Principles of Mechanical Measurement
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Module - 10
Temperature Measurement
Lecture – 2
RTD, Thermistor & Thermocouple

Hello friends. So, we are into the second lecture of our week number 10 where we are talking about the measurement of temperature. And this is probably quite apt time of talking about this particular parameter because as I have mentioned, during a previous lecture this is probably the most common parameter that not only engineering says, but we also keep on using this in day to day life the concept of temperature probably is known to even the even anyone who does not have any relation with education at all. But also it is quite apt to discuss about this during this type of the course because this is just the beginning of the summer, we are in the end of March, beginning of April, temperature started to rise up summer has officially begun. But in different parts of the country, it has already touched 40 degree Celsius.

So, this that is for heat temperature measurement has become more important as we keep on checking the daily weather reports and what are the different ways of doing that, that we are learning in this particular week or this particular module. Now in the previous lecture, we have discussed about a few thermodynamic fundamentals about the measurement of temperature or related to the measurement of temperature, the application of the second law of thermodynamics to define the thermodynamic temperature scale and subsequently we have discussed about two different types of measurement principles. One is based upon the expansion or volumetric expansion of some material and the second one is based upon the change in pressure of some gas or vapour.

Now, I was a bit down during the previous lecture, you may have noticed me losing a bit also during the lecture which was because of certain medical issues. But I hope I can keep it in a better shape in today’s lecture. Now during the previous lecture two most important topics that we have discussed which are related to the volumetric expansion.

One is the use of bimetallic strips and other is the most common temperature measurement in day to day life that is the use of liquid in glass thermometer.

Both are low accuracy, low cost devices generally applied in situations where we are more looking for direct temperature measurement that is we need to take them in direct contact with the surface or you want a temperature measurement. And we are satisfied even if there is accuracy or inaccuracy of the order of 0.5 degree Celsius or 1 degree Celsius because we are trying to get a rough idea about the exact level of temperature that we are looking for.

While the liquid in glass thermometer finds its application in medical cases and also in several stationary devices where we, generally want a permanent option of temperature measurement. The bimetallic strips are more used for certain kind of control applications like we have briefly touched upon. It can be used as thermal switches very commonly you will find those kind of thermal switches conventionally called the thermostats in domestic refrigerators like as a temperature inside the freezing compartment or a refrigerator compartment goes below a certain temperature, the thermostat is set such that it disconnects the electrical circuit Thereby stopping the entire operation electrical operation, stopping the compressor. And as the temperature inside the container or inside your refrigerator keeps on increasing, the bimetallic strips again starts coming back to its original shape and beyond the certain temperature, it again connects the circuit thereby allowing the flow of current through it and again switching on the compressor.

So, the thermostats can act as a switch on off kind of switches or like we have mentioned about, for compensation in clocks or in pendulum based watches there also you can use thermostats. The thermometer as we have mentioned are more for domestic purposes. Before we move on to the other type of device measuring principles, let us solve a few numerical examples just to illustrate the concept that we have discussed in a previous lecture.

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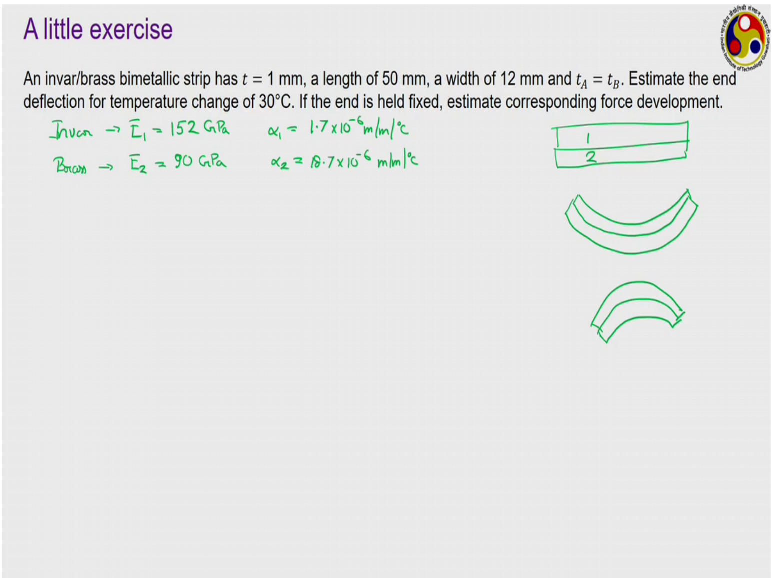

The first one is related to a bimetallic strip. Please read the problem carefully. So, we have here an inverse brass combination based bimetallic strip. So, basically we are talking about the strip where we have an invar slab and another brass lab both are coupled with each other filtered with each other and their properties are different, property values are not directly given here. But I have noted those properties. So, for invar the relevant properties are the Young's modulus let us say we call it 1 which is 152 Giga Pascal and alpha 1 that is a coefficient of thermal expansion or volumetric coefficient of thermal expansion is given as 1.7 into 10 to the power minus 6 meter per meter per degree Celsius.

What about this unit? How this ones, this one is looking like meter per meter per degree Celsius. It suggests that if the initial length of the body is 1 meter, then for 1 degree Celsius change in temperature, the change in length will be 1.7 into a minus 6 meter. Similarly for brass corresponding Nose modulus E 2 is 90 Giga Pascal and alpha 2, the volumetric expansion coefficient is 18.7 into 10 to the power minus 6 that meter per meter per degree Celsius that is for a brass bar of 1 meter length will experience a change in length of one 18.7 micrometer for 1 degree Celsius change in temperature.

So, they are having distinctly different values of this coefficient of volumetric expansion accordingly, there will be deflection a change in temperature. Let us say the top bar is 1 which is invar, the bottom bar is 2 which is brass. Now from this value can you tell if the temperature increases, then what will be the direction of the curvature or how in a better way how the bar is going to, how this bimetallic strip is going to bend? Of course, brass is having higher coefficient of expansion.

So, the expansion of brass for a given temperature change will be more and therefore, with increasing temperature, its shape will be something like this. This is for invar and this is for brass. Brass being on the outer side its length will be more which is definitely the one that we need corresponding to higher value of alpha. Similarly if the temperature reduces, it will take a shape like this with brass being on the inner side because its contraction is more invar remaining on the outer side.

So, let us come back to the problem, we know the properties for both the corresponding material. It is given that the total thickness of the strip is 1mm.

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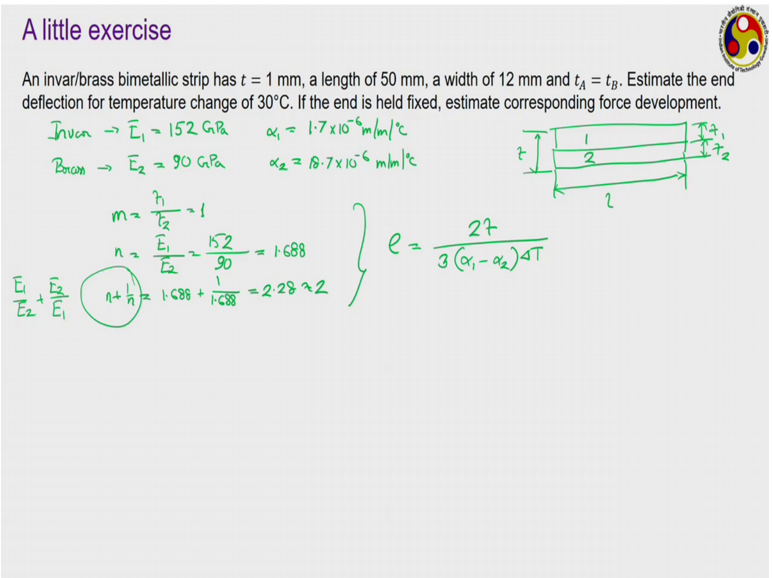

So, this total thickness is this t equal to 1 mm that is given, a length is 50 millimeter. So, this particular length l is 50 millimeter, width of 12 millimeter. The width is not shown here that is a third dimension out of the which is normal to this particular screen and t A equal to t B. That is an important information. So, the thickness of both the materials t A equal to t A and t B are equal or let us just write this one to be consistent with the notation that we were using say t 1 equal to t 2.

Now, we have to estimate the end deflection for a temperature rise change of 30 degree Celsius and if the end is held fixed estimate corresponding force development. So, that is the second part we shall be coming back to that after calculating the first part. So, just try to remember the relation of radius of curvature for a bimetallic strip that I have given in the previous lecture. So, if we take from there here m which is given as t 2 upon t 1. So, or we could have taken in any way.

So, let us say m is equal to t 1 upon t 2 and that is equal to 1 n is equal to E 1 upon E 2 which is 1 5 2 by 9 0. So, how much is n? It is 1.688 correspondingly n plus 1 by n is equal to 1.688 plus 1 by 1.688 is equal to 2.28 which can roughly be taken equal to 2 for our purpose. So, you may doubt that 2.28 and 2 is significantly different, but there are certain situations where this value can be well beyond 2 and that is why around this range, we can take it to be equal to 2.

And when m equal to 1 and n plus 1 upon n equal to 2, then what is the relation corresponding to the rho the radius of curvature? This relation the simplified relation that we have used in the or we have seen in the previous deal, it is 2 t divided by 3 into alpha 1 minus alpha 2 into delta T or t 2 minus t 1.

So, this is a simplified relation for the case when m equal to 1 and n upon 1 plus n is equal to 2. And just note one thing, here we have taken m and n definition with t 1 by t 2 and E 1 by E 2 that is we are taking the properties of invar in the numerator and brass in the denominator.

Now, as long as we are dealing with this situation m equal to 1 and n plus 1 upon n equal to 2, it doesn't matter which order we are taking because when t A and t B are so that t 1 and t 2 are equal, m will always be equal to 1 and depending on independent of whether you are defining it at t 1 upon t 2 or t 2 upon t 1. Similarly, here we are taking n plus 1 upon n. So, this practically always is E 1 upon E 2 plus E 2 upon E 1. So, again the definition of n is immaterial in this case. However, if we are made to use the make use of the full relation, then the order is important because that will designate the direction of deflection.

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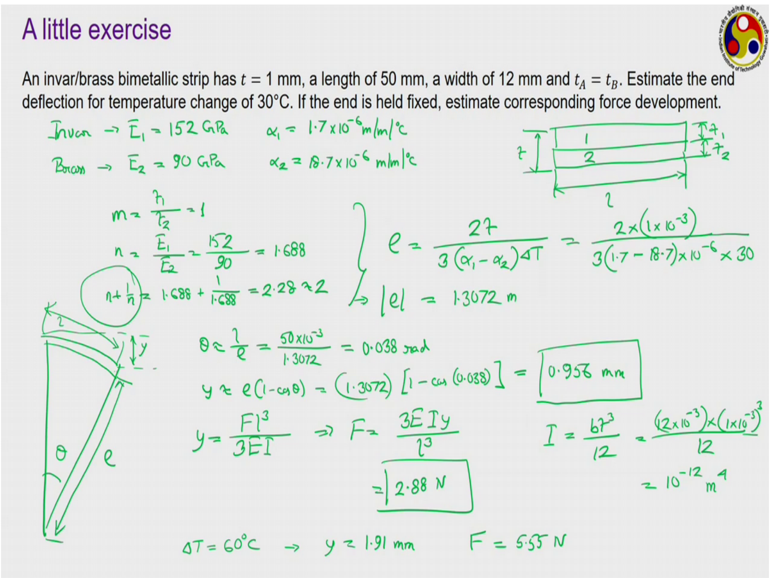

So, the value of rho is here; let us put the numbers. So, we have 2 into t, the thickness is 1 millimeter. So, 1 into 10 to the power minus; I keep on repeating always use the S I units. So, we have converted this millimeter to meter to make the calculation consistent divided by 3 into alpha 1 minus alpha 2. So, here alpha 1 is 1.7 minus 18.7 into 10 to the power minus 6 into delta T is 30.

Now here as we have written alpha 1 minus alpha 2, so we are getting a negative sign, but we are generally interested with the absolute value of rho. So, that will be coming to be equal to 1.3072 millimeter oh sorry my 3072 meter. Again I have pre calculated the numbers for reading the problem. But we have to calculate the deflection of the end of the bar.

So, let us say this was the initial bar which is a given a vertical line and after the deflection which is like this. So, this is the deflection that has taken place and given by the angle theta, then this particular situation or this particular length is this radius of curvature that we are talking about and this is the deflection that we are talking about y this particular length is l, the length of this bar. So, what is the relation between theta and rho?

So, we can roughly write theta as long as this it is small is equal to l upon rho now length of this is 50 millimeter, 50 to 10 to the power minus 3 by rho we have just calculated 1.3072. So, we are getting this one to be 0.038 radians and once you have got that then y can the deflection y can roughly be taken as rho into 1 minus cos of theta from this trigonometric portion where y is the one that we are looking for. So, putting the number rho we have calculated to be 1.3072 into 1 minus cos 0.038 putting the values you are having a deflection of 0.956 millimeter.

So, the total deflection that is taking place is equal to 0.956 millimeter approximately 1 millimeter which is extremely small deflection. But with a suitable deflection measuring instrument suitable strain gauge kind of device, we can easily detect such a deflection to and then subsequently that can be related to the corresponding temperature change of 30 degree Celsius. So, this is a first result.

Now, the second part is saying that the; if the end is held fixed estimate the corresponding force development. So, you have to calculate the force in this end is kept fixed that is a strip is not allowed to expand freely. To identify that, we can make use of the standard relation for a cantilever kind of bar means here one end is kept fixed. In that case, the standard cantilever formula from the concept of engine mechanics; we can make use of y equal to F l cube divided by 3 E I which is standard formula for any cantilever. F is the force that we are trying to estimate. So, F is equal to 3 E I y divided by l cube.

Now, the question is what is I. I for a rectangular strip it is b t cube by 12 that is the thickness is given as 12 millimeter; 12 into 10 to the power minus 3 into and the thickness is 1 millimeter 1 into 10 to the power minus 3 whole cube divided by 12. So, 12 cancels out and we are getting this to be 10 to the power minus 12 millimeter to the power sorry I mean 10 to the minus 12 meter to the power 4.

So, if we put it back here then corresponding value of force is coming to be something like 2.88 Newton. So, this is a second result that you are looking for. This is the amount of force that will get produced if the if one end is held fixed, but this of course, all these results depend upon the value of the delta T. These are two numbers correspond to 30 degree Celsius if we suppose trying to solve the same thing corresponding to delta T equal to 60 degree Celsius, then your y will be much larger, your y will be something like 1.91 millimeter and corresponding force will be significantly larger 5.55 Newton.

So, both are nearly double they can correspond in the previous value and that is expected also because the y you are solving this we are almost linear a laser relation between delta T and y.

Now, this is a problem with in relation with the bimetallic strip.

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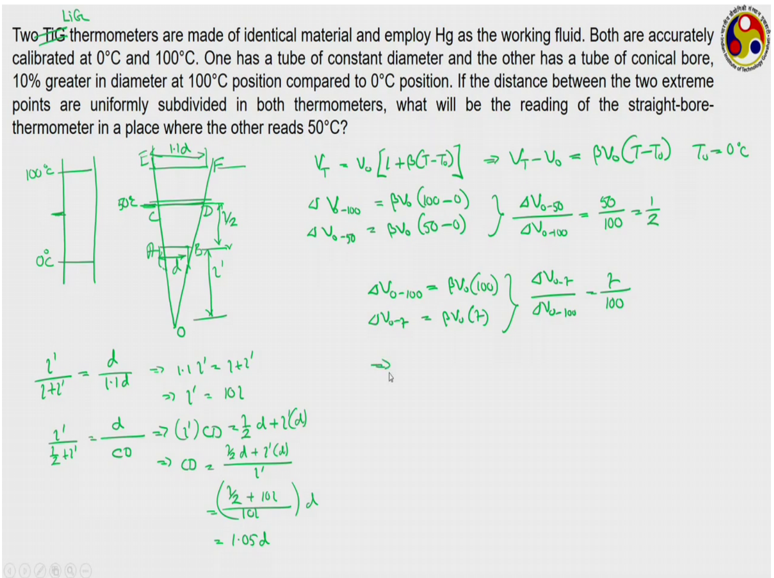

Let us try to solve another numerical problem involving the liquid in glass thermometer Two TIJ it should not be T I G, it is a typing error it should be L I G, liquid in glass thermometer are made of identical material and employ mercury as the working fluid. So, we are talking about two mercury thermometer both are made of identical materials. Both are accurately calibrated at 0 degree Celsius and 100 degree Celsius. So, on both the thermometers the position of mercury column or I should say the position on the tip of the mercury column at 0 degree Celsius and the position of the tip of the mercury column at 100 degree Celsius have been accurately identified, but it has not been calibrated for any of the intermediate points.

Now, one has tube, one has a tube of constant diameter. So, first thermometer has a tube of constant diameter and the other has a tube of conical bore 10 percent greater in diameter at 100 degree Celsius position compared to 0 degree Celsius position. So, there is a difference between the two thermometers if we roughly draw them one thermometers as a constant diameter.

So, let us say this is 0 degree Celsius portion and this is the 100 degree Celsius portion both have been accurately identified on this thermometer and the other thermometer is having a conical kind of shape where again this is the 0 degree Celsius position this is the 100 degree Celsius position and these two are also correct position, but the idea in the second thermometer keeps on changing as the temperature reading keeps on increasing.

Now, in the distance between the two extreme points are uniformly subdivided in both thermometers. So, in both the cases the all the 100 divisions between 0 to 100 are taken to be uniform which definitely seems erroneous for the second case, for the first case as the diameter is uniform so an uniform subdivision is justified. However, for the second case as the diameter keeps on increasing as they are moving in the upward direction the distance between subsequent temperature readings are called the sub width of each subdivision corresponding to 1 degree Celsius cannot be the same, but in this case it has been done.

So, the question is what will be the reading of the straight board thermometer in a place where the other reads 50 degree Celsius.That means, the second thermometer that is reaching the one having a conical bore has been taken to a place where it is showing 50 degree Celsius. Now as per the design the 50 degree Celsius position should lie exactly in the middle portion of these two 0 and 100 as it has been uniformly subdivided. However, as we know the diameter is changing so that actually is an erroneous position. Then the question is what is the correct temperature there which you can measure using the straight board thermometer.

Now, we know that for any such device the volume of mercury at temperature t can be given as V naught into 1 plus beta into T minus T naught where T naught is some reference temperature, V naught is a volume corresponding to that or volume of mercury corresponding to a temperature T naught and beta is the coefficient of volumetric expansion. If V t is a temperature corresponding to this t let me use capital T to be consistent. So, V T minus V naught is equal to beta V naught into T minus T naught.

So, let us say we take T naught equal to 0 degree Celsius, then the volume of mercury or the change in volume. So, this V T minus V naught can be also written as delta V corresponding to 0 to T. So, delta V corresponding to a change in temperature from 0 to 100 that should be how much? That should be equal to beta V naught into 100 minus 0.

Similarly the change in volume when the temperature changes from 0 to 50 then it should be beta V naught into 50 minus 0 if we combine these two, then change in volume for temperature change from 0 to 50 divided by the change in volume corresponding to 100 degree Celsius temperature change should be equal to 50 by 100 that is equal to half.

So, how do we measure with the accurate measured with the straight bore thermometer then the 50 degree reading should have appeared exactly at the middle. But as the volume of the cross or I should say the cross section area keeps on changing in the conical bore thermometer; this if this 50 degree which is erroneously marked exactly the middle position that is not correct that we have to rectify now.

So, how can we relate them to solve this? Let us expand this conical thermometer to form an hypothetical conic. Let us say this point is 0, let me remove this let us say this is A, this is B the it is the thermometer is showing 50 degree reading. So, correspondingly it is C, it is D it is E and this is F. So, when it is showing the reading of 50 degree, the mercury tip is appearing along the lines C D.

Let us mark this particular distance c as l prime the distance below A B and we are marking this particular distance as l. So, l prime divided by l plus l prime that should be what following the property of the cone this where the diameter is changing consistently.

So, we can write l prime to be equal to d where d refers to the distance at this position and how much is the distance at this position then? d refers to a diameter at the 100 degree sorry at the 0 degree Celsius position. Then at the 100 degree Celsius position that is at E F how much should be the diameter? It is given that the diameter is 10 percent greater. So, it should be 1.1times d. So, it is 1.1times d. So, if we make use of this 1.1 l prime is equal to l plus l prime. So, from there l prime is equal to 10 of l.

Similarly, if we make use of the C D position, now as the thermometer has given uniform subdivision. So, this height should be l by 2 because it has been uniformly divided. So, l prime divided by l by 2 plus l prime how much that should be, at l prime position diameter is d, at l by 2 plus l prime position diameter is C D let us say.

So, l prime into C D is equal to l by 2 into d plus l prime times d from there if we use the definition of l prime. So, we know that we can write C D is equal to l by 2 into d plus l prime into d divided by l prime and l prime have identified to be 10 l. So, if we put that we have l by 2 plus 10 l by 10 l into d; So, 10.5 that is 1.05d.

So, the diameter at this particular position is 1.05 times the diameter at the diameter at the 0 degree which is logical also because again that a cross section area is changing uniformly as it is changing by 10 percent at the 100 degree position. So, it should change by 5 percent in the 0 degree position. Now delta V corresponding to 0 to 100, position how much is that which is we have identified to be as beta V naught into the change in volume from 0 to 100, that volume and similarly delta V naught 0 to 50 or corresponding to any temperature t should be beta V naught into t. So, if we take a ratio of this two delta V naught corresponding to 0 to any temperature,e t by delta V correspond to 0 to 100 is equal to t upon 100.

Now, corresponding to t the volume is at 0 degree.

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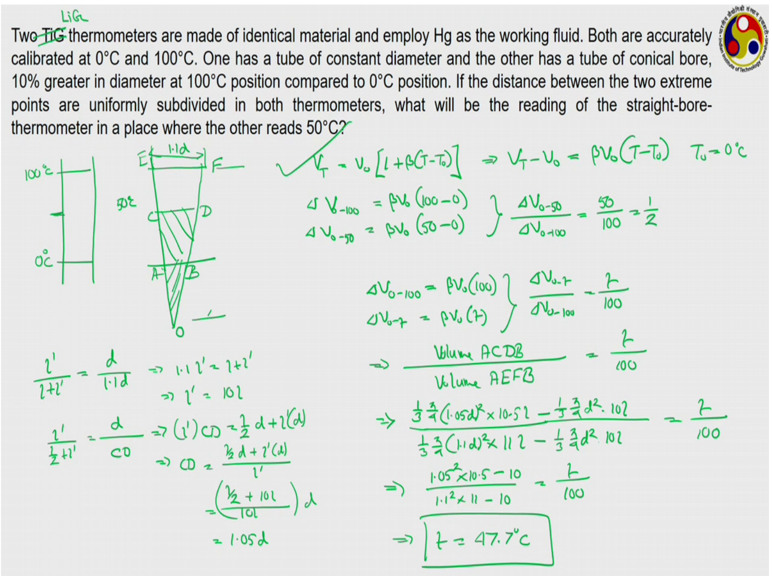

Let me remove these marks because it is looking quite. So,. So, this is your 0 degree position A B. So, at 0 degree position when the temperature is 0 degree Celsius, mercury is occupying this particular volume. When the it is showing this 50 degree position. So, the change is this particular amount and when the change it is moving to the 100 degree position the change is taking place which is the second hashed area plus the one that is left. So, the total area corresponding to this should be the volume A C D B divided by the volume when the expansion is taking from 0 to 100 should be equal to A E F B that is equal to t by 100.

So, now how much is this volume A C D B? A C D B volume should be the volume of the cone 0 A C sorry 0 C D minus the volume of the cone zero A B divided by the volume A etcetera F B which is the volume of the cone 0 E F or O E F minus the volume of the cone O A B. So, if you is the for corresponding relations. So, it will be equal to one-third into pi by 4. So, A C D B that is C D square which is 1.05 d whole square into corresponding length how much is the corresponding length? We have identified the corresponding length to be 10.5 times l minus the one-third pi by 4 d square into 10 l divided by one-third pi by 4 into 1.1d whole square into 11 l minus one-third pi by 4 d square into 10 l equal to t by 100. l and d square cancels out, pi by 4 cancels out, 1 by 3 also cancels out.

So, it reduces to 1.05 square into 10.5 minus 10 divided by 1.1 square into 11 minus 10 equal to t by 100 and if we solve this now t will be coming to be something like 47.7 degree Celsius.

So, your conical thermometer is at showing 50 degree, but actual temperature is about 48 Celsius which we can get using the relation like this, consistent volumetric expansion of the thermometer or mercury inside the thermometer. So, that’s the way we can make use of the concept of volumetric expansion of either solid in case of bimetallic strips or liquid in case of liquid in glass thermometer to get quite easy measurement of temperature.

Let us move to a different category of devices.

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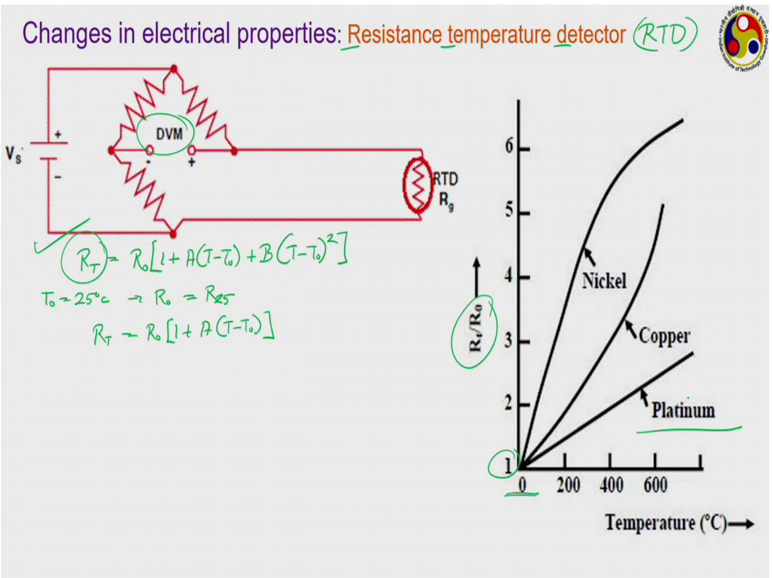

which is based upon the changes in electrical properties these are extremely popular devices for in temperature measurement in independent industrial applications and there are several varieties of that also and the first one is called the resistance temperature detector or in short taking the first three letters is called RTD extremely popular name Resistance temperature detector or RTD in certain literature. It is also called the resistance based thermal detector or thermal detection. So, the idea is very simple as the temperature changes you know that the value of resistance of any common conductor that also keeps on changing.

And the same property is made use of in this device. Here the RTD is nothing, but a resistor generally in the form of a thin wire or maybe in the form of a metallic film. As the temperature changes, its resistance also changes and this RTD is commonly put as a part of a bridge circuit which is normally in the null position and as the temperature as when the RTD comes in contact with the location where you want the temperature measurement there is a change in the resistance value accordingly there will be a deflection or some voltage current start flowing through this circuit there were giving some voltage measurement which can be sensed by the corresponding differential voltmeter.

Now, this circuit can operate of this voltmeter can operate either in the deflection mode just to indicate how much deflection has taken place or in the null mode where we get the bridge back into the null position and correspondingly try to calculate how much effort we have to put in to get this null position either of that can give you a measurement about the change in resister and that can be related to the value of the corresponding temperature because we commonly know that the resisters or value of resistance of any common conductor can generally be written as something like this R naught into 1 plus A into T minus T naught plus B into T minus T naught square plus we may have higher terms, but practical purposes generally don't go to this, we generally limited ourselves only to this second order term or the quadratic factor. Where this T naught generally refers to the is the reference temperature which is commonly taken to be 25 degree Celsius R naught is the value of the resistance at that temperature T naught.

If we take T naught equal to 25 degree Celsius then this R naught is often referred as R 25 to indicate that the reference temperature is 25. Now this once we know the value of this A and B for any given conductor then just from the measurement of this value of this R T we can calculate the corresponding value of the temperature T.

For certain materials over a smaller temperature range we can get an even simpler relation where it can be just a linear function R naught plus A into T minus T naught. But generally this kind of relation is varied only over a small range when the variation in temperature is limited only to something like 50 degree Celsius around that T naught. Certain materials like platinum can have this kind of linear relationship over a small temperature range, but if you are looking for a large change in temperature from the T naught then we have to go by this kind of quadratic relation with the knowledge of A and V.

Thankfully we know the resistance characteristics of several common metals and therefore, we know the values of corresponding A and B which may also change with temperature, but we have significant data base to know about the such variation.

And. So, RTD becomes a very good device or very popular device for temperature measurement. These are some of the common materials and their resistance behavior. You can see platinum is having a quite linear profile, the resistance is changing here look at this head we have plotted just R T upon R naught and a temperature of course, in this graph the 0 degree Celsius is shown as the reference, but commonly you take 25 degree

Celsius now at the reference temperature the value of R T is equal to R naught. So, the ratio is 1.

However as the temperature keeps on increasing, its resistance also keeps on increasing for platinum it's nearly a linear profile. However, that may not be the case with copper, nickel and several other materials.

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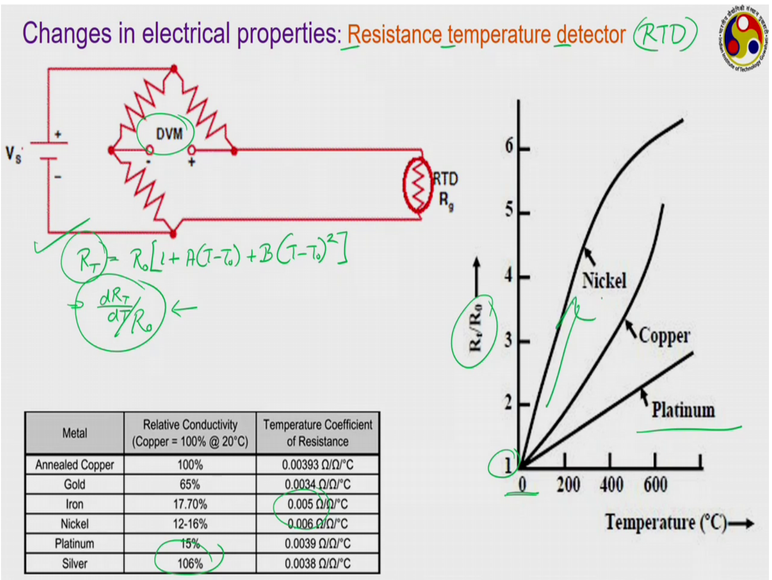

Metal	Relative Conductivity (Copper = 100% @ 20°C)	Temperature Coefficient of Resistance
Annealed Copper	100%	0.00393 Ω/Ω/°C
Gold	65%	0.0034 Ω/Ω/°C
Iron	17.70%	0.005 Ω/Ω/°C
Nickel	12-16%	0.006 Ω/Ω/°C
Platinum	15%	0.0039 Ω/Ω/°C
Silver	106%	0.0038 Ω/Ω/°C

Sometimes we may like to leap calculate the corresponding coefficient of temperature rise for that purpose we have to differentiate this expression in terms of temperature which is and then we shall be dividing this divide the value of R naught. This is called the resistor temperature coefficient of resistance or just temperature coefficient.

Now, this most of the common materials like the metals shown here they all have positive value of these resistance coefficients therefore, with increase in temperature the value of the resistance also keeps on increasing. These are some of the common materials their temperature coefficient of resistance is given. You can see the first one; in the first column it is given there is a relative conductivity with taking copper at 100 percent. So, others like higher, gold has quite high conductivity with respect to copper. Silver have, we can have higher than copper; however, certain metals like platinum etcetera can have much lower.

But the temperature coefficient of resistivity values is quite close to each other. Look at the unit, ohm per ohm per degree Celsius which is, which refers to the change in the resistance when the initial value of the resister is 1 ohm and the corresponding change in temperature is just 1 degree Celsius, then whatever we are getting that is temperature coefficient of resistance which is this particular factor only.

So, for several combinations like for copper, platinum, silver it is around 0.0038 or 3 9 for gold it is double naught 3 4. However, something like iron or nickel it can be quite high, 0.006.

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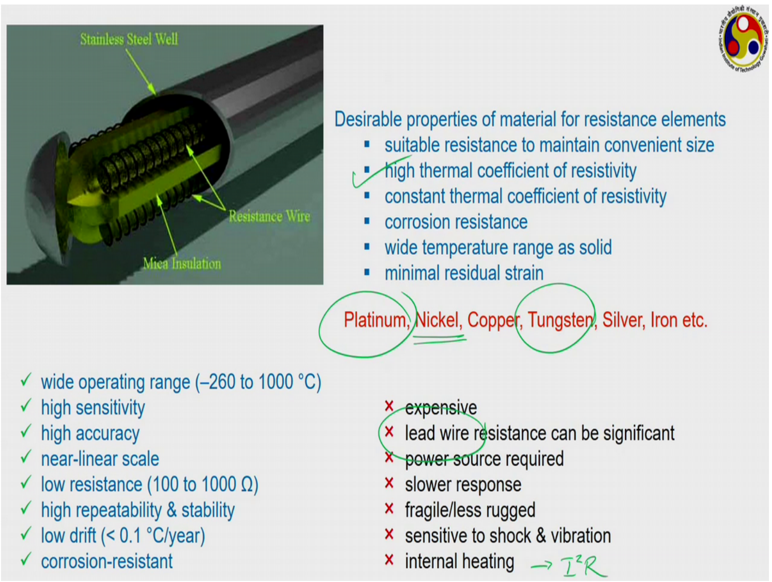

So, there is larger change in the coefficient which is proven by the steep slope in this particular curve physically an RTD sensor may look something like this where we can have the resistance wire wrapped inside stainless steel sheet or stainless steel well and the wires are separated from each other by insulating materials. We generally want their quite high coefficient of this resistance thermal coefficient of resistance from this wire there are several other properties also which are desirable for a common conductor to be considered while fabricating an RTD some of the relevant properties can be the resistance should be suitable so that we can maintain a convenient size like, we want a reasonable value of resistance within a smaller size. If the value of the resistance is small, then we need a large we need to have a very large value of the corresponding conductor which may not be suitable for application.

So, we want high resistance. So, that it is suitable to maintain a convenient size of the instrument high thermal coefficient of resistivity definitely is desirable. So, that for every small change in temperature we can have a large change in the resistance leading to significant change in the voltage output from the bridge circuit and hence a high sensitivity.

Constant thermal coefficient of resistivity, that is also very important as long as like we have seen from the graph for platinum it gives a reasonably constant value of thermal coefficient of resistivity. So, that resistance changes following a straight line with a temperature or near straight line. However, that was not the case with nickel and copper.

Now, if the coefficient of resistivity or thermal coefficient of resistance is not constant then we are not going to get a linear scale. Only if it is a constant, then you can get a linear scale which is possible for platinum over a smaller temperature range. It is for other materials we generally all for larger temperature change we generally get a non-linear scale. Corrosion resistance there has to be wide temperature range, as solid they should not get oxidized and also it should maintain the solid state to over a large temperature range and the mean residual strength should be also minimum so, that we can get a high reproducibility and quite reasonably fast response from the device.

Considering these factors there are several materials which can be considered while making RTD. Platinum remains the most common choice platinum is costly, but it is it grow wise as I have mentioned it provides a highly linear response. And also it is it has good corrosion protection characteristics and that’s why platinum is generally used for several applications involving the calibration standards also. Tungsten is another material which also gives reasonably good linear response. Copper is cheap, but copper has a highly non-linear behavior and the curse temperature range available for copper is also quite low.

Similarly, nickel the cost is low, but it is non-linear and the corresponding low temperature range can be another problem with nickel though nickel has very high thermal coefficient of resistivity. So, its sensitivity is very high, but the temperature range is a big problem with nickel. Sometimes, we produce certain alloying alloys of nickel which can provide some solution to this temperature range issue, but pure nickel generally has a much lower temperature range compared to platinum or tungsten.

RTD remains probably the most common measuring instrument if we are time temperature measuring instrument if we are looking for high level of accuracy because it provides numerous advantages something like wide operating range. Of course, we are not talking about the same device, but combining several device we can go for a wide range something in the range of minus 250, minus 260 degree Celsius to 1000 degree Celsius which covers most of the industrial applications that we can think about.

High sensitivity for certain materials like nickel etcetera, high accuracy as well, accuracy can be within in the range of 0.1 degree Celsius or even less. Near linear scale for material like platinum low resistance 100 to 1000 ohm resistance, it can provide and therefore, we can have convenient size of the device within a what I should say within a reasonable size of the resister.

Then high repeatability and stability generally we can get from RTD they are metal. So, there is very less residual strain and they can come back to the initial position quite quickly or initial resistance value they can recover quite quickly. Low drift their way they can there is no need to have repeated calibration for them and also generally their corrosion resistance which is some of the desired properties as well, but there are issues also with RTD like they are expensive there is a first consideration because we are thinking about materials like platinum or tungsten to make them which are costly materials.

Lead wire resistance can be significant. I shall be coming to this very shortly. Power source is required we need a voltage source to activate the bridge circuit whatever mode we are working deflection or null, but the power source will be required, Response is slower, but there because the resistance requires certain finite amount of time to get the modified value and accordingly the brief circuit requires certain time to respond. They can be fragile because we are generally talking about very thin wire platinum wires etcetera.

So, if we are using them in some (Refer Time: 41:12) environment there may be maintenance issues. They can be sensitive to shock and vibration which can be advantageous in certain situations or generally a disadvantage and another big problem is the internal heating because as the resistance current is flowing through the resister we can have I squared R or heating loss. So, internal heating loss definitely is there, but another big error comes from the lead wire resistance.

Lead wire resistance refers to the heating loss incurred by the long wires which are connecting the bridge with the RTD sensor itself as it is quite sensitive to surrounding temperature it. It can pick up the temperatures surround temperature of the surrounding and accordingly can lead to significant amount of I square R loss.

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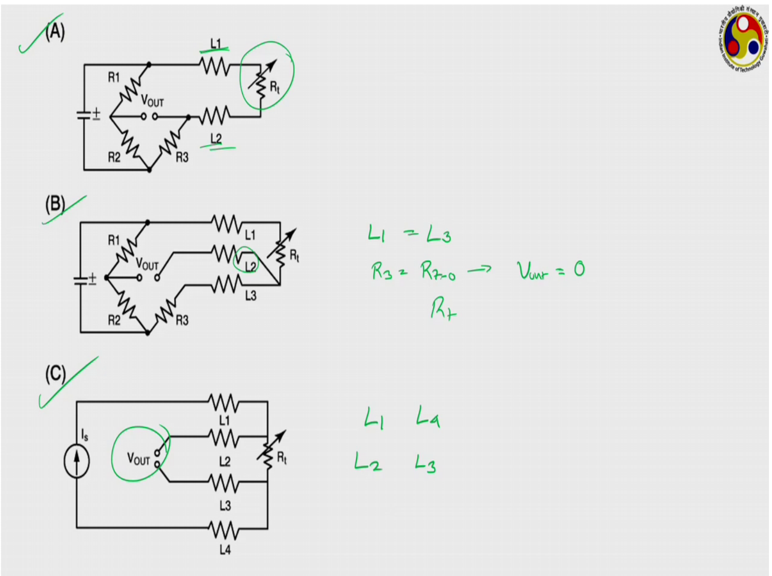

This is the one that is in early called a 2 wire configuration which is the general configuration where we are connecting the actual resistance with these two resistance L 1 and L 2.

Now, this is a situation where we can have significant I square R loss where is the while the current passes through these two resister registered L 1 and L 2. To remove that we can try a 3 wire or 4 wire design. This is a 3 wire design where you can see L 1 and L 3 are the one which are connecting the register and L 2 is some kind of potential lead.

Here they are designed such that commonly the register of L1 is equal to the resistance corresponding to L 3 so that they can cancel their the linear issue and give a stable response and it is generally designed such that R 3 is equal to the resistance of the conductor or actual sensor. Thereby, we can maintain at or at least at the beginning because I should say this is R t 0, R 3 should be equal to R t 0. In that case, we can maintain a 0 output voltage to start with and then as R 3 is not changing L 1 and L 3 may change, but their effect cancels each other.

So, only change that is happening is this R t and accordingly we can get the corresponding output. This C is a even better configuration is called a 4 wire configuration definitely more expensive, more complicated because we have to include 4 resisters, but this is the optimum configuration in constant current flows through this L 1 and L 3 whereas, L 2 L 1 and L 4 and L 2 and L 3 are connected with the actual sensor to give the corresponding output voltage their lead wire effect of L 1 is cancelled by l four. Lead wire effect of L 2 is being canceled by L 3. So, a highly stable response we can get from them without too much leading error

So, these are the resistance temperature detectors or RTDs, but there is another kind of resistance base temperature device which is called Thermistor.

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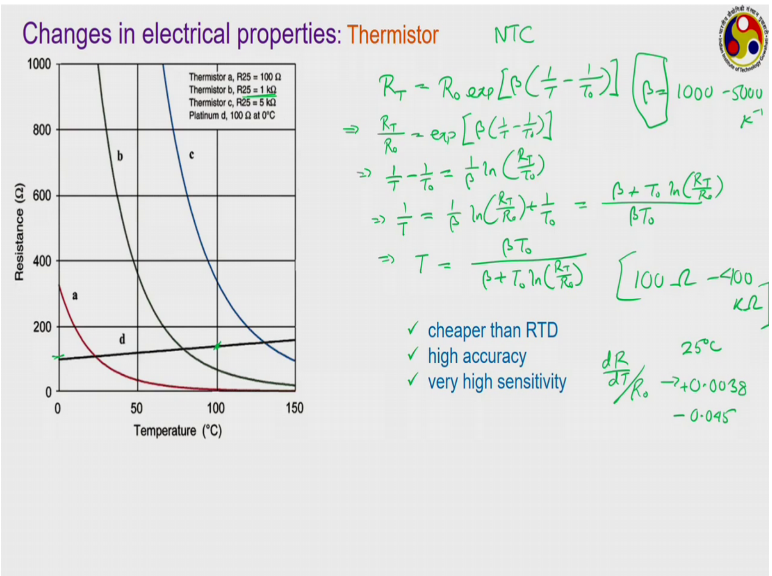

Thermistor or semiconductor based devices for and its operation is operating principle is just opposite to the RTDs. The thermistors generally had made of devices which are having negative temperature coefficient of resistance. The RTD materials generally have a positive temperature coefficient so that with increasing temperature resistance increases, but thermistors are made of semiconductor devices whose resistance decreases.

Just look at this graph. Here we have taken represented 3 thermistors a, b and c. The first one a is having a resistance of 100 ohm at 25 degree Celsius and as a temperature changes you can see there is a sharp reduction its resistance value. Just when it reaches around 50 degree Celsius when why it is 100 ohm around 0 degree Celsius. It is more than 300 ohm at 0 degree [Celsius sorry as it is, is 100 ohm at 25 degree Celsius it is more than 300 degree Celsius at 0 degree Celsius whereas, it is quite small maybe in the range of 30 ohm or something at 50 degree Celsius. So, there is a significantly sharp change.

Look at the other two. In case of b, the initial resistance or at 25 degree Celsius the resistance is 1 kilo ohm that is this particular value and correspondingly observe how much is a change when you reach 100 degree Celsius corresponding resistance value has dropped to well below 100 there is a significant change same for c.

Now, if we compare that to a standard RTD material which is platinum at 100 ohm at 0 degree Celsius and look at how much is a change. When you reach 100 degree Celsius, corresponding value may have change only to 130 or 140 ohm. So, much smaller change in temperature that we are seeing here. In case of RTD materials, but thermistors are having significantly higher well magnitude of this temperature coefficient of resistance and that is why they can give extremely high sensitivity.

Commonly there is resistance can be represented by a relation something like this R naught into exponential beta into 1 upon T minus 1 upon T naught where beta is some coefficient, R naught is the value of the resistance at temperature T naught the value of beta can be practically vary high in the range of 100 to 5000 Kelvin inverse.

So, the significantly high sensitivity that we are talking about if we want to, if you are interested in the value expression for temperature alone, then we can write this way R T by R naught is equal to exponential of beta into 1 by T minus 1 by T naught. So, T minus 1 by T naught is equal to 1 by beta into l n of R T upon R naught that is 1 by T is equal to plus 1 by T naught. So, sorry in the left hand side should be 1 upon T because t naught you have taken on the other side. So, we are getting it to be beta plus T naught into l n R T by R naught. From there T is equal to beta T naught divided by beta plus T naught into l n R T upon R naught.

So, once we know the value of the RTD the modified temperature we can easily get the value of temperature from the knowledge of T naught and beta. This is the working principle of thermistor. Thermistors our semiconductor devices as I have mentioned they generally can be oxides of manganese, nickel, cobalt etcetera which can have very high resistivity and corresponding thermal resistance also can be much higher like as we have seen the RTD materials generally have lower resistance in the range of 100 ohm to 1 kilo ohm whereas, for thermistors the resistors can be significantly higher you know. So, we are talking about resistors in the range of hundred ohm to something in the range of 400 kilo ohm.

So, they start with much higher resistance and as the temperature changes the resistance drops quite sharply as characterized by this particular beta value certain material like doped germanium, impregnated glass etcetera can also be used in cryogenic application as common materials for this. Their advantages are they are much cheaper than RTD; they have very high accuracy and very very high sensitivity much higher than the RTD like if we compare just to look at the expression the sensitivity expression.

So, you have seen the rate of change of temperature raised to switch temperature divided by the initial resistance value. So, from this particular relation if we compare say at 25 degree Celsius, the value for this sensitivity for a platinum register can be in the range of 0.003 or 0 0 3 8 as we have seen whereas, in this case for a standard thermistor it can be minus 0.045.

So, it is at least 15 10 to 15 times sorry 11 to 15 times larger sensitivity that we are talking about, that is why they can sense extremely small changes in temperature as well.

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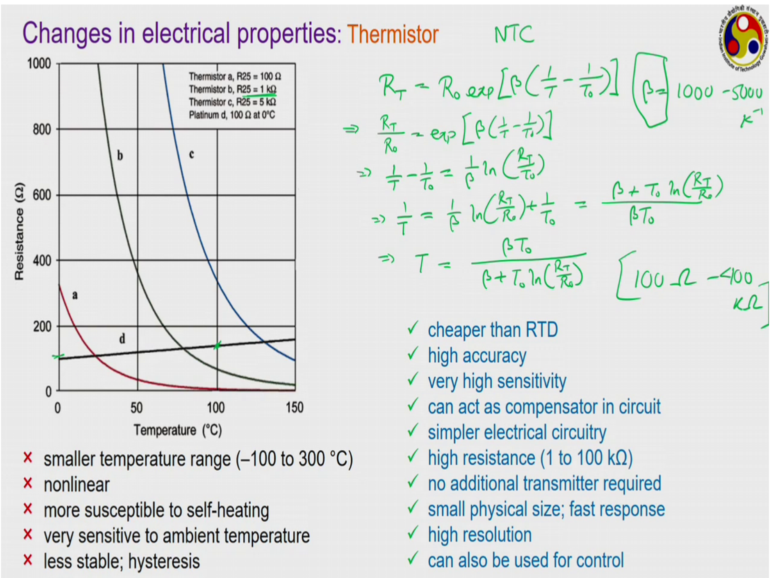

They can act as a compensator in circuit because most of the common material generally have an increase in resistance which increase in temperature, but thermistors have a decrease in resistance. So, they often can act as the compensator in common circuitry the operating circuitry or electrical circuit also becomes much smaller like they don’t have any kind of lead or issue lead or error kind of issues.

So, it don’t need any additional registers, entire thing is much simpler. In fact, we can go for very simple ohm meter kind of application or kind of circuit or we may have simple ballast circuit. We may have bridge kind of configuration in either deflection or null mode. We can also have certain times special linearizing linearizing circuits so that we can get voltage as a linear output function of the change in temperature. There are several options, we can have with in terms of the corresponding circuit. High resistance as I have just mentioned 1 to 100 kilo ohm, actually I have mentioned about 400 or 500 kilo ohm also.

So, the size of the resistor is or size of the thermistor sensor is extremely small very small resistance to start with and with a very small dimension. We can get the required level of resistance to start with. We do not need any an additional transmitter like in case of RTD we may need. Small physical size because of the high resistance and therefore, they have much faster response compared to RTDs.

High resolution and can also be used for control, temperature control or several other purposes as well this like thermistors can also be used for measurements of parameters like pressure, power. They can be also used for temperature control, sometimes as heat flux sensors, sometimes as overload protection, were load protection purpose warning symbols or warning signs etcetera. There are numerous kind of applications around stream application we can have for thermistors.

Certain issues definitely it will be having. Smaller temperature range compared to RTD like minus 100 to 300 degree Celsius. So, we are talking about the temperature range of only about 300, 400 degree Celsius whereas, for standard RTDs can cover something above 1000 degree Celsius.

So, it is one big concern for thermistor, one single device can't give you beyond 250, 300 degree Celsius temperature range, non-linear response because of the exponential relationship with temperature, more susceptible to self heating compared to RTDs, very sensitive to ambient temperature because of their high sensitivity that is one downside of having high sensitivity and less stable because semiconductor material can I have hysteresis effects also.

So, these are the issues that you need to be careful of while dealing with thermistors.

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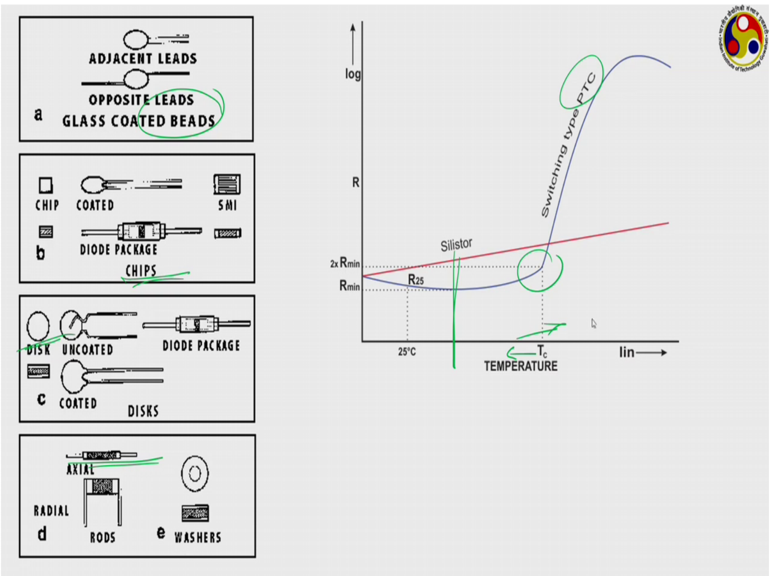

The thermistors can be fabricated in different organ different shapes like we can have glass coated bit kind of structure, we may have chip kind of structure, they can also be fabricated in disc shape or sometimes just flat axial plates like this and depending upon what kind of application we are going for and finally before I close the thermistor part, thermistors commonly we talk about materials having negative temperature coefficient. But actually there can also materials which can have positive temperature coefficient or thermistors which can have positive temperature coefficient.

Certain semiconductor materials which involves barium titanate can have quite high positive temperature coefficient just like shown here, sometimes heavily doped silicon can also act like this. Just check initially for lower temperatures, it is actually having a quite moderate negative temperature coefficient.

But beyond a limit something like this when it reaches the minimum resistance it keeps on increasing and beyond a certain threshold or critical temperature there is a rapid increase in the corresponding resistance value. For this purpose often this PTCs, PTC refer to positive temperature coefficient based material or materials having positive temperature coefficient. This PTC based thermistors can often be used as switching devices beyond a thermal switch like when the temperature crosses or is lower than this limit the switch will be remaining is saying open position.

Now, suddenly as the temperature this particular temperature is crossed this particular threshold is crossed, resistance will increase infinitely, almost infinitely and thereby causing the circuit to stop. So, this kind of thermal switch application and sometimes control switching application can be achieved with this thermistor having positive temperature coefficient. But commonly for temperature measurement or control purpose we prefer to use the materials with negative temperature coefficient.

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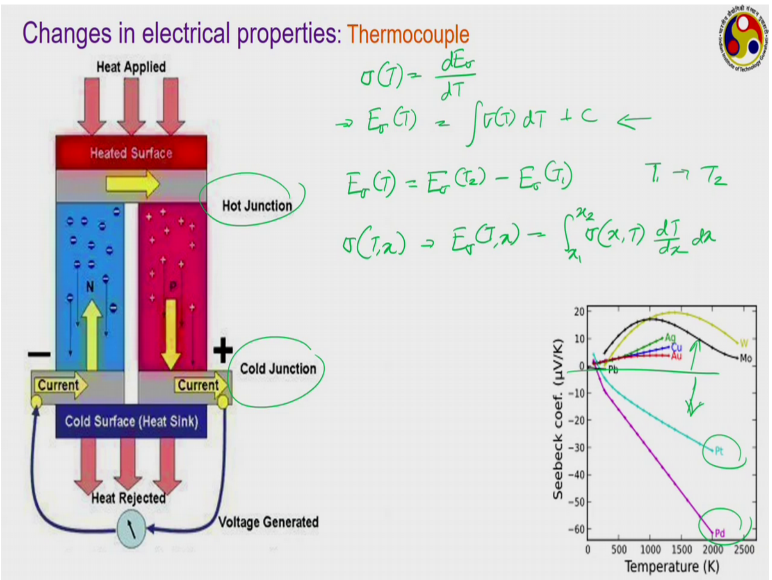

The next material that I have in this category of changes in electrical properties is probably the most common way of temperature measurement in industries which is Thermocouple. The working principle thermocouple is related to a very well known phenomenon in physics that is the Seebeck effect. I am sure all of you know Seebeck effect, when two dissimilar materials are connected such that one end of the couple is maintained at the high temperature and other end is maintained at a lower temperature then the current starts flowing through this or in a way you can say that an electromotive force or electron EMF is generated at the other end, if the ends are at dissimilar temperatures which is called the Seebeck effect.

The working principle thermocouple is the same. We take two dissimilar materials, we connect them just this way, one end of the couple is kept at the position where we want to have the temperature measurement and other end is the position where we can take the or we can measure the corresponding EMFgenerated and that EMFhas to be a function of the temperature of the other end. So, by suitable calculations we can easily relate the EMF to the temperature they are getting a simple temperature measurement and that is why thermocouples are extremely popular.

Because you can just take two wires of two corresponding materials or suitable materials and now connect in the one end of the two wires by any common method brazing, soldering or just tie them with each other and now taking them in contact with a maybe a high temperature surface you will immediately get an e m f at the other end and once you measure that e m f you can using some calibration charts etcetera you can easily get the direct value of the corresponding temperature.

The Seebeck effect is of a material is generally measured in terms of something known as the Seebeck coefficient. Seebeck coefficient sigma T is generally defined as the potential the gradient of this potential you have developed with temperature or we can also write the given temperature this is sigma T will be of course, sigma T d T over a range of temperature plus some constant C.

Now, this constant can be made to 0 by suitable choice of material and suitable choice of this reference temperature. So, if we are dealing with a homogeneous material then we can easily go for this E sigma T as something like, if the change in temperature some homogenous materials going for temperature change from T 1 to T 2 or one end is kept at a temperature T 1 other end is kept at temperature T 2, then we can easily write this one as E sigma corresponding to T 2 minus E sigma corresponding to T 2.

But sometimes we are dealing with almost often we are dealing with non homogeneous material where this E sigma is a function of not only temperature, but the position as well. In that case sigma becomes a function of both T and x and hence E sigma is also a function of T and x depends on which location we are measuring the e m f. So, accordingly we can have it as x 1 to x 2 sigma x T x T d x d x.

So, the temperature gradients also comes into equation to deal with. These are certain common materials you can see certain materials having a positive value of the Seebeck coefficients whereas, material in platinum or palladium having a negative value of coefficients. So, we generally prefer taking one material from this side and another material from this side and as soon as we connect them we are going to get that e m f generated thereby providing a thermocouple.

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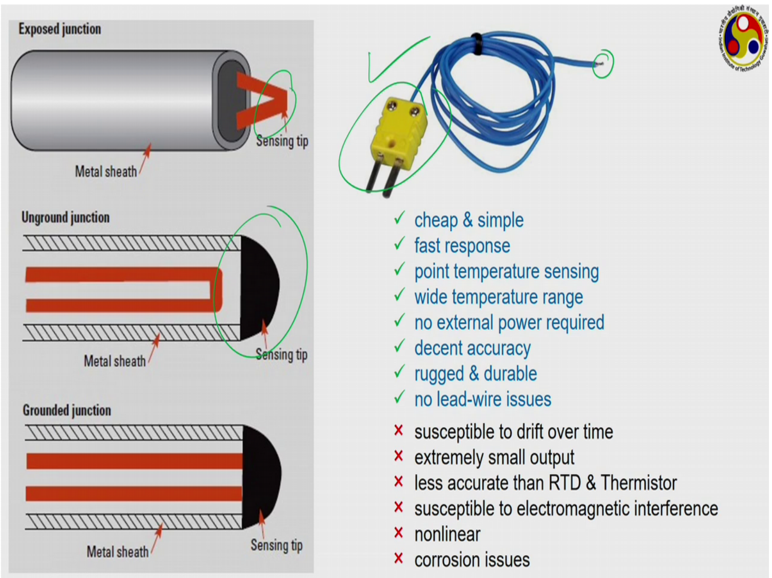

The end of the thermocouple as I mentioned we can connect them in different ways just make a tip or we can cover the tip with a cap kind of thing, the electrodes can be covered with the metal sheet which can be grounded or which can be ungrounded as well giving a very simple configuration. This is the end where we generally have a bead here and which will be taken to a point where you want a temperature measurement and this particular end will be connected to certain temperature measuring device.

So, thermocouples are cheap and simple can provide very very fast response because they are very small in dimension the bead. Point temperature sensing which is not possible with any of the ones that we have discussed earlier. Wide temperature range can be covered with suitable choice of this material couple. No external power requirement like in case of RTDs or thermistors, they can provide decent accuracy of course, lesser compared to RTDs and thermistors, but still quite workable definitely better than the expansion based devices. Rugged and durable and no lead wire issues as well, but they also suffer from issues such as the since susceptible to drift over time, extremely small output so we need to go for certain kind of magnification because the e m f that we get that quite often in a range of millivolts just 5 or 10 millivolt range.

So, we have to go for some kind of amplification to get a proper output signal less accurate than RTD and thermistor. Susceptible to electromagnetic interference as it is an electromagnetic phenomena that is going on. So, such kind interference is possible if in the neighborhood some electromagnetic device is kept. Non-linear output and there can be corrosion issues as well thereby the bead needs to be inspected very very regularly.

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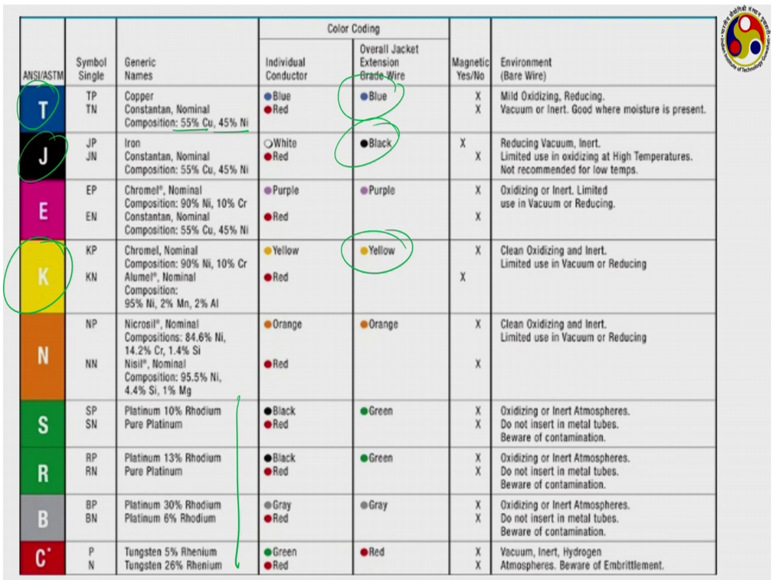

ANSI/ASTM	Symbol Single	Generic Names	Color Coding: Individual Conductor	Color Coding: Overall Jacket Extension Grade Wire	Magnetic Yes/No	Environment (Bare Wire)
T	TP TN	Copper Constantan, Nominal Composition: 55% Cu, 45% Ni	Blue Red	Blue	X X	Mild Oxidizing, Reducing. Vacuum or Inert. Good where moisture is present.
J	JP JN	Iron Constantan, Nominal Composition: 55% Cu, 45% Ni	White Red	Black	X X	Reducing Vacuum, Inert. Limited use in oxidizing at High Temperatures. Not recommended for low temps.
E	EP EN	Chromel®, Nominal Composition: 90% Ni, 10% Cr Constantan, Nominal Composition: 55% Cu, 45% Ni	Purple Red	Purple	X X	Oxidizing or Inert. Limited use in Vacuum or Reducing.
K	KP KN	Chromel, Nominal Composition: 90% Ni, 10% Cr Alumel®, Nominal Composition: 95% Ni, 2% Mn, 2% Al	Yellow Red	Yellow	X X	Clean Oxidizing and Inert. Limited use in Vacuum or Reducing
N	NP NN	Nicrosil®, Nominal Compositions: 84.6% Ni, 14.2% Cr, 1.4% Si Nisil®, Nominal Composition: 95.5% Ni, 4.4% Si, 1% Mg	Orange Red	Orange	X X	Clean Oxidizing and Inert. Limited use in Vacuum or Reducing
S	SP SN	Platinum 10% Rhodium Pure Platinum	Black Red	Green	X X	Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination.
R	RP RN	Platinum 13% Rhodium Pure Platinum	Black Red	Green	X X	Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination.
B	BP BN	Platinum 30% Rhodium Platinum 6% Rhodium	Gray Red	Gray	X X	Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination.
C*	P N	Tungsten 5% Rhenium Tungsten 26% Rhenium	Green Red	Red	X X	Vacuum, Inert, Hydrogen Atmospheres. Beware of Embrittlement.

There can be different types of combinations of thermocouples as shown in this case most common ones are like called the T type thermocouple which is made of Copper and Constantan.

Constantan is actually an alloy which has 55 percent copper and 45 percent nickel. It acts as the negative material copper has the positive material and one important thing is the outside jacket color just from like in the previous slide we have seen the out here we have two wires and these are the two wires put inside this jacket here the jacket is of color blue and from that color itself you can immediately identify which type of thermocouple it is, like J type thermocouples are having this Blue color. So, the one that was shown there is a J type thermocouple.

Another very popular one is this K type thermocouple here we use two alloys Chromel which is actually a combination of 90 percent Nickel and 10 percent Chromium that is as a positive one and Alumel which contains 95 percent Nickel 2 percent Manganese and rest as Aluminum that as the negative material and the outside color is Yellow.

So, these are come to probably two most used thermocouples. J is also used in case of J you have Iron and one side and Constantan which is an alloy of Copper and Nickel as the negative material it has a Black cover. So, others generally are used in different other purposes like this platinum or tungsten based things which are used for high temperature measurement and also limited to precise use or very accurate use because they are much expensive compared to the T or J type thermocouples.

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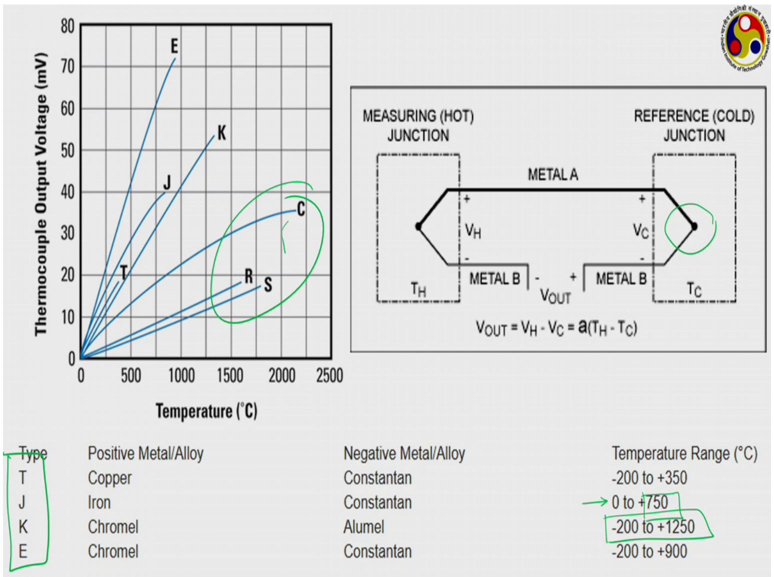

These are the response as you can see the E type thermocouple has the highest sensitivity J, K or T thermocouples also quite good sensitivity compared to this R, S or C kind of thermocouples.

Like just summary of the tables that's shown here T type is a Copper Constantan thermocouple, J is Iron constantan, K is Chromel Alumel and E is Chromel Constantan. These are generally the most popular four types of thermocouples used in industries, but their temperature range is important depending on which range you are going to work on you will be choosing the corresponding thermocouple like T type thermocouple has a maximum temperature of plus 350, but lower side it can have minus 200 degree. Whereas, Chromel Alumel is generally used in higher temperature cases though it can go to minus 200, but we generally use this one when the temperature is beyond the scope of T type thermocouples like we are going in the range of 300 degree Celsius or much higher J type thermocouple can also go to 750 degree Celsius but its lower side is quite high 0 degree Celsius.

Just one issue with thermocouples we have to be careful of which is known as the Cold Junction compensation. One end is kept at the position very one the temperature measurement, but the other end also need to be maintained at a constant temperature and that's why this second junction needs to be kept at a proper position if it is open to atmosphere we may have to go for some kind of compensation which is called the Cold Junction compensation. Generally most of the thermocouple sensing devices comes with an inbuilt Cold Junction compensation, but still this is some an issue, I am not going into the detail of this one, but this is an issue you may have to be careful of while dealing with raw thermocouple.

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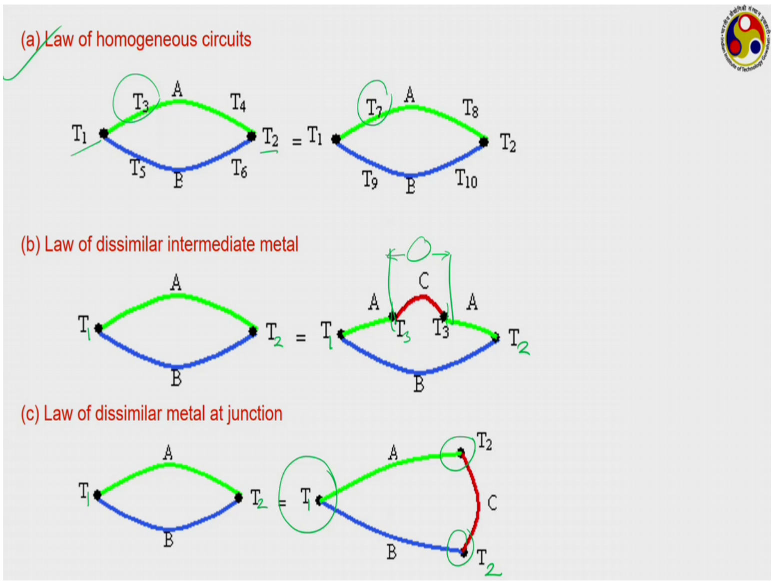

Finally there are a few laws of thermocouples, 5laws basically which we make use of while doing the reading. First is the Law of homogeneous circuit, e t as along means suppose we are having two materials A and B and the two junctions are kept at temperature T 1 and T 2. Now our interest is only these two end temperatures what are the intermediate temperatures that does not matter like if the interval temperature is T 3 or T 7it does not matter as long as the end temperatures are T 1 and T 2 that is sufficient because you are going to get the same e m f as the output.

So, all the intermediate temperatures in a homogeneous circuit doesn't matter, at all we are interested only at the two end temperatures because the final output e m f will be proportional to that only.

Second, Law of dissimilar intermediate material. Like if any of the thermocouple is having another third metal included within this then actually is some suffixes are missing. Suppose this is kept at temperature T 1 and T 2. This is also at T 1 and T 2 and this is T 3 as long as both the connections between this A and C in that is this particular connection and this particular connection both are maintained in the same temperature T 3 then the corresponding e m f will be the same.

So, this provides a very useful way while the first one provides that the first law, law of homogeneous circuit can provide that we can neglect any lead wire issue and thermocouple wires can be quite long exposed to the surrounding also it doesn’t matter if the temperature of the lead wire is equal to surrounding temperature whereas, the second case what we can do we can easily cut in one portion from one of the thermocouples and incorporate a voltage measuring material something like a voltmeter.

So, as long as these two junctions are at the same temperature T3, then there will be no issue at all. Just an extension of the same thing dissimilar metal at the junction, instead of having something in between if we put at one of the junction as long as the connection between A and C and B and C are kept at the same temperature T 2 in this case then you are going to get the same reading which is most commonly we keep on doing. This particular portion is kept at the location where we want the temperature measurement and the other end we put the voltage measuring instrument and we don’t get any error in the reading.

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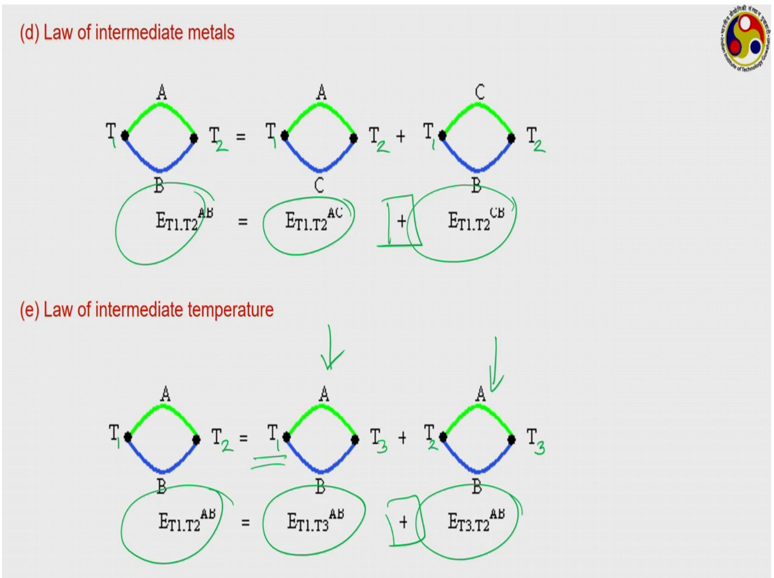

So, a fourth one very important one, Law of intermediate metals like if suppose two material A and C. Let me do these corrections, I do not know why the suffixes are missing here suppose we are using a thermocouple comprising of metal A and C and we are getting and they are maintained at temperatures T 1and T 2 both junctions then whatever e m f we are getting that is this much.

Now, we have another thermocouple comprising material C and B. Again the junctions are maintained the same temperature T 1 and T 2 corresponding we are getting this e m f. Then if we make a thermocouple comprising of A and B and they are kept at the same junction temperatures T 1 and T 2,then whatever we are going to get that will be just addition of these two earlier EMFs. This is called the law of intermediate metals.

This is a very important law from calibration purpose. It suggests that as we can use such kind of simple addition rules. It suggests that we do not have to separately calibrate each pair of thermocouples or each metal pair rather we can thermocouple each metal with certain suitable reference and then we can combine them suitably to get any kind of thermocouple combination and just the other version of the same, Law of intermediate temperature.

Suppose one thermocouple A and B one thermocouple comprising of A and B is maintained at junction temperatures T 1 and T 2 correspondingly we are getting this much of e m f.

Now, the same thermocouple is maintained at junction temperature T 2 and T 3, we are getting this e m f. Then if the same thermocouple is maintained at junction temperature T 1and sorry I am wrong here, in the first case this thermocouple is maintained at junction temperature T 1 and T 3 and we are getting this e m f. Now the same thermocouple is maintained at junction temperature T2 and T3, we are getting this e m f.

Now, if we take the thermocouple and maintain junction temperature T 1 and T 2, then what e m f you are going to get that is just addition of the earlier two thermocouples which is called the Law of intermediate temperature this is again a very useful law from for the purpose of producing calibration charts or tables where we can maintain one temperature as the reference ice point temperature and just make keep on exposing it to some other temperature T 1, T 2, T 3 or whatever and whatever readings we are going to get that generally are calibrated in suitable tables and from simple addition rule like this law five we can get the value of e m f for any common temperature combinations.

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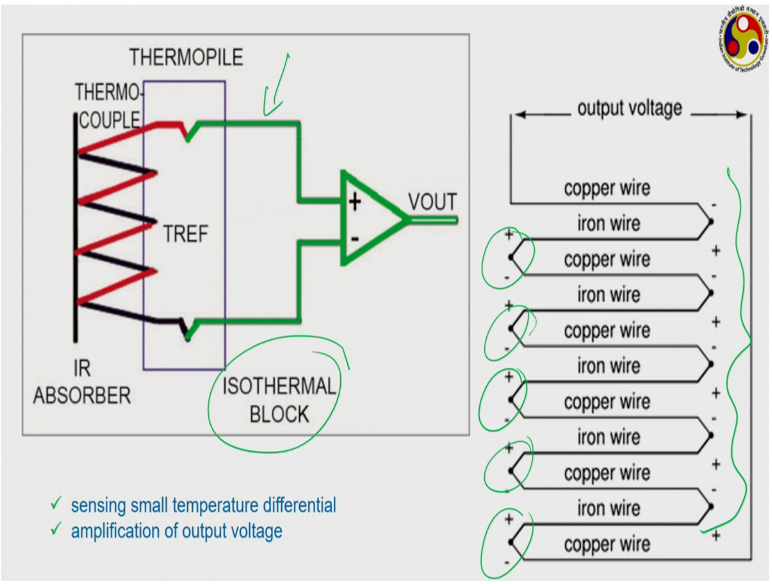

So, these are about thermocouples. As the thermocouple output is low, quite often we combine several thermocouples into a pile and which is called the Thermopile where another view of the same thing like copper and iron combination is shown here. There are several beads created. All the beads are one all combination of one junctions are maintained at one side and other combination is kept at the other side, sometimes may be a suitable reference junction or isothermal block and thereby we can get the sub we can get simultaneous temperature measurement at different points which is an application of thermocouple in the form of thermopile.

We can sense small temperature differentials and also you can amplify the output voltage if all the points are sensing the same voltage or same temperature difference. So, thermocouples we generally go for in this kind of application where you are looking for small temperature differential over along a surface.

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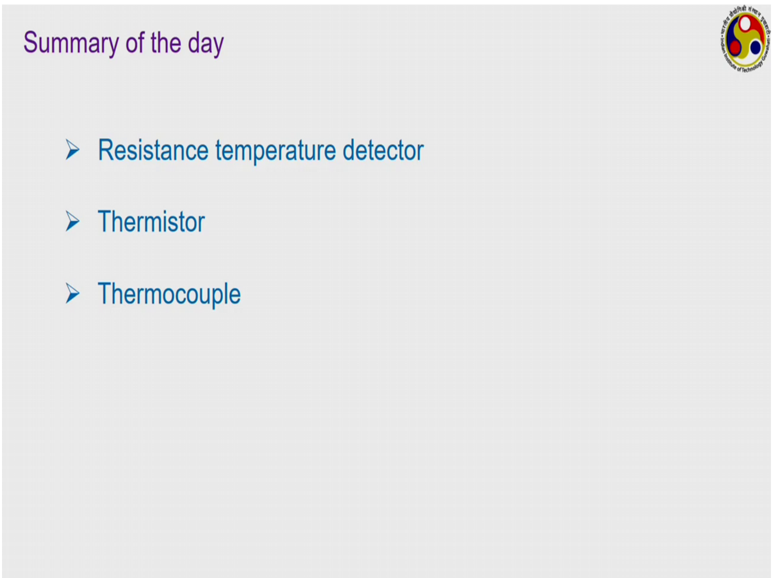

So, that's it for thermocouples. So, I am that's where I would like to stop today also. Generally there are four kinds of temperature measuring devices based on the change in electrical properties, but today we have discussed three of them resistance temperature detector or RTD, Thermistor and Thermocouple. There is a fourth one based on the junction semiconductors that we shall be discussing in the next class. Till then I am thanking you for your attention and please wait till the next one.

Thanks a lot.