Industrial Instrumentation

Prof. Alok Barua
Department of Electrical Engineering
Indian Institute of Technology - Kharagpur

Lecture - 9
Resistance Temperature Detector

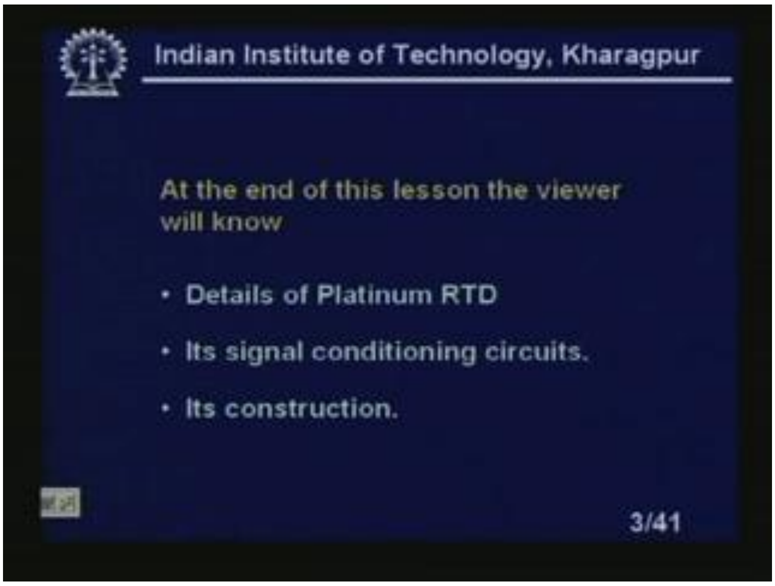
Welcome to the lesson 9 of Industrial Instrumentation. In this lesson, we will basically cover one of the most important temperature sensors that is resistance temperature detector. Resistance temperature detector, even though it is not much, I mean used in the industry, I mean in the plant, we will find the thermocouple is huge in number. Then, you will find the thermistor, but I should say for precision thermometry that means if I want to measure the temperature with high accuracy, resistance thermometer is the, resistance temperature detector is, is the only solution, because this, even though it is resistance thermometer, now what you call nowadays, we call it resistance temperature detector and there are three basic classes of the resistance temperature detector.

You will find we have platinum, then nickel, copper, tungsten; all these things will be, I mean discussed in details, also the signal conditioning circuit of the resistance temperature detector, which are basically nothing but some bridges. Either, we have seen in previous cases also, we can use it either in the unbalanced voltage mode or you can use it as a balanced mode, right?

(Refer Slide Time: 2:15)

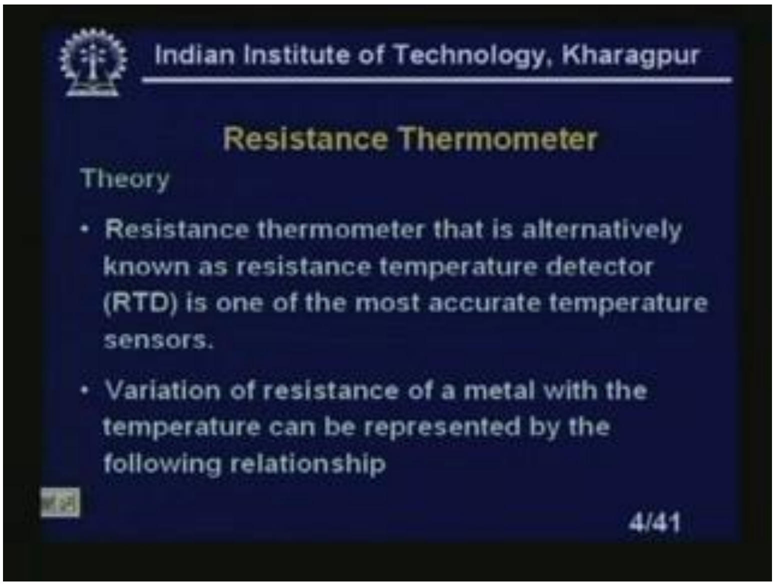
So, let us look at the contents of this lesson. First, we will consider the theory of the resistance temperature detector. Then, we will discuss the measuring bridges. What are the different measuring bridges in the resistance temperature detector? Then, we will see the construction. What is the basic construction of the resistance temperature detector?

(Refer Slide Time: 2:34)



So, obviously at the end of this lesson the viewer will know details of platinum RTD, then its signal conditioning circuits, its construction. So, these are the basic materials all the people will be familiar with. Most important is the circuits, I mean Wheatstone bridge, because from the user point of view, I mean we will get this resistance temperature detector ready from the market, but we must know that how to use it, how to make our signal conditioning circuitry, so that the lead wires errors and other different possible errors can be minimized.

(Refer Slide Time: 3:17)



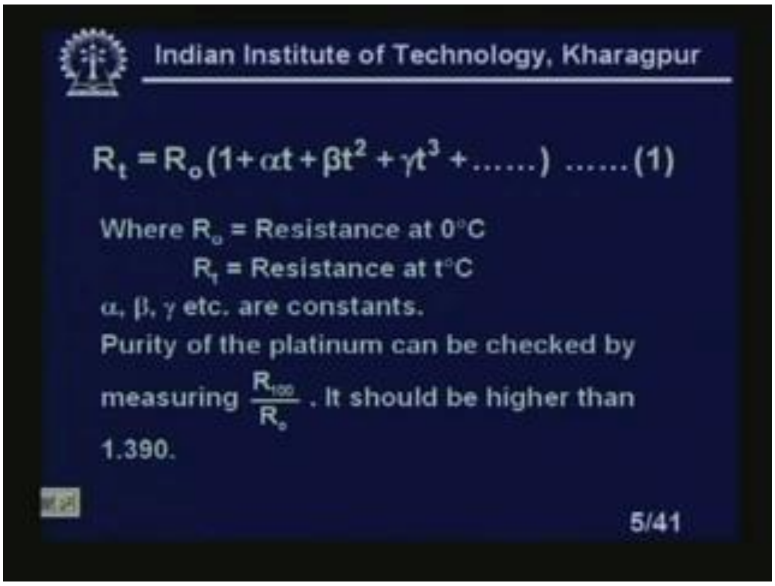
Resistance thermometer theory if I look at, resistance thermometer that is alternatively known as a resistance temperature detector or RTD is one of the most accurate temperature sensors. Using this, immediately people will raise the question that means why do you need such an accurate temperature measurements? In many industrial applications this is not necessary. Even if there is a temperature difference of 1 or 2 degree or 3 degree, it hardly matters. Especially at high temperature, suppose the temperature is around 100 degree centigrade or 200 degree centigrade, the percentage error is quite small and many process we will find, suppose in the, in a plant, in the process plant, this much of difference hardly matters. You do not need that accurate temperatures and detectors and resistance temperature detectors is not very, it is a cumbersome, its electrical circuits are complex and all those things are there, lots of precautions we have to take, but there are some applications.

One of the applications is the bioreactor application that means where the cell, you know in the bioreactor the cell grows. So, in that type of situation, the temperature, precise control of the temperature is very important, right? In that type of situation, resistance temperature detector is the only solution, because in that type of situation if the temperature varies, suppose if it is ……. temperature or set point should be 31 degree centigrade, it should be 31 plus minus .5 degree centigrade, not more than that because if the temperature deviates above or below these, then the cell may die.

So, in that type of situations, I need the precision resistance measurements, because once you make the measurement, in all instrumentation systems, once you make the measurements, I can control also the temperature. The need of measurement is to control it, is not it? That means heater power is to be controlled or some boiler temperature is to be controlled, all those things will be there, until unless we can measure it precisely. Moreover, you will find in some situations I need to measure this temperature, small temperature differences. In that type of situations also, I need resistance temperature detector, because I need a high accurate temperature difference there, right?

The variation of resistance of a metal with the temperature can be represented by the following relationship.

(Refer Slide Time: 5:29)

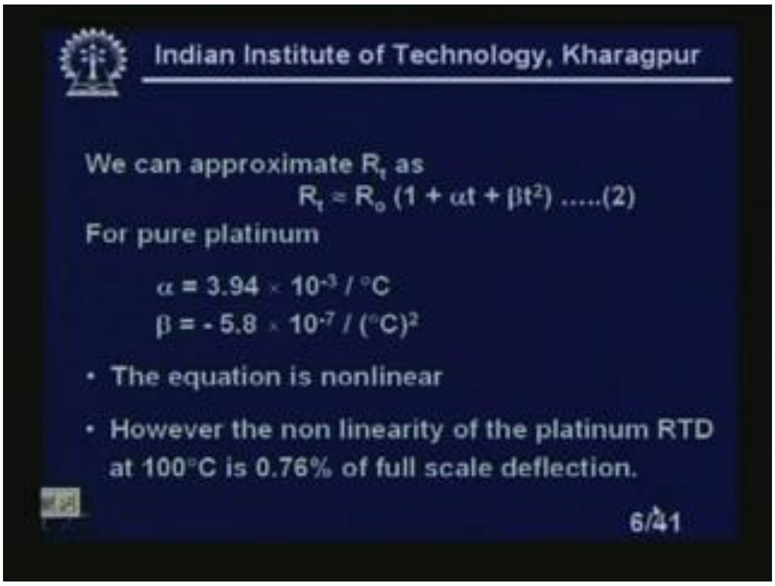


Let us look at the relationship. It is R t equal to R naught 1 plus alpha t plus beta t square plus gamma t cube plus so on. This is equation number 1 of the resistance thermometry. This is the basic equations, right, where this R naught is the resistance at zero degree centigrade, R t is the resistance at t degree centigrade and alpha, beta, gamma, etc., are constants, right? Now, the purity of the platinum can be checked by measuring this R 100 by R 0, because whatever the, whatever the, actually the materials you are using for making your resistance thermometry that should be pure. Unfortunately if it is not pure, then what will happen? You will see that it will deviate from the conventional resistance temperature graph, so, because alpha, beta, all things will change.

So, I need a pure, pure platinum and moreover, you know that the, one of the, I mean one of the basic need of using the resistance thermometer is the, especially platinum resistance thermometer is its inertness. Platinum is very inert and whenever you have, so that I can use it in very hostile environments, where there are chances of oxidation and all those things that can be avoided. In the case if we use the platinum thermometer or it won't react with, in a, suppose if I want to measure the temperature of the kiln or suppose if I want to measure the temperature of the sulphuric acid, the sulphuric acid bath or sulphur, molten sulphur, so that type of situations I need some thermometer which will not, even though we can put in a, in a, in a weld or in a shield or in a sheath, so it does not matter.

It should not, it should not react with the materials of which we are interested to measure the temperature, right? So, purity is the, one of the thumb rule to check the purity, you, once you get the resistance thermometers, you check its ratio. Resistance at 100 degree centigrade and upon resistance at zero degree centigrade, you measure it and it should be higher. If it is higher than 1.390, it is better.

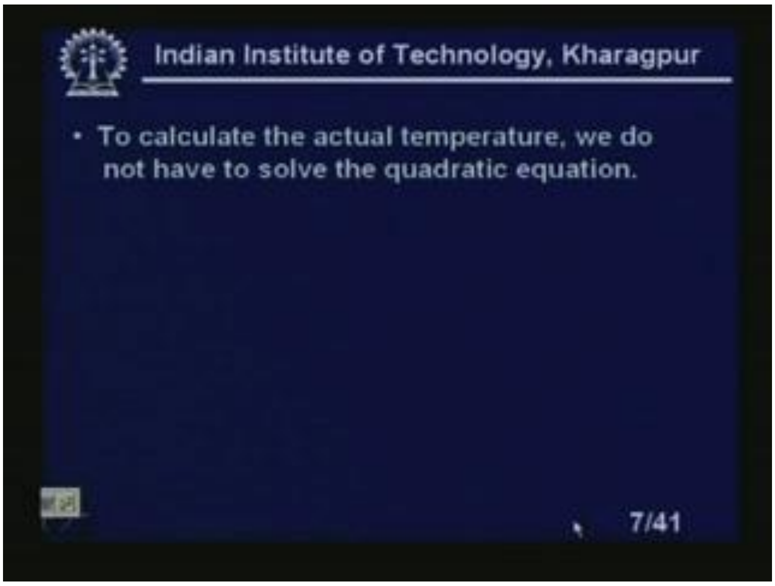
(Refer Slide Time: 7:37)



We can approximate R t as R t equal to R naught 1 plus alpha t plus beta t square; R t equal to R naught 1 plus alpha t plus beta t square. This is equation number 2. For pure platinum, alpha equal to 3.94 into 10 to the power minus 3 per degree centigrade and beta equal to minus 5.8 into 10 to the power minus 7 per degree centigrade square. Equation is nonlinear. You see, the equation 1, which we have discussed, we have seen it is a nonlinear equation.

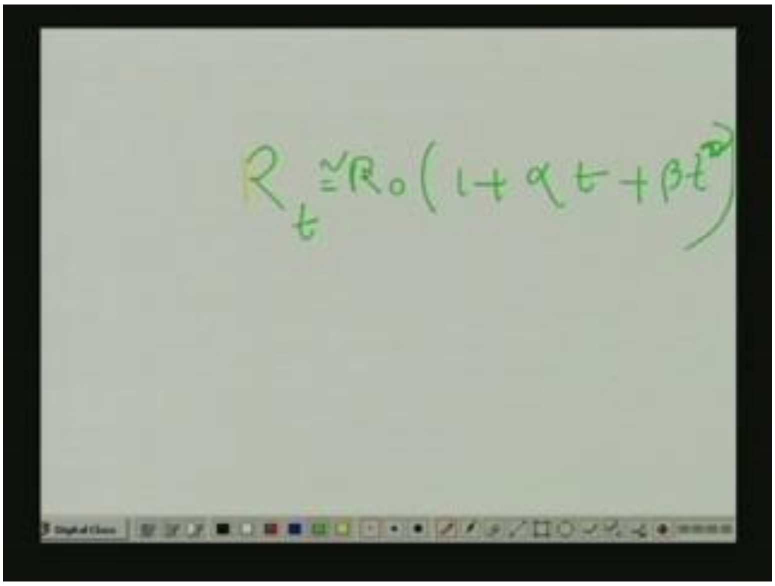
Obviously if you take, I mean above alpha if you take beta, gamma it is nonlinear. But fortunately, you see the value of the beta here, whatever the beta value you are getting, beta will be minus 5.8 into 10 to the power minus 7, so the value of beta is quite small, right and we can see that we can measure also the, how much the nonlinearity. So, you can see for the, most of the practical cases that is the reason I am saying that the, however the nonlinearity of the platinum RTD we have calculated at the 100 degree centigrade is .76% of the full scale deflection, right? It is quite small for the, most of the ……. most of the applications, right?

(Refer Slide Time: 8:46)



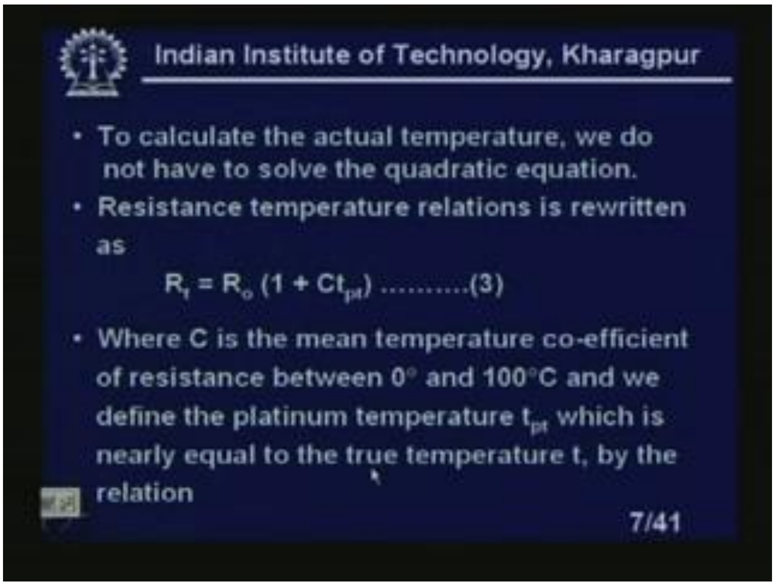
Now, to calculate this actual temperature we do not have to solve the quadratic equation. You see, the two basic scientist …….. and Griffith worked over a lot on the resistance thermometry. They suggested that instead of solving that quadratic equation that means second order differential, second order equation, because you see in the most of the cases if I take, even if I take nonlinearity, if I take up to the second order that means R t equal to R naught 1 plus alpha t that means like this one if I take, if I take a blank page, so that is okay.

(Refer Slide Time: 9:29)



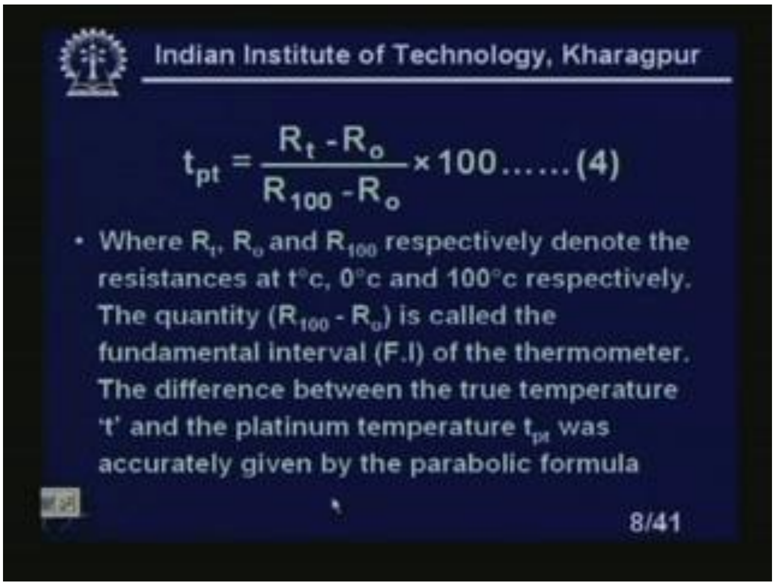
So, if I take for the, most of the practical purposes, sorry, if I take a, if I take R t equal to R naught 1 plus alpha t plus beta t square that will suffice. It is t square, please note, this will suffice, right? So, you can see that in this type of situations or I can approximate like this, because higher terms like gamma and all these things will be quite small and can be neglected. So, amount of nonlinearity will be introduced by higher order terms. It will be very, very less. So, I can take it up to, if I take up to beta or t square, it is more than, I have more than whatever we need or accuracy as I told you, we have seen the .76% of the full scale. So, it is quite small. So, up to beta if you take that means up to second order t square if I take that is enough, right?

(Refer Slide Time: 10:38)



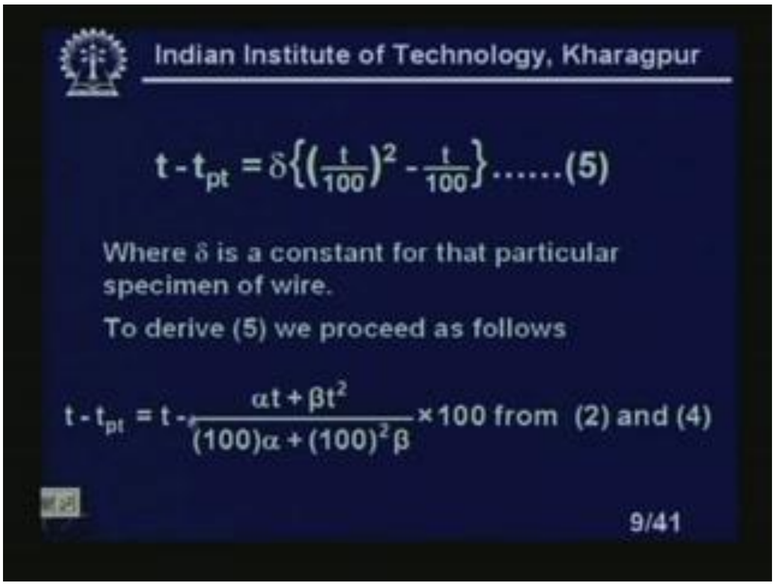
So instead, the resistance temperature relation is rewritten as R t equal to R naught multiplied by 1 plus C into t pt. This is equation number 3, where C is the mean temperature coefficient of resistance between 0 degree and 100 degree centigrade.

(Refer Slide Time: 11:00)



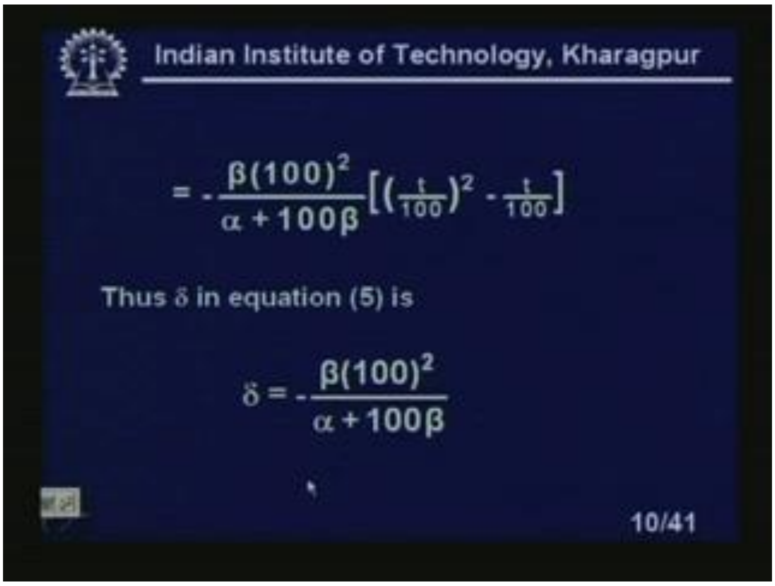
We define the platinum temperature t pt, which is nearly equal to the true temperature t by the relation t pt equal to R t minus R naught upon R 100 minus R naught into 100. This is equation number 4, where R t, R naught and R 100 respectively denote the resistances at t degree centigrade, zero degree centigrade and 100 centigrade respectively. The quantity R 100 minus R naught is called the fundamental interval of the thermometer. The difference between the true temperature t and the platinum temperature t pt was accurately given by the parabolic formula as follows.

(Refer Slide Time: 11:33)



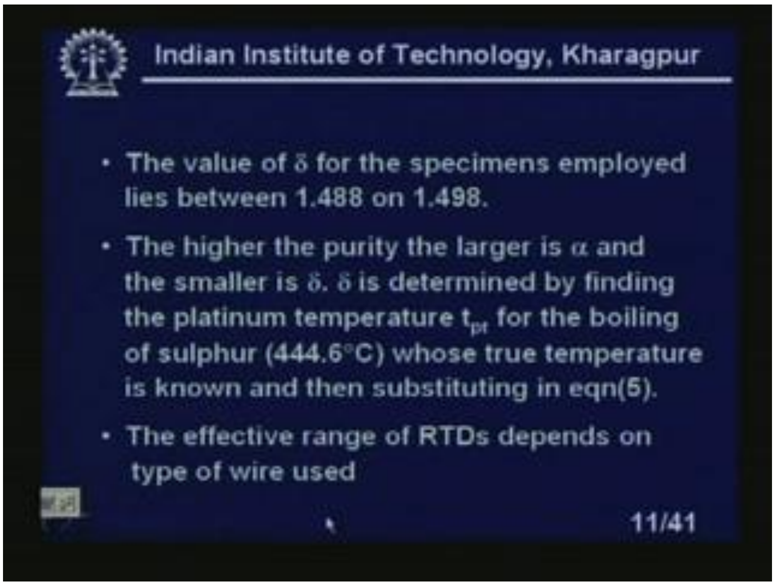
t minus t pt equal to delta t by 100 whole square minus t by 100. This is equation number 5, where delta, the delta is a constant for that particular specimen of wire. Now, to derive the equation number 5, we proceed as follows. We have taken t minus t pt t minus alpha t plus beta t square upon 100 alpha plus 100 square into beta into 100. This actually we got from the equation 2 and 4, right?

(Refer Slide Time: 12:07)



So, this can be equal to minus beta 100 square upon alpha plus 100 beta multiplied with t by 100 whole square minus t by 100. Thus, delta in equation 5 is given by delta equal to minus beta 100 the whole square alpha plus 100 beta.

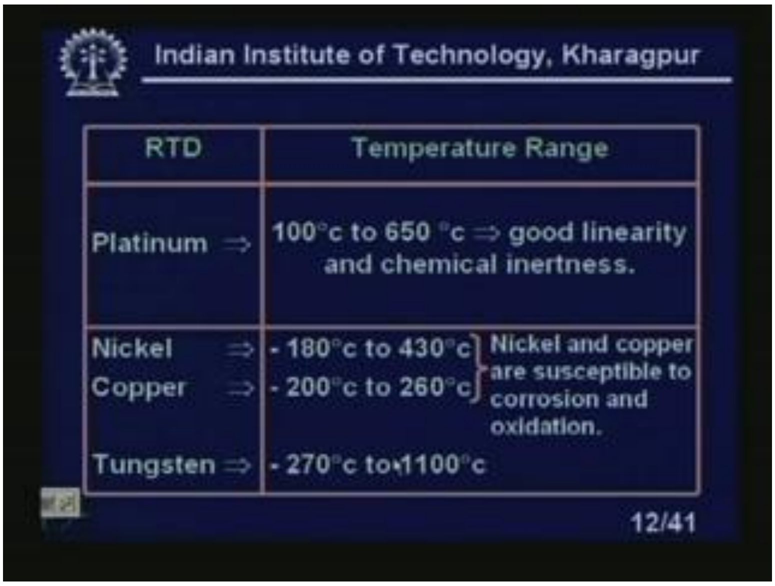
(Refer Slide Time: 12:27)



The value of delta for the specimens employed lies between 1.488 and 2, 1.498. It should be 2.498. The higher the purity, larger is this alpha and smaller is the delta. Now obviously, delta I can find from the equation 5 by finding the platinum temperature t pt, for the boiling point of sulphur which is usually 444.6 degree centigrade. The reason that we have chosen the sulphur boiling point, because it is available in the pure form and instead of taking at the boiling point of water, we are taking little higher temperature

Usually, as you know that, I mean resistance thermometer can be used, especially the platinum resistance thermometer can be easily used up to the temperature of 650 degree centigrade. So, we can take the temperature of 444.6 degree centigrade. It is fixed for the normal temperature and pressure and whose true temperature is known and then, substituting in equation 5, we can find it, right? The effective range of the RTD depends on the type of wire used. There are various, as I told you, there are three different, four different types of RTD and what are the ranges and how it will be effective, can be looked at from this table.

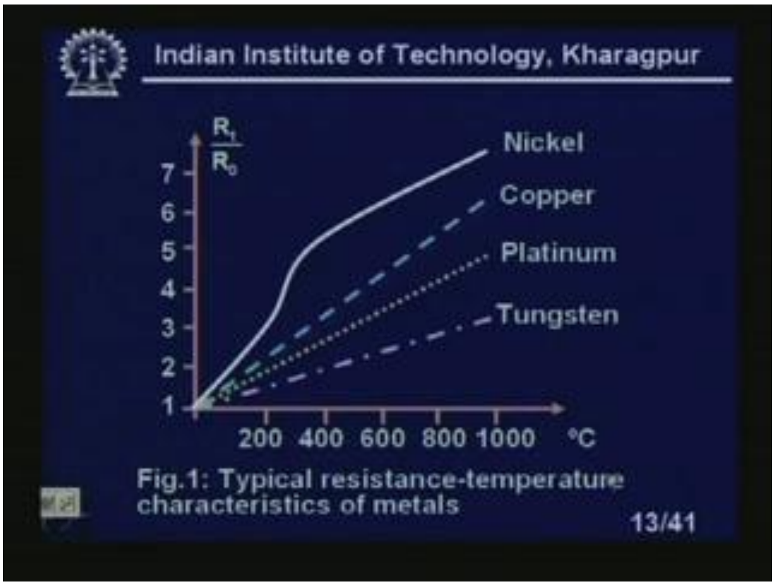
(Refer Slide Time: 13:47)



Platinum, its RTD we have made in table. Its temperature range is 100 to 600, 650 degree centigrade, good linearity and chemical inertness. That is the most important thing for the platinum RTD, its chemical inertness. You see here, this chemical inertness is the most important factor, why the platinum is used typically for making RTD or even I should say it is a ……. standard, industrial …… standard to use the platinum RTD, even though we have the nickel and copper and all those things.

Nickel I can go for minus 180 degree centigrade to 430 degree centigrade and minus 200 degree centigrade to 260 degree centigrade and nickel and copper are susceptible to corrosion and oxidation. This is the problem with the nickel and copper, but you can use it in some situation. Even the platinum is quite expensive also. If you use a large number of measurements, I can manage with the nickel and copper and in that type of situations, I have to use in, in a sheath material or I have to put this entire RTD in a, in a weld, so that it be protected from the environment, right or instead I can use a tungsten also, which is rather newer, I should say minus 270 degree centigrade to 1100 degree centigrade.

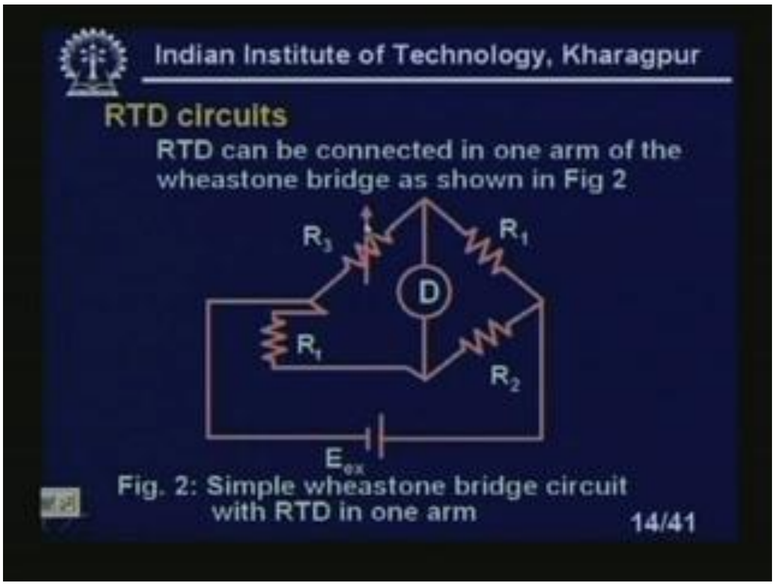
(Refer Slide Time: 14:58)



So, now this is the figure 1, where you can see the typical resistance temperature characteristics of metals. We can see, here we have plotted R t by R 0 in y-axis, temperature in the x - axis. Obviously, at zero degree centigrade R t by R 0 will be 1. You have plotted in the, first one is of nickel. Then you have plotted for copper, then you have plotted for platinum, then you have plotted for tungsten. You can see that the platinum, sensitivity of the platinum is rather low.

Even though tungsten is even lower, but the tungsten advantages we are getting the higher range, so that means per degree change of temperature. the resistor change of the platinum is smaller than the copper and the nickel, right?

(Refer Slide Time: 15:43)



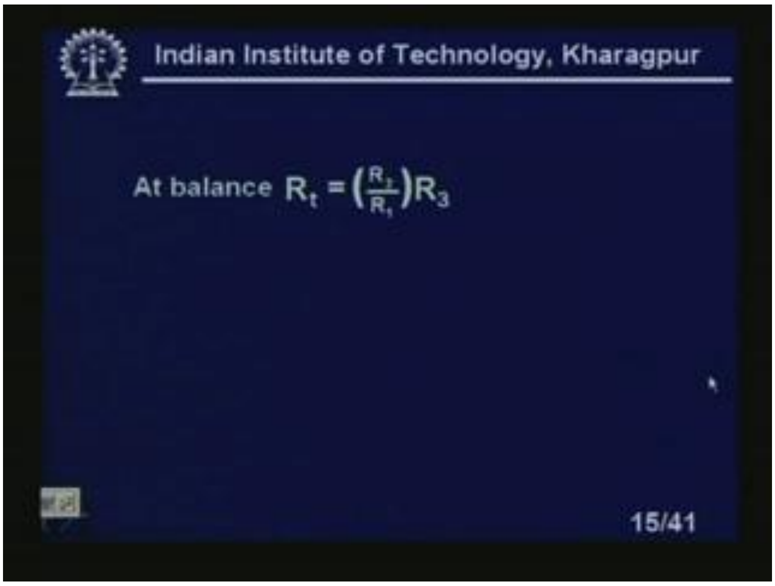
Now, RTD circuits, how will I, now actually what is in the RTD circuit? If the temperature changes, the resistance will change. So, somehow or other, I have to measure that resistance change, right, so that the resistance change can be calibrated in terms of temperature. That is the very simple, how we can make the measurements and how we can measure the, how we can make or how we can make convert this resistance change in temperature. That is our goal in formatting RTD circuits.

Now, basically these RTD circuits are Wheatstone bridge circuits, right, because Wheatstone bridge is, as you know, it is very unbalanced. It is very easy, we can find the unknown resistance with the help of another known resistance. So, it is always used for the measurement of the unknown resistance. But please note, the simple Wheatstone bridge you cannot use. We have to use some modified form of Wheatstone bridge, because RTD is a sensitive instrument. Its contact resistance, all those things, we have to take care of, we have to count on that, right?

Now, RTD can be connected in one arm of the Wheatstone bridge as shown in figure 2. You see, this is the figure 2, a simple Wheatstone bridge circuit with RTD in one arm, right? You see, the RTD , this is our, R T is RTD and these two fixed resistances R 1 and R 2, right and this is our R 3, this is a variable resistance. We will balance bridge with the, by varying R 3. Either I can take the unbalanced voltage D and calibrate that unbalanced voltage in terms of temperature or I can calibrate this R 3 in terms of temperature. It can be, in that case it will be a slide wire.

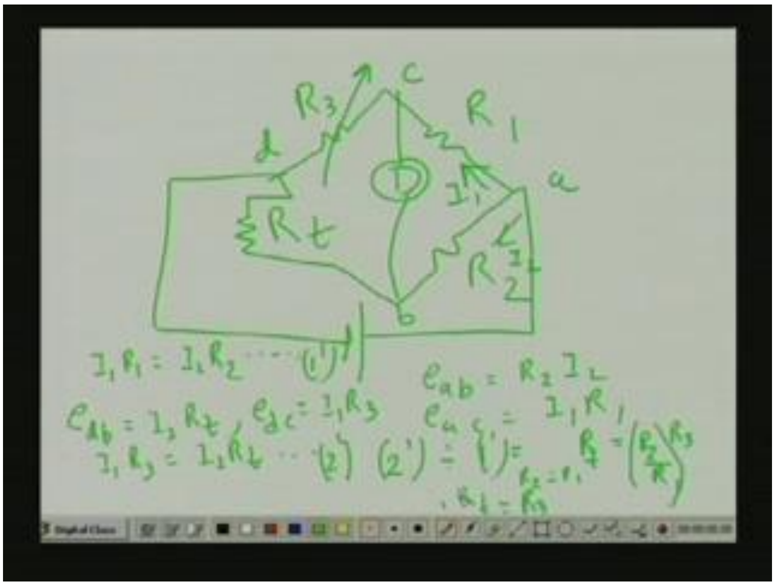
Now, I am telling, potentiometer in that case, it will be simple slide wire, where I can shift this. That means it look like this. The wire will be like this one and there is a contact. It will move like this one, right and this length will be calibrated in terms of temperature. Now, your conventional potentiometer, school level potentiometer, so where I will have a graduated scale here, so if I move this one, so I can balance it and this will be calibrated in terms of temperature by which we can measure it, measure any unknown temperature, right?

(Refer Slide Time: 18:08)



At balance, obviously you know that it will be R 2 by R t equal to R 2 by R 1 into R 3. It is very simple. I should not draw it, even though it is a basic Wheatstone bridge, anyway and for sake of completeness, I am drawing.

(Refer Slide Time: 18:25)



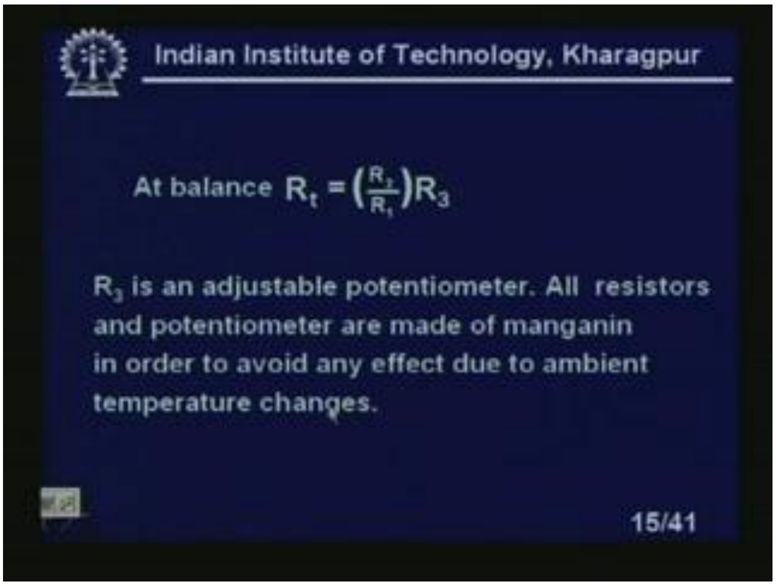
Suppose I have a circuit like this one, so we have R 1, R 2, this is our R t and this is our R 3. We make R 3 variable and this is a potential. Suppose this point is a, this is b, this is c, this is d and suppose this current is I 1 and this current is I 2, right? So, you see that e ab, e ab will be equal to potential …. across this R 2 into I 2 and e ac will be I 1 into R 1. At balance, when there is no output at the detector, so I can say I 1 by into R 1 equal to I 2 into R 2, right? Similarly on this side, because if at balance all the current will pass through this one, so no current will flow through the detector.

So, on this side, I can write the e db will be equal to I 2 into R t and e dc equal to same current will flow. So, I 1 will flow through this one; I 1 into R 3, right? So, I can write I 1 into R 3 equal to I 2 into R t. So, if I divide this equation and this equation, I will get, suppose this equation number, equation is of some one dash, suppose this is 2 dash, so if I divide 2 dash by 1 dash, I will get, I will get R t, R t by R 2 or multiplied by R 2 into R 3 by R 1. So, I can put R 1 here and put this in a bracket like this one. So, you see that if I take now R 2 and R 1, these two resistances R 2 and R 1 equal, then what will happen?

This will, you will see that this will cancel out. So, R t will be, so in that case if R 2 equal to R 1, so I can write that R t equal to R, R t equal to R 3, right? R t equal to R 3, fine.

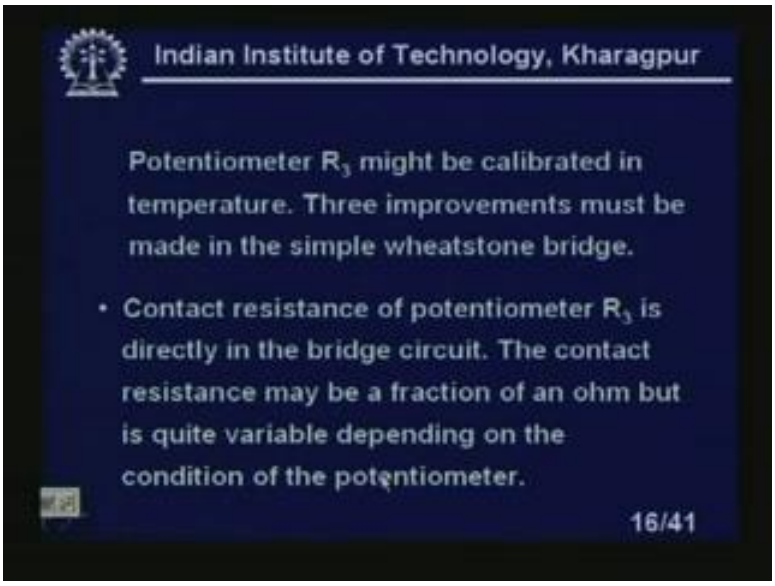
So, any change in, so R 3 will give you, at balance, I will balance ….. varying R 3, so obviously R 3 will give you the unknown temperature. So, R 3 should be calibrated in terms of temperature, fine.

(Refer Slide Time: 22:20)



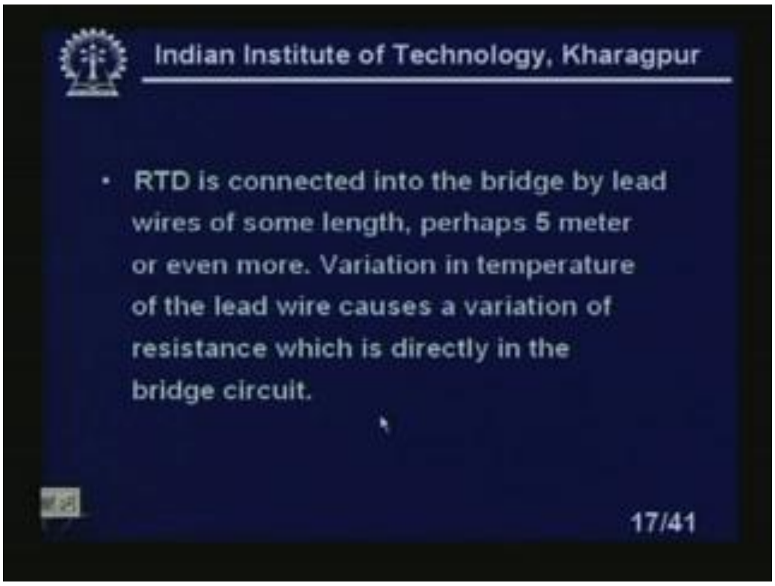
So, this is the balance equation; I have taken R t equal to R 2 by R 1 into R 3. So, R 3 is an adjustable potentiometer. All resistors and potentiometers are made of manganin, in order to avoid any effect due to ambient temperature changes. You know, manganin has a lowest temperature coefficients of resistance, so we always choose manganin to avoid any ambient temperature change, right?

(Refer Slide Time: 22:46)



Potentiometer R 3 might be calibrated in terms of temperature. Three improvements must be made in the simple Wheatstone bridge. There is some, simple Wheatstone bridge you cannot use, some modification you have to need. Why you need these modifications? We will explain one by one. You see, the contact resistance of the potentiometer R 3, if you remember the potentiometer, the bridge, basic bridge, the contact resistance of the …….. is directly in the bridge circuit and this contact resistance may vary. They vary from fraction of an ohm, but it is quite variable. Since it is in the bridge circuit, so depending on the contact, your bridge balance equation will change. That is very undesirable properties, right? This is number one problem.

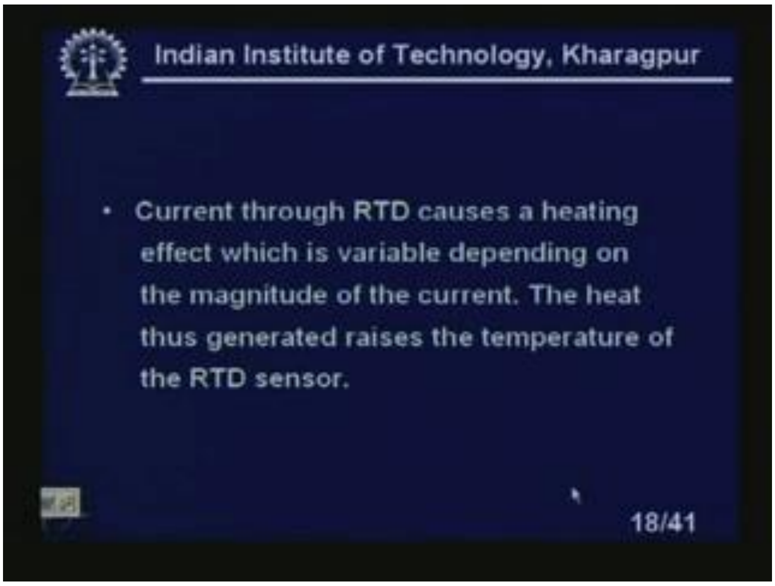
(Refer Slide Time: 23:30)



Now, another problem is RTD. You, you see that you, you cannot put the RTD very close to the point of measurements, right. I need certain amount of distance from the point of, from the, where I will install the RTD and there should be certain amount of distance, so where I will make the measurements, right? Even though nowadays all these intelligent sensors and all those things are coming, where the transmitter itself are, because you have to, if you want to make the unbalanced voltage as a, as a, if you want to calibrate this unbalanced voltage as it happen in most of the control systems that unbalanced voltage in terms of temperature, so we have to convert that in the current domain, but certain length of wire is there. Even though 1 feet of length or suppose 1 meter length of wire is necessary, also. These are basically lead wires, because you cannot install the bridge itself on the sensor.

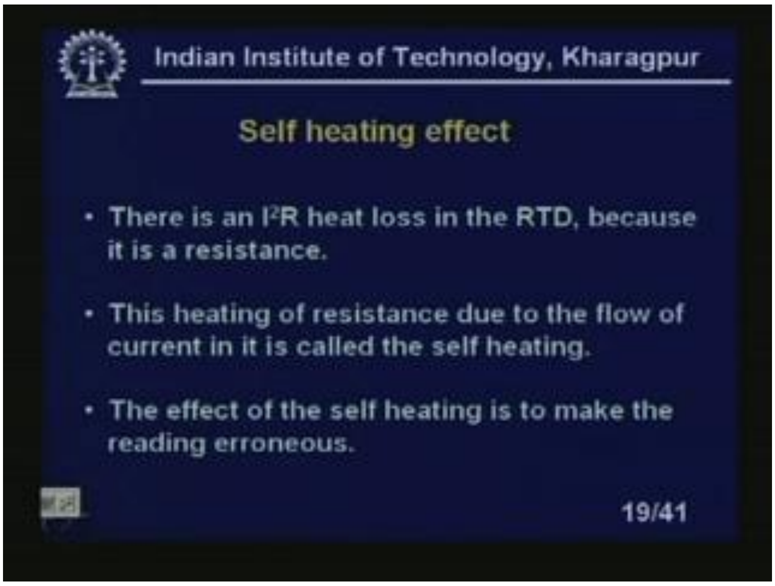
So bridge will be, that Wheatstone bridge will be starting from, might be 1 meter away from the actual sensor or actual bulb, I should say ….. bulb, right? So, there is a variation of temperature along the length of this lead wire, so that will create the problem, right?

(Refer Slide Time: 24:41)



Now, current through RTD causes a heating effect, which is variable depending on the magnitude of the current. The heat thus generated raises the temperature of the RTD sensor.

(Refer Slide Time: 24:51)



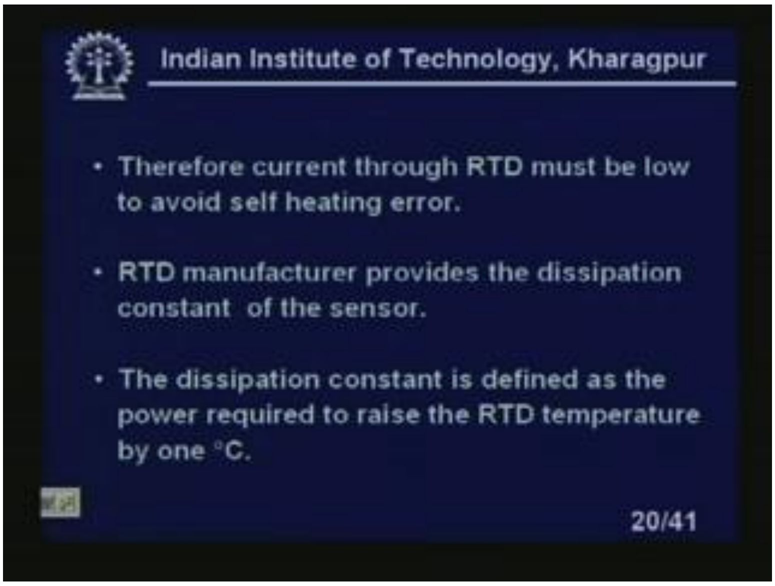
Self heating effect - there is an I square R heat loss in the RTD, because it is a resistance. There is an I square R heat loss in the RTD, obviously any resistance. So and this self heat is called a self heating effect. You see, it cannot avoid, it, this is, this will be, this remains. So, only thing you have to make a compromise between the sensitivity and because, I can reduce this supply voltage as I reduce the excitation voltage to the bridge, obviously what will happen? You will find this self heating effect will be reduced, because you are reducing the current I in the bridge circuit. But if you reduce I, current I, what will happen?

You know, you will lose the sensitivity also, but that is not a big problem. Nowadays, we have, we can easily make the signal conditioning, we can amplify the signals. So, but we can avoid by, this by, I can avoid the, you see everything it is, it is very simple. If I say that I am using a, I, I will make the self heating error very less, I will reduce the current and then no problem, sensitivity will be reduced. But, please remember whenever we are using amplifier it has inherent noise, so that if we use the amplifier, so that inherent noise will come in the picture also, right and moreover, if you reduce the current ,the unbalanced voltage will be not, will be not that small, not that large rather to operate a V to I convertor.

V to I convertor has some input voltage range. You have to, you have to raise the voltage up to that range. Only then the V to I convertor, because at the beginning of this I mean course, you have seen that in all your industrial applications, we do not transmit the voltage, we always transmit the current. So, even the V to I convertor is necessary. If suppose zero to 5 voltage, if I say zero to 10 volt, whatever it may be of your V excitation voltage, so maximum output is zero to 10 volts.

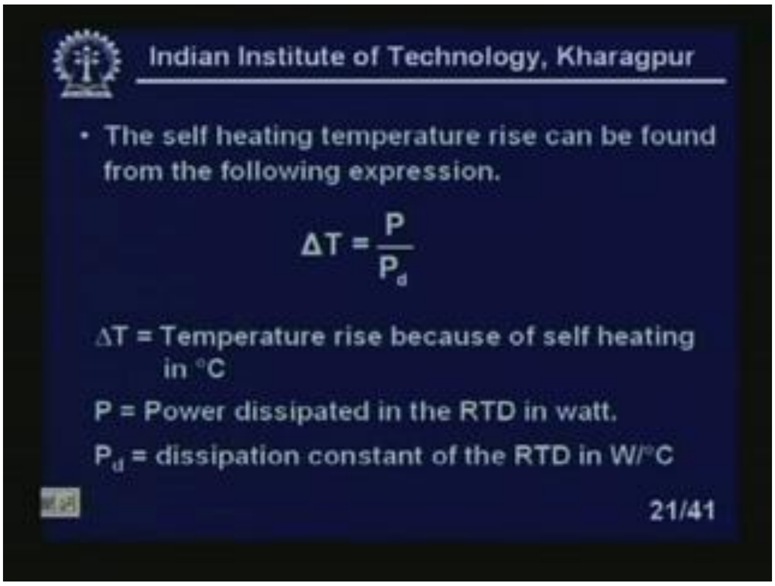
In that type of situations, you know that the current will flow to 20 milliampere. If the V excitation voltage itself is very, very small, if I make purposefully, to avoid the self heating error, so it may not work. So, we have to look at that what should be the minimum V excitation voltage, right? The heating, heating of the resistance due to the flow of current in it is called the self heating, right? The effect of the self heating is to make the reading erroneous, quite obvious.

(Refer Slide Time: 27:08)



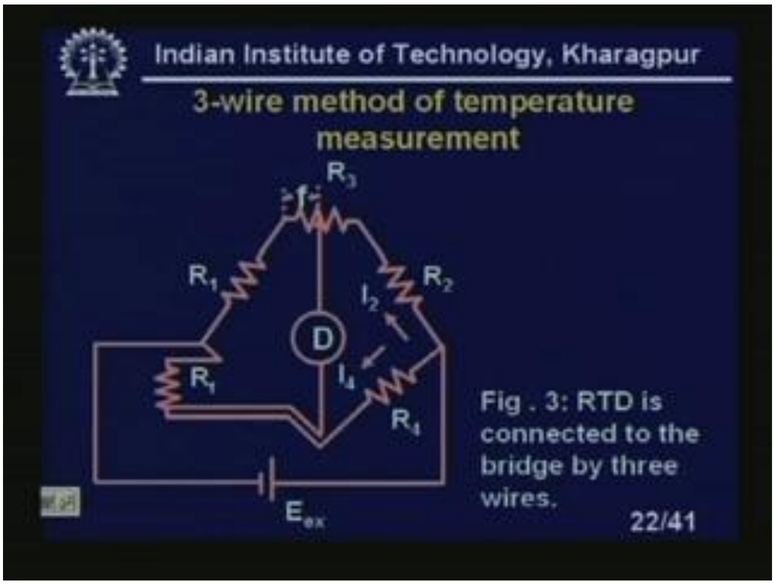
Therefore, the current through RTD must be low to avoid the self heating error. Now, usually RTD manufacturer provides the dissipation constant of the sensor. What is the dissipation constant? The dissipation constant is defined as the power required to raise the RTD temperature by 1 degree centigrade, right?

(Refer Slide Time: 27:28)



Now, the self heating temperature rise can be found from the following expressions; very simple, delta T equal to P by P d. What is this P? Delta T is the temperature rise, because of the self heating in degree centigrade. P is the power dissipated in the RTD, in the RTD in watt and P d is the dissipation constant of the RTD in watt per degree centigrade. This is a constant for particular RTD. Usually the manufacturer will supply this value of the P d. Now, all thing will control the what is the minimum resolutions we can take the measurements? Because you see, if the P is fixed, if the P d is fixed, then delta is, T is fixed, right? So, in that sense, I can control, I can reduce it, but I, I can, it will control, the self heating temperature error will control the resolutions of your instrument or resolutions of your thermometer.

(Refer Slide Time: 28:24)



Now, let us look at, as I, even though I discussed the self heating effect, let us discuss the first problem in the conventional Wheatstone bridge, when I am using the bridge for measurements of temperature using RTD, because we have seen in the conventional Wheatstone bridge, we have put the RTD in one arm of the bridge and put one arm of the bridge and we will see that the, we are varying the other resistance to get the balance and the problem I told at the beginning that the, the contact resistance comes directly in the bridge circuit.

So, depending on the, how much contacts you are getting, so it may vary. Suppose if it is, even if it changes to 1 to 2 or 3 ohm, see it will change your bridge balance equation, right because I have to change the R 3, again to make the bridge balance.

So, I might, this is quite erroneous. It is not undesirable, because contact resistance we are not, when while we are calculating the bridge circuit, Wheatstone, when we are writing the Wheatstone equations, bridge equations or bridge balance equations, we are not taking care of the contact resistance, right? So, that will make the circuits total erroneous, make our measurement total erroneous. Since it is a very precision instrument, so I have to take care of all these factors.

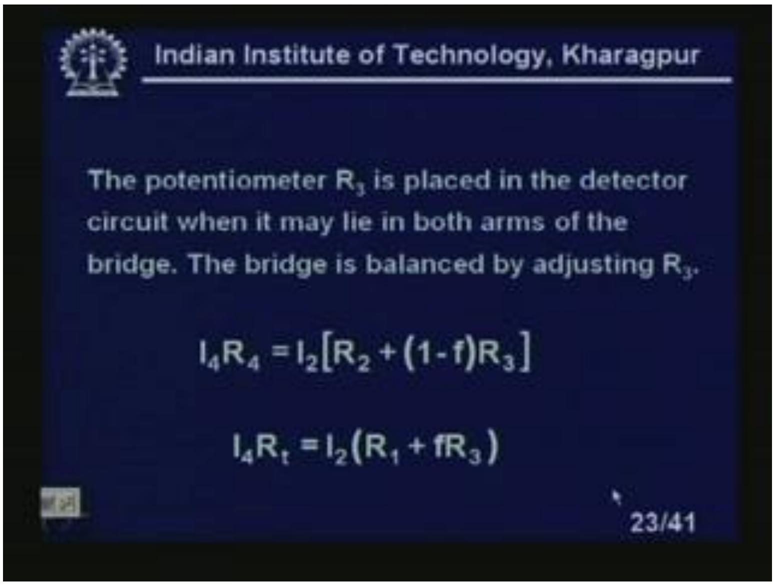
So, this is the circuit. You see, this RTD is connected to the bridge by three wires. You see, three wires means you see here, there is one wire, there is another wire, there is another wire. Now you, interestingly you will see this R 3 now is known in the bridge. R 3 is in the bridge, but the contact resistance is not in the bridge circuit, it is in the galvanometer circuit. It is not in the detector circuit. How do you know it is in the galvanometers or you can see it is just a multimeter or a voltmeter, is not it, right?

So, if there is little increase in the contact resistance or little decrease in the contact resistance, nothing will happen. What it will do? It will simply make your bridge more sensitive or less; your detector more sensitive or less sensitive, you usually use it, is it not? Suppose in the case, some cases I want to make a, use a milliammeter in a bridge circuit, which is carrying a current of suppose 500 milliampere, even though our detector circuits can only, can read 10 milliampere, usually we use a shunt, is not it, right?

You use a shunt and once I am very close to the measurements, so I remove the shunt, so that, because I know that bridge is almost balanced. There is a little chance of, I mean passing a large current through the bridge, through the detector. So, that type of situation may arise. So, any contact resistance will not, this contact resistance will be no more in the bridge circuit, so no calculation, nothing, whatever the bridge balance equation we will write that will be absolutely correct, but it will be in the detector circuit. So, it will make the detector more sensitive or less sensitive, it does not matter, it is no way, I mean coming in the picture.

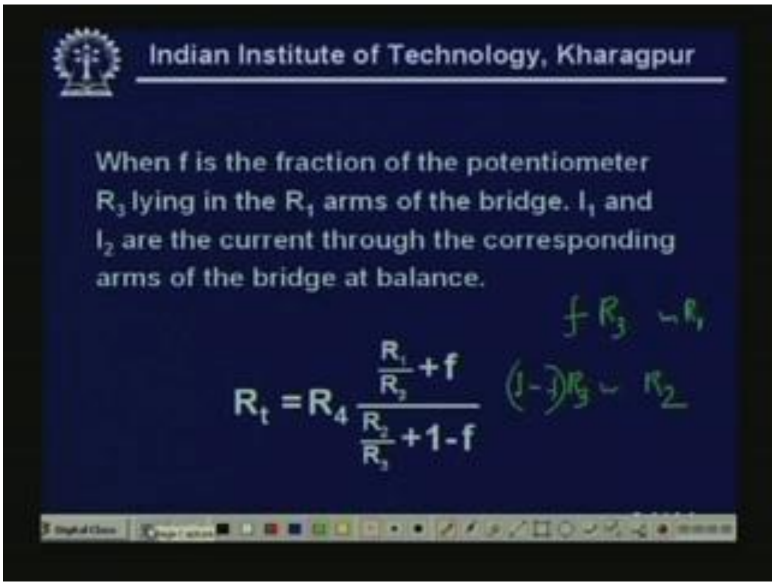
So, I am denoting some current, because we have to calculate something. This I 2, which is the resistance, which is the current through the resistance R 2, I 4 is the current through the resistance R 4 and at balance, this R4 is, I 4 is also flowing through R T and since it is, no current is flowing through the detector in balance and also this I 2 is, full is flowing through the, this R 3 as well through R 1 back to the battery, right? This is called the RTD is connected to the bridge by three wire method, right?

(Refer Slide Time: 31:58)



Now, the potentiometer R 3 is placed in the detector circuit when it may lie in both arms of the bridge. The bridge is balanced by adjusting R 3. So, I am writing the equation I 4 R 4, if I look at the top one, equal to I 2 R 2 plus 1 minus f into R 3 is the first equation on the bridge balanced on the right hand side or and also I can write I 4 R t I 2 R 1 plus f R 3.

(Refer Slide Time: 32:26)

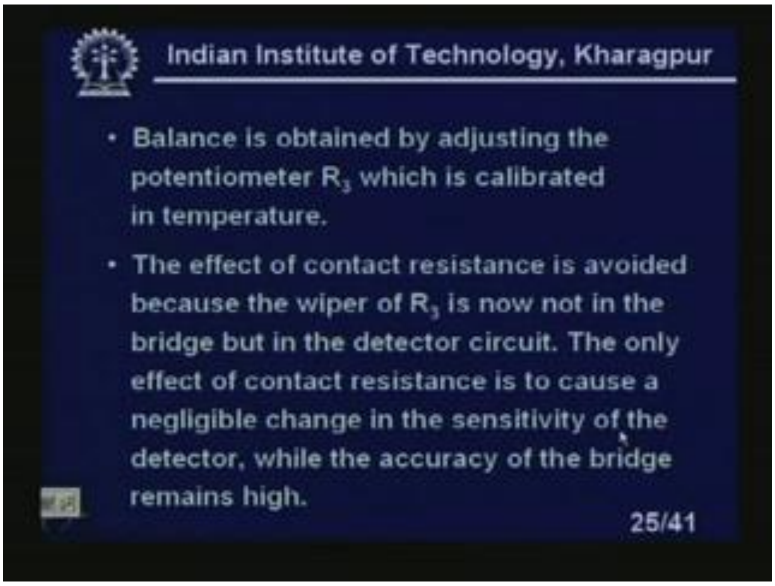


So, when f is the fraction of the potentiometer R 3 lying in the arm, R 1 arm of the bridge and I 1 and I 2 are the current through the corresponding arms of the bridge. This, actually it should be, sorry this will be I 2 and I 4, it will be I 2 and I 4, also the bridge. So, it will be I 4, I am sorry, this will be, if I take a, so this will be I 4. I 4 and I 2 are the current through the corresponding arms in the bridge circuit. That means the currents which is flowing through the R 4 it is I 4 and current which is flowing through the R 2 is I 2.

Please note that I 4 is also flowing through the, our, that resistance R t that means …… resistance of the thermometer and I 2 is also flowing through the resistance R 1 as well as R 3. It is flowing through R 3, then through the, and because at balance, so detector is not drawing any current. So, at mid balance equations we can write, I, R t equal to R 4 R 1 by R 3 plus f. If I take ratio R 2 by R 3 plus 1 minus f, right? f is a fraction of the potentiometer, R 3 lying in R 1 arms of the bridge.

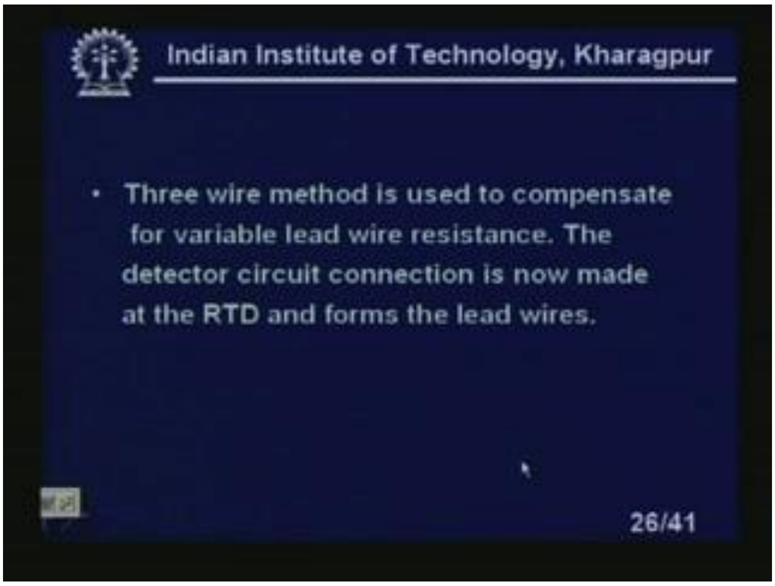
So, obviously in the R 2 arm, the fraction of the potentiometer will be R 3 multiplied by 1 minus f, is not it? Because, on R 1 arm it is f into R 1 that means I should say like this one, if I write that means that the f R 3, f R 3 will lie in the R 1, in R 1 arms of the bridge and 1 minus f into R 3 will lie, 1 minus f into R 3 will lie in the R 2 arms of the bridge, right? No problem.

(Refer Slide Time: 35:09)



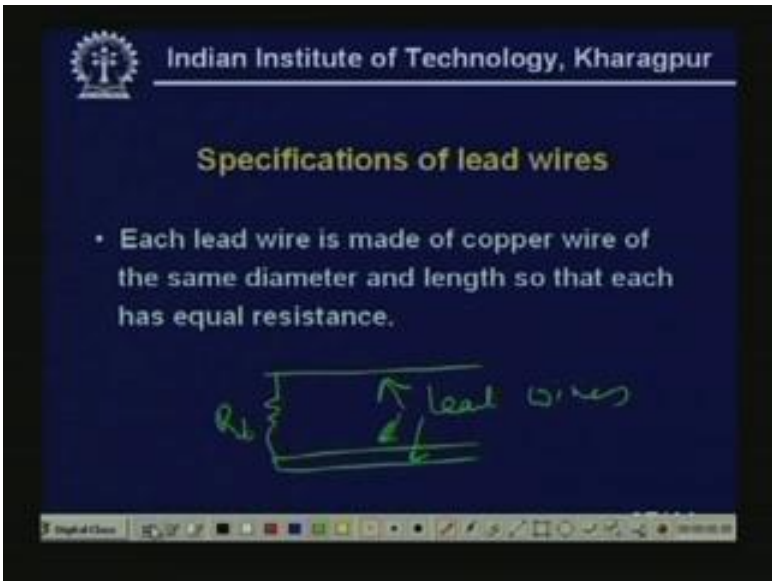
So, balance is obtained by adjusting the potentiometer R 3, which is calibrated in terms of temperature, no problem. So, the effect of the contact resistance is avoided, because the wiper of R 3 or jockey of R 3 is now not in the bridge, but in the detector circuit, which I told several times before, right? The only effect of the contact resistance is to cause a negligible change in the sensitivity of the detector, while the accuracy of the bridge circuit remains very high. This is most important thing.

(Refer Slide Time: 35:40)



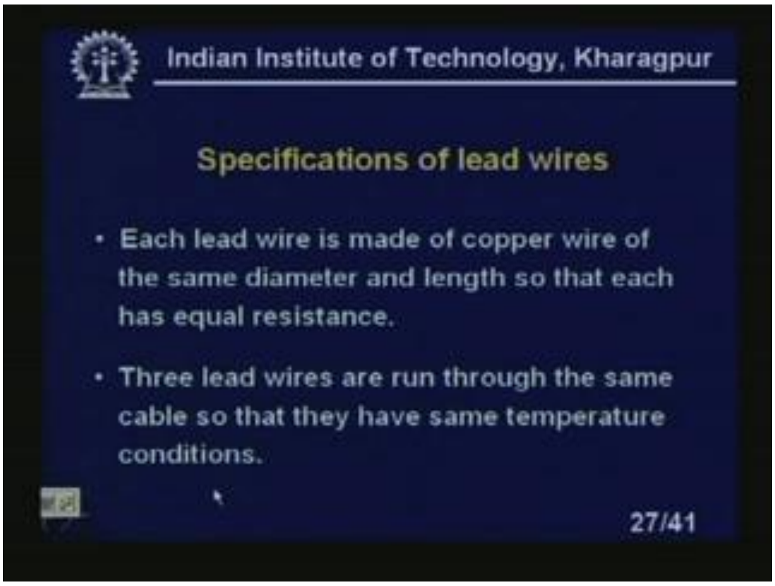
Three wire method is used to compensate for variable lead wire resistance. Now, the detector circuit connection is now made at the RTD and forms the lead wires, right?

(Refer Slide Time: 35:51)



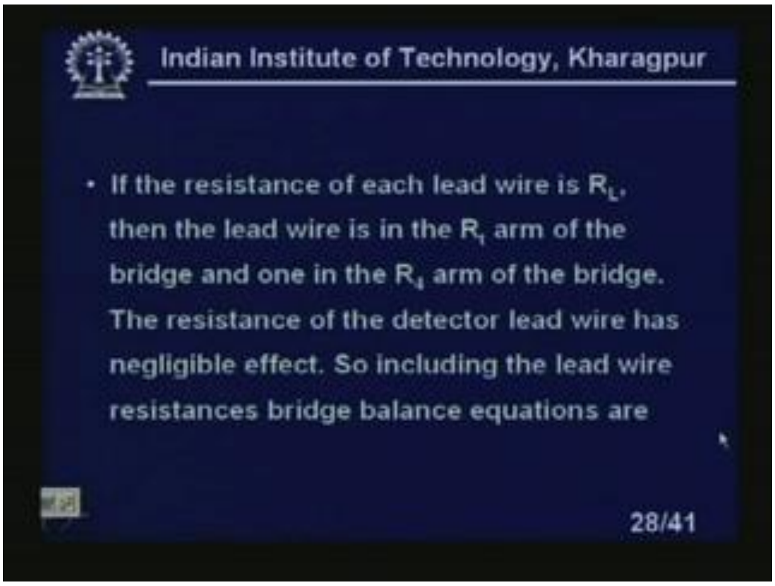
But you know, the lead wires, even though lead wire resistance will remain, in the case of three wire methods even though contact resistance problem will be overcome, self heating error will be inherent that will remain as it is, as well as lead wire errors will remain in the three wire method of RTD. Now, specifications - each lead wire is made of copper wire of the same diameter and length, so that the each has equal resistance. This is the specifications of lead wires which will connect from the bulb of the thermometer to the bridge circuit, right, because it looks like this. I have a thermometer bulb, R t. This will be connected by bridge, so this is our all lead wires, so this is our lead wires, right?

(Refer Slide Time: 36:46)



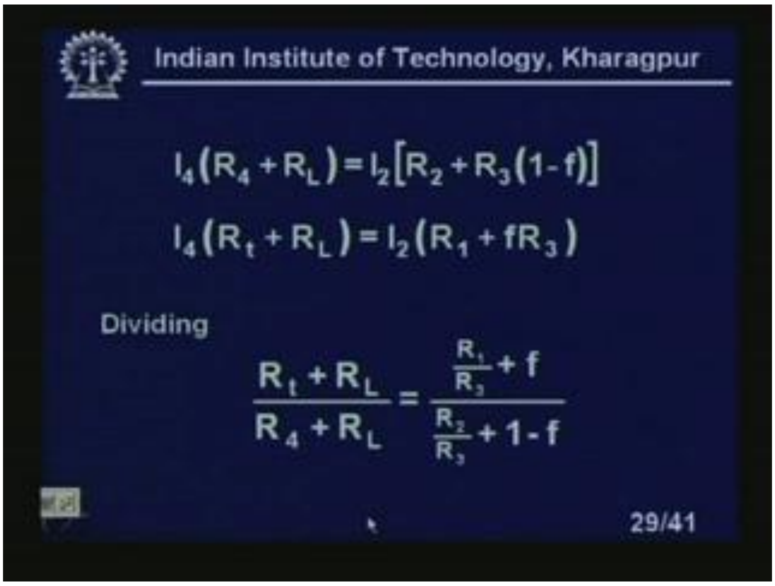
The three lead wires are run through the same cable, so that they have assumed or they have the same temperature conditions. This is also necessary.

(Refer Slide Time: 36:54)



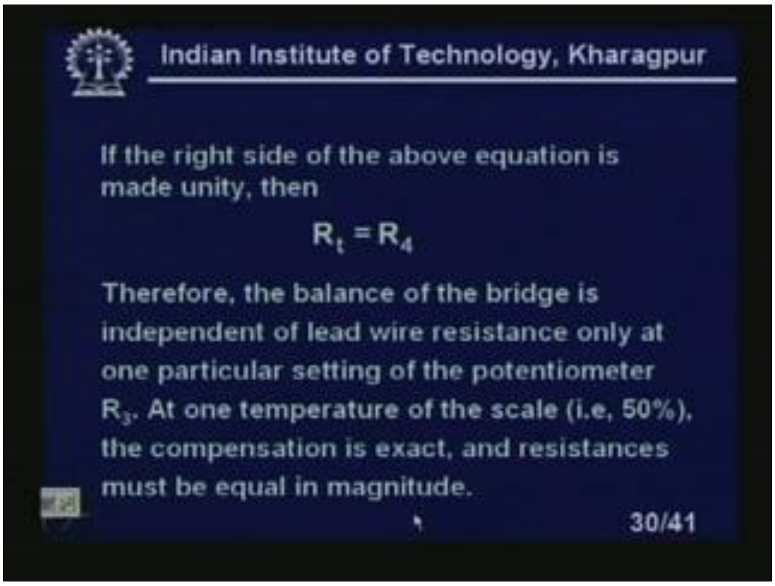
If the resistance of each lead wire is R L, then the lead wire is in the R t arm of the bridge and one in the R 4 arm of the bridge. Quite obviously, it is in the R t arm of the bridge and the R 4 arm of the bridge. The resistance of the detector lead wire has negligible effect, because it is not coming in the picture. So, because it will make, again it will make more sensitive or less sensitive the detector circuit, because whatever the resistance in the detector, if it is high, so we can ignore that once we write the bridge balance equation, clear?

(Refer Slide Time: 37:30)



Now, this equation, we rewrite the bridge balance equations for the three wire method, when I am taking the length resistance of the lead wires, right, in effect. Previously we have not considered the resistance of the lead wire, so we assume that each lead wires as the resistance of R L. So, it will be I 4 R 4 plus R L equal to I 2 R 2 plus R 3 1 minus f. So, it will be I 4 R t plus R L equal to I 2 R 1 plus f R 3. If I take the ratios, R t plus R L R 4 plus R L equal to R 1. If I divide on the right hand side by R 3, I will get R 1 by R 3 R 2 by R 3 1 minus f, sorry.

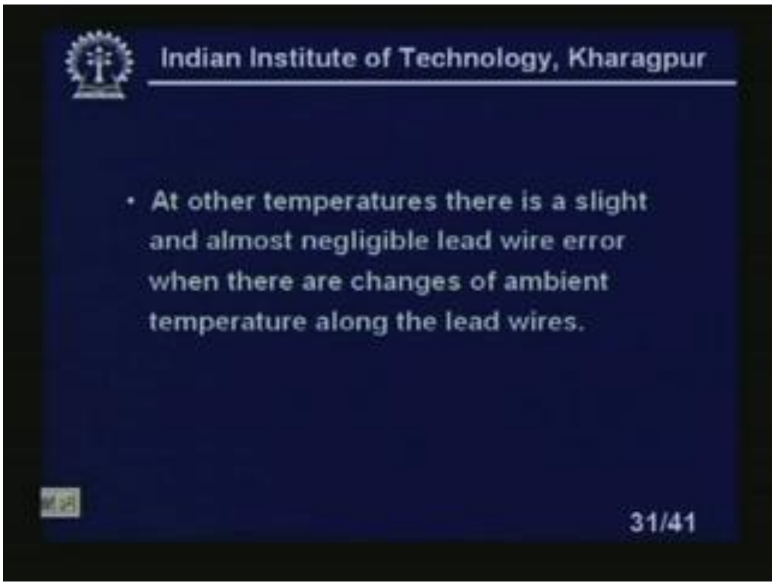
(Refer Slide Time: 38:15)



If the right side of the above equation is made unity, obviously then what you will get? I will get, if I, R t equal to R 4, right? If the right side of the equation is unity R t equal to R 4. Now, interestingly when this right side of the equations will be equal or right side of the equations will be unity, only the cases when my potentiometer at the mean position that means f is .5, so only at that position of our bridge balance we will find that the lead wire resistance can be totally eliminated.

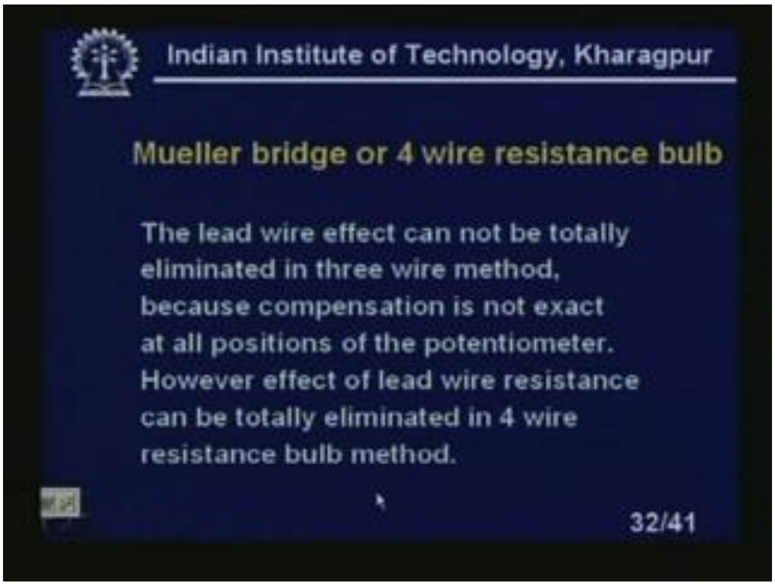
So, whatever the temperature variation of the lead wire, so we should not bother of, it is not coming in the bridge. But any other position of the, our jockey or of the, our slide wire or our potentiometer wiper, there will be the or any other position, then 50% there will be error, right? Therefore, the balance of the bridge is independent of the lead wire resistance only at one particular setting of the potentiometer R 3. At one temperature of the scale that is 50% of the, the compensation is exact and the resistances must be equal in magnitudes.

(Refer Slide Time: 39:23)



At other temperature there is a slight and almost negligible lead wire error, when there are changes of ambient temperature along the lead wires. Ultimately these are, if there is a change in ambient temperatures along the lead wires, I want to compensate it. This is not possible for all position of the bridge balance. So, only at 50%, but that is very quite ….. I mean, it is quite I mean funny. I mean you cannot expect that the bridge will be always balanced at 50% of its, I mean position, right? f should, cannot be always .5; can be any position.

(Refer Slide Time: 39:57)

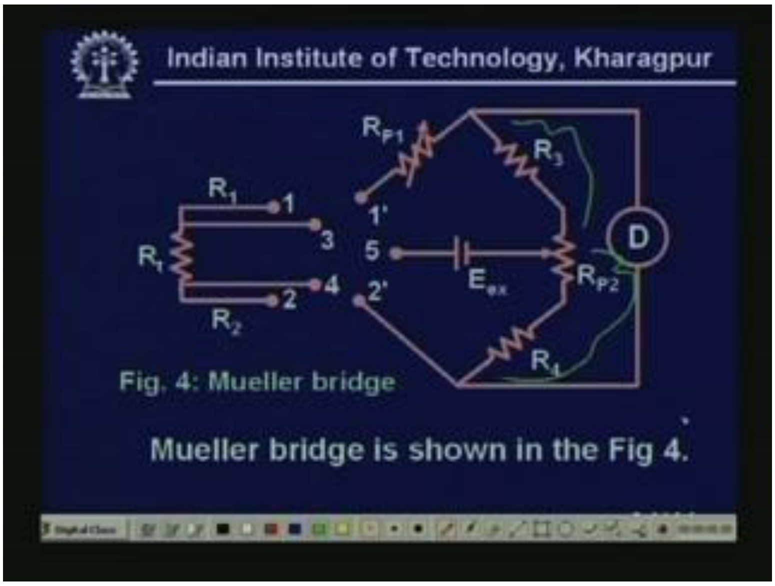


Now, Mueller bridge or four wire method is a method, where using four lead wires and the lead wire effect can be totally eliminated in this type of bridge. Even though it is cumbersome, but for precision thermometer this is the only alternative method and we have to use it for making the, our circuit. Both you are independent of the contact resistance, independent of the lead wire resistance. Self heating error will remain as it is. The lead wire effect cannot be totally eliminated in the three wire method, because the compensation is not exact at all positions of the potentiometer. However, the effect of lead wire resistance can be totally eliminated in four wire resistance bulb method.

(Refer Slide Time: 40:42)

Let us look at; the method involves switching the resistance thermometer bulb lead from one arm of the bridge to the other arm of the bridge, right? We will see how it can be done.

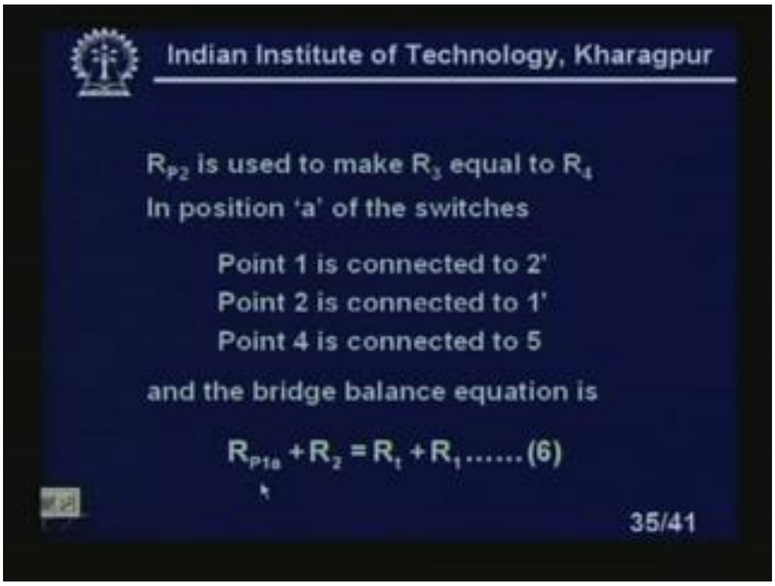
(Refer Slide Time: 40:54)



You see, this is our Mueller bridge. Mueller bridge is shown in figure 4. This is the Figure 4. You can see this is our four lead wires and you see that potentiometer is R p2 and R p1. R p1 is the, which, I mean, wire used to balance the bridge and R p 2 is actually, perfectly it is not used once it is set. It is used to make the resistance of the right hand side of the bridge. That means I want to make total R 3 that means R 3, R, total R 3 like this one. That means if I take, ….. that means I want to make this R 3 and this R 4 equal that means bridge, resistance up to this, it should be equal to resistance up to 3. Only then I can write the bridge balance equation. Only in that cases, only the lead wire resistance will be totally eliminated, right?

The excitation, we will find that what is the different connections and what is the bridge balance equation? So, in this case, we can totally eliminate our lead wire resistance problem. You see it looks like this.

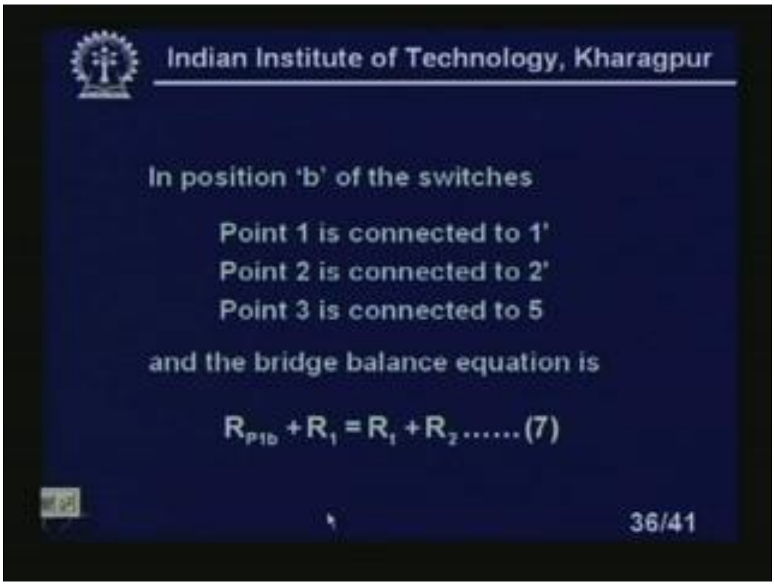
(Refer Slide Time: 42:08)



R p2 is used to make R 3 equal to R 4 in position ‘a’ of the switches. There are two different positions. Point 1 is connected to 2 dash, 2 is connected to 1 dash and point 4 is connected to 5, right? So, these are the different contact points, which will be modified and in the case of, right, so in that case, you see the 4 is connected to 5, right? So it is in the and my bridge balance equations will be like this one: R p1a that means at the switch position a, the value of R p1 this I am giving the name R p1a. What is that?

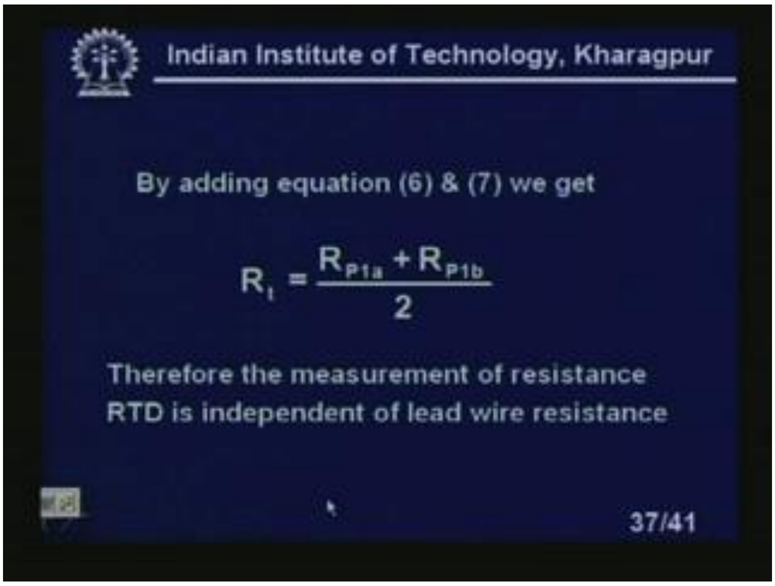
Again I am repeating, it is the, for the switch position a that means all this connection that means what are those connections? Connections are that I said that 1 is connected to 2 dash, 2 is connected to 1 dash and 4 is connected to 5. In that situations that I will, we will use, we will balance the bridge by varying the R p1 and suppose this new position is R p1a. So, R p1a equal to R 2 plus R 2 equal to R t plus R 1. This is equation number 6.

(Refer Slide Time: 43:23)



And in position 'b of the switches, we have changed the connections. We have changed the connection. Point 1 is connected to 1 dash, then 2 is connected to 2 dash and 3 is connected to 5, right? So, the bridge balance equation is R p1b plus R 1 equal to R t plus R 2, right. This is bridge balance equation.

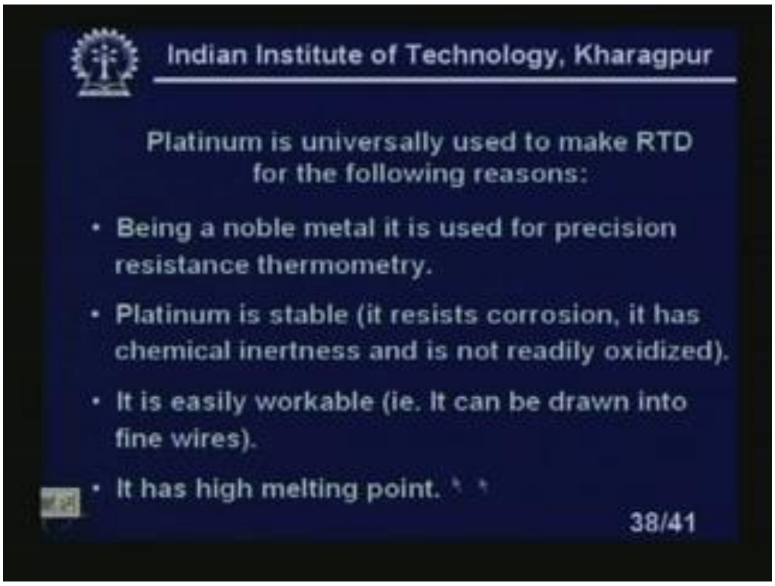
(Refer Slide Time: 43:47)



By adding equation 6 and 7, we get R t equal to R p1a plus R p1b divided by 2; R t equal to R p1a plus R p1b divided by 2, right? If I add, so obviously this will cancel and we can see that the, if I measure the bridge balance, I mean if at the two, I mean positions of the switches, if I can measure the value of R p1 that is R p1a and R p1b, I can totally and add and average it. So, I can totally eliminate the lead wire resistance. So, this is the beauty of the Mueller bridge, but there are many precautions. You see that it is suggested that the, all the resistance should be in a thermostat except the RT, RTD, so that it will equal resistance and all the lead wires should be of equal length.

If we can satisfy all these things, this is excellent thermometry mankind have so far developed. Therefore, the measurement of resistance RTD is independent of the lead wire resistance.

(Refer Slide Time: 44:48)



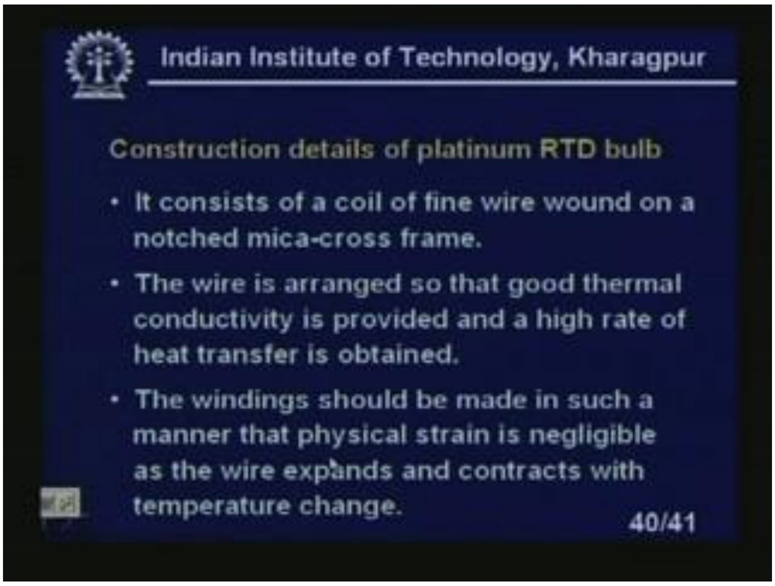
Now, platinum, as you know is universally used to make RTD for the following reasons: there are some advantages of the platinum, I mean which is now de facto standard, I should say of the platinum. Being a noble metal it is used for precision resistance thermometry. That means it does not, platinum is stable that is another important thing. It resists corrosion, it has chemical inertness and it is not readily oxidized. It is easily workable or it can be drawn into fine wires, because it is ultimately to make the wires, some of the RTD I have to draw it in wires, so it is possible. So, this is another advantage of the RTD, why we use the RTD, right? It has a high melting point; melting point of the platinum is quite high.

(Refer Slide Time: 45:32)

It is obtained in high degree of purity. This is another advantage of the platinum, the impure platinum, hardly we will get. So, we will always get pure platinum, because if the impurity comes, obviously it is, all these inertness, stability, everything will go away. So, if it is available in the pure form, so it will retain all this original property, which is quite obvious. Now, these desirable and necessary features however do not come without effort.

The resistance temperature relationship of platinum alters with little impurity present in the platinum. This is another disadvantage that means if there is, little impurity is there everything will be altered, right?

(Refer Slide Time: 46:12)



Now, construction details of the platinum RTD bulb - you see here the construction details. It consists of a coil of fine wires wound on a notched mica cross frame. We will show that. The wire is arranged, so that the good thermal conductivity is provided and a high rate of heat transfer is obtained. This is, another thing is necessary and the windings should be made in such a manner that the physical strain is negligible as the wire expands and contracts with the temperature changes.

This is a typical problem, because you see RTD is made of, it is not a semiconductor device, so that type of thing. So, what will happen? It is the metal. So it will have, if the temperature rises, the wire will be stretched. If the temperature falls it will be, wire will be contracted in length. So, if the temperature rises, already, so if already it is very tight manner, then what will happen? The strain will be developed. If the strain develops in the wire, then what will happen? It is as you know that, as we have in the strain gauges, this property is utilized to measure the strength, because if the resistance, if the, if the, if the wire is in tension, so its resistance changes, right, which is undesirable because we are not counting, we are, what we want?

What we want that the, our resistance change will be totally due to the change of temperature in the thermometer bulb only. That is the reason we have even did so much of the work - three wire, four wire method for the, the, to avoid the resistance temperature change due to the change of the lead wire. This is the number one thing. At the same time, we do not want that the change of resistance will be for any other factor. We want the change of the resistance should be totally due to the change of temperature, not for any strain or anything, right?

So, for that it is a different, a typical construction will be available. So, we have to use that type of construction for making RTD.

(Refer Slide Time: 48:23)

We can show here; the construction details of platinum RTD bulb is shown in figure. You see, this is our typical construction details of the RTD. You can see here, this is our mica cross, you see this is our mica cross. This is the mica cross, right? This is mica cross here on which the RTD wire, it is wound on like this one in the coil form so that it will have a least amount of, I mean strain developed while the temperature rises. We have evacuated space, the mica crossing. This is another problem with this mica crossing. The mica crossing also limits the temperature of the, high temperature …...

Even though it is hardly used above 650 degree centigrade and this is the platinum coil. This is our platinum coil, this is evacuated space and the whole thing is put in a stainless steel, so that it will be, can prevent the, prevent the any outside environment to react with the, even though RTD is quite inert, but in the case, suppose we are using other type of nickel, copper or tungsten type of things, so it should be protected from the environment; it should not react with the environment.

Now, all this thing whenever using, you see one thing is very obvious, RTD is not for dynamic temperature measurement. That can be only utilized for, you can use it either thermocouple or thermistor is the best, because thermistor time constant is, I mean very slow. We have seen that if we increase the time constant of the systems, once you put a RTD inside a sheath material like this one, so what was the, what is the effect? It will increase the time constant of the system that it also very undesirable, right? But for steady state temperature measurement it does not matter. Suppose it will take 2 minutes to come to the steady state condition, it hardly matters.

One thing is quite obvious, whether you are using thermistor or RTD, it does not matter, once you use a, I mean you balance a bridge. So, in that type of situation, you cannot expect a large, I mean small time constant. There will be a time, sometimes it is necessary to balance the bridge, but if I use it for any dynamic measurement, suppose in the case of thermistor I will take, instead of making a, the bridge balance I will take the unbalanced voltage, so that unbalanced voltage I will calibrate.

I will convert in current domain and I will calibrate in terms of temperature. That is quite obvious. But in this case what will happen that you see, in the case of RTD, it does not matter, even we use, even if we use an unbalanced voltage to make the measurements, so what will happen? You see that this, if you put inside a sheath, then what will happen that your temperature, if your, if your temperature changes, so rapid temperature changes, I cannot measure it by this type of equipment. In that case, what I will do? I will simply use some other. So, it is not very used for dynamic measurement.

It is used for, I mean steady state measurements or very slowly varying temperature measurements, right, ….. rapid measurements in some situations. You see, any process you please note that the temperature measurement is not very, I mean very rapidly measured. In the case of bioreactor suppose if the temperature is very slowly measured, in that type of situations you will find that it, you need only few minutes. I mean you sample the ……, you measure the signal suppose every 6 degree centigrade or 10 degree centigrade, not more than that, not more frequent than that that is most of the cases suffice. In some situation, say rapid temperature changes also necessary to shut off. Suppose, I mean, I mean very frequent temperature changes also measurement is necessary, especially where the safety problem is there, where you have to shut off the power supply or fuel supply to the boiler, so that type of situations I need some rapid temperature measurement.

So, it is, I mean in the and that type of situation, obviously people will not, will not use RTD, right? Shut off means it is basically the, any, any protection measurement means on, off type of measurements, I have to shut off everything. So, that is on off type of measurements. In that type of on, off control so I do not need that precision measurement, so it will limit ….. Suppose some, suppose 500 degree centigrade, I have to shut off the power supply or fuel supply to the systems, I have to supply the, stop the supply to the heating coil and all those things that can be easily achieved with some other temperatures and not for RTD. But RTD needs very precision measurements and only problem is the self heating error.

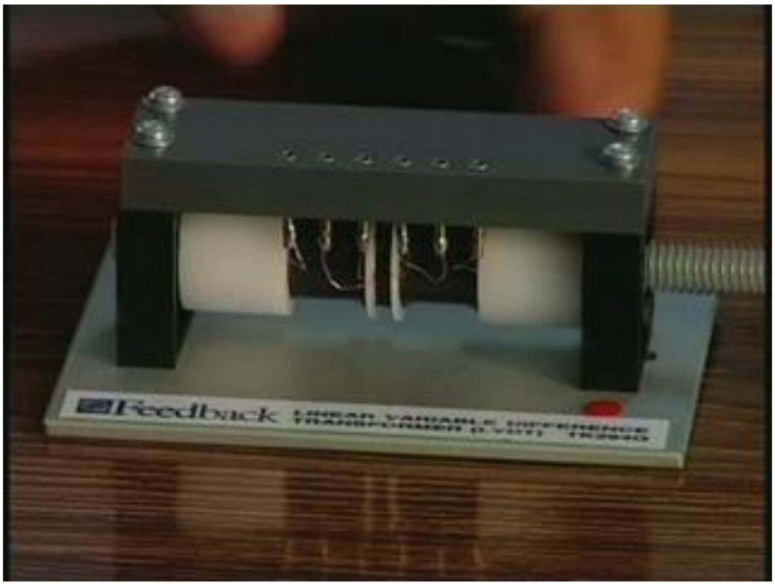
Other things can be easily resolved like four wire and all these things and it can be, that is nowadays very standard. Please note that ….. RTD is, is used in the industry; …. RTD is to be used with the transmitter itself. For all, whatever the unbalanced voltage you are getting, so for the standard RTD, I mean transmitter is there. That is utilized to make your measurement further. That means it will convert that voltage, unbalanced voltage in the current domain and that can be utilized to control, because that is to be again converted to the digital domain, because the signal which we will get in analog and that is to be fed to the computer through the …. chord and our signal will come out of the ….., convert in the current domain, transmit. Again at the receiver side you convert in the voltage domain, then you use it to some actuator, right? Some action is to be taken and on the final control elements valve is to be operated. So, this is all about your RTD, one of the most accurate temperature sensors.

Preview of next lecture.

Good morning! Welcome to the lesson 10 of Industrial Instrumentation. In this lesson, we will study LVDT. The full form of LVDT is the linear variable differential transformer. It is basically an inductive based sensor or inductance based sensor and primarily it is used for the measurement of displacement. However, I can use it for measurement of pressure and other process parameter also. In this particular lesson, we will consider the, lesson I mean the basic concept of the LVDT, its circuitry, its signal conditioning circuits and its basic constructions and how will you design an LVDT? These are the basic things which we will discuss.

Let us go to the instrumentation lab of IIT - Kharagpur and have a look on the LVDT.

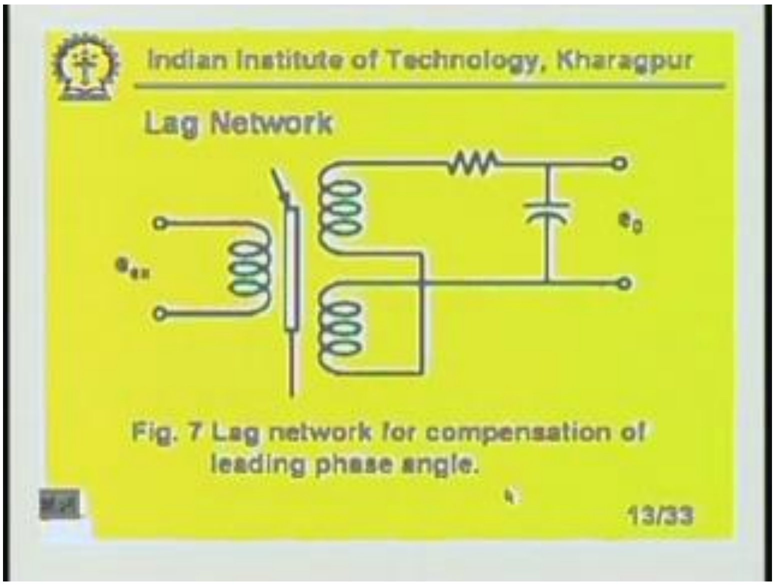
(Refer Slide Time: 55:32)



You see here, this is an LVDT - linear variable differential transformer. It has one primary and two secondary. The secondaries are usually connected in opposition to get a null position and …. after doing the phase sensitive demodulations, I can sense on which side of the, which side of the null position my, the core lies? You see here the core is there, soft iron core which will move like this, which will move like this, so and I am moving, I mean it, it will move like this and since, there are two secondaries, what will happen if you put in opposition? Obviously, you will get some output voltage and at null point it is at the, exactly at the null positions the two secondary coils will be, output voltage will be nullified and I will get zero voltage. At any position other than that will give you nonzero output voltage. So, LVDT already we have discussed in details, so this is actually pictorial view of the LVDT.

Welcome back to our classroom again. So, the lag network, as I told you, we need some lead and lag networks. So lag network look like this one.

(Refer Slide Time: 56:49)



You see, this is the phase, this is the circuit if there is a, there is a lagging phase angle. If there is a, phase angle is lagging, in that situation we will connect … This is our lag network. So, it will kill the lag and it will have, the output voltage will be in phase with the input voltage. It is not very important, in most of the cases we will find, right? So, this is the lag network for compensation of leading phase angle.