Transducers For Instrumentation
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Lecture - 06
Thermal Sensors: Thermocouples

Hello, welcome to the course Transducers for Instrumentation. Last time we were discussing about the thermal sensors. These are the sensors which measures the thermal energy of an object in form of temperature and we saw that we have two kinds of techniques to measure one is predictive based technique and one is the equilibrium based and we saw some advantage and disadvantage of both the techniques. So, now we will discuss today about different type of thermal sensors. So, as we discussed the temperature is the measure of average kinetic energy of the molecules of a gas, liquid or solid. So, we have an object which has its thermal energy stored in it.

So, the average kinetic energy of the molecules that is what we measure using these thermal sensors and a very well known thermal sensor is the mercury thermometer as almost everyone has seen this. This is nothing but a glass tube in which we fill up the mercury which is a liquid metal and we expose this to the temperature and as soon as that we connect it to the heated body because of the thermal energy exchange the temperature rise in the mercury metal this expands and because when it expands it moves up in that glass tube and we have different marks on this through which we measure the temperature. So, it is a very old technique of having of making these thermometer this is nothing but the glass tube we fill it with liquid metal like mercury and when we expose this whole thing to temperature which is T b the body temperature which is higher than the sensor temperature or the mercury T b is higher than T s then this mercury expands and we have different demarcation different marks on this glass tube. This is how we measure the temperature using this mercury thermometer, but it is not suitable for multiple applications.

For example, the very first thing is there is a glass tube involved which is very fragile many a times when in some rough environment you cannot use this kind of thermometer it is subject to break down mercury is also not a very good element to use in these mercury thermometer it is not very good for health. So, it has multiple limitations where we cannot use this mercury thermometer. So, we have multiple different kinds of thermal sensors available one is the thermocouple, second is resistance thermometer or RTD we call it in short, third is the thermistors and the fourth is some novel semiconductor based sensors. So, these are the type of sensors which we are going to discuss. The first one is thermocouple as the name says thermocouple means it has one pair of metals different metals metal 1 and metal 2 we join them together these two metals are in the form of wire we take these wires twist them at their end we make this kind of couple and that is what we call it thermocouple.

These are the sensors composed of two different materials here I want to put material not metal. So, it is not that the concept what we are using here is not limited only to metals it can be two different materials one may be the silicon one may be some other material need not to be metal only it works in semiconductors as well. So, the basic architecture of thermocouple is shown above we have two metals one is this wire which is metal 1 and this bottom wire which is metal 2 and we join them together here physically they are connected here and this is our sensing arm and the other side we have these two wires here we can connect some multimeter or so voltmeter let us say this voltmeter is going to measure the voltage developed across it. So, when we have this kind of assembly and we subject this assembly to two different temperatures one is the reference temperature we call it cold reference temperature and one end is at some hot sensing arm. So, when there is a temperature difference between this end and this end of these thermocouple then a voltage will be build up across these two materials this voltage is linearly proportional to the temperature difference between cold arm and the hot arm.

So, this voltage is generated when there is a temperature gradient between the hot element and the cold reference junction. This change of voltage is linearly proportional to the change in temperature for a quite wide range the voltage developed is very linear to the temperature difference in the hot and cold junction. And the amount of the magnitude voltage or EMF generated is proportional to or is dependent on the metals used. What materials or metals we use that depends the magnitude of EMF depends on those materials. These thermocouples have multiple applications for example, plastic injection molding machineries, food processing equipments, dicing, semiconductor processing, heating elements, heating treatment, medical equipments, industrial heat treating, package equipments there are multiple applications where we use these thermocouples currently.

And some advantage of and disadvantage of thermocouples are the advantage of thermocouples are these are very simple in nature we just need to have 2 wires join them together in this is what a sensor we have made. So, this is very simple in structure very rugged high temperature operation is just limited by the melting point of materials. So, we can subject to higher temperature, but the metals what we use that should not be deteriorated by this temperature this is what the only limitation otherwise this thermocouple is has a very high temperature range. It is a low cost it is no resistance led wire problem this we will discuss in some later slides point resistance testing. So, when we make this thermocouple we twist both the metals wire together we make a sensing node.

So, this is a kind of point we have which we use to measure the temperature. So, it is a point measurement sensing this has quite fast response to temperature changes if there is a temperature change at hot junction it detects quite fast. The disadvantage of thermocouples are these are least stable and least repeatable. So, if you do the same measurement using the same equipment 100 times the readings are not very reliable and repeatable it has low sensitivity. So, if the changes are very small in temperature.

So, you have it is difficult to measure the output generated voltage very accurately extension wire problem is there which must be of same thermocouple type. So, this extension wire problem is there, but if you use the same kind of wire you can eliminate that up to a point. Another problem is wire may pick up radiation this is kind of a noise they can pick up because these wires are very long in in size they can start picking up RF radiation from nearby sources and this noise comes as a error in the measurement. It has not very good accuracy of the temperature measurement. So, these are some advantage and disadvantage of thermocouples.

The next is the resistance thermometer or we call it RTD's the resistance temperature detector or in RTD in short. So, these are the sensors which are typically made of a single pure metal. So, we have a metal and we measure the temperature using the property of the property of measurement is the resistance of a metal changes with the temperature. If we have a metal and its electrical resistance is let us say R0 the electrical resistance are equal to R0 plus alpha into delta T. So, this is the resistance of any metal the resistance depends on the base value of resistance and it also depends on the temperature difference with a proportionality constant.

So, the electrical resistance of a metal is a function of change in the temperature with a base value. This electrical resistance is function of temperature the most accurate resistance thermometers are the one that use metal that have a very linear relationship. So, in this expression we have just written only one term alpha into delta T, but there may be some other second order terms let us say beta delta T square and so on, but we are limiting our discussion only to the very first term delta T. So, if we want to choose a metal which gives which should give a very linear response we want to have a metal that does not have this delta T and other high order dependencies. So, we carefully choose the metal which has a linear relationship with temperature one such metal is the platinum.

So, if we use a platinum as a metal and we make a sensor using this that gives you must very much linear relationship and the characteristic of this RTD is you have this on the y axis you have resistance on the x axis you have temperature and the characteristic is quite linear. And we see when we are increasing the temperature there is a increase in the resistance. So, this is R equal to R naught plus alpha T when we increase the temperature delta T there is a increase in the resistance of this wire and the construction of these RTDs are very simple you have just a tube on which you can bound this lead wire let us say we take platinum. So, we take wire of platinum and we just wound it on this tube like this on this core and this comes out with two terminal one and here. So, we have two terminals now we measure the electrical resistance here using a multimeter and we expose this whole assembly to the temperature let us say the body temperature and here this is our sensor which is at temperature T s.

So, we expose this whole body to the measuring temperature what we want to measure and we measure the electrical resistance of this platinum wire which is a linear function of change in the temperature. So, these RTDs has multiple applications for example, air conditioning and refrigeration servicing is one application, furnace servicing, food service processing, medical research and textile production these are some applications they are used at other places as well. We have some advantage and disadvantage of these RTDs for example, these RTDs are most stable over the time the they are quite stable for a very long time they are very much accurate they are most repeatable temperature measurements very resistance to contamination this is one property which sometime is very important because let us say we have a we have a sensor it should not react with the environment. For example, we have a gas chamber and we want to measure the temperature of this gas chamber from inside we do not want to put a sensor which can react with this gas. So, if we use a platinum as a wire platinum is very inert material it does not react with the gas or any other liquid which is inside.

So, we can easily put this sensor inside that chamber. On the other hand if we have some other metals let us say copper or some other metal which can easily react with even with water or even with some other liquids. So, they contaminate the whole chamber if we put this kind of sensor in the chamber they contaminate everything. So, that time we want a sensor using materials such that it does not react with environment. So, these sensors or these RTDs are very resistant to contamination corrosion of the RTD elements the disadvantages are the high cost.

High cost means the platinum is very expensive metal and we want to have a very long wire of this platinum wire to make a sensor and to wound it on a on a core. So, the cost goes up they have a very high cost of metal and they have very slow response to the change in the temperature. Low sensitivity to small temperature changes they still cannot measure a very small change in the temperature. Sensitive to vibration strains the platinum element wire. Decalibration if used beyond sensor temperature readings and this is also again somewhat fragile because the core core is also sometime made up of quartz or glass.

So, it is somewhat fragile. The third is the thermistors. So, the thermistor is a specific type of resistance thermometer they are also a special type of RTD, but in RTD we have R equal to R naught plus alpha T means there is a positive temperature coefficient here this plus sign and this alpha is plus. So, the resistance of a metal always increases with temperature increase the temperature is rising. So, resistance of metal will always increase.

However, in thermistor we have a different. However, in thermistor we have this differently. Thermistor can have positive temperature coefficient as well as negative temperature coefficients NTC or the negative temperature coefficients. So, the relationship here is not very linear. In the RTD case we saw the output response which is very linear with temperature.

However, in thermistor it is not very linear it is some other curve depending upon the material used and this makes it different than the RTD. However, we are still measuring the electrical resistance just like the RTD's. The temperature range in which thermistors can be used is small compared to the normal RTD's. So, these thermistors are useful for a very short range of temperatures in that range only their sensitivity is very good. Let us say we have this is the typical input output characteristic of a thermistor we have electrical resistance on y axis temperature on x axis and we see this type of graph.

Now, the sensitivity is the slope of this curve. So, if we have let us say a linear graph like RTD the slope is not very high. So, sensitivity is less, but here if we see this exponential graph if we take the sensitivity or the slope which is very high, but it is for a small range of temperature. This characteristic may be deviating at some point to some positive temperature coefficient just like this. So, the thermistors are useful for a small range of temperature.

We will discuss all these thermocouples, the RTD's and thermistor in detail after studying these advantage and disadvantage. Some applications of thermistors are they are most are seen in medical equipments because the most of the time in medical equipments the temperature range is very small. Thermistors are also used for engine coolants, oil and temperature measurement in the transportation industry. So, multiple places they are used. Advantage of thermistors are they are highly sensitive to small temperature changes because of their NTC or the negative temperature coefficient.

Temperature measurement becomes more stable with use and copper or nickel extension wires can be used. At disadvantage of these thermistors are limited temperature range. We do not have a very wide temperature range for thermistors. They are still somewhat fragile some initial accuracy drift is there. Decalibration if used beyond the sensors temperature ratings and lack of standard for replacements.This is also one bottle neck of thermistors and the fourth ones are semiconductor based sensors. So, these sensors are made of semiconductors for example, silicon. So, these are entirely different structure compared to these conventional thermal sensors. So, this we are all these four sensors we are going to discuss now in detail. So, before jumping to actual structure of these thermal sensor let us brush up some fundamentals of heat transfer.

So, we have basically three mechanisms of heat exchange which is first is conduction, second is convection and third is the radiation. So, these are the three modes of heat exchange and conduction is the heat transfer primarily through solids and it can also occur with flutes as well. So, when there are two bodies in close contact to each other then there is a heat transfer between one to another and that is the conduction mode and the rate of heat exchange is let us say Q conduction equal to K into A into difference in temperature which is delta T here T hot minus T cold divided by L where Q is the heat flow, K is the thermal conductivity, T is temperature, L is the length of material how long the material is and A is the cross section area of the heat flow. So, this is the formula for the heat flow how much heat is going to flow when they are in close contact and there is a contact resistance when two materials join to form a conduction path. There is a resistance at the point where the two materials join this occurs because of the two surfaces are rarely completely flat when we have two materials join them together the surface when they are making contact this is not very clean or very kind of flat.

So, there is always a gap between these two surfaces because of that the contact area is not the actual physical area which is in contact. So, because of this voids of air there are some contact resistance on the contact. So, let us take one example for this a rectangular block has an area of 400 mm square a engineer would like to use it to cool his heat source that is producing a total of 50 watt with a specification of 90 degrees. The heat source is placed in a chamber with an air temperature of 65 degrees. So, the environment temperature is 65 if the length is 10 mm what is the minimum conductivity of the material in order to cool the heat source to specification used in the block.

So, we know the equation Q conduction equal to k a T hot minus T cold divided by L and these are the values which are given to us from here this is T cold this is T hot and this is the area and the length is given here which is 10 mm. So, we can put all these values together here it will come out to be something like this. So, we can solve for the conductivity k which is the last here in this example. So, this is one example of conduction based heat transfer. The next method is convection, convection is the heat transfer from a surface to a fluid and some common fluids include air and water.

So, when we have a heated body placed in the air through the convection mode it can lose the heat to the air and the formula for the convection based heat transfer is Q convection equal to h c into a into this temperature difference which is delta T where h here is the convection heat transfer coefficient. So, this is the different coefficients from the earlier one. This mode of heat transfer is used mostly to cool down the heated body for example, we have fin like structures placed next to the heated body. So, that the contact area between the metal and the fluid increases the air can flow between these fins and these fins lose the energy which take the heat energy from object and lose it into the air keeping the object cool down. This is the way of removing the heat from the heated object.

The third mode is the radiation, the heat transfer between surfaces via electromagnetic waves. So, when a body is having certain thermal energy it has the temperature which is higher than the ambient it loses its energy the heat energy in form of electromagnetic waves as well. So, this is third mode of radiation all matter is at a non zero temperature emits electromagnetic waves whatever the temperature is that all these object emits these electromagnetic waves including gases and liquids. So, typically this mode of heat transfer can be more complex than conduction and convection, but at very high temperature this is the mode which dominates to radiate the energy because if we see the equation for Q radiation equal to h r into A into T source minus T surrounding and we put all these values together the actual equation is Q radiation equal to epsilon C sigma A T source to power 4 minus T surrounding to the power 4. So, here you see the rate of heat transfer is dependent on fourth power of temperature it means at low temperatures this mode does not dominate, but as soon as the temperature start rising this mode starts dominating at high temperatures and very high temperatures T to the power 4 is the term which dominates compared to the linear order of convection and conduction.

So, this radiation is the most common mode of heat transfer at elevated temperature. So, now coming back to the thermocouples, so to understand thermocouple we investigate how the current actually flows in an isothermal conductor. So, we have this block and inside this we have free electrons all these free electrons which are free to move in any direction. So, the there are certain equation for example, current density J equal to E into N into V E is the electron charge N is the electron density and V is the drift velocity. So, based on that you have certain current density in this material.

Similarly, you can write the heat flux as well JQ equal to QN into V the Q is the heat per charge instead of having electrical charge now we have heat per charge in into N into V or we can also write pi into N into V or we can also write pi into J where pi is the Peltier coefficients. So, what the thermocouple is we have as we discussed we have in thermocouple 2 different materials material 1 and material 2 and material 3 and material 4. So, we have 2 different materials we join them together at 1 junction and on the other junction we measure the EMF generated between these 2 and this junction we need to put it at cold junction or we can call it the reference junction typically 0 degree using R 1 and R 2. So, this is the ice or so we can put this junction into the ice which is at 0 degree C and we can use this as a sensing arm or sensing junction. This junction we put to the in the in the close contact of body temperature and we the voltage build up here is linearly proportional to this temperature difference between 0 degree and the sensing junction.

This effect was observed by Thomas John Seebeck discovered in 1821 and this is this effect is called the Seebeck effect which is the temperature difference generates the voltage. How does it generates the voltage? A pictorial view is something like this we have this object where 1 junction is cold junction and this other junction is hot junction and inside this block we have all these electrons which carrying charges as well as they are also carrying heat or the thermal energy. So, when these electrons are close to hot junction they pick up this kinetic energy from this high temperature when they pick up this kinetic energy they move fast. So, when they move fast they spend less time towards the hot junction and when they move towards the cold junction they lose this kinetic energy because this junction is cold it takes away heat from these carriers. So, this slows down here this slow down here and they spend more time in cold junction.

So, if we can see statistically more electrons will be confined in this cold junction because they are spending more time here compared to the hot junction where the electrons are less. Let us say we have only 10 electrons here and 100 electrons here this side and these electrons are carrying the charge as well they have negatively charged. So, we can see there is a potential build up delta V because of this mismatch in the in this charge carrier. So, this is the basic principle of this Seebeck effect how a temperature change from hot to cold is generating the voltage difference. So, this charge diffusion under a temperature gradient and built in potential resisting diffusion this was observed by Seebeck and we write Seebeck coefficient S is equal to minus delta V upon delta T where delta V is the change in the voltage V hot minus V cold divided by delta T which is the change in the temperature T hot minus T cold and this is called the Seebeck coefficient.

The opposite of this effect is Peltier effect. The Peltier effect says we have same thermocouple, and we make these junctions this is the material 1 and this is material 2. If we apply a current or the voltage from outside here, we are applying external electrical stimuli here then this junction and this junction will have temperature difference or the temperature difference or the temperature gradient will can be produced using the electrical signals and this is called the Peltier effect. So, Peltier discovered this in 1834 an electrical current creates a cooling or heating effect at the junction depending upon the direction of current flow where the current you are flowing. So, this is kind of reverse of Seebeck effect observed by Peltier and the Peltier effect is like this you have two different metals let us say this is 1 and this is 2 when you connect external voltage source the current flows like this and it generates a heated surface on one side which is hot junction and this junction becomes cold. So, we can control this external voltage or the current flow in this assembly and we can controlled how the hot and cold junction are different in temperature this delta T we can easily control using this delta V.

The Peltier effect this is called the Peltier effect and the Q Peltier is equal to pi 1 minus pi 2 into J this is reversible with current direction where Q is the heat absorbed or released pi is the Peltier coefficient these are the Peltier coefficients and J is the current flowing through the system. The other effect is the Thomson effect the Thomson effect says the amount of heat released or absorbed by an object it depends on how much current is flowing through that object. So, let us say we have this material and there is a current flowing inside this how much heat is being absorbed from environment how much heat is absorbed or released to the environment it depends on how much current is actually flowing into the material this is called Thomson effect this was invented by William Thomson. And the Thomson effect if we see pictorially we have this object where the current is flowing current is nothing but the mobile charges which are flowing from one end to other end they are carrying charges and they are carrying the thermal energy as well because in the form of kinetic energy. Now this area is exposed from environment so amount of heat absorbed here it depends on how many charge carriers are picking up this energy from environment and when they pick up this thermal energy they go to other side.

So, if we have higher current for higher current you have large number of electrons large number of electrons present here which are ready to pick up this thermal energy from environment and move away. So, you have large number of electrons means the large thermal energy they pick up if they the number of electrons are lesser the lesser energy will be absorbed. So, this is what the Thomson effect is the heat absorbed or released depends on how much current is flowing into the object. And Thomson coefficient tau is equal to 1 upon i dQ by dx upon dT upon dx and there is a Kelvin relationship which connects all these thermal coefficient Thomson coefficient to the Peltier coefficient and Seabag coefficient. So now we are coming back to sensors the thermal sensors these thermocouples consist of a pair of dissimilar wires as we discussed joined at one end.

This connecting point is known as a measuring junction only the junction itself does not produce the thermocouple small signal voltage. This is the when we make this thermocouple by twisting two wires we make it sensing junction. This junction itself is not creating the output voltage in fact the whole length of wire is creating the output voltage where the temperature difference is between the hot junction and the cold junction. But entire length is contributing to the linear EMF build up. The actual thermoelectric effect is an extended and continuous that is distributed along the entire length of the thermocouple.

So, we have let us say this is our thermocouple which has material 1 and material 2 this junction is hot junction and this is cold this is hot junction. Now if we just think about only one metal let us say metal 1 the thermal profile when we subject this metal to the temperature gradient as we saw the hot junction is let us say at some potential and the cold junction is at different potential because as we discussed the electrons spend less time in hot junction and spend more time in cold junction there is a potential build up. So, this metal or let us say metal 1 this has this field or the electric potential profile this Y axis electric potential. So, hot junction is at different potential compared to the cold junction this is your delta V because of this is your the delta T the temperature gradient.

So, this profile is for the material 1. Now we have material 2 which has different profile. So, this is material 1 now if we have material 2 this will have different this is material 2 this is material 1 let us say. So, these profiles are different it means at this junction we are forcing the potential to be same. So, the other end will develop different potential because of this delta V let us say we have delta V1 and for material 2 we will have delta V2 material 2 will have delta V2. So, this and because of this delta V1 and delta V2 there will be an effective delta V the potential build up across these two terminals.

So, if we have two same metals let us say we take two same metals and we join them together make a thermocouple it will not be possible to have EMF build up why because metal 1 will have this thermal profile and the metal 2 which is same as metal 1 will also have the same material profile. So, the difference between these two profiles will be 0. So, this delta V will be 0 if we have two same metals that is why we in the thermocouple we need to have two different metals join together then only it will produce a EMF which is linearly proportional to the temperature. All thermo electric activity takes place in the center zone we see this is the center zone which is creating this voltage difference otherwise at the junction the voltage is same the junction the voltage is same and at the cold junction the voltage is same this is the entire length in between this hot and cold junction which is creating this voltage change which is the center zone of decreasing temperature. So, this is the actual working principle how we use this thermocouples in practice we have this hot junction and this is material 1 and material 2 these are bring together to a cold junction or the reference temperature typically 0 degree using ice or so.

So, this is filled with ice which is which keep this junction at 0 degree. Now, we connect both of these wires to volt meter and this is the hot junction and this is the cold junction. Now, we connect both of these wires to volt meter and this is the hot junction and this is the cold junction. Now, we connect both which are connecting this volt meter to these 2 junctions this is material 1 and material 2 which are different to each other and we connect copper wires to connect volt meter to this end. Now, this volt meter will read a different it change in the voltage depending upon how much is the difference between the cold junction and the hot junction.

So, this delta V is proportional to the delta T this is the actual measurement setup of thermocouples. Materials for thermocouple what we need to be careful about the melting point of thermocouple material should be higher than the measuring temperature. So, let us say we use 2 different metals the limitation of this thermocouple is it cannot measure a temperature which is higher than the melting point of these metals otherwise these metals will melt down and the wire will kind of damaged. The dissimilar materials on joining should be able to produce large EMF. So, if we choose a metal carefully we need to have a metal 1 and metal 2 which are very different in the electrical profile when they are subjected to these temperature gradients.

If both the metals we choose are of same potential profile then the delta V will be very small and it will be very difficult to measure the output voltage. So, we need to carefully choose all the these 2 different metals so that they produce large EMF at the output. Temperature is determined indirectly through calibration of EMF with temperature. So, for as possible the linear variation of EMF with temperature is desired. We want to have a linear EMF or the delta V is proportional linearly proportional to delta T this is what we expect from the thermocouples.

These thermocouple materials should be resistant to atmospheres in furnaces. So, these metals which we choose for making these thermocouple these metals should not react with the surroundings or the chamber where we want to put this thermocouple as a thermal sensor otherwise they can contaminate the chamber itself. They should be chemically inert as well. There are multiple materials are available for thermocouples for example, type B we use metals as platinum 6 percent rhodium and platinum 30 percent rhodium these are 2 different metals we use if we use B type thermocouple. Similarly, we have E type thermocouple J type thermocouple K depending upon the industry standards we have multiple types of thermocouples where we use different metals depending upon our goal of measurement.

So, we have R type S type T type. So, all these types they have their specific metals to choose and there are certain characteristics are given here. For example, C back coefficient is given degree centigrade standard wire error is there or ohm per double foot 20 AWG. So, this is the dimension of wire the cross section. So, depending upon the type of thermocouple the material for the metal 1 and metal 2 are fixed. Let us say for J type we have material 1 as iron and the material 2 as Constantin.

And for example, we take J type thermocouple then we have this is the table which is giving the delta V which is the voltage build up proportional to the temperature how much temperature we change and how much voltage is generated by this J type thermocouple this is given in this table which are easily available in the market when we buy that is a J type thermocouple from market we can always have this table downloaded from various sources. So, this table says when there is a change from minus 200 to minus 90 it means 10 degree change how much is the voltage change and this is 200 then this is 201 this is 202 we have here 10 degrees. So, here this is 200 this is 199 this is 198 197. So, from this is the 10 degree step and for each 10 degree we have this row which is 10 in nature. So, we can read this table to measure the voltage for 1 degree centigrade rise in temperature.

So, we see the example let us say we take a J type thermocouple whose reference junction is at 0 degree c. So, all these measurements are done the table in the previous slide this is all reference to 0 degree this produce a EMF voltage of 4.115 milli volt what is the temperature at the measuring junction. So, 4.115 is the voltage measured by voltmeter now we want to calculate how much is the temperature of heated junction.

This produce a EMF voltage of 4.115 milli volt what is the temperature at the measuring junction. So, 4.115 is the voltage measured by voltmeter now we want to calculate how much is the temperature of heated junction. So, for a J type thermocouple we seen the table earlier we simply need to find the temperature from the table which would generate a EMF of 4.115. So, if we go back to this same table and we try to calculate this 4.115 milli volt potential that come out to be between 78 and 79 degree. So, 78 degrees somewhere this is 70 this is 80 and here it is 7.

So, our 4.115 milli volt is in between this 4.079 and 4.113 which is which corresponds to 8 and 9 and here 70 degree. So, the temperature is around 78 degree or 79 degree or we can even extrapolate as well to calculate the exact temperature. So, this is how we read these the tables for given for this thermocouples which are standard in J type thermocouple. Another example is example number 2, in example 2 we have a J type thermocouple whose reference junction is at 21 degree C. So, instead of having 0 degree C we generally we keep a reference temperature now the reference temperature itself is higher than 0 degree by 21 degree C 21 degree centigrade it is higher than 0 degree.

Now it is producing a EMF voltage of 2.878 milli volt. Now we want to calculate what is the temperature of hot sensing junction. So, we discussed that the voltage developed is linearly proportional to the temperature gradient and the EMF generated from 0 to T 0 degree to T we can split it up between 0 to 21 and then 21 to the temperature T because the relationship is linear. Now our cold junction is at 21 degree.

So, from this cold junction to this temperature we are known that EMF is 2.878 2.878 and for because this is J type thermocouple. So, we can calculate from the table that how much is the EMF for 0 to 21 degree that we can calculate from the table and we can calculate the effective EMF which is 3.54 and we can again go back to the table and calculate what is the temperature for this effective EMF which is 75.7 degree centigrade. So, these are some examples of thermocouples which you can use and they shows how you can calculate the values of thermocouple using the truth table for that type of thermocouples.

So, this is all for today.

Thank you.