Mechanical Measurement Systems
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Lecture - 30
Temperature Measurement (2)

Hello, I welcome you all in this course of Mechanical Measurement System. Today, we will continue to discuss on thermocouples, then we will discuss the working of RTDs and thermistors.

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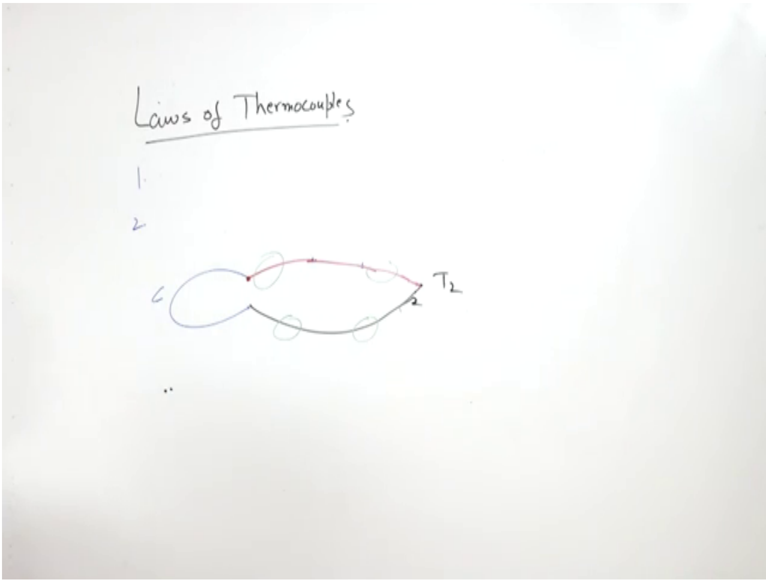

So, regarding thermocouples we will start with the laws of thermocouple, the working of thermocouples is governed by certain laws, right, and the first law of thermocouple is if there is a thermocouple having junction 1 and 2 and depicting the temperature T 1 and T 2 and these two junctions, they are two dissimilar wire that is depict another one with red.

So, these wires are of two different materials and let us name them A and B and the junctions are at two different temperatures, right and it will definitely show some EMF some EMF will be developed the EMF can be noted with the help of a voltmeter right and this is EMF is of the order normally is the order of few micro volts. Now suppose I increase at this portion of the wire, I increase temperature T 3 this portion T 4.

This temperature portion T 5 this portion temperature T 6 will it affect the output? As per the first law of thermocouples output will not be affected or temperature measurements will not be affected for any change of temperature in the conductor connecting between T 1 and T 2. So, this is the first law of thermocouples.

Now the second law second law states that in a thermocouple having wire a and B having wire A and this is B and a third metal is inserted C, this is C and again, the entire system is at different temperatures, this part is at a particular temperature, this part at a particular temperature it will not affect. The third metal C is inserted, the output will not be affected till these temperature as these two junctions is cocaine it does not vary, if this temperature is remaining same.

And we are inserting a third metal this these temperature as T these two junctions same the performance of the thermocouple will remain unaffected or output of the thermocouple will not be affected now instead of adding a material here C, right.

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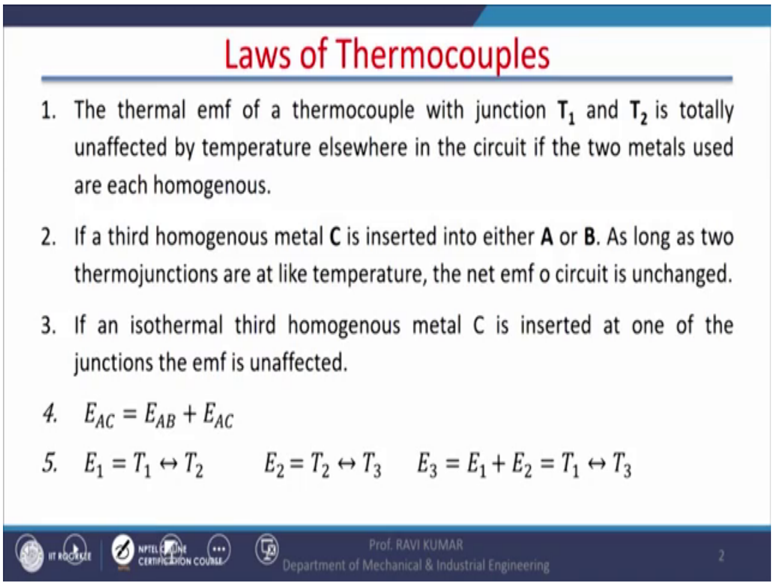

These are two suppose connected wires if we had material C here at T 1 at T 1 a material metal, a wire of material C is connected this is C, right, then as long as long as the temperature as these 2 junctions is same, the change in the temperature or the presence of this C will not affect, it means it means high with thermocouple, this is sub straight where I am doing the temperature measurements.

So, instead of making it junction I just 2; weld 2 wires separately, right, but these temperature as these 2 points is same when the temperature has these 2 points are same, the output of a thermocouple will not be affected or performance of thermocouple will not be affected that is the this is I think this is third law the fourth one is simply the law of addition, it means EMF generated for a given temperature difference EMF generated for metal A and B and E F generated metal B and C will be added, if you are using a thermocouple made of metal A and C.

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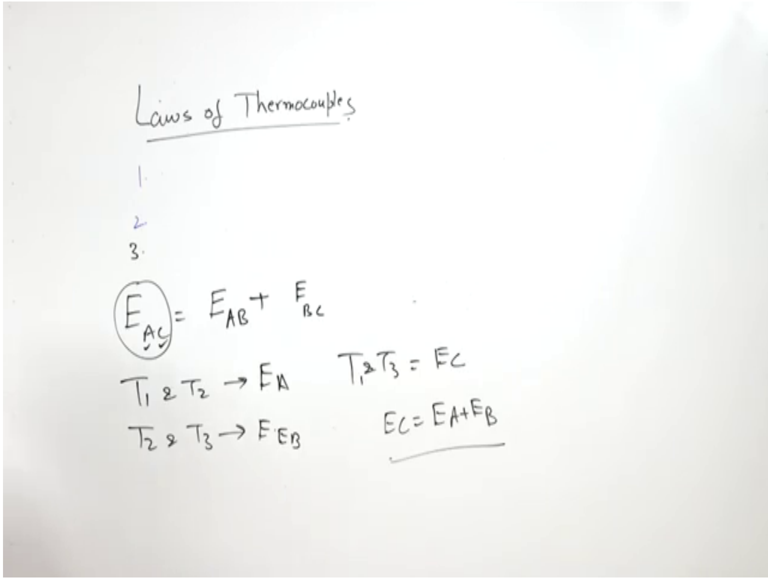

So, EMF generated by A and B and EMF generated by B and C shall be added when we measure the when we measure the temperature using the metal dissimilar materials A and C; similarly if T 1 and T 2, they cause EMF E 1 and T 2 and T 3; they cause EMF E 1.

So, E A suppose this is E B, then T 1 and T 3 will cause EMF E C and E C is equal to nothing, but E A plus E B; this is law of addition now using this law nowadays when you measure the thermocouple temp temperature with the help of thermocouples all the tables which are available between the relationship between change in temperature and change in the microvolt output of the thermocouple they have one difference temperature 0 degree centigrade.

So, it is always assumed that 1 pa 1 end of the thermocouple is at 0 degree centigrade and this end is at temperature T, but in actual practice practically always maintenance of this temperature 0 degree centigrade it can be maintained, but it is a tedious job means you always have to replace the ice because this 0 degree centigrade will be maintained with the help of distilled ice made out of distilled water and in a flask or in insulated flask, you will have to keep the spool of water and this and will be put into this flask, it is a some arrangement has to be made. Now it is in most of the data acquisition systems, there is a isothermal terminal block.

So, in ISO thermal terminal block one end of the thermocouple is guessed simply used for measuring the unknown temperature T other end is Connected to a block which is known as isothermal terminal block which the temperature of this block remains constant and thermocouples are you can add number of thermocouples ok.

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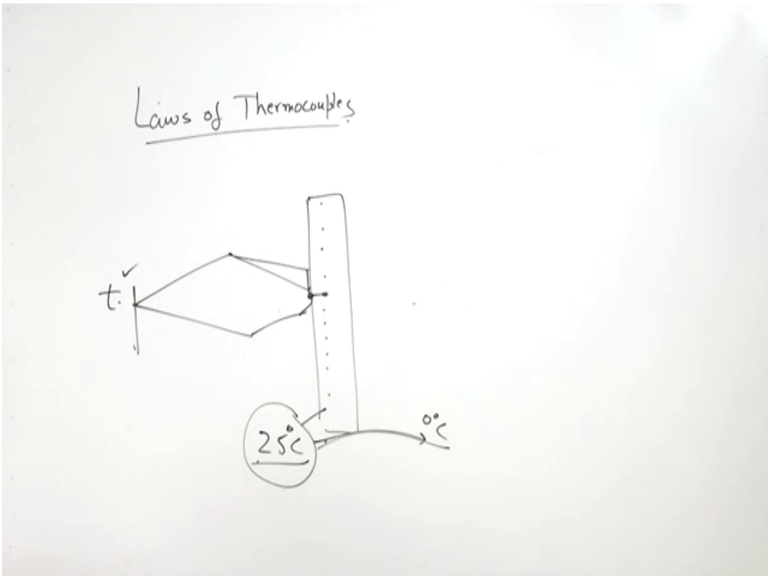

5, 10, 20, 30 depending on the design of the block, right and this block remains at room temperature let us say 25 degree centigrade, it can automatically detect also or you can fix this temperature as 25 degree centigrade. Now from 25 degree centigrade to 0 degree centigrade, this EMF is automatically added in the output thermocouple. So, we do not require actually the reference temperature of 0 degree centigrade.

So, EMF equivalent to this 0 degree centigrade and the room temperature is added into the output of the thermocouples and final EMF is noted and final EMF is converted into the temperature and this is how the temperature sensing is done in nowadays, in modern or nowadays, in modern data acquisition systems second thing is sometimes this happens often happens when we have to take a change in temperature suppose the fluid is flowing in a pipe right and the temperature change is only 1 degree centigrade right or let us say 2 degree centigrade or 3 degree centigrade or let us say two degree centigrade right.

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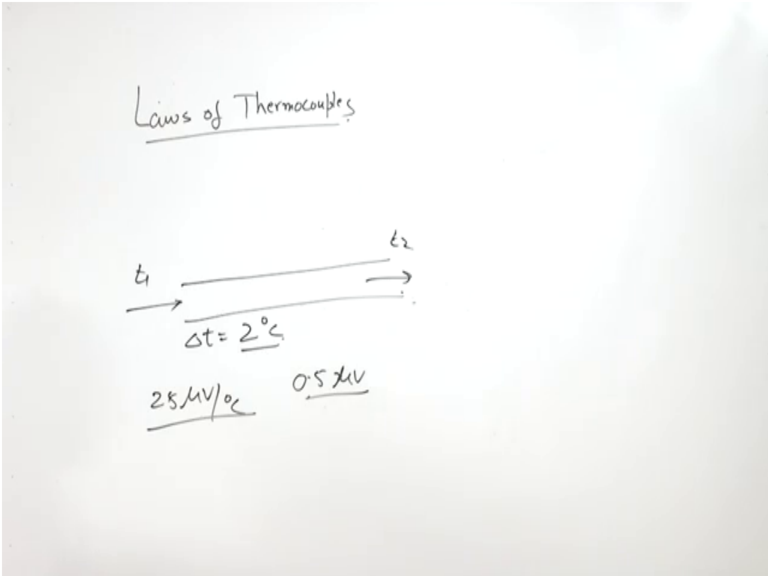

And fluid is entering from this side at temperature T 1 and leaving from this side temperature T 2 micro voltmeter the sensitivity energy the output is only if it is 0.25 micro sorry if it is sensitivity is let us say 25 microvolt per degree centigrade. So, change in the voltage is going to be 0.5 microvolt.

Now here, we can make use of thermo pile thermo pile in thermo pile the thermocouples are connected in series in a thermopile, suppose, I have to take temperature difference between temperature 1 and this is temperature T 2, suppose, I have to measure a temperature between T 1 and T 2, then I can maze make use of thermopile let us say of 3 thermocouples.

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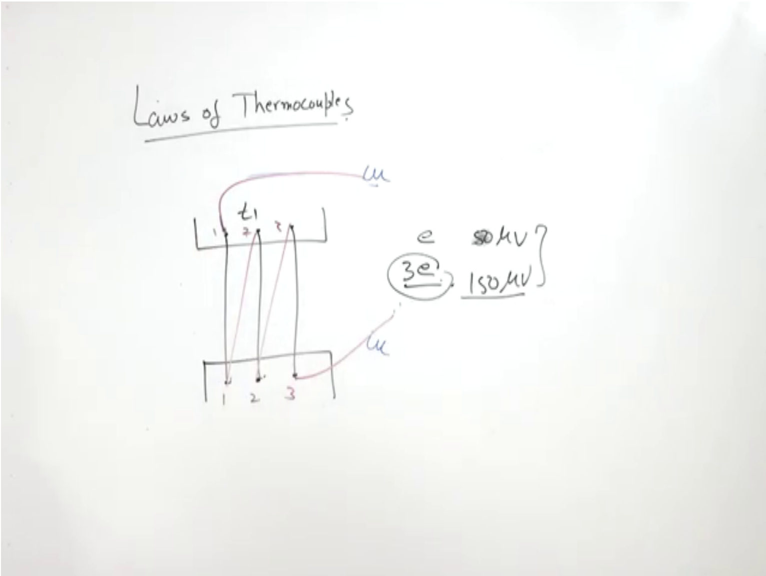

So, all thermocouples will be connected in series. So, that is one wire and another wire is like this m this is a copper wire which is connected to the system and this is also a copper wire this is a copper wire and we have now we have 3 junctions this is also copper wire. So, now, this is a copper wire and defective with blue it has to be depicted wire this is.

Now, this will make a junction. So, one junction 1 2 3; 3 junctions here and 1 2 3; 3 junctions here; sow it is a thermopile of 3 thermocouples and here in this thermopile suppose with one thermocouple the output was E thermopile of 3 thermocouples will give output of 3. So, once we are getting output of 3 it means equivalent to two degree centigrade where we are getting point sorry 50 microvolts.

Now we be getting 150 microvolts voltmeter is same error absolute error is same. So, definitely accuracy of the measurement will increase we can have a thermopile of 5 thermocouples 10 thermocouples depending upon the application a thermocouples are also joint in parallel arrangement this is one thermocouple; suppose A B and this is second thermocouple.

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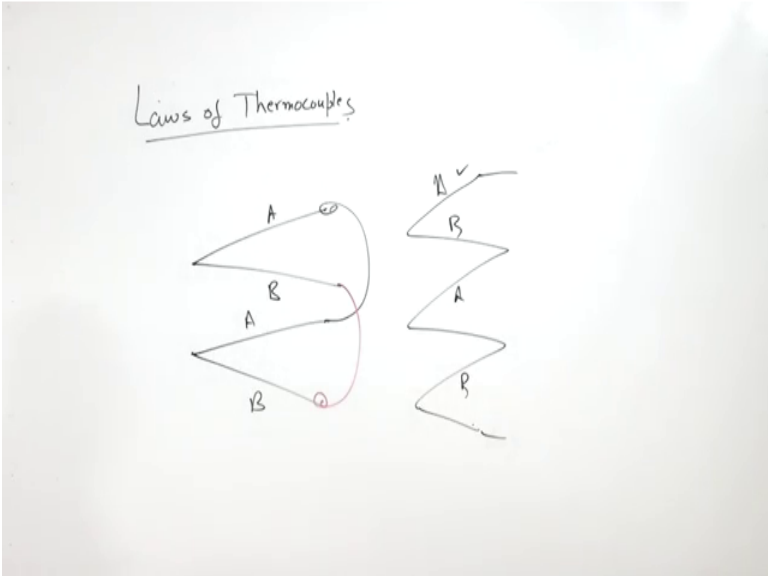

So, B of second thermocouple B and A; so, this is B A B, right. So, in this case all a S are connected and all B S are connected. So, thermocouple are not in series in previous case when we are making thermopiles we were connecting A B, then A B, they were all in series, now all A are connected and all B are connected thermocouples are in parallel the net output of the thermocouple will be average of the reading of all these thermocouples.

This is going to be average of the reading of all these thermocouples right this also improves the reliability of the measurement by thermocouples. Now after the thermocouples we will take up the discussion on RTDs; RTD is very important device and very reliable device for temperature measurement R T D

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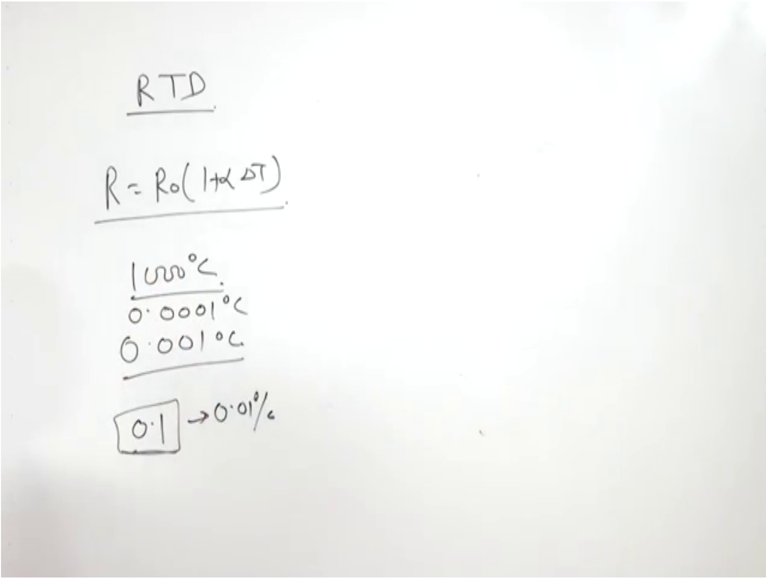

Now RTD stands for resistance temperature transducer, right and the working principle of RTD is the resistance changing with change in temperature this is the working principle of RTD and RTD can I mean if we take platinum wire the RTD can measure up to 1000 degree centigrade accuracy of RTD for low temperature is 0.001 right or in fact, it can go and for a higher temperature it remains 0.1, but 0.1 for 1000 degree centigrade is quite high, right.

So, and if you measure very low temperature, I mean we can have the accuracy of the order of 0.001 also and for high temperature, it is 0.1 even if we take 0.1; if we go percentage wise it is going to be 0.01 percent at 1000 degree centigrade. So, 0.01 percent after a I mean temperature measurement accuracy is quite high accuracy the readings are or the measurements is highly reproducible in RTDs. So, we can reproduce the same reading if. So, the temperature it means the temperature measurement is very reliable.

So, in RTDs, there is a thin foil and in this foil a constant current is passed right and the change in temp resistance is determined by measuring the voltage across the foil as the temperature increases the voltage increases and the drawback of this RTD is first of all its costlier than the thermo couples and an electronic circuit backup is required for the measurement from RTD this is the I mean only drawback of RTD, it requires a sophisticated instrumentation right and normally platinum is used as a platinum because platinum has a linear variation if you look at the change in resistance R by R O.

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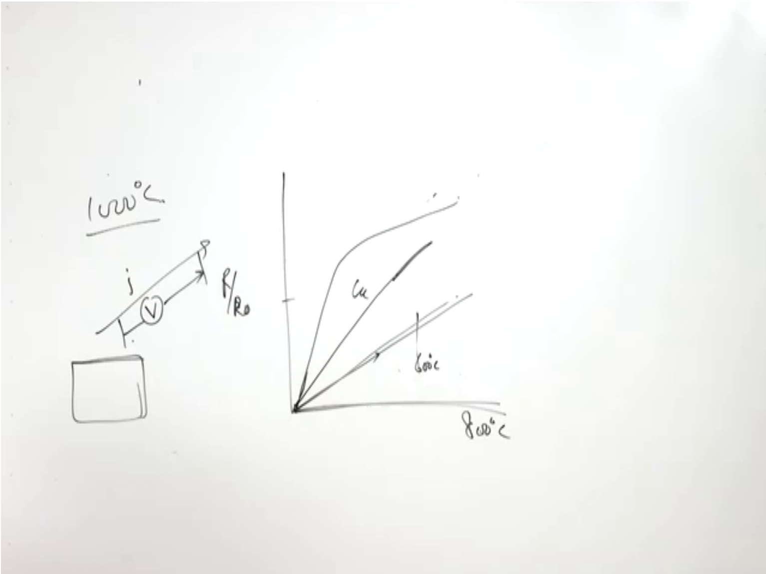

So, this ratio may be less for aluminum if on this they ate going let us say up to 800 degree centigrade. So, so it can go up to between 3 to 4 times in this range, but the variation is linear with temperature if you look at pau copper, copper has better sensitivity then, but its temperature limitation does temperature limitation or the temperature is a shorter than that in the case of platinum sensitivity is more. In fact, what happens beyond 600 degree centigrade?

The copper is considered to be more linear than the platinum now nickel nickel is also used as a as a resistance material in RTD. So, nickel is non-linear they are I mean it is something like this linear to then like this. So, nickel is highly non-linear. So, normally for the temperature measurement, but the temperature this resistance variation is high.

So, resistivity of nickel is high sensitivity of copper is higher than the sensitivity of this platinum, but platinum is a linear relationship and very I mean and the relationship between R and R r o does not change with temperature much. So, that is why platinum is and is it can sustain high temperature also if I have to go for thousand degree centigrade I have no option, but platinum to be used as a RTD.

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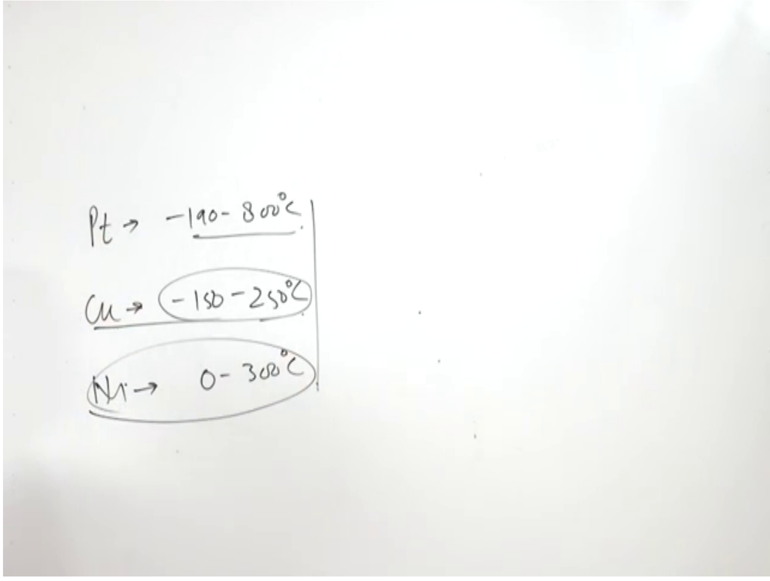

So, platinum is normal I will write the working range the platinum.

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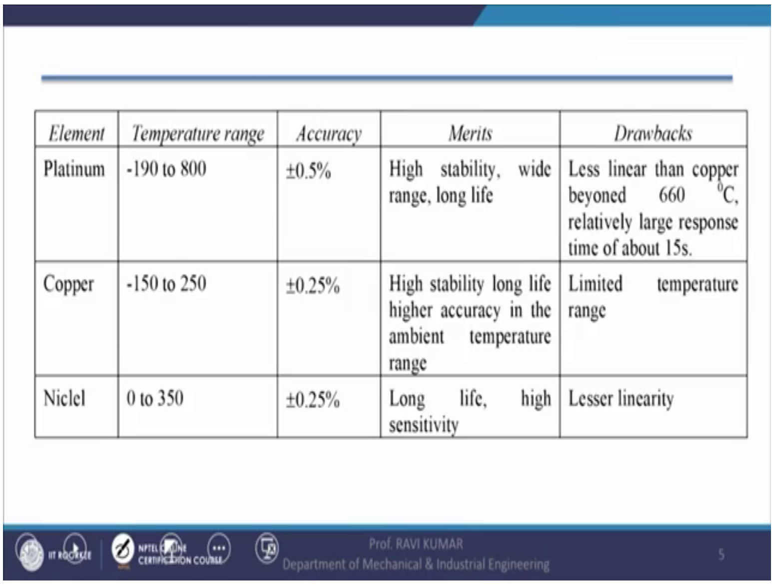

Element	*Temperature range*	*Accuracy*	*Merits*	*Drawbacks*
Platinum	-190 to 800	±0.5%	High stability, wide range, long life	Less linear than copper beyoned 660 ^{0}C, relatively large response time of about 15s.
Copper	-150 to 250	±0.25%	High stability long life higher accuracy in the ambient temperature range	Limited temperature range
Niclel	0 to 350	±0.25%	Long life, high sensitivity	Lesser linearity

It works between 190 to 800 degree centigrade minus 190 to 800 degree centigrade copper is used minus 150 copper is melting point of copper is more than 900 degree centigrade and, but copper is not recommended beyond 250 degree centigrade melting point of copper is high.

But it is normally in not recommended below above 250 degree centigrade, otherwise and the nickel nickel is recommended for 0 to 300 degree centigrade; so, copper has a limited temperature range minus 150 to 250 degree centigrade though it has melting point of I think nine 60 or more than nine 600 degree centigrade nickel is used up to 0 to 300 degree centigrade because beyond 300; 300 degree centigrade it becomes non-linear. So, due to linearity related issues it is not recommended, but copper if you are using up to 200 degree centigrade 250 degree centigrade.

It is highly stable and it has a longer life because life of the sensor is also important platinum also we can go beyond 800 degree centigrade or 1000 degree centigrade, but the issue is life of the sensor because the foil is very thin. So, if it is persistently it is exposed to very high temperature that may damage the coil now we can have a comparison between thermocouple and RTDs.

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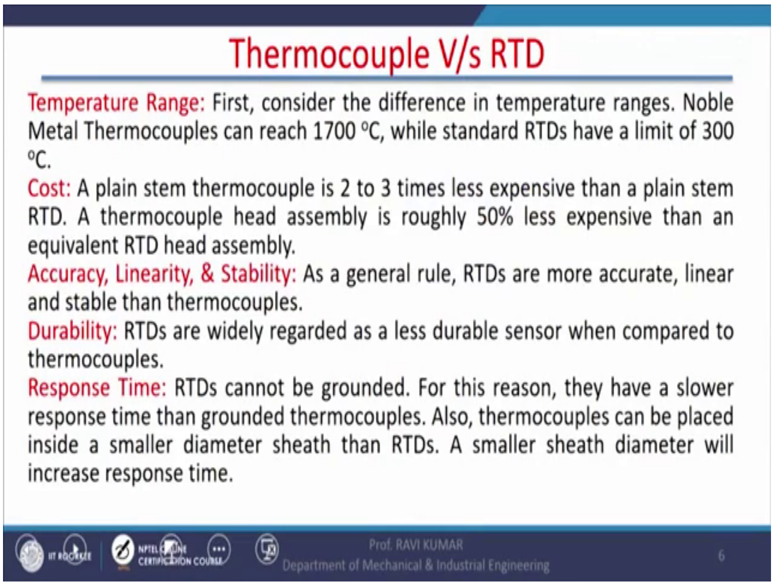

So, thermocouple and RTDs first is temperature range. So, RTDs have a limited temperature range of thousand degree centigrade thermocouple can go up to 1700 and. So, the thermocouples can go up to 220 degree centigrade also exotic thermocouples can go up to 220 degree centigrade also. So, plane thermocouple I mean ordinary thermocouple is cheaper than an RTD; RTD approximately 2-3 times costlier than thermocouple, but if you go for the exotic thermocouple or a high temperature thermocouple definitely their cost is higher than the RTDs and accuracy a linearity and stability.

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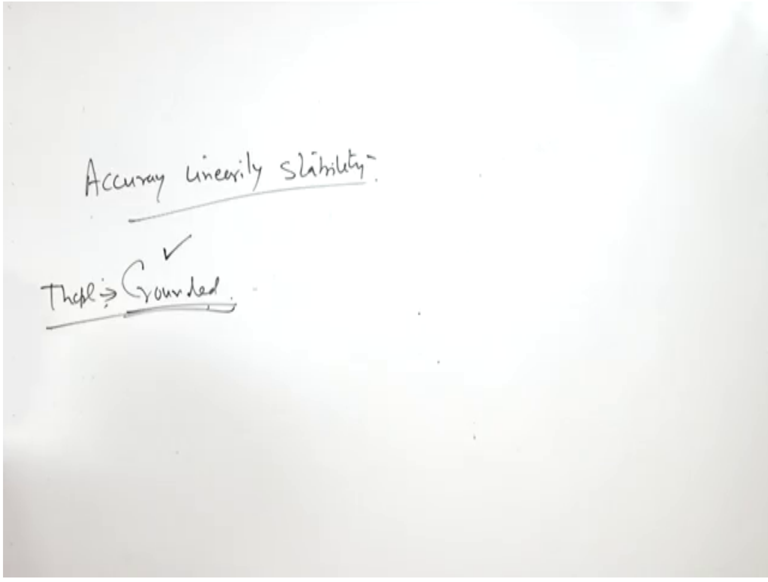

And stability, accuracy, linearity and stability they are high for alternatives accuracy of measurement is high their linearity they are high linear and stability RTDs are high, but they have finite size of RTDs have finite size. So, for very pas narrow passages RTDs cannot be put we are we can put the thermocouples on those narrow passages. Now durability their reliability stability and durability thermocouples are more durable and this is simply wire. So, thermocouples are more durable than then the RTDs and sensors RTD cannot be grounded.

So, we can have grounded thermocouples, but RTD cannot be grounded. So, once it cannot be grounded it has lesser response or lesser or slower response time in comparison to the thermocouples. So, so response time of thermocouple is higher sorry response time RTDs cannot be grounded RTDs cannot be founded this they cannot be grounded thermocouples cannot be grounded.

So, when thermocouples is grounded it has lesser response time or time constant is less, but as RTDs can be grounded their response time is higher in comparison to the thermocouples. Now there is one more device which is very often used for a temperature measurement it is used for the controls also in electrical systems that is thermistor.

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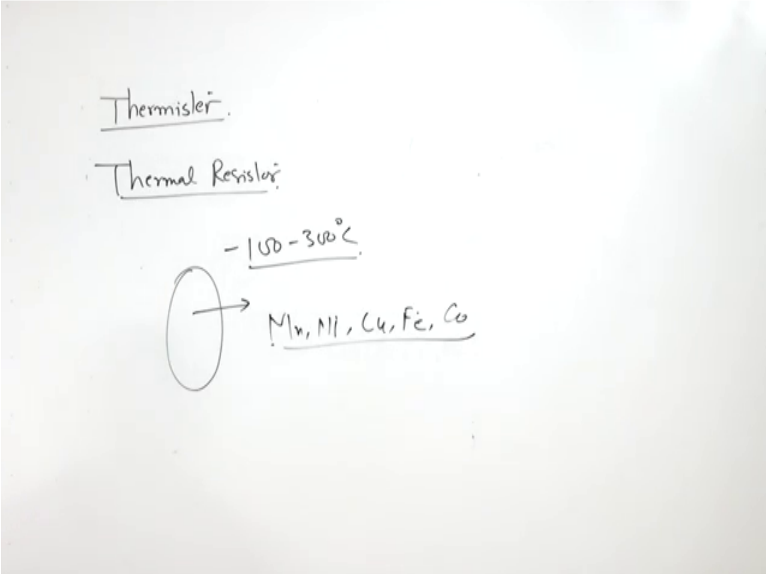

It is an acronym for thermal resistor it is a thermal resistor.

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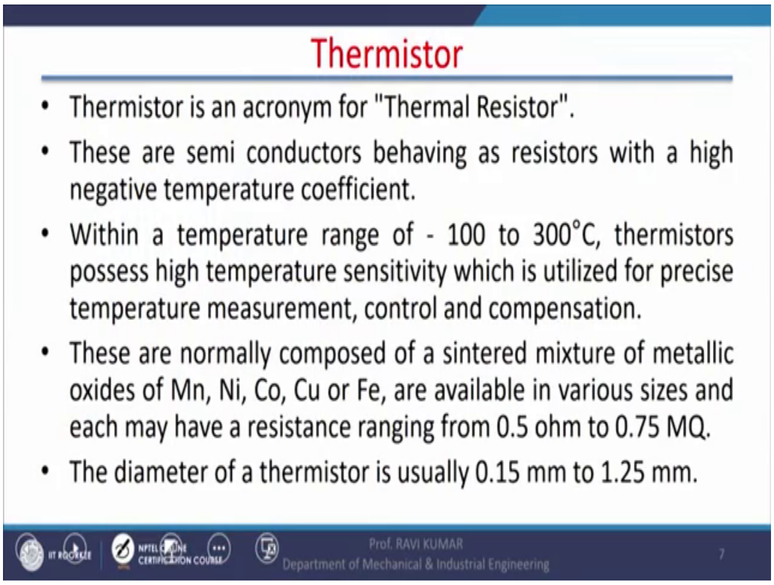

It is a semiconductor and it has negative temperature coefficient; that means, when the temperature of thermistor rises the resistance goes down when resistance goes down more current will flow in to the thermistor more current will flow is thermistor again this resistance will go down.

So, but this group does not go up to RTD it does not mean that the resistance will keep on reducing and the power will keep on increasing. So, what happens the steady state in thermistor comes when heat generated by a thermistor is equivalent to the heat conducted to the surroundings when all heat generated by the thermistor is dissipated to the surrounding then the steady state is retained and the temperature range of thermistor is minus 100 to 300 degree centigrade. So, higher temperature we can go up to 300 degree centigrade nowadays; we have thermistor which can go beyond 300 degree centigrade 600-700 degree centigrade, but normal a thermal thermistor a thermal resistance type of sensor can go up to can measure temperature in a range of 100 to 300 degree centigrade.

Student: Minus.

So, minus minus 100 to 300 degree centigrade and they are manufactured by taking the central mixture of metallic oxides of magnesium nickel copper iron or cobalt. So, it is the central mixture of these metallic oxides and the resistance also for I mean the thermistor can range from F u ohms to some let us say 100s of kilo ohms and the diameter of a thermistor can be 0.2 or 0.15 mm to it can go up to 1.25 mm, right and. So, initially the thermistor draws a very small current it follows a ohms law till the heating starts when the heating starts the change variation in resistance is highly non-linear.

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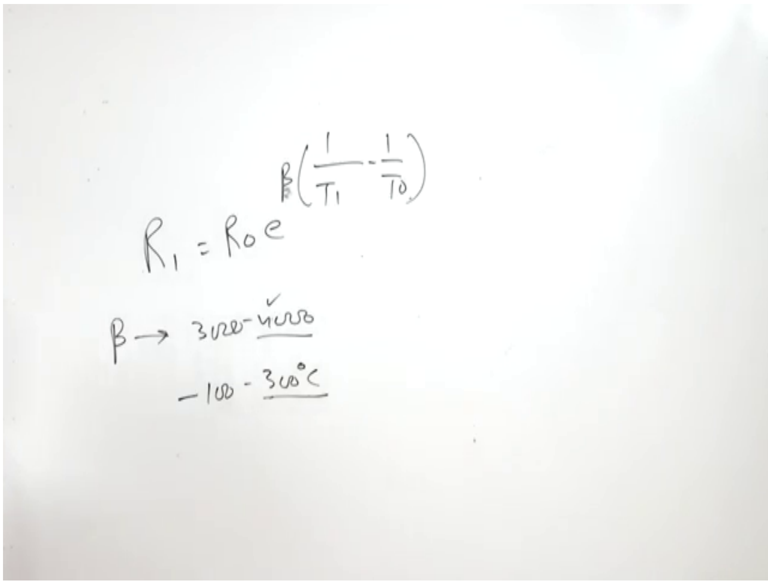

And it is like R 1 is equal to R o e raised to power sorry theta 1 by T 1 minus 1 by T o, it is the variation in distance is governed by this equation and the value of beta is normally if 3000 to 4000 some in some close to 4000 and the temperature range which is covered it is I as I said minus 100 to 300 degree centigrade, nowadays, there special type of thermistors which can go to 600-700 even 1000 degree centigrade can also be measured with the help of a thermistor. Now after the thermistor we will go for high temperature.

Now we have am plies discussed about the low temperature measurement low temperature measurement means the temperature in the range of thousand or 1500 degree centigrade or in some of the application the temperature is quite high in some of the applications the temperature is let us say 4000 degree centigrade or 3500 degree centigrade for example, space applications.

Now, if I want suppose if I want to measure 3500 degree centigrade temperature for such type of high temperature measurement there is no direct contact type of measuring technique we have to go for indirect type of measuring technique for example, we want to measure steam of gas which is at 3500 degree centigrade.

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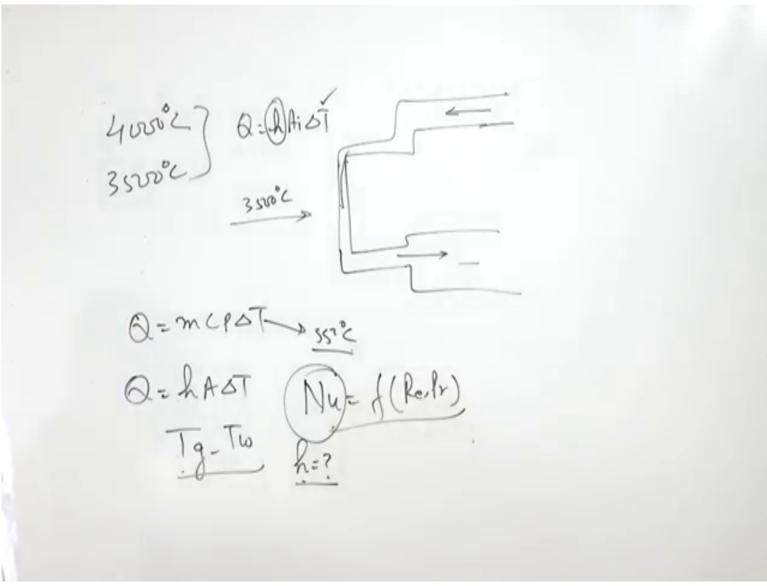

Now, in this case; what we have going to do, we will have to use indirect measuring method in this indirect measuring method.

We will connect this to a cooling water system cooling water system cooling water will be entering from this side and leaving from this side cooling water will take away heat and this Q can be measured with the help of mcp delta T. So, this delta T is normally taken as in the range of 50 to 255 degree centigrade 50 to 60 degree centigrade, let us say 55 degree centigrade and this is the vertical tube once, we have the value of Q and we have the heat transfer coefficient at the surface we can always use Q; Q is equal to ha delta T and delta T is nothing, but temperature of the gas minus temperature of the wall now what about the temperature of the wall, we cannot fix thermocouple there.

So, in order to find the temperature of the wall will have to calculate and find the temperature of inner wall. Now inner wall temperature we cannot fix thermocouple there also right we can make use of some already establish correlations then Nusselt number is the function of Reynolds number and Prandtl number right from here will calculate the Nusselt number and from Nusselt number we will calculate the value of h and once the value of h is known and bulk temperature is known, then Q is equal to hai delta T from here, we can get the value of this delta T and from this delta T is nothing.

But wall temperature minus fluid temperature bulk temperature right or we can fix because this is a inside wall inside wall temperature is going to be much higher than the fluid temperature right. So, this is a indirect temperature measurement technique this an in indirect temperature measurement technique and another technique can be instead of this suppose high temperature has to be made high.

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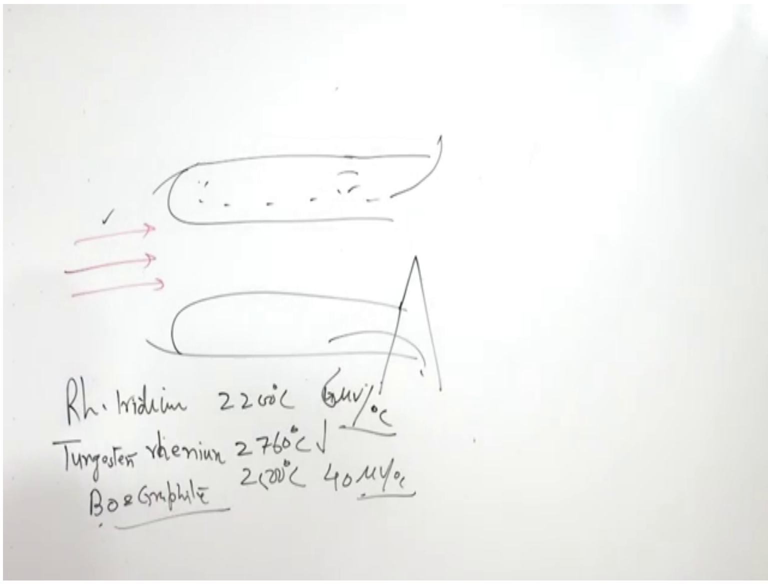

So, will take one tube a bigger tube and there is a cooling system and this tube is opened from this side. So, there is a cooling system within the tube the cooling water term is coming in and is going out. Now high temperature gases are entering from this side. So, in this passage these gases will be cooled down, right and here we can fix thermocouple here we can fix a thermocouple.

Now, we have thermocouples which can measure range up to let us say 22 100 degree centigrade that is rhodium and iridium thermocouple rhodium and iridium thermocouple rhodium and iridium thermocouple can measure temperature up to 220 degree centigrade with 6 micro volts sorry 6 micro volts per degree centigrade sensitivity, then other thermocouples also the tungsten rhenium thermocouples tungsten rhenium thermocouples it can go up to 2760 degree centigrade there all exotic thermocouples and they are very costly and boron graphite thermocouple it can go up to 2500 degree centigrade, but these two have accuracy of 6 micro volts this can have accuracy of 40 micro volts per degree centigrade. So, they are all these are all exotic thermocouples right and they are very costly.

So, temperature of the gas is reduced to this range through cooling of this passage and temperature measurement is made and through a after that doing certain calculations right doing certain calculations we can find the actual temperature of the gas another method of the measurement of high temperature is that in the stream of the gas itself if you put a thermo couple.

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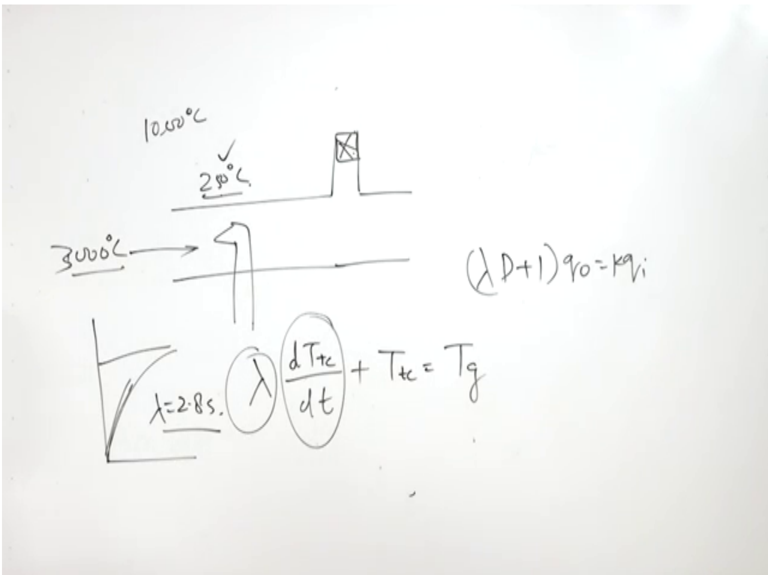

So, if you put a thermocouple in the stream of the gas itself and this side there is a cooling air and used with the and controlled with the help of a solenoid. So, here we have inserted a thermocouple initially it is at 250 degree centigrade. Now the stream of hot gases is coming, let us say at 4000 degree centigrade right initially the air is flowing over the thermocouple and it is stabilized at 250 degree centigrade when hot gases are coming right like they will increase the temperature of thermocouple right and the response of the thermocouple is going to be something like this now what we will do from 250 degree centigrade let us say the moment temperature reaches 1200 degree centigrade.

We will open this wall the moment we open this wall high velocity cold air will come and it cool the tip of the thermocouple, but we will come to know the trend of otherwise of the thermocouple and then using this equation lambda d thermocouple divided by d t plus T thermocouple is equal to T of the gas temperature of the gas now this equation can be used lambda d plus 1 q o is equal to kqi right q o is temperature final temperature of thermocouples.

Now, from here we can take the rate of the rise of the thermocouple temperature of thermocouple time constant is known this is how we can measure or we can determine not measure the temperature of hot gases now suppose temperature of hot gases let us take some example temperature of hot gases is 3000 degree centigrade right and lambda let us take some value is equal to 2.8 seconds time constant of thermocouple is 2.8 seconds we limit the temperature this 2000 the thermocouple temperature should not exceed 1000 degree centigrade. So, in this case for how much time the thermocouples should be exposed to the hot gases.

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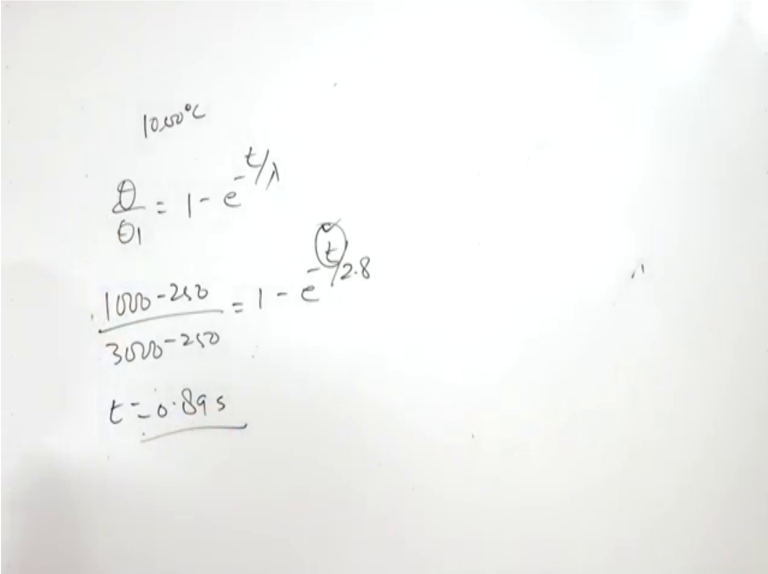

So, it is always theta by theta I is equal to 1 minus E 2 power minus T by lambda now theta is the gas temperature is 3000 degree centigrade. So, and you should not exceed 1000 degrees or minus 250 divided by 3000 minus 250 is equal to 1 minus E to rate power minus T by divided by 2.8. Now; from here you calculate the value of T and the answer is 0.89 seconds this is all for today.

Thank you very much.