Chemical Process Instrumentation
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Lecture – 38
Temperature Measurement (Contd.)

Welcome to lecture 38 we are talking about temperature measuring instruments. In your previous lecture we have talked about thermocouples which are based on thermoelectric principles. Today we will talk about temperature measuring instrument based on variation of resistance with temperature.

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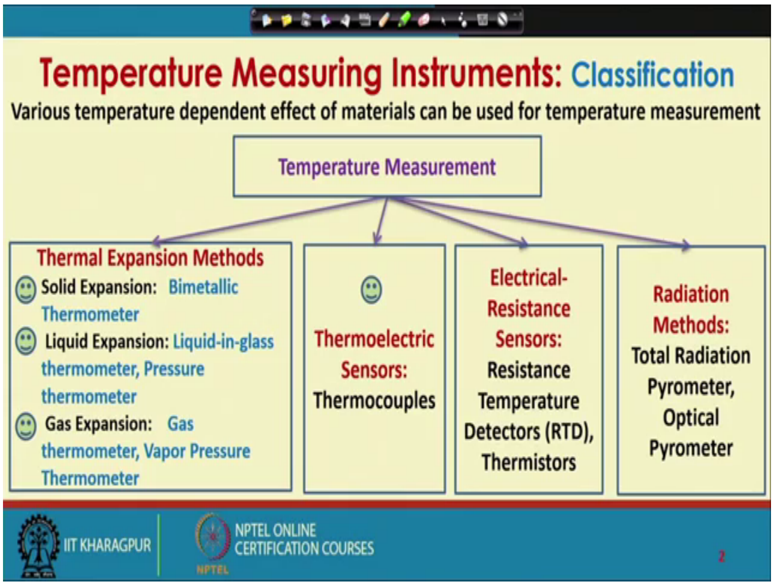

So, we have talked about thermal expansion methods, we have talked about thermoelectric sensors and now today we will talk about electrical resistance sensors. And an electrical sensors we will talk about resistance temperature detectors or resistance temperature device commonly known as RTD and Thermistors.

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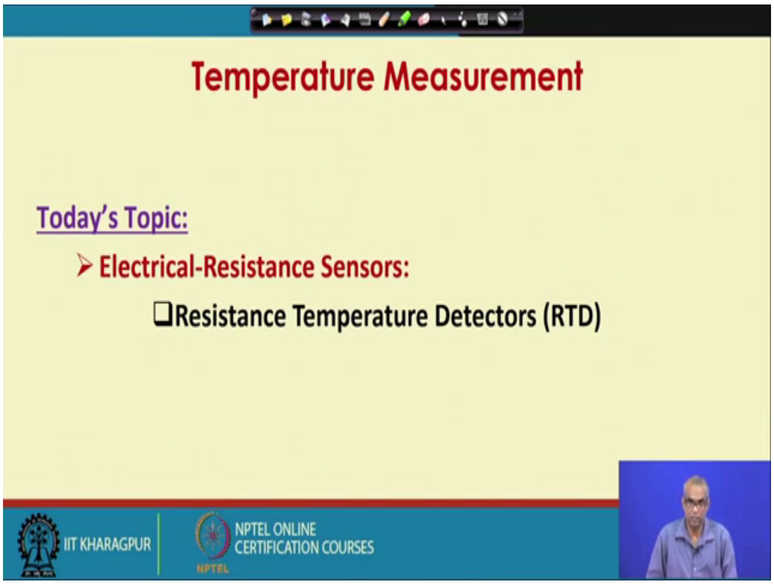

So, today we will talk about resistance temperature device or resistance temperature detector or RTD.

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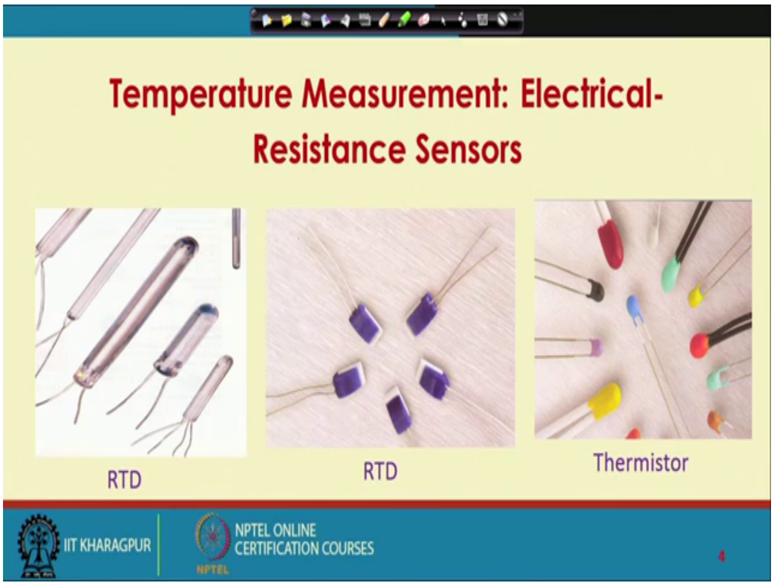

So, what you see is some images of RTD and thermistors.

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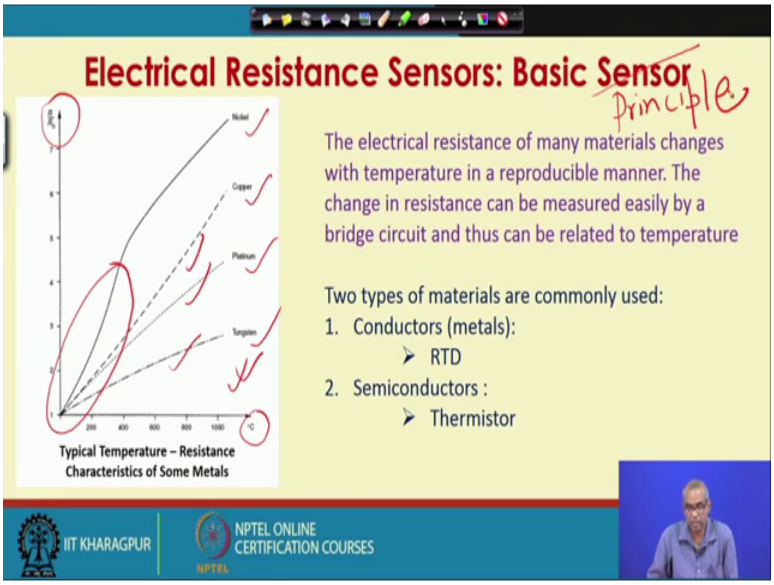

Now the basic principles on which this electrical resistance sensors works are as follows, the electrical resistance of many materials change with temperature in a reproducible manner, the change in resistance can be measured easily by bridge circuit and thus can be related to temperature.

So, the variation of electrical resistance with temperature is reproducible for many materials. So, if we can change if we can measure the change in resistance due to change in temperature using say a Wheatstone bridge principle we can relate the change in resistance to change in temperature.

Two types of materials are commonly used conductor metals and semiconductors. The sensors made from conductors or metals known as RTD or resistance temperature device and sensors made from semiconductor materials are known as thermistors. On the left what you see is typical variation of resistance with respect to temperature for certain materials such as nickel, copper, platinum and tungsten they are all metals and RTDs are made of these metals. So, they are common metals for making RTDs.

You can see that there is a region over which the relationship between temperature and resistance is linear or approximately linear is called this principles. So, both RTD and thermistors are based on the same principle which is variation of electrical resistance with change in temperature and you see that for some metals such as nickel copper platinum tungsten the variation is to some extent linear with respect to temperature and they can they are good candidates for making RTDs.

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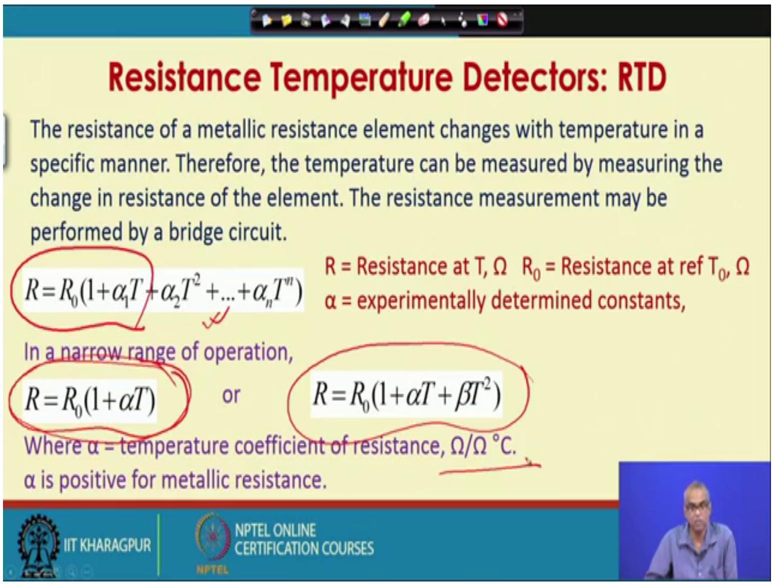

So, the resistance of a metallic resistance element changes with temperature in a specific manner. Therefore, the temperature can be measured by measuring the change in resistance of the element. The resistance measurement may be performed by a bridge circuit Wheatstone bridge principle.

So, this is a typical equation which has been used for relating resistance of a metal at temperature T, with temperature. So, R equal to R 0 into 1 plus alpha 1 T plus alpha 2 T square it can go up to alpha n T to the power n, where R is resistance at temperature T expressed in ohm, R 0 is the resistance at difference temperature T 0 expressed in ohm and alpha are experimentally determined constants.

Now, if I apply this equation in a narrow range I can retain only the terms which are first order in T and neglect all second order and higher order terms. So, in that case the resistance may be expressed as, R equal to R 0 into 1 plus alpha T which shows a linear relationship with respect to temperature. If you retain up to second order term it will be R equal to R 0 into 1 plus alpha T plus beta T square and then you will have a slightly non-linear equation.

The equation where R equal to R 0 plus 1 plus alpha T you call this alpha as temperature coefficient of resistance and expressed as ohm pre ohm degree Celsius alpha is positive for metals.

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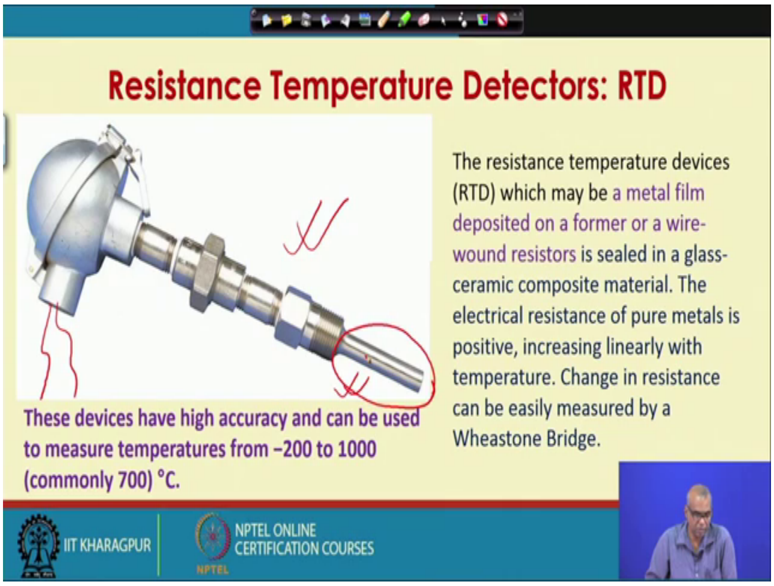

So, this is typically how a RTD will look like a commercially available RTD will look like, I will show you a real RTD today. So, the resistance temperature device may be a metal field deposited on a former for it where own resistor. So, it is basically the resistance temperature device or RTD is basically electrical resistance where it may be a resistance where or it may be a thin metallic film.

So, it is a thin metallic film it is deposited on a former and if you consider a resistance where to be RTD, it is it will be owned on some support. Let us say a ceramic bobbin support and the change in resistance of this thin metallic film or the where will be considered as measurement for the temperature.

So, the RTD which may be a metallic film deposited on a former or a where own resistor it is still in a glass ceramic composite material. The electrical resistance of pure metals is positive and it increases linearly temperature. Change in resistance can be easily measured by a Wheatstone bridge principle.

So, inside this you have the resistance where or the thin metallic film which will work as a resistance thin film. And the extension leads will come out here and this will go to one arm of the Wheatstone bridge.

So, you can establish first the null point and then can expose this to the medium of temperature of measuring. Due to change in resistance there will be an unbalance in the bridge and accordingly you can measure the change in resistance and that can be related to the temperature. These devices have high accuracy and can be used to measure temperatures from minus 200 to 1000 degree Celsius although, commonly it is used up to 700 or 750 degree Celsius.

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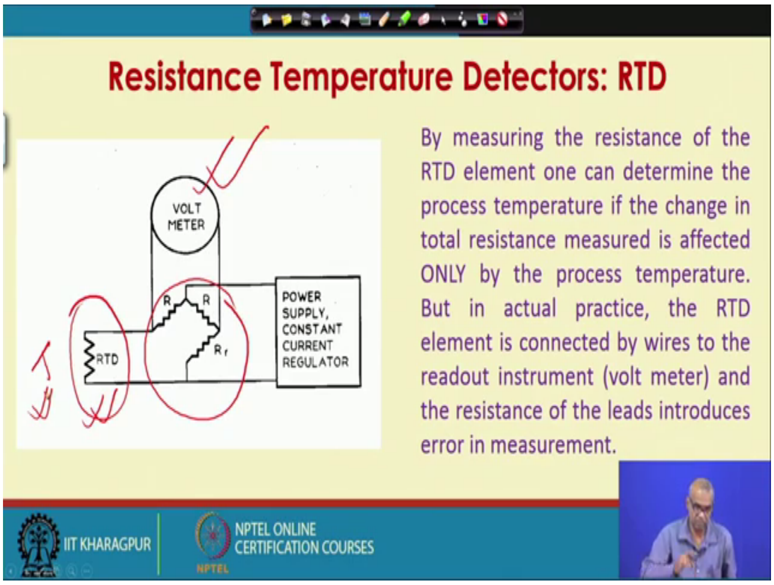

Now, by measuring the resistance of the RTD element one can determine the process temperature, if the change in total resistance measure is affected only by the process temperature. So, this is my RTD which is basically one arm of this Wheatstone bridge and this is the voltmeter.

Now when I want to measure the temperature of a medium using this RTD, I will expect that the change in resistance of the RTD element should happen only due to change in temperature, but the resistance element which is where or a thin metallic film will be connected to this Wheatstone bridge it will be connected to this read out element voltmeter by extension leads.

So, in actual practice the RTD element is connected by wires to the readout instrumental voltmeter adventures of the leads will introduce an error in the measurement. So, you have to compensate for that error.

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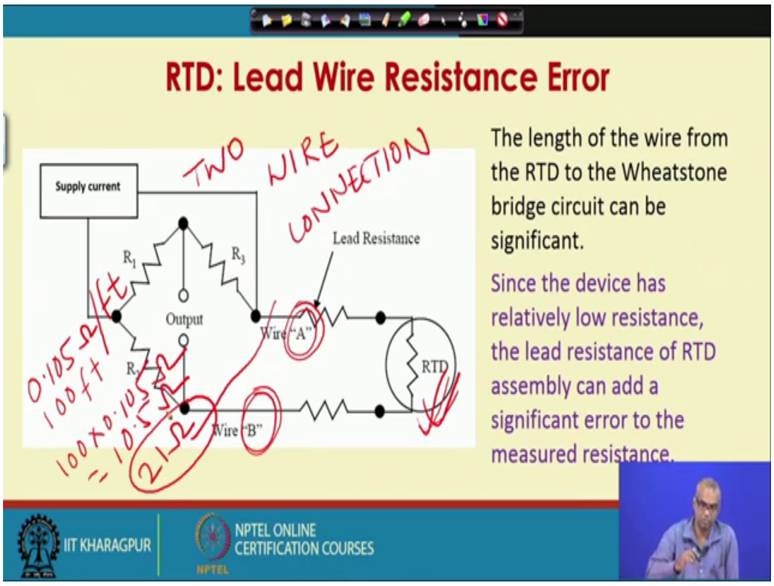

Let us look at this bridge circuit again you have this RTD element which is connected to the Wheatstone bridge using wire A and wire B so, these are lead wires or extension leads of RTD element.

Now, the length of the wire from the RTD to the Wheatstone bridge circuit may be significant. If this is significant it will add a resistance. So, the change in resistance will happen only due to change in temperature as indicated by RTD, there is additional resistance of wire A and wire B. Since the device has relatively low resistance the lead resistance of RTD assembly can add a significant error to the measured resistance. What is shown here is known as two wire connections.

So, the RTD element is connected to one arm of the Wheatstone bridge using two extension leads or it is two wires. So, this is known as two wire connection. So, in this two wire connections the resistance of both the wires will add up let us say I am using copper wire to connect RTD to one arm of Wheatstone bridge.

And let us say for example, the copper wires resistance is expressed as say 105 ohm per feet and let us say I am using 100 feet long wire. Because the Wheatstone bridge may be

100 feet away from the point of measurement the RTD element will be inserted to the medium.

So, each lead where will add 100 into 0.105 ohm which is 10.5 ohm per lead wire. So, two extensive leads together will add 21 per ohm. So, this may be substantial to increase the error with significant extend.

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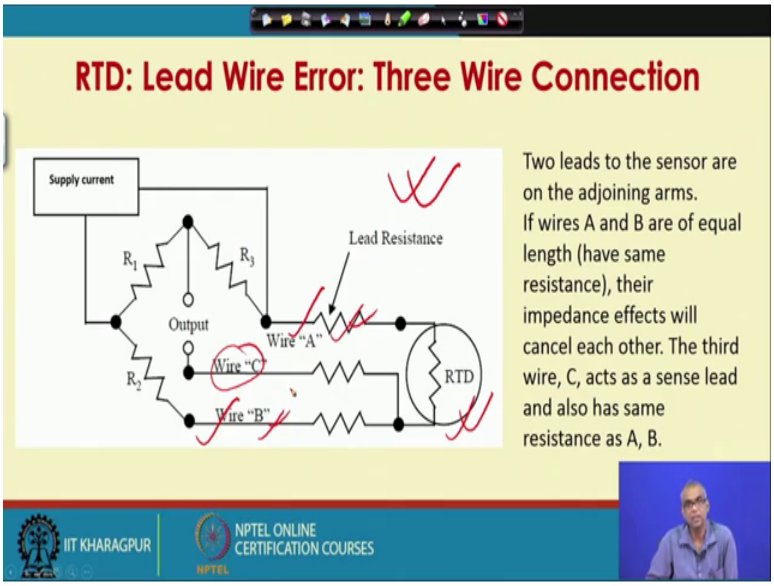

So, as the compensation for this we use three wire connection. So, we will take an additional wire which works as a compensation for this lead wires resistance. So, if you look at the schematic this is the RTD element connected to Wheatstone bridge using wire A and wire B. Now this two leads to the sensor around the adjoining arms if wires A and B are of equal lengths.

In other words if wires A and B have same resistance where impedance effect will cancel each other the third wire C acts as a sense lead and has same resistance as A and B. So, if you write down the conditions for balance you will now see that the effect of lead resistance A and B are getting cancelled out. So, commonly RTD elements will have three wire connections as shown in the schematic.

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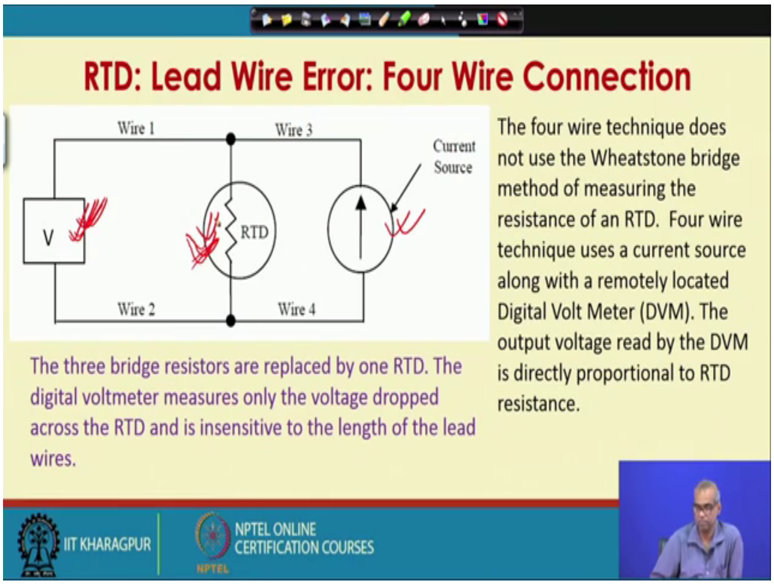

Note that this is that read out or the voltmeter of the Wheatstone bridge to which the wire C is connected. There is another connection known as four wire connection for RTD, the four wire technique does not use the Wheatstone bridge method of measuring the resistance of an RTD four wire technique uses a current source along with a remote we located digital voltmeter. So, this is the resistance element this is the current source and this is the digital voltmeter.

The output voltage read by the digital voltmeter is directly proportional to RTD resistors. So, the output voltage read by the digital voltmeter is directly proportional to the resistance of the RTD element. The three bridge resistors are replaced by one RTD here the digital voltmeter measures only the voltage drop across RTD. So, this voltmeter measures the voltage drop across RTD and is insensitive to the length of the lead wires. So, these four wire connection leads to improved accuracy.

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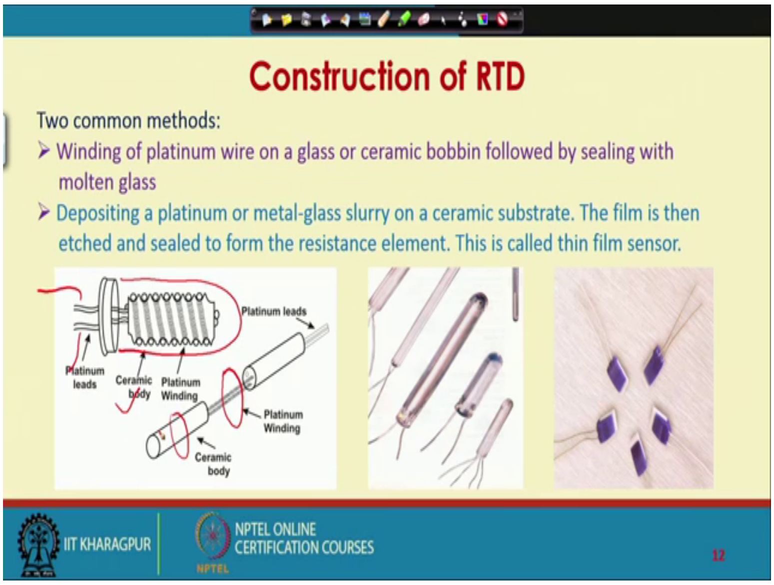

For construction of RTD there are two common methods; winding of platinum wire on a glass or ceramic bobbin followed by sealing with molten glass or depositing a platinum or metal glass slurry on a ceramic substrate. The film is then itched and sealed to form the resistance element this is called thin film sensor.

So, you can have winding of say platinum wire on a glass or ceramic bobbin followed by sealing with molten glass. So, this is the ceramic body and platinum winding is shown. So, this is put with the a protective tube and what you see is that two extension leads are coming out. So, two extension leads will come out for two wire connections we will see three extension leads coming out for three wire connections. So, the platinum winding is enclosed in a ceramic body.

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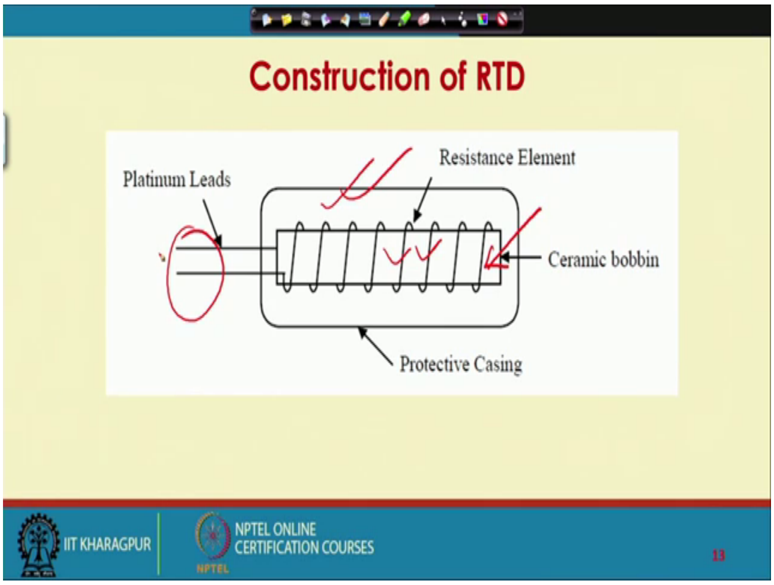

So, this is another schematic you have the platinum wire which is wound around the ceramic bobbin and then put inside a protective casing. So, the platinum leads are here and they will be connected to the Wheatstone bridge for measurement of change in resistance which will be related to temperature.

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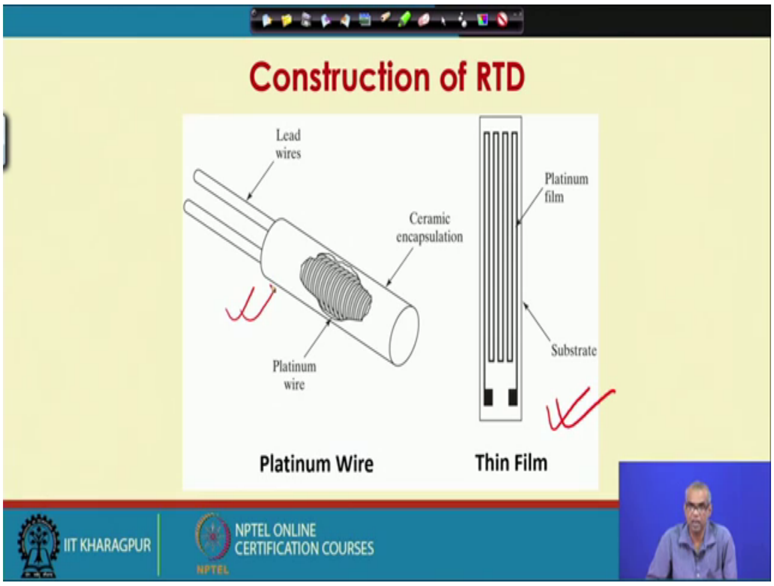

So, this is a schematic representation of thin film sensor again it shows the wire wound around a ceramic or glass bobbin and there is a protective encapsulation around it. So the difference between these two is one is wire; another is thin film. Both work as resistor element.

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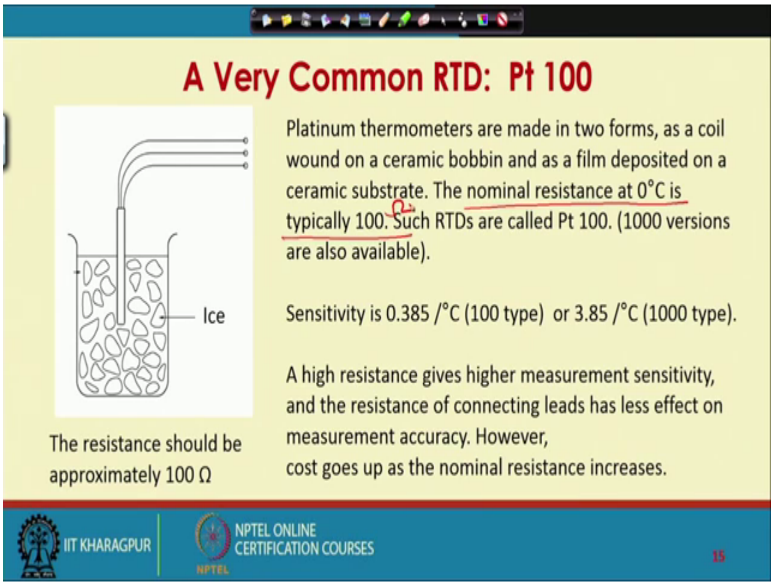

A very common RTD is Pt 100 or platinum 100 Pt stands for platinum. So, you will very commonly find in laboratories or in industries an RTD known as Pt 100. So, platinum thermometer are made in two forms as discussed previously as the coil wound on a ceramic bobbin or as a film deposited on a ceramic substrate.

The nominal resistance at 0 degree Celsius is typically 100 and that is why it is called platinum 100. So, Pt 100 means this is a RTD made of platinum and the nominal resistance of this platinum RTD is 0 degree Celsius that is 100 ohm at 0 degree Celsius. So, the nominal resistance at 0 degree Celsius is typically 100 per ohm such RTDs are called Pt 100. So, Pt stands for material of construction platinum and 100 stands for the fact that the nominal resistance of this RTD is 100 ohm at 0 degree Celsius.

Also 1000 ohm versions are also available; that means, the nominal resistance at 0 degree Celsius will be 1000 ohm, but typically the nominal resistance is 100 ohm and you call this resistors or you call this RTDs as Pt 100.

The sensitivity for Pt 100 is 0.385 per degree Celsius and 3.85 per degree Celsius for 1000 ohm time. A high resistance gives higher measurement sensitivity and the resistance of connecting leads has less effect on measuring accuracy.

Note that if the resistance of the resistance element is low then the effect of the lead wires resistance will be significant. But if the resistance of the resistance element is very high then the lead wires resistance will have relatively a less sig significant effect.

However, when you go for high resistance RTD or platinum RTD the cost goes up. One test for Pt 100 RTD you can perform in laboratory is you take the RTD they make shows that it is a three wire connection and three wires are coming out. So, you dip this RTD in a beaker where you have ice and water mixture.

So, ice water mixture will at 0 degree Celsius temperature. So, an equilibrium is established if you measure the resistance you will see the resistance is approximately 100 ohm.

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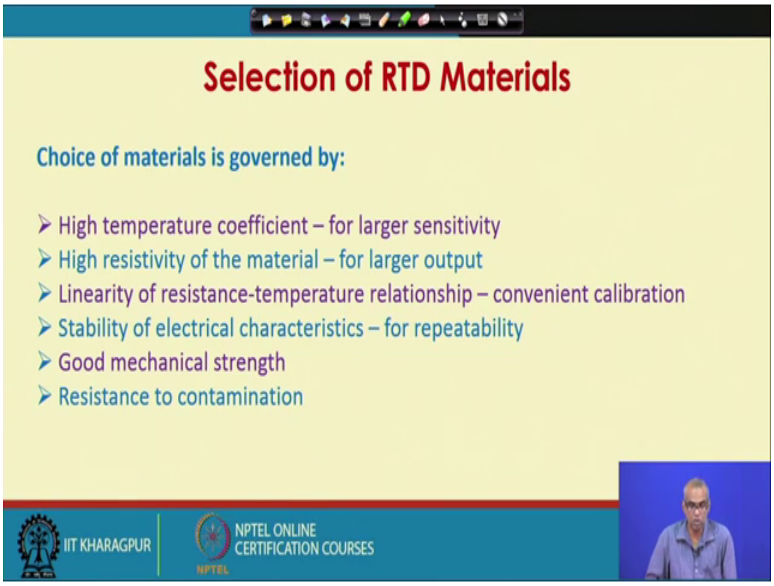

So, you will know that your Pt 100 is working properly. The selection of RTD materials is governed by high temperature coefficient if you have high temperature coefficient there will be improved sensitivity high resistivity of the material for larger output. Linearity of resistance temperature relationship this makes the calibration very convenient stability of electrical characteristics for repeatability. Good mechanical strength and resistance to contamination.

So, when you select RTD materials, we will choose materials with high temperature coefficient high resistivity of the material; the material which shows linear relationship between resistance, and temperature which has stable electrical characteristics which has good mechanical strength and which is resistance to contamination.

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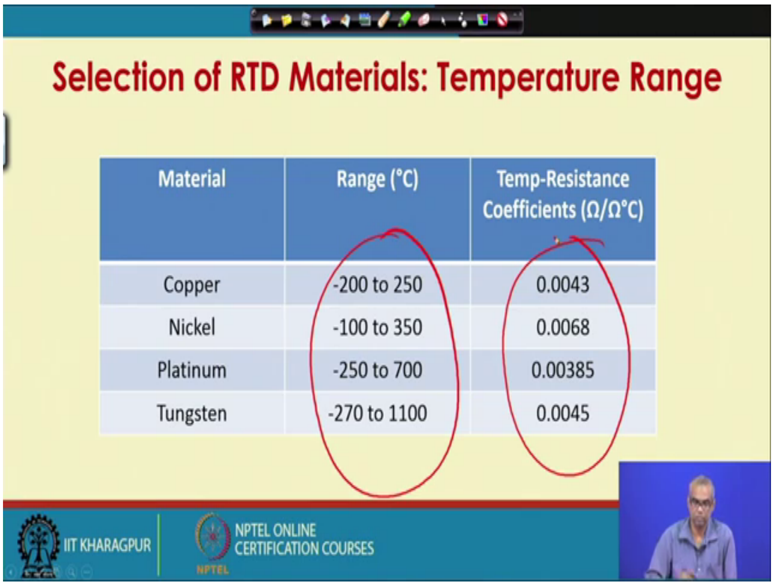

Here we present some materials which are commonly used for making RTD such as copper, nickel, platinum and tungsten. Their ranges are also given copper can be used between minus 200 to 250; nickel minus 100 to 350 degree Celsius, platinum minus 250 to 700 degree Celsius and tungsten minus 270 to 1100 degree Celsius. The temperature resistance coefficients are also given.

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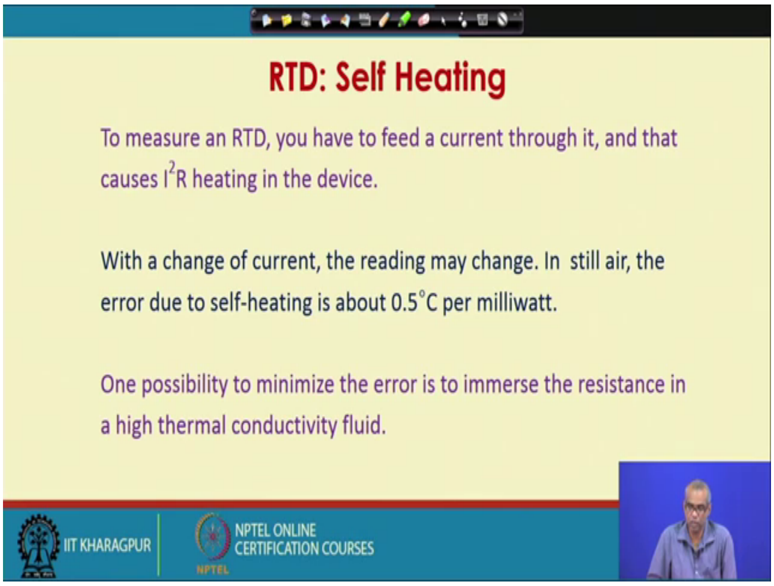

Now apart from lead wire error or lead wire resistance error there is another source of error in RTD this is known as self heating. When you want to measure temperature using RTD you have to feed a current through it and that will cause I square R heating in the device with a change of current the reading may change because of the heating because if it is heated if RTD is heated its resistance will change.

In still air the error due to self heating is about 0.5 degree Celsius per milliwatt. One possibility to minimize the error is to immerse the resistance in a high thermal conductivity fluid so that the heat is immediately dissipated.

So, we will stop our discussion on RTD here.