Introduction to Uncertainty Analysis and Experimentation
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Module - 05
Uncertainty in a Measurement
Lecture - 16
Examples of uncertainty in a measurement

Welcome to the course Introduction to Uncertainty Analysis and Experimentation. In this lecture we will look at Examples of uncertainty in a measurement.

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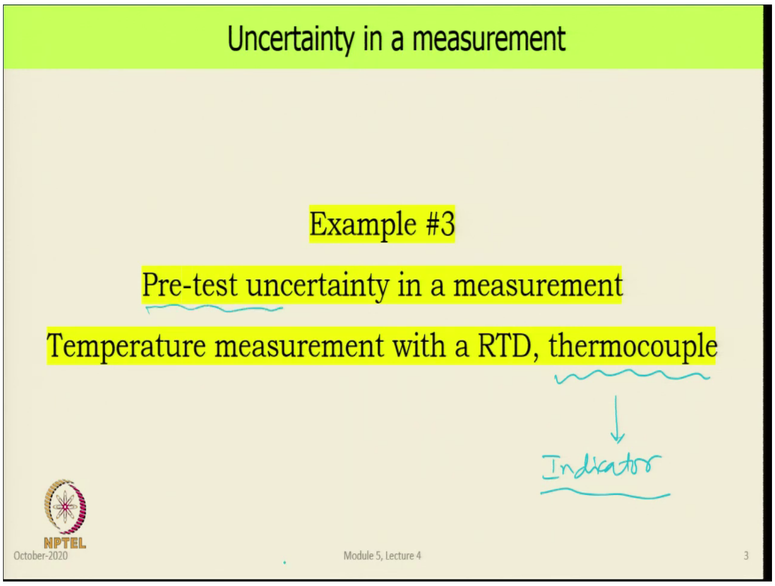

We will take the example of making a temperature measurement during an RTD sensor or a thermocouple sensor along with a indicator. Temperature measurement is probably the most extensively conducted measurement not just an industry or in experiments, but also else where as we have seeing in a COVID checking.

It is one of the most trickiest measurements there are many techniques for making temperature measurement their accuracies, the cost everything comes in a wide range. We will take one simple example of a sensor which will be a thermocouple sensor and see we will connected with an indicator.

And look at the situation where we have not done the experiment, but we want to assess that if we get this particular thermocouple RTD and indication combination, what uncertainty can I expect? So, this is an example of pre test uncertainty analysis in a measurement.

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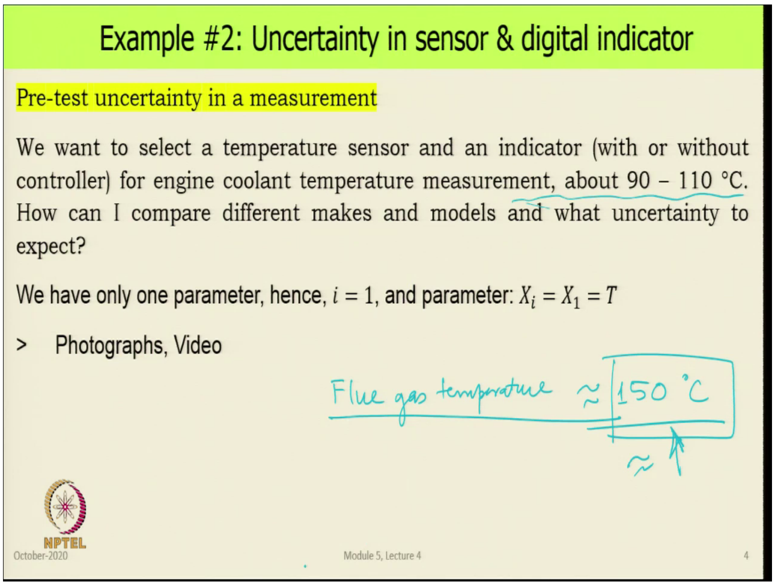

So, here is the problem statement we want to select a temperature sensor and an indicator with or without controller for engine coolant temperature measurement about 90 to 110 degrees Celsius. How can I compare different makes and models? And what uncertainty to expect? So, this is one application I have listed, in the example of taken at one more example; which is a temperature of a flue gas.

And the temperature we said this is a approximately of the order of 150 degree Celsius. So, this is a application, it could be in general using where the fluid temperature is about 150 degree Celsius in that range and this range matters because as we can see the uncertainty will change depending on the temperature being measured even if it is the same instrument.

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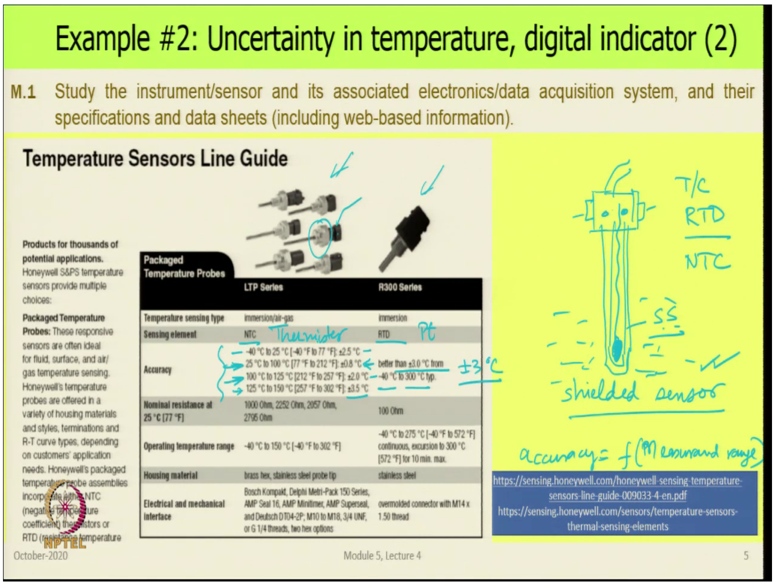

So, let us see first step in our procedure study instrument sensor and its associated electronics and data acquisition system and their specifications and data sheets and including web based information. So, if we do go to the web and start asking, what are the type of sensor available? What are the type of indicator that I can have? What is any other permutation combination that is there? You will get the very large number of options and then you have to decide; how to go forward?

The first thing is let us get the information and here I have displayed some samples of what you would expect to see. All these are from particular manufacturers, there is no real preference I am using these for illustration only. So, this is a type of a sensor we can see here these pictures and what they have is an outside there is a stainless steel tube hollow stainless steel tube, say you can say its like this close that one and inside this here we have our sensor.

And here there is packaging which is closed and finally, there will be wires which can be connected and this side your arrangements to fix it to something else. So, this is the fixing arrangement here and from this yours wires can be taken out. So, will be a connector inside which is got screws on which you can connected and it sensor is sitting inside this stainless steel tube.

So, this is a typical arrangement which is called a shielded sensor and what it does is that the element does not come in contact with the environment in which the measurement is being made. Sometimes the environment can be quit harsh and they can damage this device and so thermocouples in some cases they can be just without the shield and in the domain.

But RTDs are always with a shield and so are the NTC which is written here negative temperature coefficient or thermistor. Now from this data sheet let us see what we can learn, its say that accuracy ok. This side is thermistor this side is a RTD the Resistance Temperature Detector. So, the thermistor works on the principle that you have a device was there is a temperature increases its resistance decreases, so that is the negative temperature coefficient.

RTD is a resistance temperature detector which as a small platinum element small wire element or foil and as the temperature increases its resistance increases. So, what we have measuring in both cases is a change in resistance and from that we are interpreting what is the change in temperature. So, for the RTD it is says that the accuracy is better than plus minus 3 degree Celsius from minus 40 to plus 300 degree Celsius.

So, over this range accuracy of this is plus minus 3 degree Celsius for thermistor its a little more involve thing what you can see here. We said minus 40 to plus 25 the accuracy is plus minus 2.5 degree Celsius, minus 25 to 100 plus minus 0.8 degree Celsius, 100 to 125 plus minus 2 degree Celsius and 120 to 150 degree C plus minus 3.5 degree Celsius. So, this is an example where the accuracy is a function of the range of the measurement and this happens in many other instruments also.

So, we have to do a two way adjustment in the experiment design that if you want minimum maximum accuracy you may have to make a compromise and go for low temperatures where as if you want to work at this temperature then this option is precluded we cannot use it. So, that is the accuracy about these two devices.

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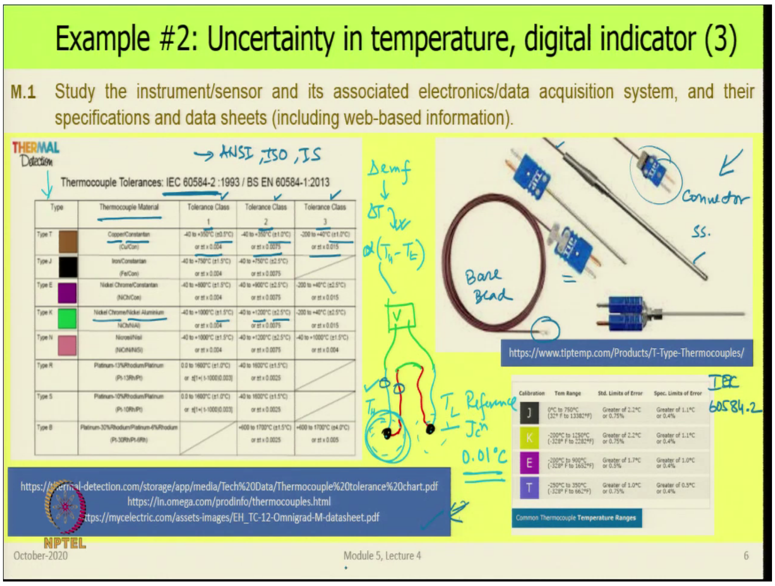

Now, let us look at thermocouples. So, the principle of a thermocouple is that we take two different types of wires and make a, and fuse them at one end to make what is called a bead; it looks like a small bead and we fuse this also. And then we make the electrical connection that we connect these two as a directly or through a common wire.

And then we connect these two to an indicator which tells us the voltage, then we subject this and this two different temperatures. One, so this is the higher temperature T H this is the lower temperature T L then the emf produce is proportional to the difference T H minus T L. So, if you can measure this by measuring a change in the emf. So, we measure change in emf from there we get delta T which is the difference of these two temperatures.

And now if you want to know the temperature of this or this we need to know the temperature of the other junction. So, one junction we call it the reference junction. And one very good the reference that we have is the triple point of water 0.1 degree Celsius. So, if you keep one as the reference junction as this one then we add this value to this delta T and we get T H.

So, that is how the thermocouple works, but the signals are very low and so what we do is send it to an amplifier and then digitise it and then do this reverse calculation; convert the emf into a delta T, we need a calibration there and then add the reference junction temperature to it and we get the temperature that we are trying to measure.

So, when we are measuring it is this part here which we will take and locate it where we want to make the measurement. Now thermocouples come in a few common categories or types that they are called and that is listed here. So, this table is a taken from an international standard which governs thermocouples.

So, this is the international standard IEC 60584 and there are equivalent standards from ANSI, ISO, IS. So, when you look up a manufactures catalogue they will all say that this thermocouple is as per IEC 60584 and within that they will give more information that, what is the type T, J, E, K all that; that tells you what is the type of that material of the two wires.

We said that there are two wires here this wire and this wire and this tells you what is the material of those two wires and then it tells you about the accuracy. So, is that there is tolerance class 1, tolerance class 2 and tolerance class 3. And we will look at the type T thermocouple where there one wire is of copper, the other is of constantan.

And its says that if you a class one thermocouple with this you can expect a temperature we can expect the uncertainty of plus minus 0.5 degree Celsius or the value times 0.004 whichever is greater. For tolerance class 2 you have for the same range you have type T which is good for minus 40 to plus 350 degree Celsius, plus minus 1 degree Celsius or plus minus the temperature multiplied by 0.0075 whichever is greater either this or this.

And for class 3 it is plus minus 1 or the temperature measured into 0.015 whichever is greater, so this is the highest accuracy then less accuracy and the least accuracy. And there is a similar numbers given for each type of thermocouple and the range over which it can be used through. For instance here type K type thermocouple which is nickel chrome and nickel aluminium or called chromel alumel.

This works from minus 40 to 100 degree Celsius, plus minus 1.5 degree Celsius or if it is class 2 it goes to 1200 degree Celsius plus minus 2.5 degree Celsius the uncertainty is there. So, this is a table where we are now learnt that even without buying anything or having an instrument with us if you can look up IEC 60584 or any of its equivalent standards, we know what accuracy to expect in these type of devices whose picture is shown on this side here.

So, what you are seeing here is in this case this is the shielding stainless steel shielding, inside this is the thermocouple, the wire is coming out there and it is connected at the other end to a plug which is the connector. This is an picture of something where there is no shielding this is the bead you can see here this is called bare bead. And then it have called it wire which is a made into coil and finally, it as got a connector over there.

And this is a configuration where you have a shield inside that the thermocouple and right on top itself with a connector integral to this body. So, there are very large number of permutations combinations that are available standard and on top of that you can yourself design your own sensor also. So, that is what we have seen about thermocouples and this is a same chart put in a different way, but the values here this is also from IEC 60584 dash 2.

There are different websites that one can look up and there are many many more to this is just a representative sample here.

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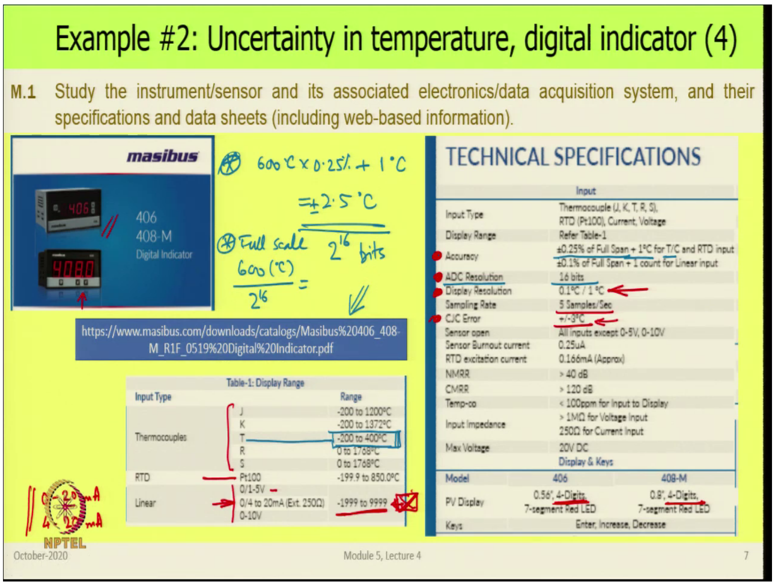

Now let us look at the other part of the device that we take that connector we saw that its ended up in a wire that wire can be connected to an indicator and so this is one example of an indicator here. The website from which this is taken is over here and I am using this for illustration only.

So it gives the technical specifications here its an input type can be J, K, T, R, S thermocouple or RTD PT100 thermocouple or a current input or a voltage input. And the display range is as per this table its say. So, we have so we are going to look at T type thermocouple the display range here is minus 200 to 400 degree Celsius.

Then accuracy its says for thermocouple plus minus 0.25 percent of full span, full span means in this case we are going minus 200 to 400 which is 600 degree Celsius; so 0.25 percent of 600 degree Celsius is these thing plus 1 degree Celsius. So, if you want to calculate this becomes 600 degree Celsius into 0.25 percent plus 1 degree Celsius and this you can see this is 2.5 degree Celsius.

And it does not matter whether you are measuring minus 100 degree Celsius the near 0 degree Celsius or 350 degree Celsius the uncertainty or the accuracy of this is the same. That is one piece of information we got about what to expect on the indicator. The next thing is that as we have learnt in measurement it thermocouple output is a analogue signal it is amplified finally, digitised and then display or record it.

So, in this case its A to ADC resolution 16 bits; that means, the entire input signal that was coming in it has been programmed in a way. So, that the full scale; the full scale of temperature which translated into full scale of voltage which the instrument sees that is divided into 2 to the power 16 bits. And we can then see that if these was our input range this 600 divided by 2 to the power 16, this will tell us; what is the minimum temperature difference that this particular indicator can discriminate in the digital form.

So, that is one more piece of information we have; we have got this one, we got the other one there. So, this was 1, this is the 2nd one and now let look at the 3rd one is a display resolution 0.1 degree C slash 1 degree Celsius. So, depending on where we are measuring the temperature what we see here is got 4 digits on the display they have shown here.

So, as you can see in this picture the decimal is over here in which case we are looking at display resolution of 0.1 degree Celsius, whereas here we are looking at the display resolution of 1 degree Celsius; so this is we can select this. So, this is a third piece of information we have about this device which influences the uncertainty that we can expect in using this device, along with the thermocouple, or an RTD or just the current or voltage measurement.

And it also says what type of inputs it can take, so these are all the thermocouple inputs it can take which can take an input from the PT100 which is a resistance temperature detector good from minus 199 degree, 0.9 degree Celsius to 850.0 degree Celsius. And you can also can takes input as voltage 0 or 1.5 volt 0 to 1 or 0 to 5 volts. So, we can input a voltage to it or as you can see here this says 0 to 20 milli amperes or 4 to 20 milli amperes over a range minus 19999 to 9999.

So, as I was mentioning many instruments in the real world which are used in process, processes control and all that they would all have on the top of the instrument a transmitter which will convert the signal into an equivalent current signal and send it out. So, this could signal could be 0 to 20 milli amperes or 4 to 20 milli amperes and then it gets into that much that is a range of over which the signal will come. So, minus 19999 will correspond to say in this case 0 and 9999 will correspond to 20 milli amperes.

So, if the temperature indicator was transmitting the current signal we would use this. What we will do is; we will say I will directly connect our temperature sensor to this indicator and see what happens. So, we are not having wanting to get into this part for now. But in the real world this is all things will happen one will have to work with one of these things because the distance would be long you do not want to signal attunement, and so that is what you do.

Then there are many other specifications given here like sampling rate 5 samples per second. So, in a every 12 seconds it can take the reading, then cold junction compensation error plus minus 3 degree Celsius. So, these are the thing we could look at that is our cold junction is not an ice point an ice point will not give this problem, but if we do not have an ice point and we rely on the cold junction in that device then we are looking at yet one more source of error.

Then these are all electrical aspects we will we do not need those here. The last part here is of course, it is got a 4 digit display and we can see from this indicator what it looks like. So, these are indicator we will try to connect to a thermocouple. So, that is and if you look up the web you will find many more indicators and you will get lot more information about the technical specification. So these are typical one that we are looking at.

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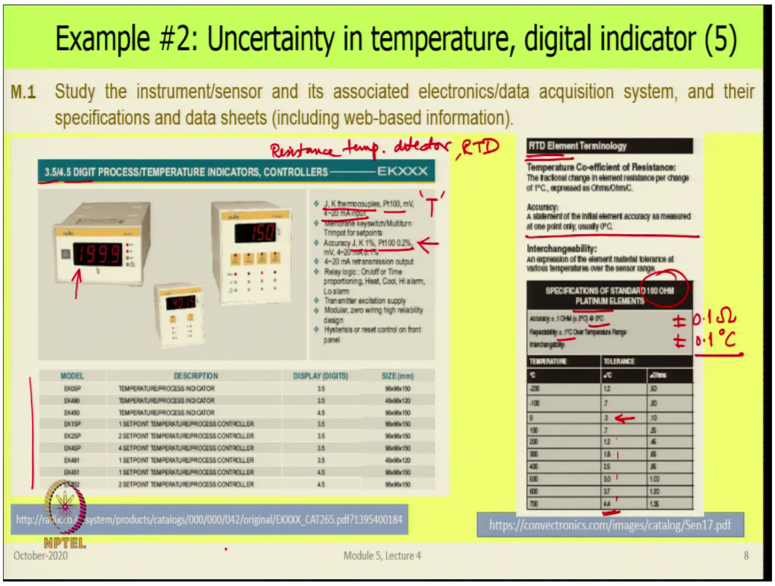

So, here is a yet another one, but it is for RTD which is the resistance temperature detectors this is also very widely used in industry for temperature measurement. Although it has to be used with the stainless steel shield where as the thermocouples we can use it without shield also and those could be much smaller also than RTDs.

So, they have their own pros and cons and depending on the application we have to make a call. So, it says RTD elements the terminology is given there and accuracy, say this statement of the initial element accuracy as measured at 1 point only usually 0 degree Celsius. So, here is the information given here typical resistance of RTDs is 100 ohms, these are all platinum elements platinum is a noble metal.

So, it does not corrode or degrade in that sense. Accuracy is plus minus 0.1 ohm at 0 degree Celsius, so this is plus minus 0.1 ohm and repeatability is plus minus 0.1 degrees Celsius over the temperature range.

This is pretty good repeatability; that means, if you come back to the same thing with the same instrument again and again you will get all temperature which are within this much. And then here is that all that information at different temperatures as of, so as a function of temperature how does it change? This is the table that is there.

So, in degree Celsius at is minus is 1.2 degree Celsius and minus 20 it decrease to 2.3 at 0 degree Celsius and again increases to 4.4 degree Celsius at 700 degree Celsius. So, RTD also has got similar situation that we saw for a thermistor, that it had the best accuracy point in some range at the far ends of the instrument its accuracy decreases.

So, that is a another indicator which we could use along with these or with thermocouple and it says you got three and a half digit and four and a half digit in the display. The half digit is that this is 1999. So, this digit does not go beyond 1, it is maximum is 1 and the maximum number it can display is 1999.

It can take J, K thermocouples PT100 or 4 to 20 milli ampere input current. And then again get they have it is not good, so if you want to T type thermocouple this is not suitable, we cannot we cannot use it. But let us see what does it tells us accuracy is 1 percent, RTD its 0.2 percent and for current its 0.1 percent. And there is a various models that are there. So, here is slightly different type of a device, but its not good enough for T type thermocouple.

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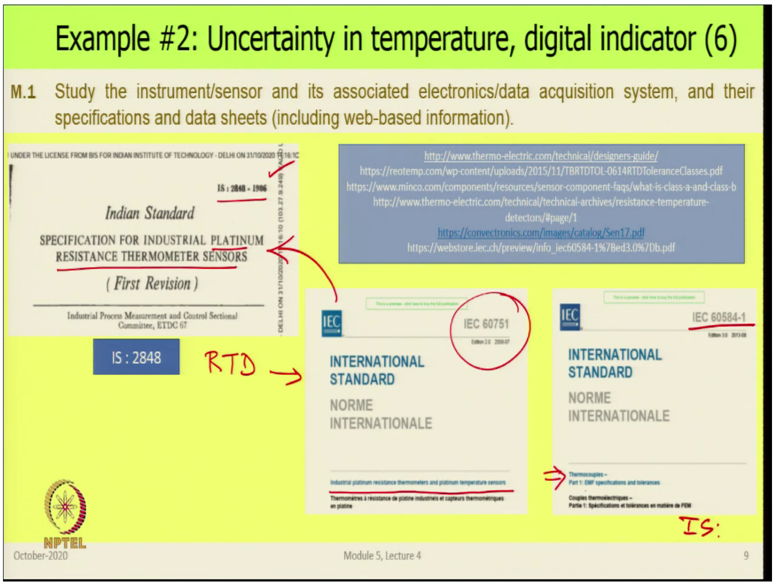

Now let us look at some standards for resistance temperature detector which is called platinum resistance thermometers sensors, this is what we have been calling RTD. We have IS 2848 with the latest version which is few years back and it gives us what all is there in this for getting the details of the sensor.

So, this is one standard and you can freely download it and have a look at it, but as far as RTD is goes there is an international standard, you can see here IEC 60751. IEC as you we have seen in ISO gum also they were part of the process international electro technical commission. And this is the standard on industrial platinum resistance thermometers and platinum temperature sensors.

So, much of what is there in IEC 60751 has been incorporated into IS 2848. So, we are if you do not find the standard we can definitely get the Indian Standard. So, this is one standard for

RTDs. Similarly for thermocouples here there is a standard IEC 60584 part 1 part 2 and as you saw is instruments sensor manufacturer, they will say our sensor is class 1 as per IEC 60584 and what it mentioned we saw that in one of the earlier slides.

So, the title of this here is thermocouples part 1 EMFs specifications and tolerances. So, there is also an equivalent Indian Standard on this one, so we can look at that, but we saw how if someone tells us that this instrument is in conformity with IEC 60584 class 2, then we know from that earlier table what they mean. We do not need to separately ask them what is the accuracy of this instrument.

So, that is some more information we got about standards and as you look up catalog you will find all the good manufacturers we will say that their sensors confirm to one of these two standards or an equivalent standard.

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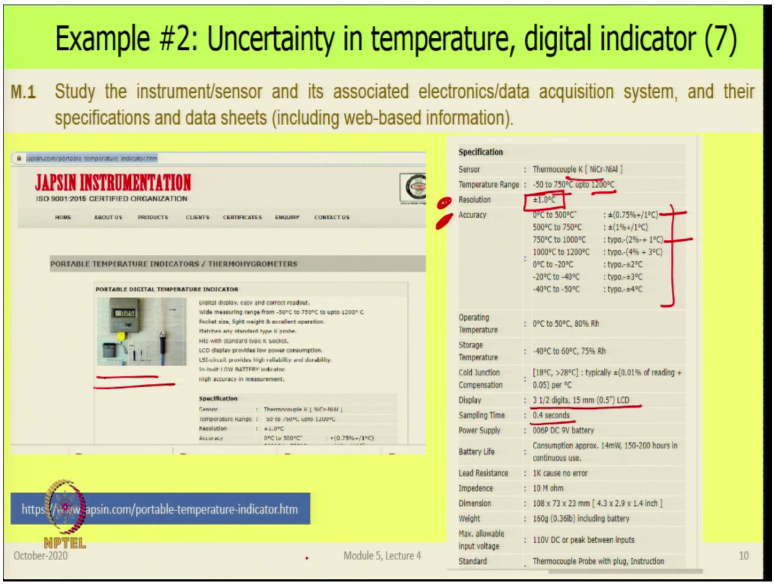

There are some instruments where everything is together only, so here is one example of that. Portable temperature indicators from this one particular company so; that means, there is a sensor and it tells you the temperature and humidity in one shot. So, it gives their sensor is K type thermocouple chromel alumel it can go in temperature ranges minus 50 to 750 and even up to 1200 degree Celsius. Resolution point plus minus 1 degree Celsius.

So, this is one input that you would read if you are looking at uncertainty from this. Then accuracy it shows you that there for different temperature ranges the accuracy is different. So, we have to be picking up that value of this accuracy where we expect to make our temperature measurement. If I expected the temperature measurement is 100 degree Celsius we would pick up this one 0.75 percent plus 1 degree Celsius.

If you are making a temperature measurement of 800 degree Celsius it would be here 2 percent plus 1 degree Celsius, so it is a 0.75 plus slash 1 degree Celsius whichever is greater. So, that is the accuracy that is another piece of information we would like to have. Then there is coordination temperature display three and a half digits sampling time 0.4 seconds and then the rest of the information is there.

So, this would be a case like we saw with the infrared temperature measurement device where we do not know what is inside the electronics in this we just know these broad parameters and we have to work with the indication that the instrument gives us.

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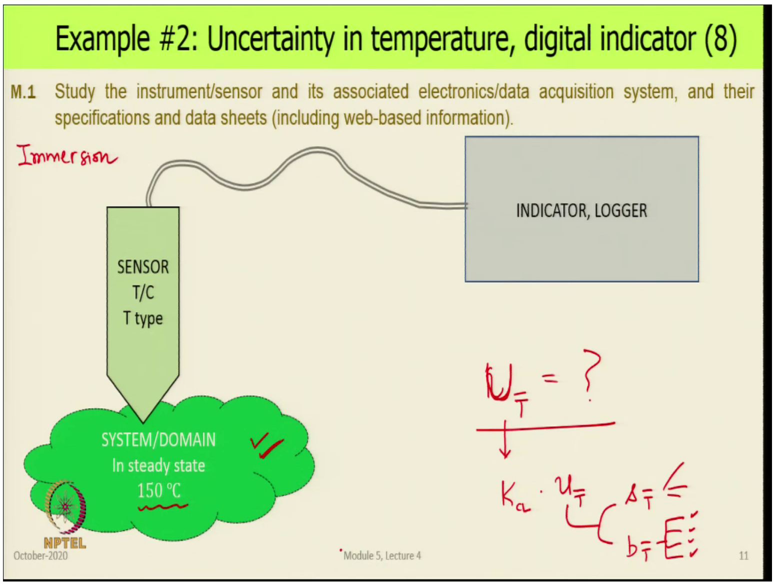

So, now we will get into our example we say what we will have in our system domain where in steady state we are having a temperature of about 150 degree Celsius. In that we all these devices thermocouples RTDs and thermistors they are intrusive devices. So, in the catalogs and everywhere you will see that it says immersion. So, what is the environment in which they can be immersed? What the pressure temperature? What are the chemical composition of that environment? All of that will come over here.

We will use a sensor thermocouple T type and take its wires and connected to an indicator or logger that we saw in one of these pictures here. And we will say that look, I want to make such a measurement in my experiment in the future, when I make my experiment. If I use this particular sensor and I use this particular indicator or data logger or DAS, then what is the overall uncertainty I can expect in my temperature measurement? This is a question.

Which we know that for this we need the multiplying factor and the standard uncertainty in the value and for this we need to get s T bar and b T bar and then in each one of these we have something is coming in. So, we have to calculate this, this, this, this we have estimated this, then calculate this; estimate this calculate this, then come here, then come here we got the answer. So, that what we will do now.

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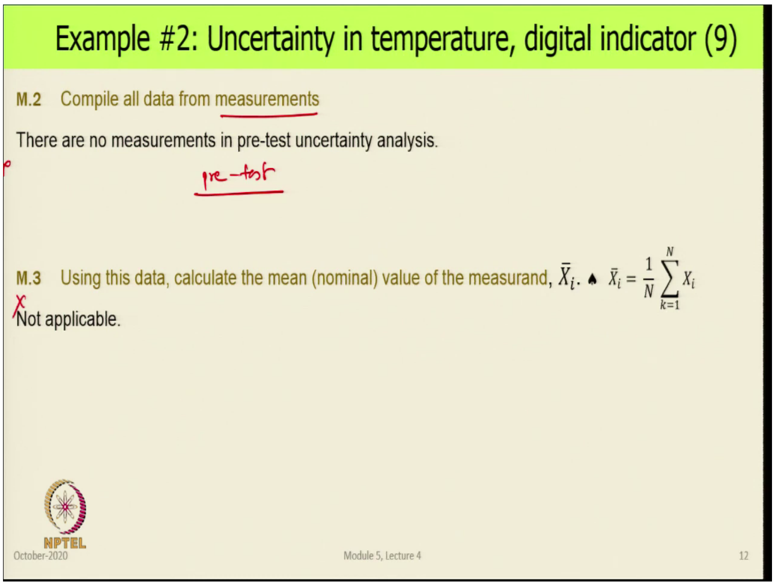

So, first the same step by step procedure that we have seen earlier we say compile all data from measurements. Now we are in the pre test stage we do not have any data either we can set it to 0 or we can use some number from our experience. So, this step goes away here it is a data using the calculate the mean value of the measurand we do not have any data this step also goes away.

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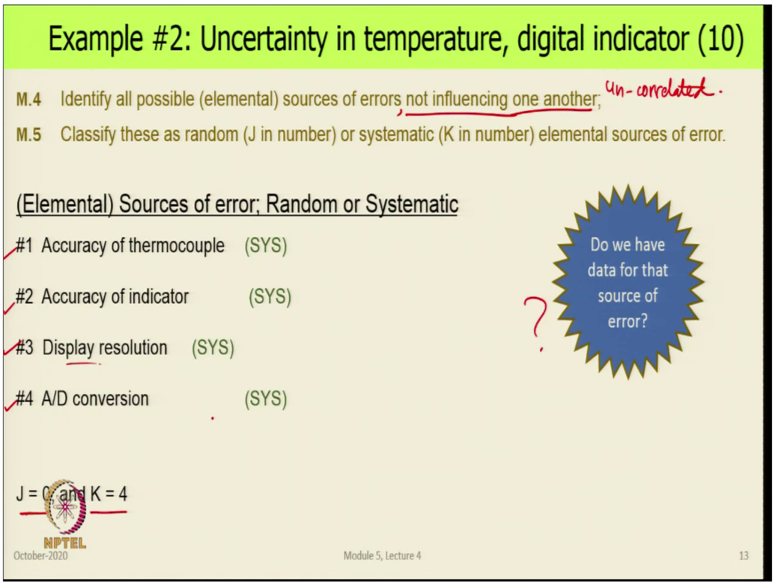

This identify all possible elemental sources of error and not influencing one another, so we are again and again saying these are uncorrelated errors. And what we see here we can say that look from the instrument the sensor thing I have got accuracy of the thermocouple, then the indicator gave us some data that it has got its own accuracy; so that is another source of error.

Then the same indicator has a display resolution that is another source of error and A to D conversion that is another source of error. So, we have J equal to 0 K equal 4, so J was the number of independent sources of random uncertainty elemental random uncertainty and this is a number of sources of elemental systematic uncertainty.

Now we see what all data we have, we could have at more thing, but we may not have data which is what distinct tells us, but we have got all the things that we want and we can estimate our uncertainty from this.

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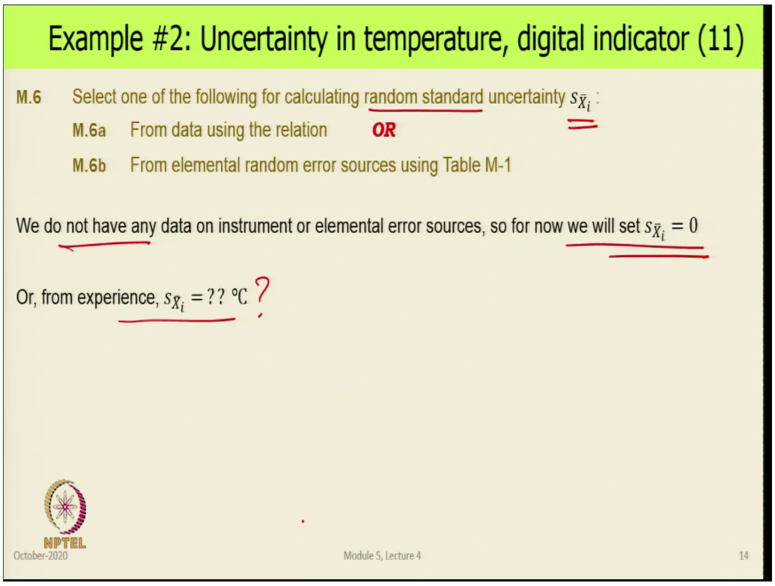

So, the next thing is about calculating the random standard uncertainty and we said well we have no data. So, we have an option either we have set it from experience some number, but for now we will just say it is 0.

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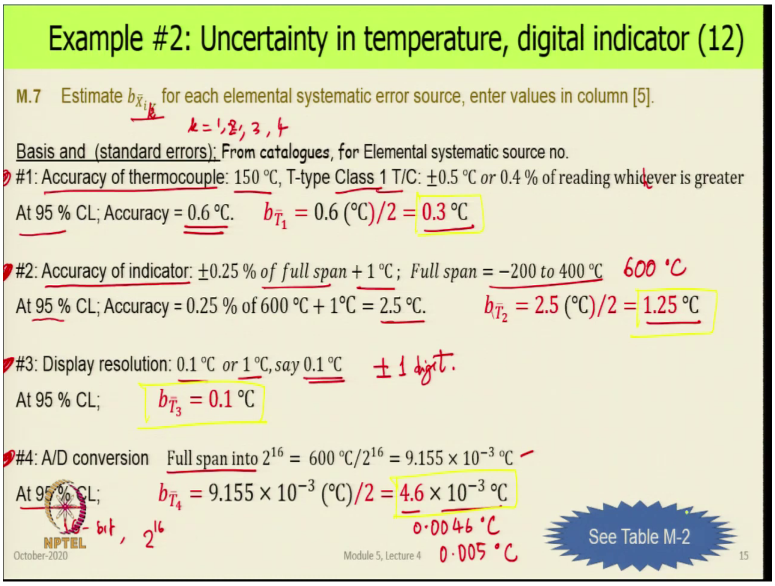

Now, how do we can estimate the standard error for each one of those until error sources? So, that is our 7 step work estimate b X i k for each elemental source this k is a small k. We have k equal to 1, 2, 3 and 4 we had 4 sources of 4 elemental sources of systematic error and now we go one by one see what happens.

So, number 1 accuracy of the thermocouple we are measuring 150 degree Celsius we have a T-type thermocouple and let us say we got class one thermocouple as per that IC 60784. Which said that the accuracy is plus minus 0.5 degree Celsius or 0.4 degree of Celsius of reading whichever is greater. So, 0.4 percent of 150 degree C becomes 0.6 degree Celsius this is greater than 1.5 degree Celsius, so we use this value.

And assuming that this is a reported number at 95 percent confidence level, but is 2 sigma; so the standard elemental standard error. Due to accuracy of the thermocouple is 0.6 divided by 2 which is 0.3 degree Celsius. That is systematic uncertainty source number 1.

Now look at number 2 this is accuracy of the indicator the first one was accuracy of the thermocouple. And from one of those earlier catalogs we decided let us take this particular indicator and see what it has got which has minus 0.25 percent of full span plus 1 degree Celsius.

And we saw that the full span was minus 20 to 400 degree Celsius which is 600 degree Celsius. So, this becomes 0.25 percent of 600 degree Celsius plus 1 degree Celsius which is 2.5 degree Celsius and again we go with 95 percent confidence level 2 sigma. So, our standard error due to accuracy of the indicator b T 2 bar is this value 2.5 by 2 which is 1.25 degree Celsius.

A 3rd source of uncertainty systematic uncertainty was display resolution which is 0.1 degrees Celsius or 1 degree Celsius we let us say we will configure it for 0.1 degree Celsius. And in this case we say that the uncertainty will always be plus minus 1 digit. So, b T 3 is 0.1 degree Celsius which is the standard error due to display resolution.

And fourth A to D conversion we saw this was 2 to the power 16, it was 16 bit converter; that means, the input got divided into 2 to the power 16 parts and that was used to convert the full span into equally spaced bits and that becomes 9.155 into 10 to the power minus 3 degree Celsius. So, at 95 degrees confidence level this becomes this by 2 which is 4.6 into 10 to the power minus 3 degree Celsius or this is 0.0046 degree Celsius or we could even have been quite ok we are writing 005 degree Celsius.

So, there we are we got the 4 values that we were looking for, 1 is over here sorry. 1 over here, the 2nd is here, the 3rd is here and the 4th is here. Now we put them altogether as it says here in table number 2. So, let us see that.

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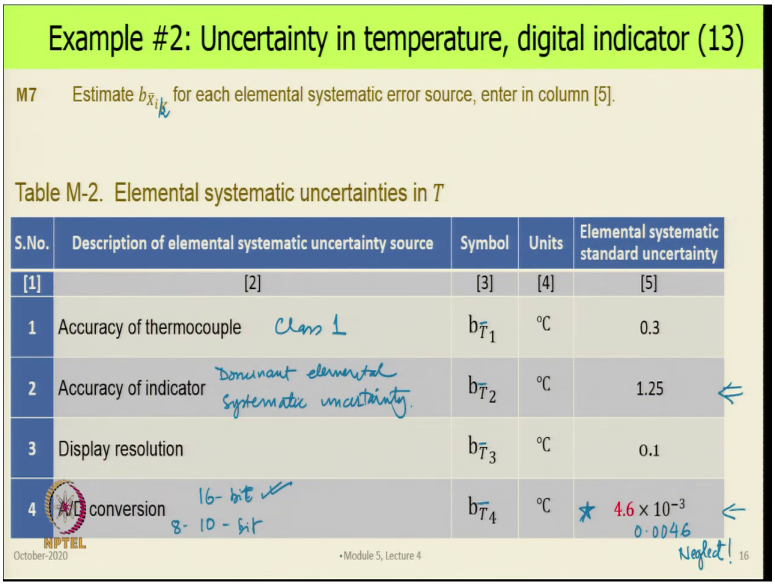

So, table M-2 estimate b X i k this is k is small and enter in column 5. So, we have done that accuracy of thermocouple b T 1 bar 0.3 degree Celsius. Accuracy of indicator b T 2 bar 1.2 degree Celsius display resolution b T 3 bar 0.1 degree Celsius A to D conversion b T 4 4.6 into 10 to the power minus 3. So, we got all the things in one go and just by looking at it now we start see some interesting things that this value is 0.0046 much less than any of these 3.

So, A to D conversion we could even say that I can neglect this. The other seen by looking at it we look at this number 1.25 others are 0.1 0.3 almost like this is 10 times this and at least 4 times this one. So, this is a big uncertainty which will reflect in the final uncertainty very significantly. So, we could even say that this becomes the dominant, elemental, systematic uncertainty.

So, it helps us in a way that if you want to make the uncertainty less in the measurement well do not worry about the thermocouple it looks good shape, we picked up the right thing we remember we picked up class 1. If you are picked up class 2 this number would have been bigger. And then we said indicator we should get a better one. A to D conversion this is more than good we have 16 bit converter that is really good had we used say 8 or a 10 bit converter.

This number would have been comparable to say this or this and then uncertainty coming in due to A to D conversion that would have been significant. In that case our strategy would have been increase the number of bits in A to D converter.

And then we could say ok, I will take this one with 16 bit converter then the uncertainty due to conversion is negligible. But as you go from 8 to 10 to 12 16 20 22 24 bit converters the cost increases substantially. So, we have to be ready for that.

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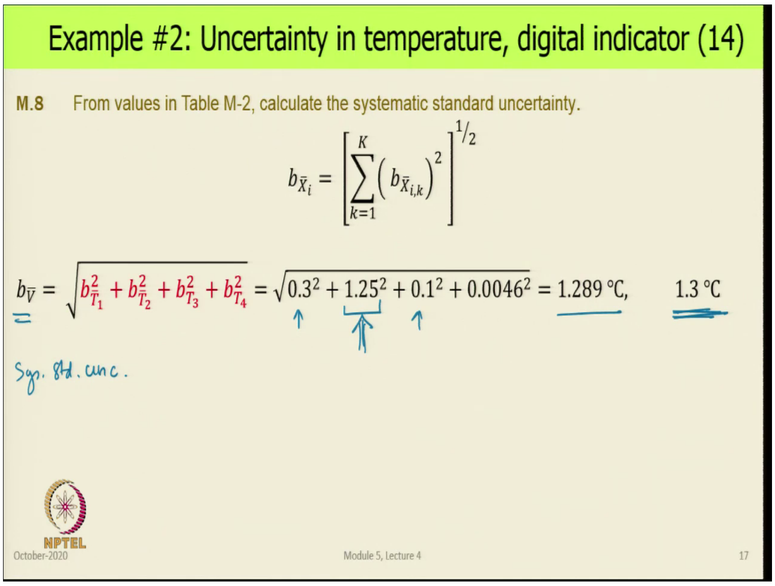

Now you go to the next step we put all of these things together and calculate the systematic, standard uncertainty in the temperature with sum of the squares of all these numbers; which is this much which we can say is 1.3 degree Celsius. And although it is coming as the squares you can see now this one dominates much much more than this one, because further we have taken squares.

So, this is definitely something that should be of concern to us if you want to improve this the 1.3 degree Celsius systematic standard uncertainty is ok, good enough for what we want to do then we do not need to do anything else. We could then think of when are you reduce the cost of my device instead of indicated in 16 bit converter, can I go for a converter with say 12 bit converter and indicator; it will reduce my cost and this may not change too much.

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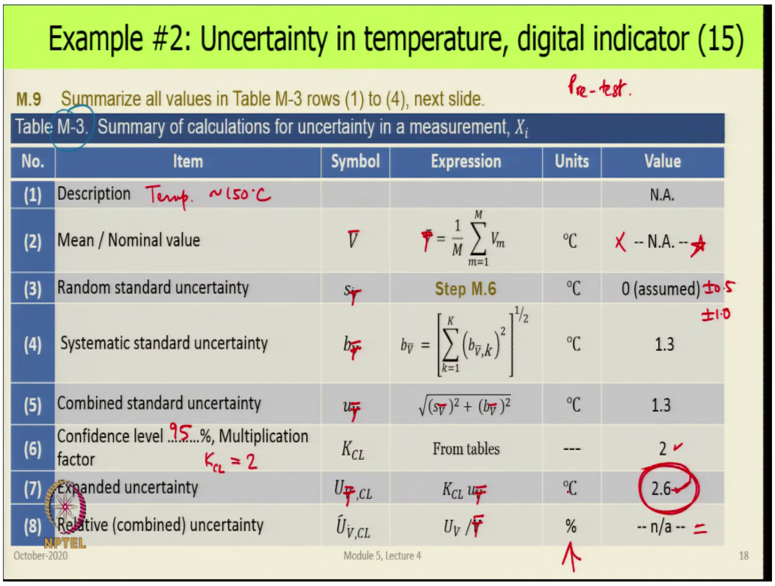

And all of this is possible because in the pre-test stage. Then we come to the complete summarization of everything that we have, this is the table M-3. And here we can see that description where we want to make temperature measurement in about 150 degree Celsius environment 150 could have been 120 to 180 200 that is ok.

Mean nominal value V bar not applicable we do not have data we are in the pre-tests phase or the designed phase. Random standard uncertainty we are assumed to be 0 be could have put a number here based on the experience. Say plus minus 0.5 or may be plus minus 1 and then the calculation see what happens.

Systematic standard uncertainty we are done the calculation b v bar this is equal to 1.3 degree Celsius we are not writing the units in this case. Combined standard uncertainty u v bar is equal to s v bar plus b v bar which is 1.3 degree Celsius confidence level. We are going to go with 95 percent confidence level which give the K CL is equal to 2.

So, that is 2 over here, expanded uncertainty in temperature this is this should all being T sorry this is u T bar which becomes 1.3 into 2.6 degree Celsius, so this is also T, And finally, relative uncertainty we cannot compute simply because we do not have the mean value over here. So, this was not there, so this is not applicable. So, having done all that this is a number that we wanted for which we did it whole exercise.

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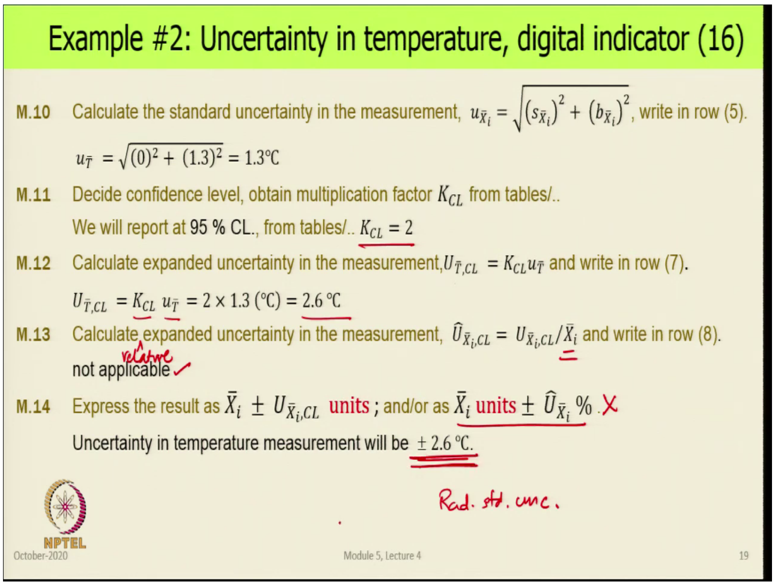

So, all of those that steps in the table we are put here u T bar is equal to 1.3 degree Celsius it defined the confidence level K CL as 2. Then we calculate expanded uncertainty in the measurement u T bar and this is K CL times u T bar 2.6 degree Celsius and then we calculate the relative expanded.

Uncertainty in the measurement we do not have this value, so not applicable and finally, we express the result in this case as a percentage we can a do it we just say that the uncertainty in the temperature measurement will be plus minus 2.6 degree Celsius at the least.

On top of that we could have added random system of random standard uncertainty. So, with this selection of sensor an indicator this is what we could except. We will take a small discussion on analog to digital converters.

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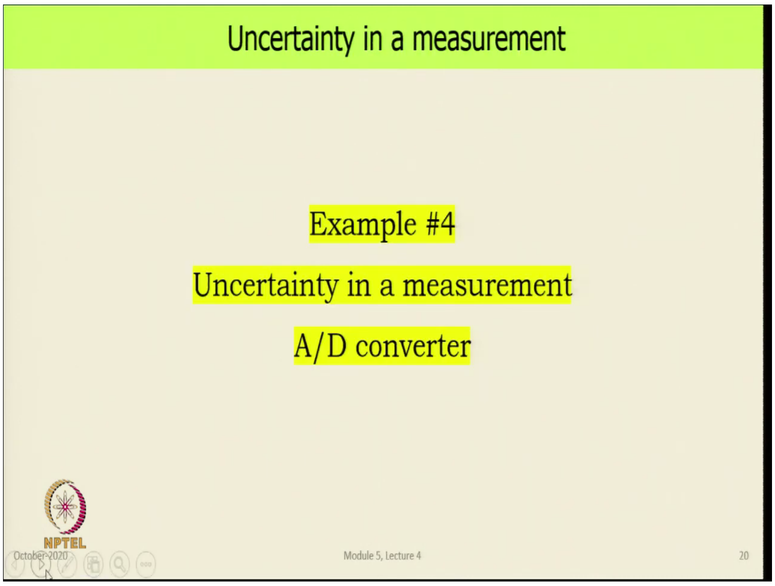

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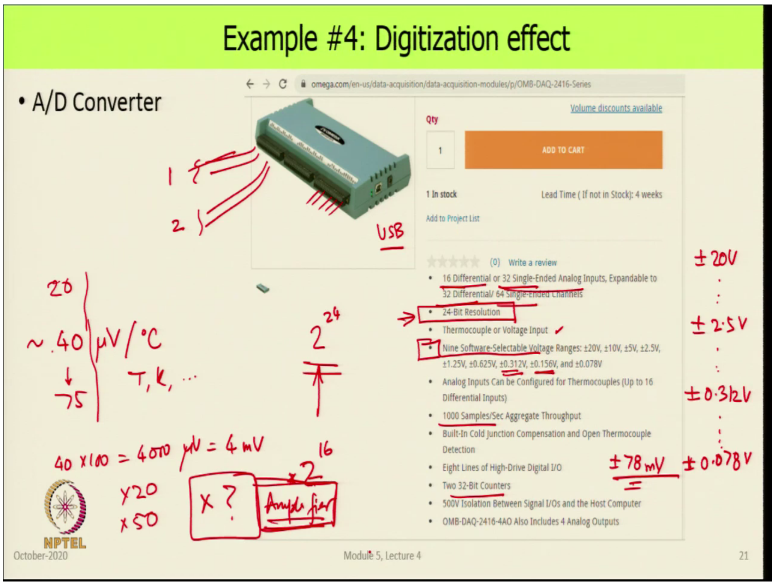

(Refer Time: 48:24) already we have seen that, now let us see what is a type of converters which are there and this is from one of the manufactures and you will see lot more of these. So, what there which is like a small box in which one side we connect our analog inputs and the output could be typically now USB cable.

So, let us see what they tell us. If we have to select A to D converter and from there we get the uncertainty due to the digitization here is what we have to see. So, thus this particular case 16 differential or 32 single ended analog inputs expandable to 32 differential slash 64 single ended channels.

That means, differential means when you have both signal wires coming from each instruments. So, from one sensor we got two wires, we so that in the thermocouple, so this is thermocouple number 1. Then we got two more from thermocouple number 2 like that if you have this is a differential mode we can put 16 things single ended means you put only 1 and all the other wires you make it common and take it as a single input.

In which case we can get 32 signals in. We say that this particular A to D converter 24 bit resolution, its pretty good. 2 to the power 24 is what it will divide the signal in to that many bits, this is very good and you will see that with a type of errors and uncertainty that we can get in practical life in making a temperature measurement for instance.

This thing will not matter it might be an over kill because the uncertainty due to this as we saw is negligible already 2 to the power 16 was a very small uncertainty 2 to the power 24 will be none practically none. The input here can be thermocouple or voltage and then it says what is the input range that we can select and this is 9 software selectable input voltage ranges. So, in the driver software we can decide what is that we want?

So, range is vary if sub top here is plus minus 20 volts then there is 10, 5 then there is plus minus 2.5 volts and then it is goes down and comes down here 2 plus minus 0.312 volts and the list it can take 0.78 volts or this is nothing but plus minus 78 milli volts. To give you lot of flexibility here now whenever thermocouples has sensitivity of the order of like 40 micro volts per degree Celsius may be going at to 75 micro volts per degree Celsius depending on the type of thermocouple.

In which is T or K or what and there are some which are even less than this may be 20 micro volts per Celsius. So, the temperature difference is 100 degree Celsius then will get, so for in this case 40 into 100 which is 4000 micro volts or 4 milli volts. Now what we sees that no matter what we do here even at the smallest range, we have been going to using only very small fraction of this 78 milli volts.

Just the few bits out of the 2 to the power 24 bits will be used the rest will unused and we will not get that fine difference in the measurement. So, the early option is that we amplify this into something, so we need to have an amplifier and this particular device does not have this amplifiers.

So, we have to get a separate amplifier or we could get 0 to 20 milli ampere signal and work with that. So, we can amplify it and bring up this 4 say if you multiply it 20 times then it will be 80 milli volts, but will be going out of range for this may be you can try this one, but if you go here with 80 milli volts here you have only using half the available scale; so in the compromise being made.

So, like this will at go back and further say I will have X instead of having X 20 I will use X 50 times amplification. So, I get up to this into this is 200 milli volts 0.2 volts and now you can see that this might be a best 1 to use. So, that in the type of calculation we have to do to decide what is that will you really want. Then it gives 1000 sampling rate and then there are counters and then the remaining thing over here.

So, that tells us how amplifiers and the input signal, so this could be a thermocouple input or if it is just voltage signal in that range it makes no difference the instrument will this device will take it.

And that is the way in which we are bits as an issue, range as an issue, this was one and amplification as an issue and when you are designing and experiment you got match all these together. So, that you do not chop of the signal or go out of range and we do not end up having to use a very small fraction of the full width of the A to D converter.

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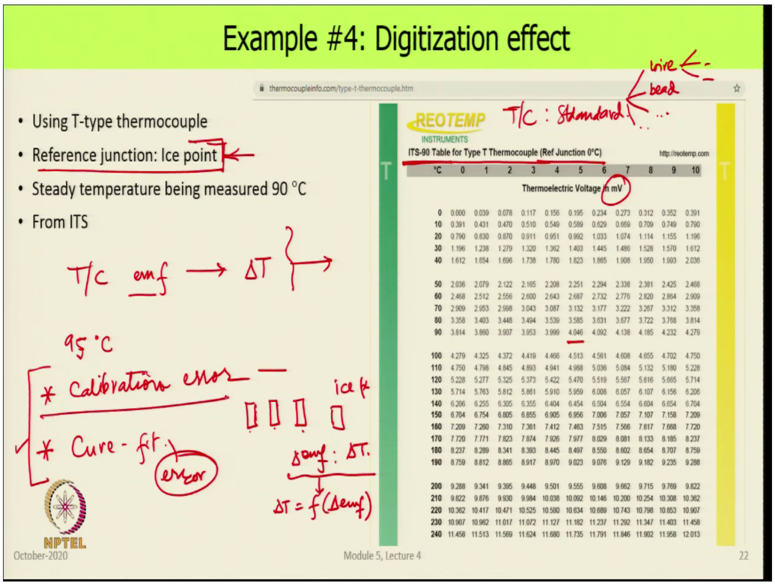

For thermocouples we have to worry about another thing the reference junction is an issue and this can be a quite significant as we saw in that one of the catalogues. If the best practice is to use ice point because it is simply very easy to make, it is nothing but take a thermos flask put ice water and makes sure that it stay ice and water and you will be at 0.01 degree Celsius or hopefully that water is pure or very clean or water are distilled water.

And to convert for the thermocouple emf into delta T we have here as you can see ITS table International Temperature Scale table refrozen junction 0 degree Celsius. So, one could say that will what voltage did I get and you say I have got 4.046 milli volts. So, this is the milli volts (Refer Time: 55:40) there is (Refer Time: 55:41) my temperature difference was 95 degree Celsius.

And we could even interpolate between that may be to 1.2 more 2 decimal places depending on how good our other instruments are. So, that what tells us that if you adjustment of emf I used this table and get the temperature, but there is a problem. This thing is applicable for a thermocouple made according to the standards and the standard include specifies on the quality of wire the quality of the bead which is made by fusing many other things.

So, if you have to go buy wire which are of that quality and make a bead by that process you will have to spend a lot of money and if you buy something which is made that way it will be more expensive than what you make yourself. So, if you make the bead yourself by wire which is not exactly the top grade wire in this, but medium or a lower grade wire which is what we normally we end up using.

Then we make a thermocouple and measure the emf and use this table then we will be off, so that introduces a systematic error called the calibration errors. And this will result units one elementary systematic standard uncertainty the others in that we could do is we take a thermocouple as which whatever we have we make a curve fit.

So, we take a thermocouple we make two reference junction to the temperatures one is off course ice point and then we use say the boiling point of water and boiling point of alcohol or some other material there are, but does not half standard temperature which have been defined which we can create in the lab. And measure at these points and see what is the delta emf we get and then we know that that corresponds to certain delta T.

So, at least 2, 3 points is not more we do this thing and from here we get a curve which tells us that delta T is equal to this function of delta emf, that is a curve fit that is not calibration.

So, this will introduce yet another systematic error in the measurement. In the example I have of give did not have to worry about it because the indicator itself had all these thing built into it and after doing all that they have caughted the error or the accuracy of the device as something. So, they took care of these things, especially calibration.

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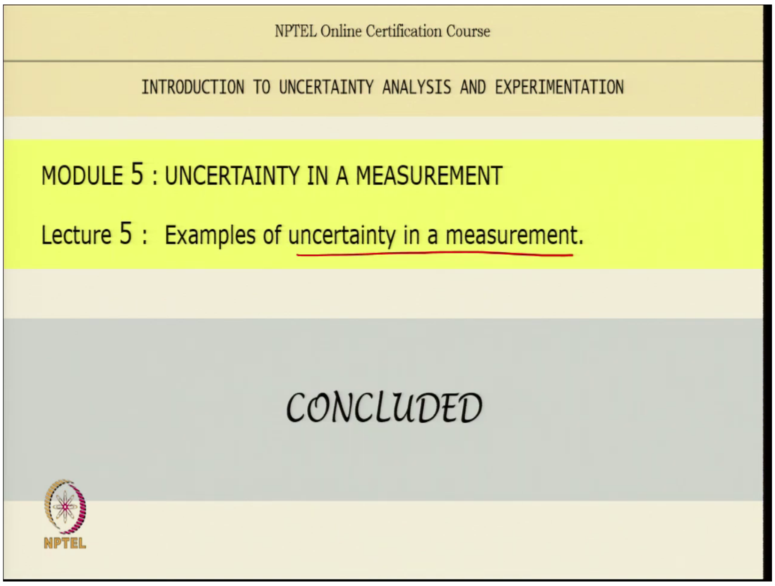

So, those are some examples of how to go about doing uncertainty in a measurement many of the term that look at in the lectures now came alive when we looked at practical examples. All of this gives as in the end the uncertainty in the measurement whether it is the pre test to stage or the post test stage this value we take over to doing estimation of uncertainty in the result. So, on that note we conclude uncertainty in a measurement. Thank you.

Student: (Refer Time: 59:50).

With these discussion we end our with these discussion we end our lectures on uncertainty in a measurement, next type is uncertainty in a result.

Thank you.