a voltage which I am going to measure using the data logger. It is just like a conversion factor or a conversion from the voltage value here which will be in microvolts or may be in millivolts that will be assigned a particular value on the precision reference thermometer. This particular way of calibrating a thermocouple is actually valid for small ranges. Because, we may even assume that there is broadly linearity in the scale, and therefore I may do this calibration by choosing only a few temperatures.

For example, I can take the ice point, I can take the room temperature, I can take some other elevated temperature like boiling water so two or three different temperatures can be used in the constant temperature bath, and corresponding values of the temperature indicated by the precision reference thermometer can be assigned to a particular thermocouple output in terms of millivolts or microvolts. So I will just say there is a correspondence between the output of this thermocouple which is going to be measured by the data logger, and the value indicated by the precision reference thermometer. This calibration is not calibrating one thermocouple with respect to a standard thermocouple. This was already explained when discussing about temperature measurement.

Let us look at the kind of data one is going to get. I have taken the actual data which was gathered in the laboratory. It is a typical calibration over a small range assuming linear response. In fact, we have found that the linear

response is pretty good, and we are talking about room temperature to about 100 degree or may be a little more as that is the range.

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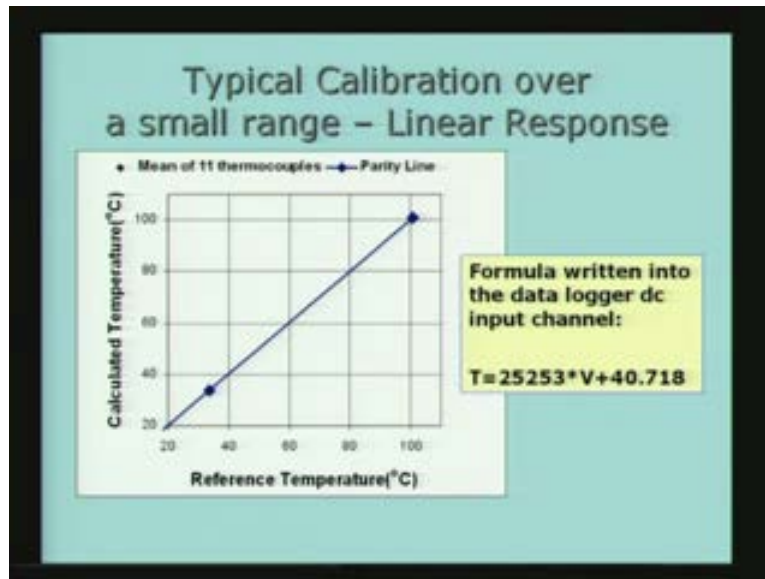
I have just shown two points corresponding to a low value and a high value. For actual calibration, if the low value happens to be the room temperature, and the high value happens to be less than 100 degrees or little more than that then it is advisable to have several temperature in between. For example, if you consider this as the full scale and this as the 0 or the reference value, I should have three or four between these two limits not coinciding with the end values. So in this case if I have taken the 100 degrees here, it means that I am going to use this for a temperature little above that may be 120 degrees or 130 degrees and so on this side, and on this side, I am going to use up to about 20, and not necessarily with respect to up to 0, so up to 20, therefore I have chosen these two within this range so the temperatures at which I am going to calibrate, I am going to compare the output of the thermocouple with a precision reference thermometer that must be within the range and not at the bounds of the range or the boundaries of the range.

Of course, I have taken only two assuming that the response is more or less linear.

In fact, what I have done is I have taken eleven thermocouples and I have taken the average behavior of these eleven thermocouples, and then made a simple plot of the temperature calculated based on this linear relationship which is given here. I am using the formula given here as, T equal to this constant times the output of the thermocouple 25253 V plus 40.718. This is the formula which corresponds to this particular straight line which is the average of eleven thermocouples.

Of course, each thermocouple would show a slight variation with respect to this value, and what I have given here is a mean for all these thermocouples. And the blue line I have indicated is, what is called parity line which is already known to us. It represents the parity between the calculated and the reference temperature. Of course, in this case, the scale of the figure is such that we do not see much of an error between the thermocouple, and the reference temperature.

Of course, they must coincide, because whatever calculated temperature it is it should be corresponding to this, this is just equality. The only point is that I have taken the mean of eleven thermocouples and they seem to follow this rule very well. In fact all thermocouples don't follow the exact values given here. They have some variations among them, and the mean value on the average there is equality between the calibrated or the calculated value and the reference temperature. That means, this figure is really giving you only part of the answer, the correct answer is here.

So what I am going to measure is this value V, this V is going to be measured by the data logger or gathered by the data logger. We measure this V, and then you can say T as a function of V is the linear function, this is some kind of a transformation from V to T. So arithmetic operation is required where you have a parameter, this is a slope parameter 25253 and the intercept parameter 40.718. So you see just a line y is equal to mx plus c where m is the slope, and c is the intercept parameter.

What is it that we have achieved here?
We have not done anything, but we have just made the temperature indicated by the thermocouple equal to a temperature indicated by a reference thermometer which is highly accurate, highly precise, and we have simply mirrored the values which would be obtained by using the temperature reference thermometer onto the thermocouple. Therefore the actual thermocouple behavior in terms of it's Seebeck coefficient and so on does not enter here.

We simply have a comparison. We have mirrored the values given by the precision thermometer on to the measurement given by the thermocouple. So this is not a calibration in the strict sense of the term it is actually making the thermocouple equivalent to a precision thermometer. This is a different way of doing the calibration.

What I have done is I have taken the data logger Agilant, it is called Agilant Benchling and Hewlett Packard is the manufacturer of this. What I have shown in this slide is the graphics setup. That means you can set up all these, there are several channels, and you can see that the channels are named. This is channel 1, channel 2 etc, so several channels are possible, and each channel can have different quantities indicated. For example, I can have voltage, I can have current, I can have some other quantity here so this is units per division, I can specify here I can also switch on or switch off the channel.

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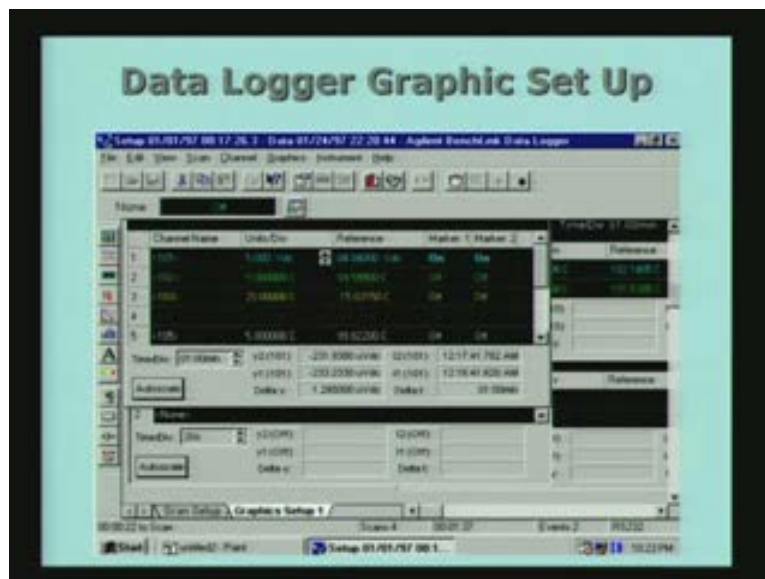
So in this case the channel is on and these four channels have been switched off. So what you see here is a virtual instrument in some sense of the system, because whatever is happening in each of this channel can be actually followed in real time. The next slide shows that how we setup the data logger for scanning the data. What is a scan? Because the data loggers have several channels, each channel has to be measured in a definite way.

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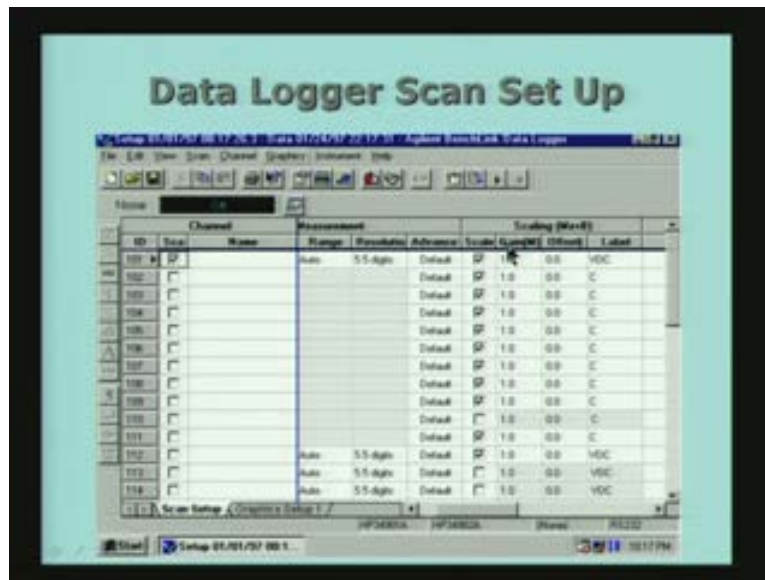
Suppose I have four channels, I cannot measure all the four channels at the same time so what the data logger will do is, it will go to one channel make a measurement go to the next channel make the measurement so a series of measurements will be made in time.

Of course, the duration between the channels, that is when it switches from one channel to another channel can be very small. That means instantaneously at the same time all these channels are scanned.

Some of the salient features are as follows:

Here, we have the name for the channel, I can give any name by the way. For example, I have ticked this channel, that means that this is being used, I can give a name here, I can name this channel so that I can note down or I can immediately find out what this channel is doing. It may be measuring simply a current or a voltage or it may be measuring a temperature. So I can say this is temperature 1, channel 1, corresponding to temperature thermocouple 1. The range is auto that means the instrument will determine what the maximum and the minimum is, automatically it will change so that you do not have to intervene. The resolution is the most important thing.

We have got a 5 ½ digit or 5.5 digit resolution, and this happens to be the default for this particular channel. For all these channels, the default is 5 ½ digit, and if you want to change it you can change it to a lower value. And here you see the gain and the offset. Actually this is nothing but your slope,

for a straight line behavior this will be corresponding to the slope and this will correspond to the offset, or this intercept as we call it. In this case, I have labeled it as voltage dc so this channel is now available, to measure output in voltage dc with a 5.5 digit resolution, and we can immediately see on the board that, this is suitable for measurement of voltage output from a thermocouple.

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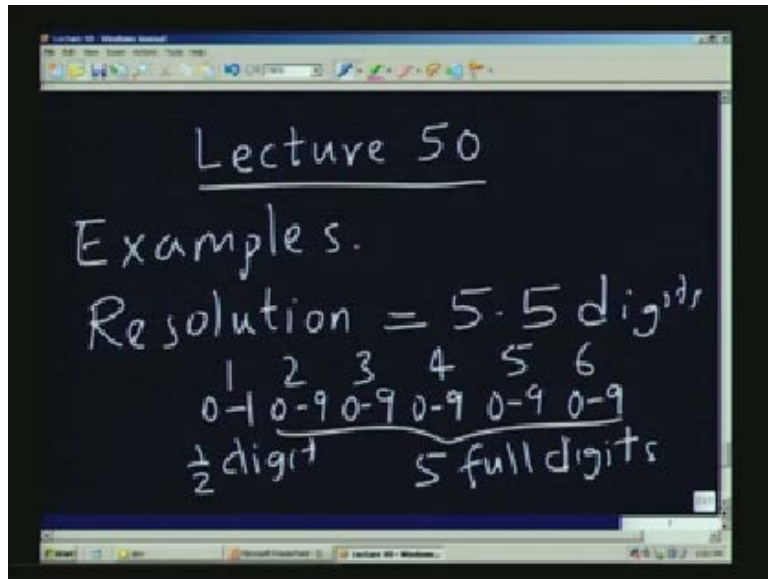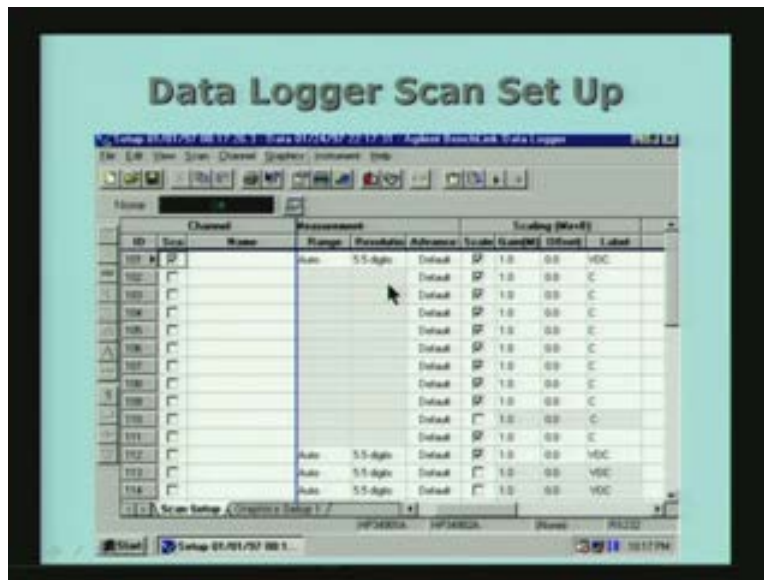

Why is it so? The resolution is 5 ½ digits, what does it mean?
It means, if I have a number like this, it has got 1 2 3 4 5 6 the number can be having six places, and this can go from 0 to 9, this can go from 0 to 9, this can go from 0 to 9, 0 to 9, and this can be either 0 or 1. So these are 2 3 4 5 6 digits go all the way from 0 to 9, and the very first one goes from 0 to 1. This is five full digits and this is called half digit. The reason why this terminology has come 5 ½ digits is actually the following. In the olden days when digital voltmeters were made they always had, for example, it will have a range of 3V or 30V or 300V, 3V means you can see here instead of 0 to 1, it can go up to 0 to 3, and 3 is nothing but 0.3 is nothing but logarithm of 2. That is how the 5 ½ digit idea comes.
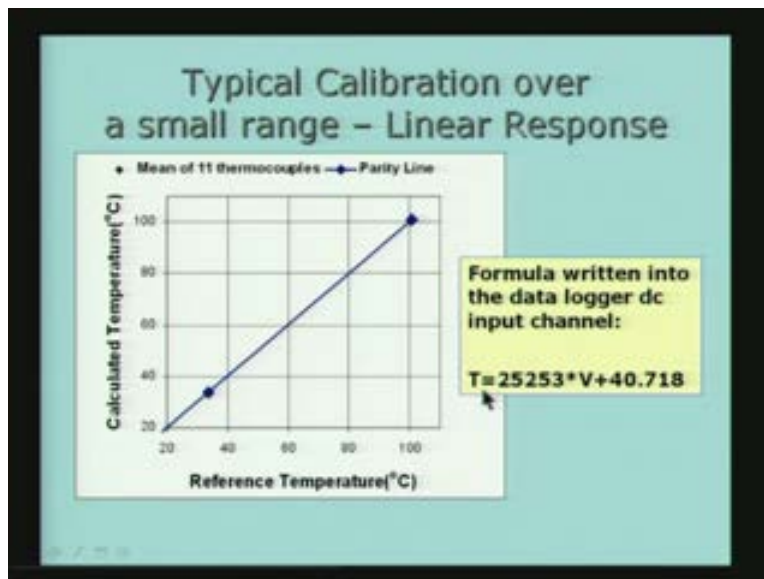
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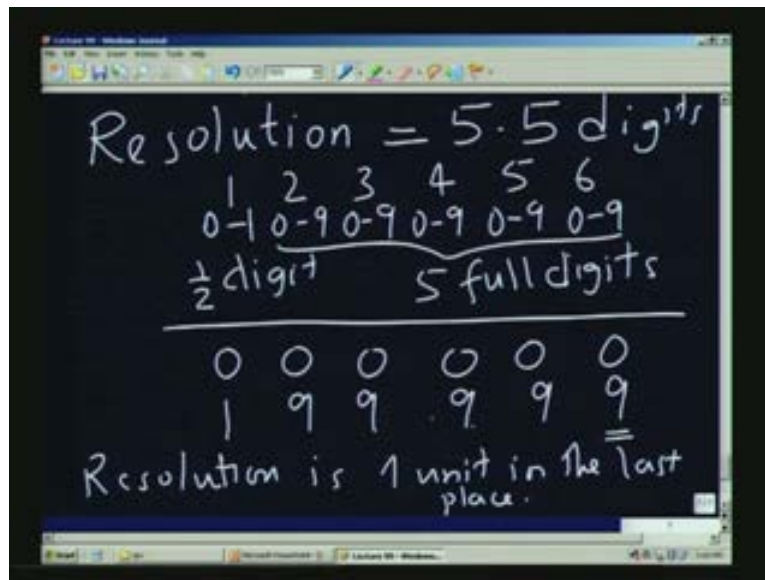
So, the resolution of the instrument is, now, if I represent, the output in the form of six digit number 1 2 3 4 5 6 there are six digits, of course, one is a half digit, that means it can go up to 0 to 1, I can have a minimum of course, I can have this, this is the 0, I can have the maximum, I can have 1 9 9 9 9 9. So you see that, this is different from 200000 by just one digit in the last here, actually one digit in the last place. This is the last digit or the last place that is one unit in the last place. One unit is nothing but this is 1 followed by five zeros and 1 into 10 to the power 5 here. So what it means is that the data logger which I showed is capable of 5 ½ resolution so that is what it means, from the next slide I am showing.

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Data Logger Scan Set Up

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Typical Calibration over a small range – Linear Response

Formula written into the data logger dc input channel:

$$T = 25253 * V + 40.718$$

How to enter the conversion formula?

Earlier we saw an example where the formula was here in the form of T is equal to 25253 into V plus 40.718 this is the number I had. So what I am doing is I am entering these formulae into these boxes. I have got channel 1 2 up to whatever number, 10 is left out so 11 thermocouples are there. So channel 1 to 9 and then 11 and 12, all I have 5.5 resolution and all these are given the gain values.

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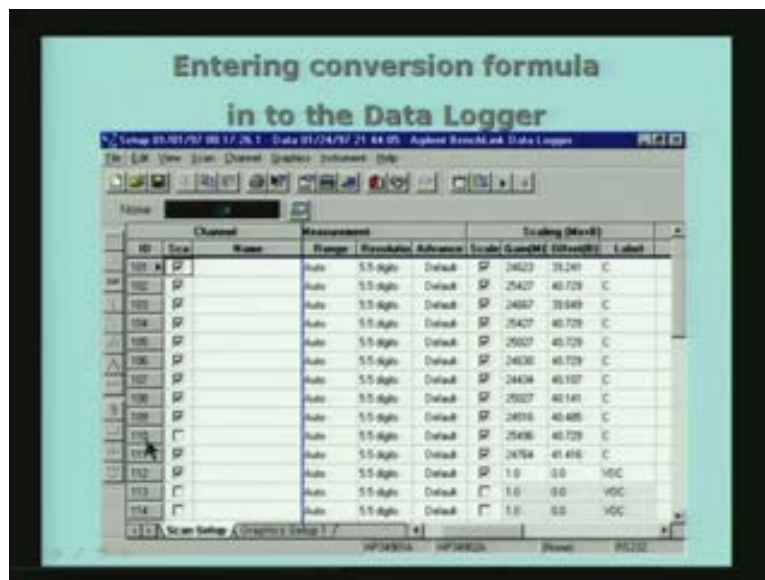
You see that the gain values vary slightly from the mean value which I gave earlier, 24623 is the first one, this is 39.241 you see that the offset and the gain both are slightly different for this thermocouple. In other words, the conversion formula from voltage to degree Celsius is different for this thermocouple as compared to this one, because the values are slightly different.

You can see that it is so for all of them. So all the eleven cases or ten cases whatever we have got here we have got the values of gain set here. In other words, this is software which is going to do the background calculation. When the voltage is scanned, or when several channels are scanned consecutively by the data logger, the first channel it will get the value in voltage in the output in the volt value, and immediately, it will use this conversion formula and convert it to Celsius, C is the Celsius and what is coming is voltage, the voltage is converted to Celsius so the temperature automatically is going to be recorded by using this particular form.

So, for each channel, I can have a different formula, or it may be the same, if all have the same constant or coefficients given here they can be the same. In each channel I can have a different formula, and then I can convert the input to the channel in the terms of voltage to degree Celsius and that can be done. In this case, I can follow the temperatures of these eleven channels independently at any given instant of time.

Of course, I can instruct the data logger to scan each one of these logger at regular fixed intervals of time. I can command it to do this every one second or every five seconds or every ten seconds or every half an hour whatever is requirement we have in our particular experiment, if it is a fast experiment where things are changing very rapidly, I may ask you to scan it at a rapid pace and if it is a slow variation I can ask you to scan it slowly or may be five minutes or ten minutes intervals. The point is, if you are scanning over a long length of time the amount of data which has to be saved becomes very large.

For example, I cannot save data over one day by taking every second; it will become a very voluminous amount of data. So, depending on the experiment depending upon the amount of time you are going to conduct the experiment for and depending on the requirement you can scan. If it is a very fast variation you can scan faster at smaller intervals of time, or if it is a slow variation you can do it at slower or larger intervals of time. In fact, I have also shown the other things that can be done. You can see here that, in this particular case, the data logger has got several types of thermocouples already built into it.

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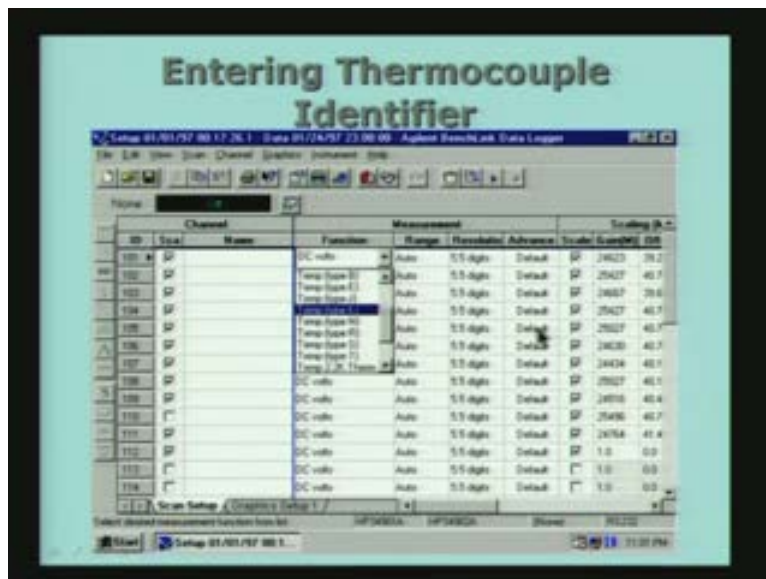
I do not even have to do the calibration, what I can do is, I can simply tell the computer which type of thermocouple has been used, in this case the highlighted one is temperature type K, so if I say type K here the to the gain

and to the offset you do not have to give it but we can actually command it to do this by itself. That is, automatically it will determine the type, and it has a table of values corresponding to type K, and then it will compensate for the cold junction, and then automatically find out what is the temperature for a given input in that particular channel. All these are possible with the data logger.

What we try to do is to just indicate, how measurement is done over a number of channels by using a data logger. Of course, the data logger costs a lot of money. This data logger for example costs about Rs 50,000, and number of channels are there in a data logger. The number of channels can be 16 or 64, 128 and so on, different data loggers can be with different channels. The data logger can also be plugged into the USB port of a pc now-a-days. The one which is shown here does not do that, it has to be connected through an interface, and it has got its own controller and so on. But the new ones come with USB, you can communicate with the computer using the USB port directly, it is the plug in play method.

Let us see the second calibration example. This is more like one would be really doing in practice if you are making measurement over a certain range.

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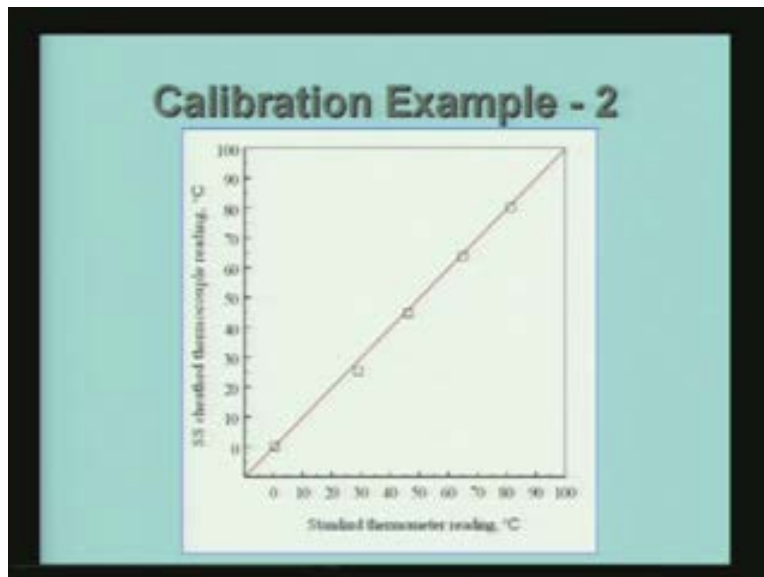
In this case, I have taken the range between room temperature or 0 degree and 100 degrees. And if you notice here, I have got a value around 30,

another about 50, another about 75 or 80 and another about 90 and I have avoided using the end points. It is a good practice to choose four or five calibration points or temperatures, in this case it is the temperature, it is valid for any instrument. If I am using a voltmeter if I want to calibrate the voltmeter, I must calibrate not at the extreme points extreme points are not reliable, what I have to do is I have to take 10%, 30%, 50%, 70, 80 and so on.

We have to take several points in between the minimum and maximum and then use the calibration if it is a voltmeter. If it is some other meter it is exactly the same thing. If it is a flow measuring device for example, I would not go to the extreme, but I will only do it in between the range. So this range will be known to us, and therefore we will pick up the values like this. In this case, you can see that there is a difference between the thermocouple, this is a stainless steel shielded thermocouple K type and this is a standard thermocouple that means I have taken the reading from a handbook which gives the data for this particular type of thermocouple, and I have compared the two. That is exactly what I have done.

Now I am giving you the value of the voltage which is converted to temperature and I have plotted it here. Here there are some differences, this is for a particular thermocouple but another thermocouple may show a slightly different behavior. And if I plot the error, you can see that the error is almost 10% here and of course, it becomes small here between 40 and 80 so it is about 2 to 3% or so.

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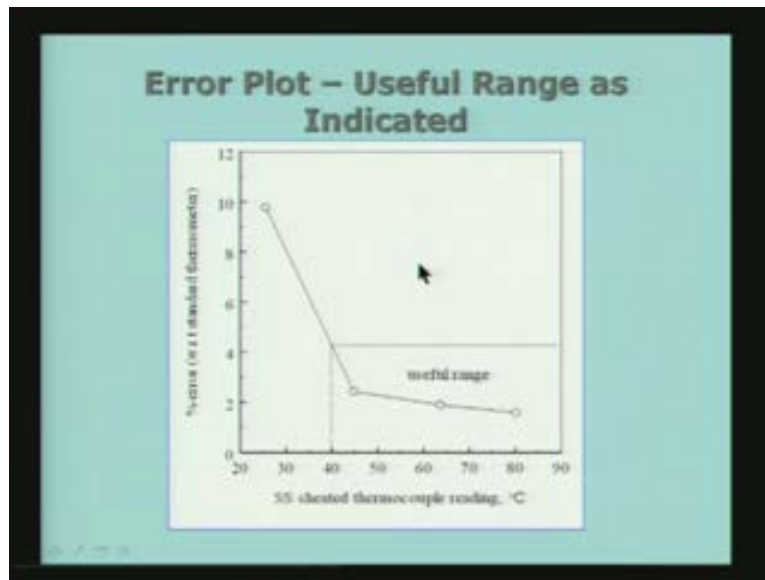
So what I can do is, I can use this value as a correction. When I am making actual measurement, the data in this form, the error plot useful for this particular range around 40 to 90 degrees is where I am going to make these measurements, I can use this information as a correction to correct the information, or correct the temperature obtained by using the thermocouple, and make it agree with the standard thermocouple. This is real calibration, where I am trying to bring it in agreement with a standard reference thermocouple.

The other one was utilitarian, this is a slightly different way of doing the same thing but we are comparing the thermocouple of the same types for which the output is known so I would like to use this table for the purpose of determining the temperature. The next one I am going to look at, is the calibration of flow meter.

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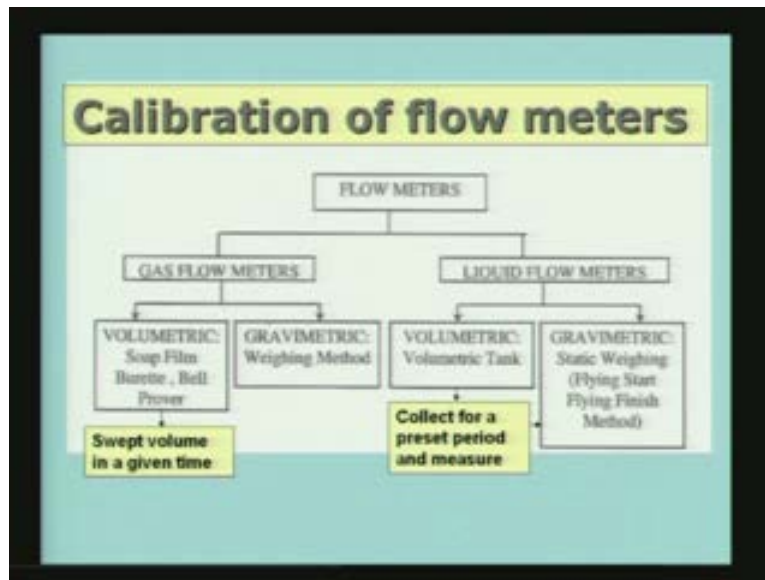
Let us see the schematic of how one goes about calibrating flow meter. We may have either gas flow meters or liquid flow meters, I am avoiding solid flow meters or solid flow. The gas flow meters can be either volumetric or it could be gravimetric, that means mass flow or the volumetric flow and liquid flow metric again you can have volumetric or gravimetric.

And if you look at the gas flow meters when you have a volumetric flow rate, the difference between liquid and gas is that, the liquid can be collected easily, and it can be measured. Here I am collecting the liquid for a certain length of time in a tank whose volume I can easily measure.

For example, I can have a beaker in which I can collect the water, or I can have a bucket in which you can collect the water, and weigh the bucket before and after collecting the certain volume of liquid which has flown through the system. So, by measuring the volume, find out the density of the material of the liquid, and I can find out what is the volumetric flow rate or by weighing it, I can find out what the mass flow rate of the liquid is. These are the two methods which are available, and both of them depend on simply collecting the liquid which is flowing through the system or through the flow meter for a certain period of time, note down the period and in fact, this is absolute calibration because, we are actually measuring the volume, actually measuring the time for which the volume flow rate has occurred, and

dividing one by the other we will be able to get absolute value of the volumetric flow rate so this is direct calibration.

If you come to the case of gas flow meter, what one does is, if you have a burette, a highly accurate bore so that I can measure the volume swept by the liquid or by the gas.

How is it done?
A soap film is allowed to get into the system, and the gas simply displaces the soap film, and you find out the amount of time taken in sweeping a certain volume of the burette by the soap film, and that is the volume flow for that particular period of time, and all I have to is to divide one by the other, where I will get the volume flow rate. So, by knowing the actual volume flow rate by this method, I am calibrating the instrument, because the instrument will indicate something else. The instrument will give you output in the form of a voltage, or delta p so I can now relate delta p directly to the volume flow rate or the mass flow rate as the case may be.

So let us take one or two examples of how they can be done. This is a case where gas flow meter is calibrated.

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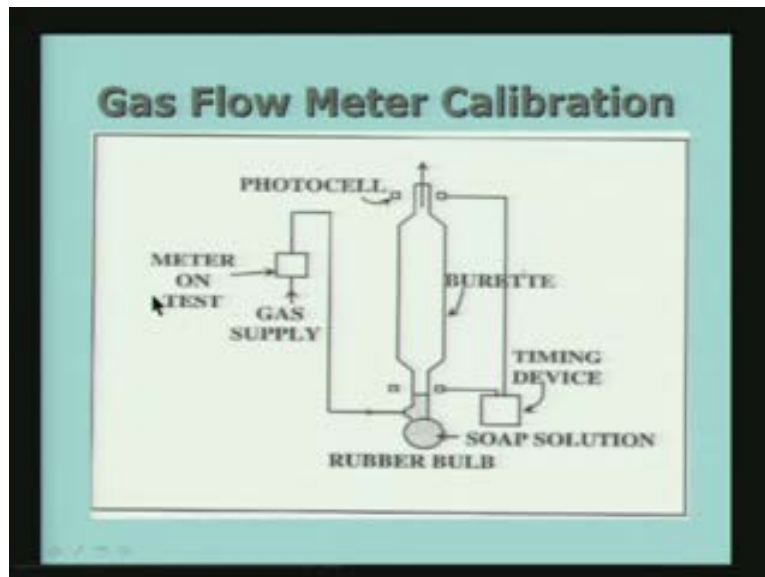
I have the meter on test, this may be any meter for example, a rotor meter and then I have gas supply it may be air in which case it will be air supply if

it is gas you supply the gas, and it flows through a vertical burette, and I have a soap solution here, and at some particular time I will allow a soap bubble to enter soap film to enter, and then the gas flow is going to carry this film across this.

There is a photocell here, and when the soap film crosses that, the time device will start and when the soap film passes the next photocell the timing device will stop. So the time duration over which this soap film has traveled from here to here, is noted by the timing device and the volume of this vessel or the burette between this point and this point is predetermined or known earlier which can itself be measured by using water or liquid, and then filling that and determining the value of the volume by using an accurately calibrated beaker or some such arrangement.

So you see that we are measuring the volume soaped by the gas as it flows through this thing and the same amount of gas must have passed through the meter, and I can determine the flow rate through the meter on test by measuring this volumetric flow rate and whatever the output is of the meter on test it will be corresponding to that particular volume flow rate. So what normally we do is,we vary the flow rate may be to 30%, 50%, 70% of the range and then for three or four values I can do the calibration.

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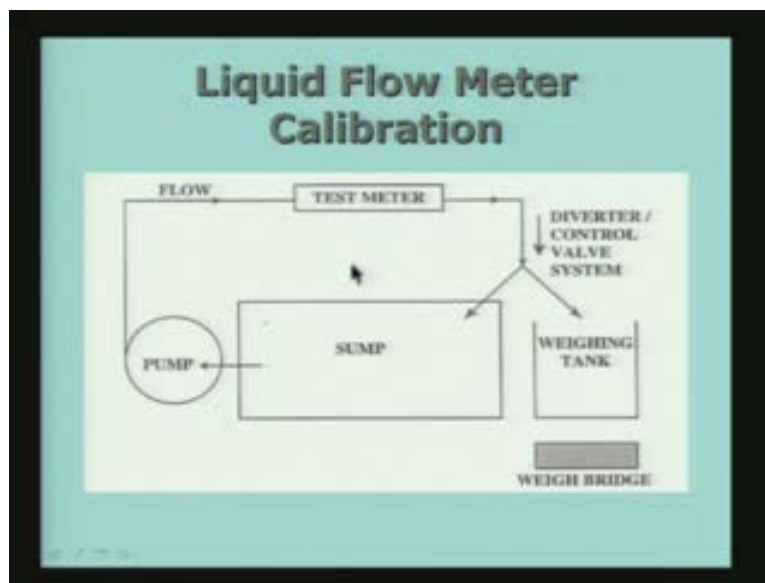
The second method is very simple in the case of liquid flow. There is a pump, there is a sump here, the liquid is circulated it goes through the test meter, and then it either can go into the weighing tank, or it can go to the sump. So what I have here is a diverter or a control valve system so what it does is it will either send the fluid to this side or this side by opening very quickly a quick acting control valve. It will either flow this side or this side, it will either go back into the sump or either the weighing tank.

What we do is, we start the measurement process by allowing it to come to weighing tank and after a certain length of time you stop it, and divert it back to the sump, you find out how much liquid has been colleted in the weighing tank either weigh it using a weigh bridge or you measure the volume by noting down the volume of the water, or the volume of the liquid which has been connected. So, the volume divided by time will give you the flow rate, and test meter will indicate whatever, may be it is a delta b or some other voltage signal. So you can see that, there is a correspondence between this value, the value indicated by the meter, and the weighing tank measurement system. This is one way of calibration.
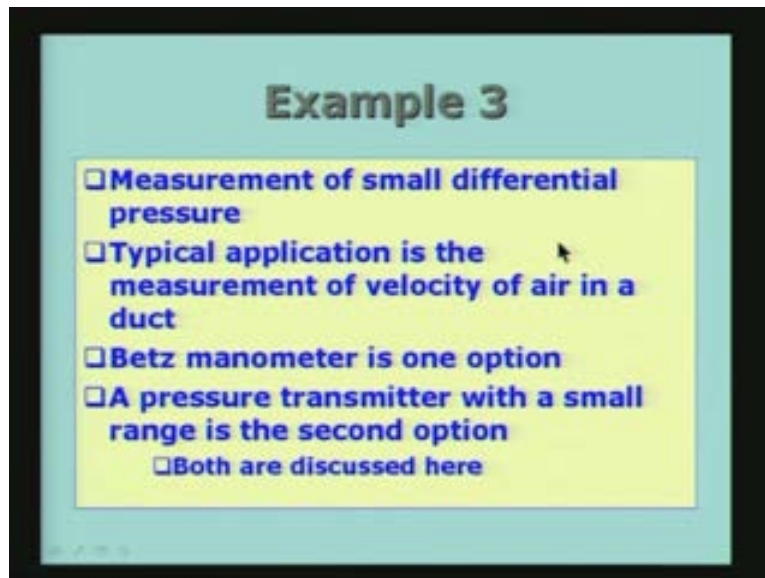
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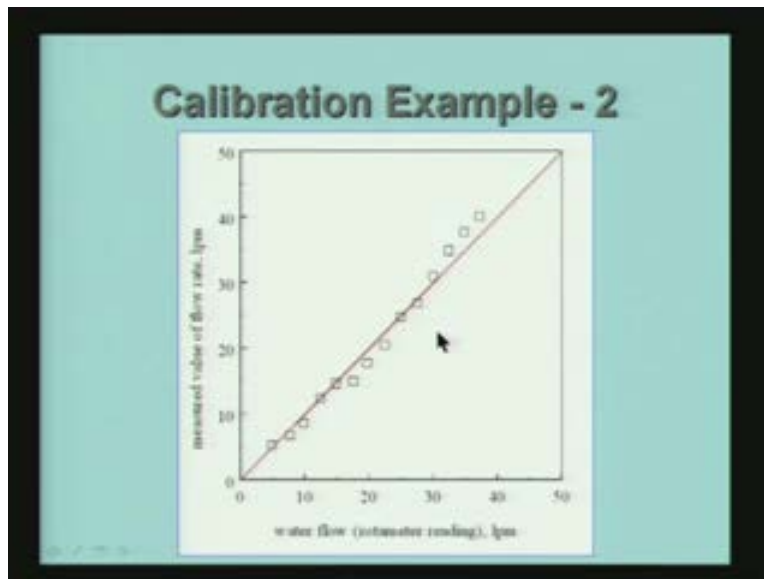
In fact, I have shown an example here. I am trying to calibrate a rotameter and essentially we have a similar set up and then the calibration looks as something like this. We have the measured value of the flow rate liter per minute and the water flow rotameter reading, the rotameter is calibrated and

the scale on it says the value whatever it is and you can see that there is some systematic variation between the two, the measured value which is measured by the using the absolute value collecting a certain volume of the liquid for a particular amount of time compared with the reading indicated with the rotameter. It is more or less a good comparison but of course there are some variations which can be used as calibration information or you can use correction factor for that.

For example, here the reading of the actual measure is smaller than that indicated by the rotameter and here it is the opposite. The error is both positive and negative in this particular case. The third example is, the measurement of small differential pressure a very small delta p. Typical application is the measurement of velocity of air in a duct or a wind tunnel. When you want to measure very small pressure differences there are several options.

Here we have two options. One is, I can use a mechanical arrangement which is simply a manometer,which is called a Betz manometer, otherwise I can use a pressure transmitter with a small range so the range I am going to determine by using the data is from this typical application. In the application, I will know what is the range of the velocity I am going to measure, and then I can convert this velocity information to a suitable information in terms of delta p that is where the pressure transmitter is coming or it would be a delta p, where the Betz manometer is going to measure the delta p.

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Let us look at a typical example of delta p measurement; this will correspond to the measurement of air velocity.

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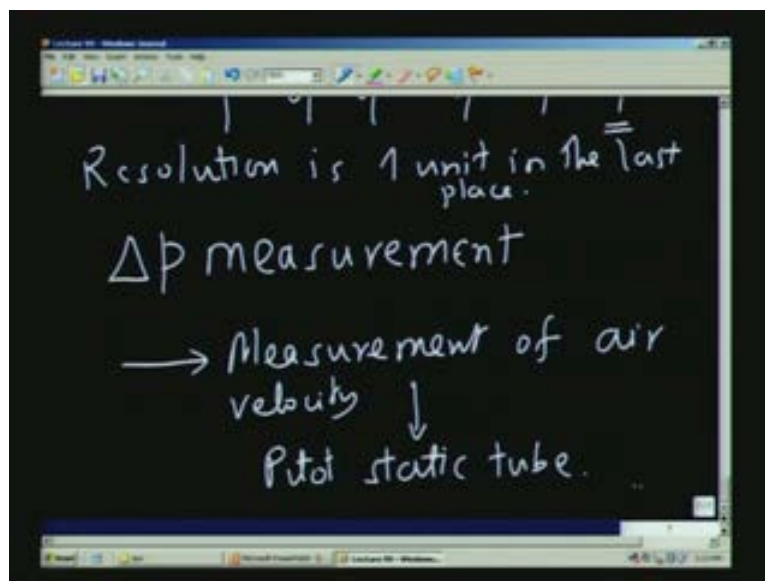
The primary instrument I am going to use is a pitot static tube. Let us find out the typical values of the velocities that are to be measured, and then accordingly we will find out the suitable instrument for that purpose of measuring the delta p.

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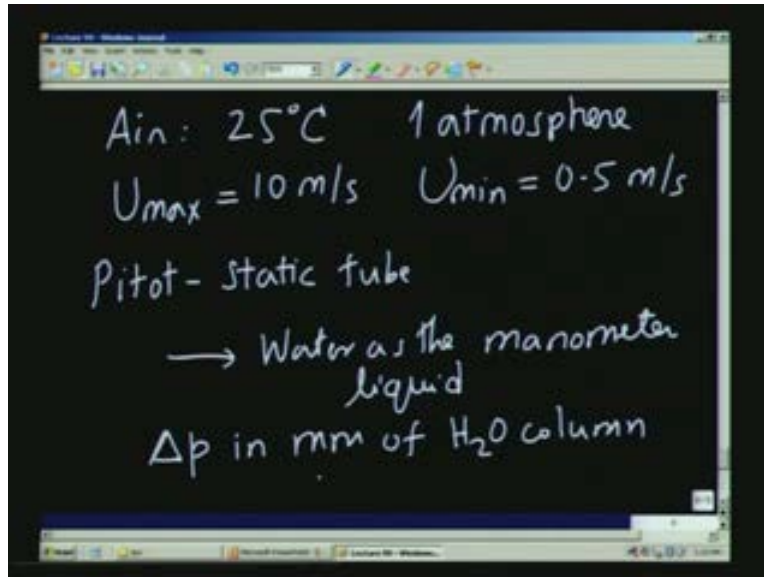
I will consider air as the flowing fluid at 25 degree Celsius, because the flow rate is dependent on the density, and I will assume that it is at a very small difference with respect to one atmosphere because delta p is there. The delta p is very small compared to the atmospheric pressure. The maximum velocity I know is about 10m by s, and the minimum velocity is about 0.5m by s this is the measured value, I am going to measure such values. In fact, I can find out what is the dynamic head.

If you have a pitot static tube, I may be using water as the manometer liquid, and therefore it will be convenient to represent the reading of the pitot static tube in terms of millimeters of water or millimeters of water column. That is delta p in millimeters of water column. Let us look at the values.

The dynamic head we know is what is going to be indicated. It is nothing but delta p is equal to ½ into (rho U square), where rho is the density of the air or the fluid through which it is flowing, this is the velocity and in fact all I have to do is to calculate the delta p_{max} and minimum it will be ½ into rho of air I can calculate using the ideal gas relationship so p is one atmosphere so one atmosphere is 1.013 into 10 to the power 5 Pascals, and the value of R is 287, and temperature is 273 plus 25 so I can just put the value as 298. So this gives you a value of 1.184 kg per m cube.

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So all I have to do is to introduce here, into 10m by s is the maximum velocity 10 square this will be in Pascals. This gives you a value of 59.2 Pascals. I can similarly determine the minimum pressure which is going to be measured. All I have to do is, to change the velocity to 0.5m by s into 0.5 square Pascals, and it comes to 2.37 Pascals, so we are talking about very small delta p. In fact, I will convert this to millimeters of water. So delta p is equal to some (rho into g into h), where h is the height of water column, g is the acceleration due to gravity, and rho is the density of water. I will take the density of water simply as thousand for the sake of simplicity. So delta p_{max} will correspond to h_{max} which will be delta p divided by, so delta p is 59.2 P by 1000 that is the density of water into 9.8, and to convert it to millimeters I will multiply it by 1000. So it is 59.2 P by 1000 into 9.8 into 100.

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These two 1000 will cancel and you simply divide this by 9.8 and you get that value and that happens to be 6.043 mm of water. So the maximum we are going to measure h_{max} is 6 mm, and I can also calculate h_{min} it will be simply the value of delta p in Pascals 2.369 by 9.8 mm of water that will be 0.242 mm. Here we are talking about very small changes in h. So one option is to use a Betz manometer, where we use optical arrangement to measure delta h with a high degree of resolution.
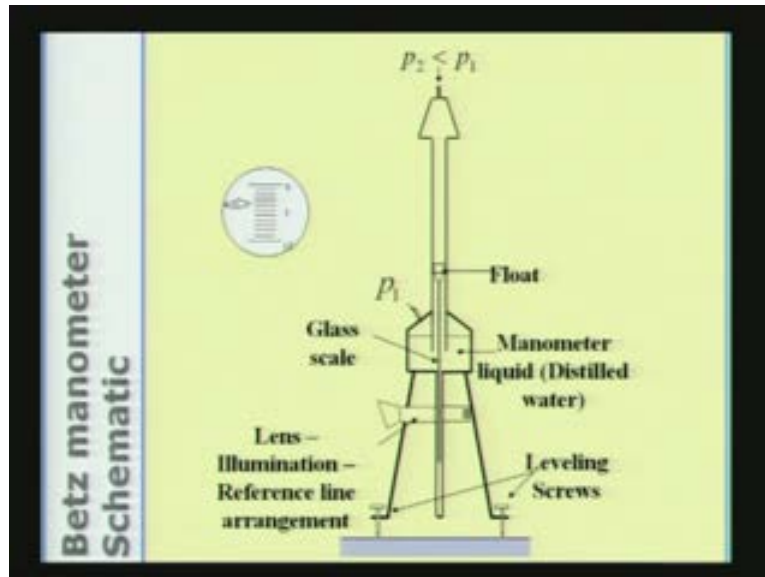
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Let us look at a typical schematic of a Betz manometer. Basically it is a well type, there is no U-tube and instead of U-tube there is a vertical tube sitting into the well.

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It is actually a well type manometer, we have a well here, that means it is a very large reservoir of water, I am going to use a liquid in the form of distilled water, and what I have is a tube which is sitting in the middle of that and the space above the well is connected to the higher pressure P_1, and the space above the column above this vertical tube is connected to the second pressure P_2, the lower value.

What I am measuring is the dynamic head which is in the form of P_1 minus P_2 related to h here. This h is the height difference between the two sides. How it is measured is, I have a float this float is going to be stay at the meniscus of the water in this tube, and to the bottom of the float is connected a glass scale which is dipping into this chamber here, the lower chamber. This is a small tube into which this glass scale is going to be dipping.

What I will do is, I will use a lamp some two lenses here, and using the eye, I can focus on the scale, I can put a spot on the scale and that is what I have. And you have a Vernier, which will indicate the value of the height, in this case, I have simply shown 42.4 or 42.5, or some three or four so this is so many millimeters, or so many whatever units of water column. What is

being done is the height of the meniscus is measured by having a floating scale, the scale is actually floating, because there is a float here, and the scale will go up and down, and the marks are on the scale corresponding to the main scale division, and the other one is the Vernier which is projected by the optical arrangement, and therefore what we do is, we measure the two in this particular option.

The delta p can be measured with very good resolution, it is supposed to be possible to measure, for example, 0.02 mm of water column. This is a very standard experiment, which is usually found in laboratories where wind tunnel work is done.
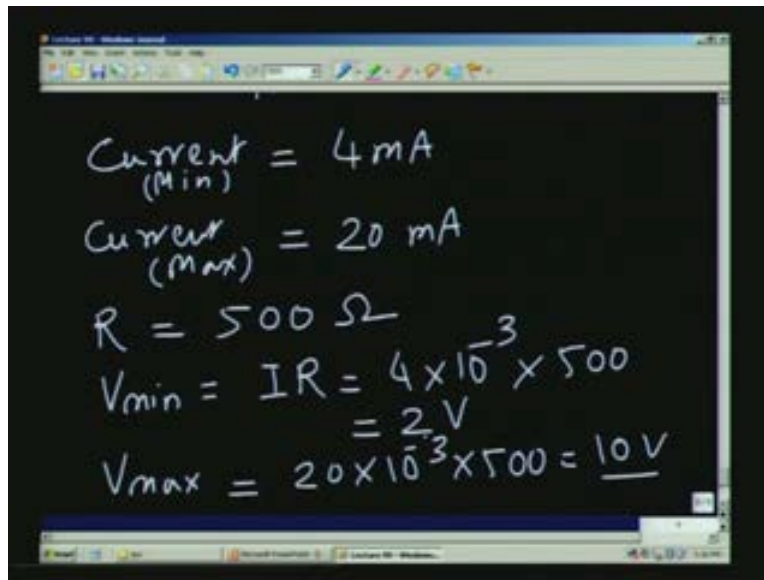
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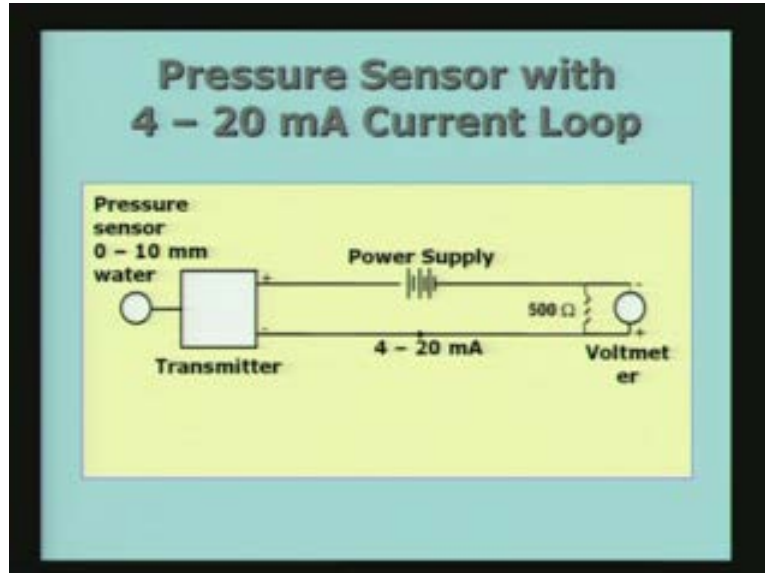
The next one is the 4 minus 20 mA current loop. What I am doing is I have a pressure sensor with 4 minus 20 mA current loop, and the pressure sensor is now capable of measuring 0 to 10 mm of water. If you remember, the example, which I worked out is about 6 mm the maximum so we have 0 to 10 mm as the range of the pressure sensor, and the pressure sensor is going to be transmitting the pressure signal, in the form of the 4 to 20 mA current. This current is maintainable by using a power supply. It can be either 12V or 24V or some such power arrangement or power supply of such voltage.

In this case, what I am doing is at the downstream end, I have a digital voltmeter or voltmeter in general, and I have connected a load resistance of

500 ohms the 500 ohms is the load resistance which is going to be here. So the minimum reading I am going to get at the voltmeter correspond to 4 mA and the maximum will correspond to 20 mA. We can easily work out on what are the voltages which we are going to get by using these numbers.

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We have current equal to 4 mA which is the minimum, and the current maximum is equal to 20 mA, and I am using a 500 ohms resistance or we can simply use ohms law, resistance is 500 ohms, so I can calculate the corresponding voltage values, voltage minimum is simply IR, 4 into 10 to the power minus 3 into 500, so this will give you 2V and the v maximum will correspond to 20 mA, and this will correspond to 10V. So the output of the instrument, when delta p is 0, that means there is no flow in the internal. So delta p is equal to 0 translates to 2V output, delta p is equal to 10 mm of water in this particular case, will correspond to 10V output.

In other words, now I can convert the voltage output, into a resolution value. What is resolution?
The resolution in this particular case, will depend on, how I am able to measure these voltages, what is the resolution of the voltage measurement, and that is the choice of the particular voltage measuring device.

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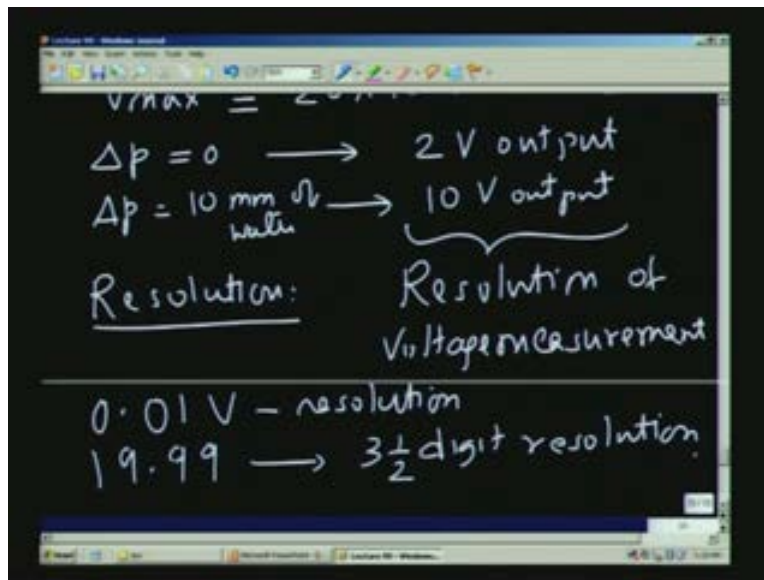
Suppose, for example, I am able to measure 0.01V resolution what does it mean?

I can go up to 19.99. You realize that there are four digits, four numbers here, the first one is ½ digit, because it can go from 0 to 1, the other three can go to 0 to 9, this is a 3 ½ digit resolution. But the point is not that, the point is what does this correspond to?

In this case, you can see that the 4 mA, corresponds to 0, 20 mA will correspond to 10 mm of water. So we have, 10 mm of water corresponds to 20 mA which now corresponds to 10V.

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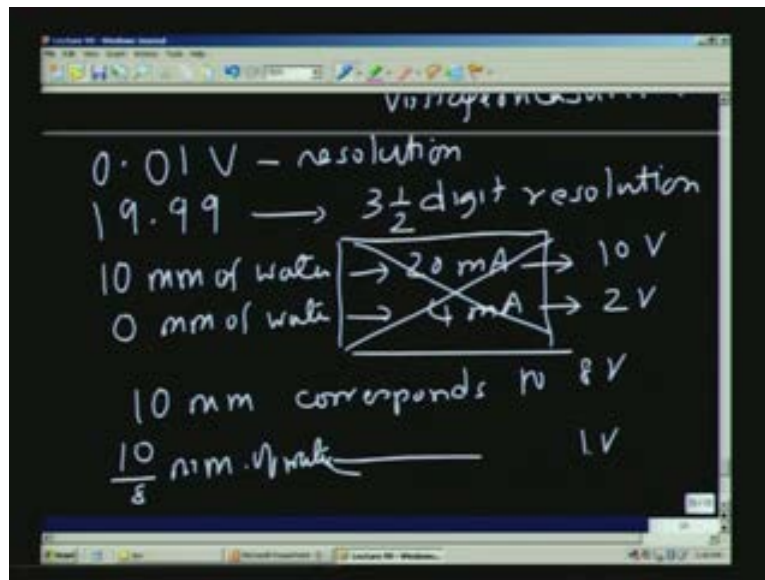
Therefore at the other end, we have 0 mm of water that corresponds to 4 mA, which corresponds to 2V. So we can now forget this, we now have a transfer function or transform from the pressure reading to the voltage reading. Actually the difference is 8V so the 10 mm of water corresponds to the difference, I am talking about the difference in values so 8V will correspond to 10 by 8 mm of water so it is 1V. Now, depending on if I am able to measure 0.01V, this is divided into hundred parts with 0.01V resolution. That means I am going to divide this by 100.
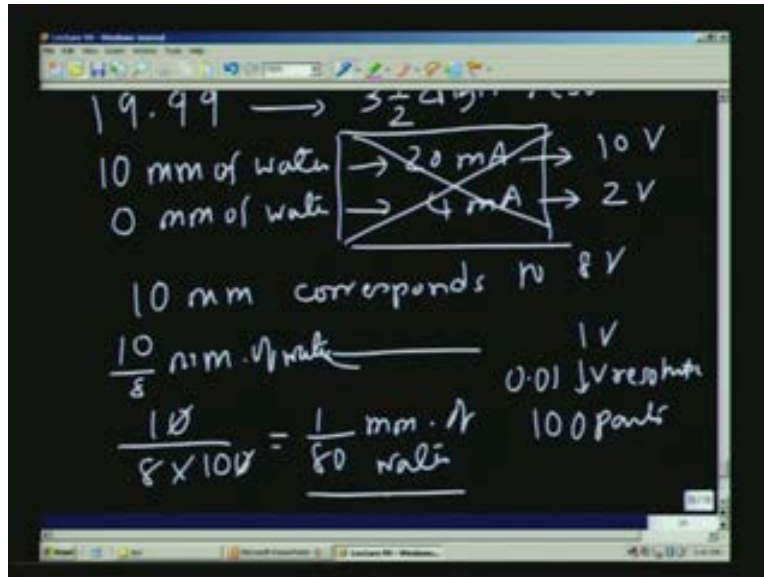
So 10 by (8 into 100) 1 by 80 mm of water which is slightly less than 0.01 because this is 1 by 80 and 80 is less than 100. In this particular case, you see that by using a 4 to 20 mA current output, and using 500 ohms as load resistance, I can actually have an accuracy of a resolution of 1 by 80 mm of water column. You can now see that this 1 by 80m of column must correspond to a certain velocity change. Here, the velocity is non-linear, velocity there goes as a square, but here it is going as a linear scale, because after conversion of delta p only we are doing it. Therefore, when I want to translate this to a certain least count in terms of velocity, I will have to work backwards and find out what this 1 by 80 mm of water will correspond to in terms of velocity which is resolved.

What we have tried to do in lecture 49 and 50 is to just give a flavor of what is required in the laboratory. We described various methods of measurement, the characteristics of these, the analysis of errors and so on. Even for a simple measurement of voltage or current there is a lot of things are involved and one has to do a lot of work before setting up an experiment in the laboratory. Thank you.