Industrial Automation and Control
Prof. S. Mukhopadhyay
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 4
Temperature Measurement

Welcome to lesson 4 of the course on industrial automation and control, so today we are going to look at temperature measurement temperature is a very important quantity. Especially, in the process industries all big process plants like you know chemical plants steel plants they, for them monitoring of the temperature is very important, so we will see how these measurements are done both in the online and the offline case.

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Looking at the instruction objectives the first one is of course that there are various principles of operation of the different temperature sensors. So, thus student will be familiar with that, here she would all will be able to describe the various you know signal conditioning aspects as we have already discussed. That measurement involves transformation from one variable to another till the measured or the variable of interest comes in to an electrical form that can be used very easily.

So, for that you need signal conditioning and processing and they are specific to the kind of sensor that are used, so the student will be used to describe the signal conditioning aspects. Then the major applications of each sensors the situation in which these can be used and, finally they will be able to explain the comparative merits and demerits and will be able to hopefully. They will be able to make an intelligent choice of the of a sensor given a given a practical situation, so these are the objectives of this lecture, so we come to temperature measurement and why it is needed.

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It is needed for various purposes firstly it is needed for control typical example would be a heat exchanger. So, in a heat exchanger we want to control the temperature of the, in a heat exchanger there are generally 2 streams, one stream which is called the cold stream which is getting heated and another is a hot stream which is heating. So, generally we need to control the outlet temperature of the cold stream, so for that we definitely need a temperature feedback and that will involve temperature measurement.

Similarly, for a reactor because most of the chemical processes the reaction rate and the pressure inside the reactor these are all you know related to the temperature. So, the temperature is actually a very important quantity to monitor and measure for reaction control. Similarly, for supervisory control you know there are, for example suppose you want to roll a hot steel bar, so you are going to actually pass the bar through two heavy rolls, which will press and flatten the bar in to a thinner piece that is called rolling.

So, it turns out that obviously the rolls are going to going to experience a lot of force they are going to push the bar. So, that it gets flattened now this how much force is actually required depends critically on the temperature of the bar. If the, if the bar becomes too cold then the, then an undue amount of load will come on the rollers and which may also break, in fact this is happened, I am, I am, I am personally aware of situations where this has happened. Basically, because the operator before he was trying to move the bar in to the rolls, he there was, there was, there was no temperature sensor which could tell him.

That is this bar is suitable to be rolled its temperature is beyond the certain minimum value, so he was pushing any bar through the roll. So, that was creating sometimes creating tremendous force on the roll because the bars were cold and the rolls were breaking. So, this is supervisory and operator controls operators many times perform operations looking at the temperatures for that you need temperature measurement, temperature measurement is very much needed for safety as well as energy efficiency.

Energy efficiency is actually a very critical task because large thermal processes take a lot of energy and much of the cost of the production comes from, comes from the energy cost which is rising all the time. So, one need to ensure that heat is not lost it is optimally utilized, so for such purposes temperature has to be monitored at various places on the plant. Similarly, safety because temperature is often related to pressure and other things, so I mean a very high temperature may lead to burns it may lead to over pressure it may lead to explosions it will lead to various things.

So, safety and energy efficiency for these purposes temperature measurement is needed, similarly the temperature measurement may be needed in a variety of applications. So, for example a variety of ranges below hundred degree below 0 degree, above 0 degree, several 100 degrees at various accuracies at various resolutions. In various kinds of you know environments some of them may be inert some of them may be oxidizing some of them may be reducing some of them may be corroding.

So, these are there are various kinds of application features which 1 has to keep in mind when 1 selects a temperature sensing, since we are talking about control and, since this course is mainly about control. So, one has to also mention that and remember the temperature measurement generally involves time constants because it involves thermal time constants of various things including the sensor.

So, there are the thermal time constant of the plant is there, but sometimes if you assume that the temperature measurement temperature sensing is going to be instantaneous. Then that is an error because in many cases the sensor itself, I mean contributes nontrivially to the overall time constant and that can affect control performance.

Similarly, non linearity there are sensors which are highly non linear and one has to keep in mind apart from that fact it also effects accuracy there could be noise associated with temperature sensors also. Basically, noise sometimes comes with if you are trying to measure temperature in a flowing fluid because of flow turbulence and other things. So, having said this as the introduction, let us look at the various temperature measurement strategies.

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So, you can divide them in to basically two parts, one is contact and other is non contact, so in the contact part the thermometer usually comes in contact with the medium at which you want to measure the temperature. So, for example simplest ones are expansion thermometers either solid expansion or liquid expansion or gas expansion thermometer. So, you have in solid you have these bimetallic thermometers in liquid you have the well know liquid in glass thermometers generally there is, there is spelling mistake here.

Generally, we have mercury in glass sometimes we can have, you know ethyl alcohol in glass and things like that we have gas and vapor thermometers. Other than that, we have I mean generally resistance variation is a very standard phenomenon resistance variation with temperature which we utilize for temperature measurement.

So, we have generally have 2 kinds of sensors here one is called a thermistor which is actually a semiconductor resistance and the other is a metallic resistance like resistance temperature detector. So, we are going to look at these two, apart from that there is something called thermocouples which basically rely on the, on the fact that thermoelectric E M F are generated. When one of the junctions of two similar metals are put in to a high temperature, so that EMF is measured and used as an indicator of the temperature of the so called measuring junction, we will, we will look at all these.

Similarly, among the non contact types we will look at the radiation pyrometer which basically does not directly get in to the mediums always. But, sometimes can take the radiation out from the medium may be through a window or through an aperture and then that radiation itself is used for sensing the temperature, so such things are called radiation pyrometers.

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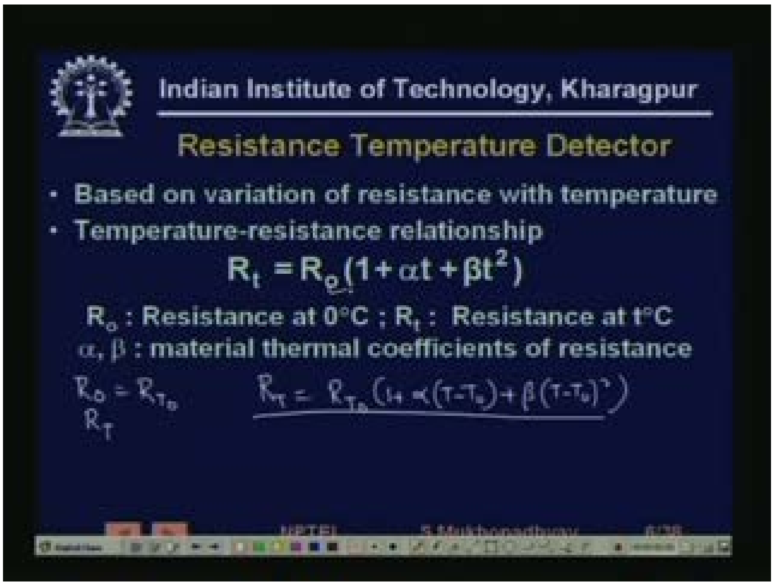

Let us start with resistance among these classes the so called expansion thermometers are we are going to put less stress on because they are not they are generally used for used as indicating instruments and so much used for control or automated monitoring. So, therefore we will begin and put more stress on the resistive temperature sensors and thermocouple. Because they are easily integrated with the control and automation equipment coming to resistance temperature detectors, these are simplest, these are basically metals and we know that resistance of a metal varies with temperature.

Although the temperature ratio, I mean if the temperature relationship can be quite complex, but it is generally sufficiently accurate to model it as in by this form in which. So, R t this t is actually a temperature difference, so you see we are writing R 0 is resistance at 0 degree centigrade, it is not always necessary to make it at 0 degree centigrade you could have it at some R t 0. So, if the resistance at temperature some T 0, in this case we have assumed 0 degree centigrade is R 0. If the t is the temperature difference between the, between this, between the temperature at which you want to know the resistance suppose this T.

Then t is equal to we can also have this is this is a generalized you know if the special case where R 0 is assumed at 0 degree centigrade. But, in general you could have R 0 is resistance at you can write it as the R T 0 and R T then you will have the formula R T is equal to R T 0 into 1 plus alpha into T minus T 0 plus beta into T minus T 0 square. This is the general form, in this case since we have assumed T 0 to be 0, so it is coming to be this form.

So, this t is actually though it is said that its resistance at t degree centigrade, actually this t stands for the temperature difference between this one and this one. So, in other words it is sufficiently accurate, so in fact this coefficients of alpha and beta if you see they are actually constants.

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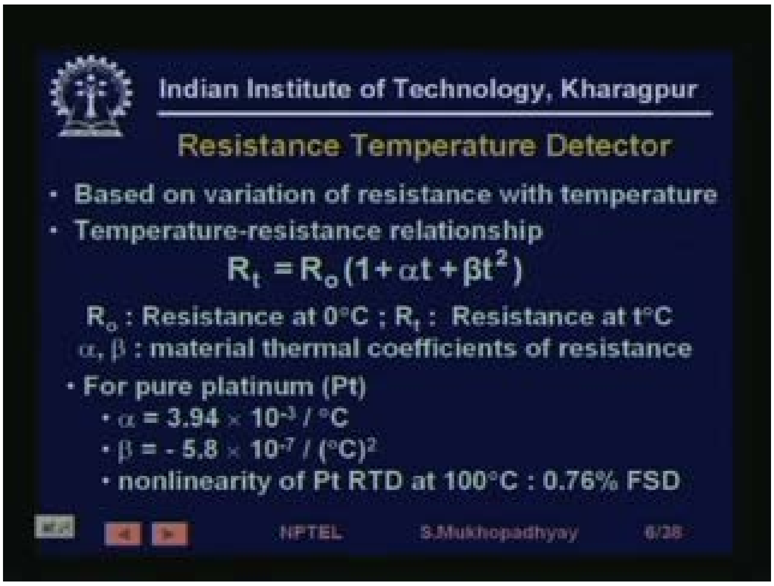

For example look at look at the, look at one of the metals which are typically used is platinum see that beta is actually very small, very small and beta comes in to play only at very high temperature ranges. Otherwise, compared to alpha it is about ten to the power minus four times small, so therefore it is the response if you if your temperature range is not too large then the response is largely linear. Well, you can always compensate for that and, therefore it is for this reason that these sensors are very popular and they can be used as more or less you know linear sensors except in certain metals like nickel.

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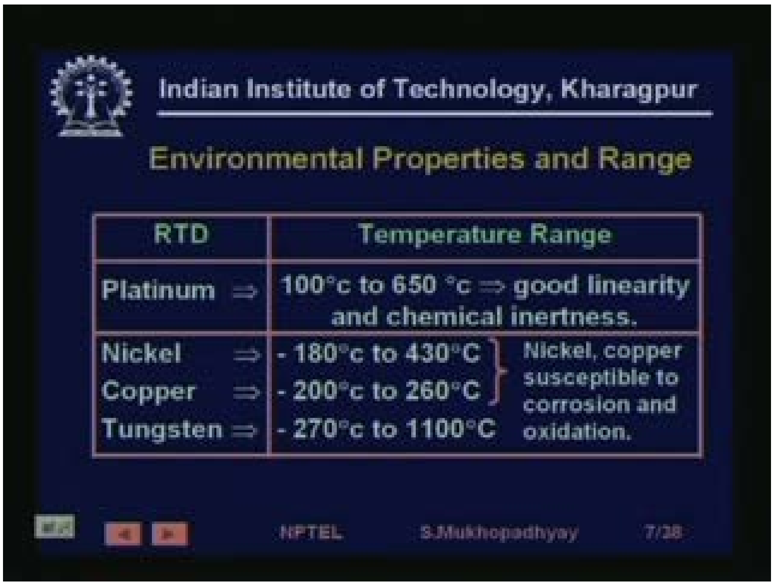

So, typical metals which are used for example are platinum nickel copper and tungsten and they can be used in various ranges, basically depending on environmental conditions depending on melting points of the metal etcetera and you get quite good linearity.

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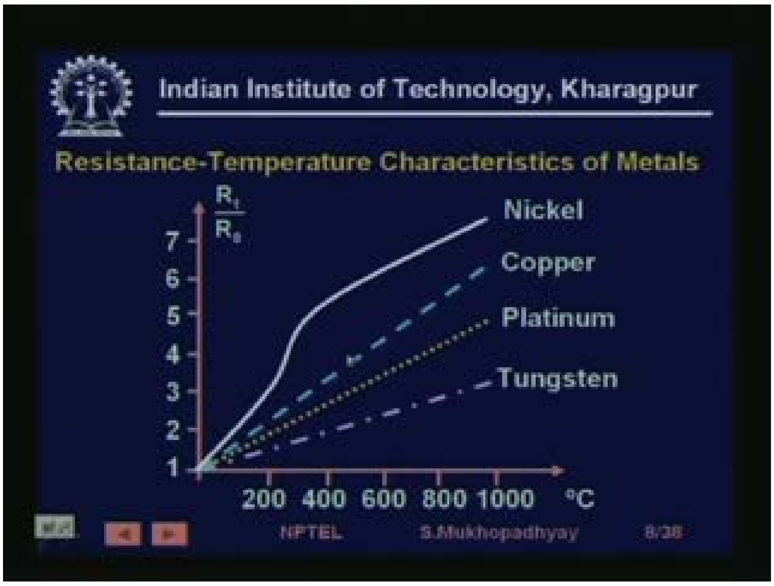

For example, if you see the resistance temperature how the resistance ratio increases then you will find that for copper platinum and tungsten. They are more or less linear while for nickel it is somewhat non-linear although it is the most sensitive. Then of course nickel and copper are much cheaper than platinum, so therefore except in critical applications where you really need to know the temperature accurately you do not use platinum.

For example, in most of the air conditioning applications you know this building air conditioning applications people generally use nickel RTD because of the fact that is the cheapest and anyway the application is not. So, critical it does not demand a very high level of accuracy range is also, range of temperature variation is also small, so in that range nickel can be assumed to be linear.

So, if you want, so you have a resistance here whose resistance you have an element whose resistance value changes with temperature. So, now how are you going to generate an electrical signal out of this resistance value one of the one of the simplest things that we have seen.

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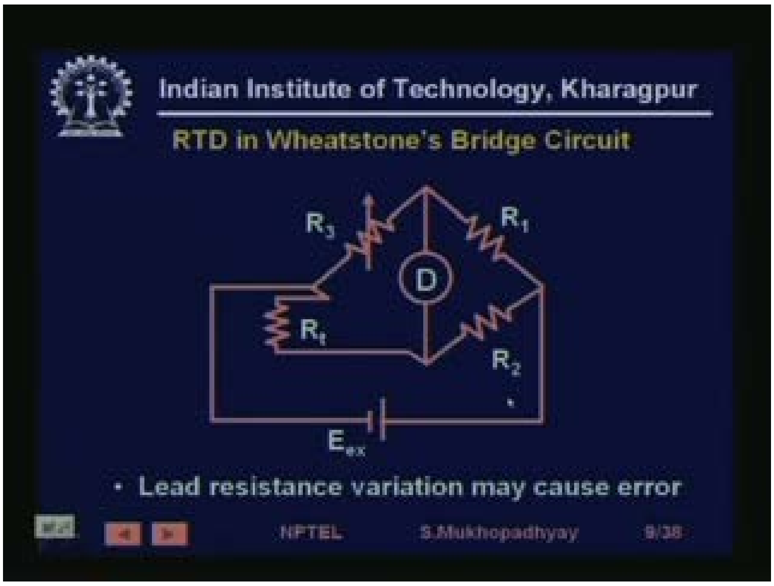

To convert a resistance value to a nearly proportional voltage value is the Wheatstone's bridge it is the D C Wheatstone's bridge which looks more or less like this. So, it is well known and I am not going to cover this, here that this detector voltage across the detector for small changes in this R t which is the sensor are going to be proportional to the resistance change. Now, here note that although it looks like this resistance is drawn in a slightly different way just this is just to emphasize the fact that while these actually, this bridge will be possibly somewhere in the control room.

So, from the control room two long pieces of wire and they are those two pieces of wires will actual go to the field and connect the R t. So, these are actually long pieces of wire which is which must be realized these are called the lead wires. Since, they go through various places, so temperature can vary along their path and the resistance of these lead wires can also change. As far as the detector is concerned, the detector is going to interpret that as a temperature change, so this is called the lead wire error, which can occur.

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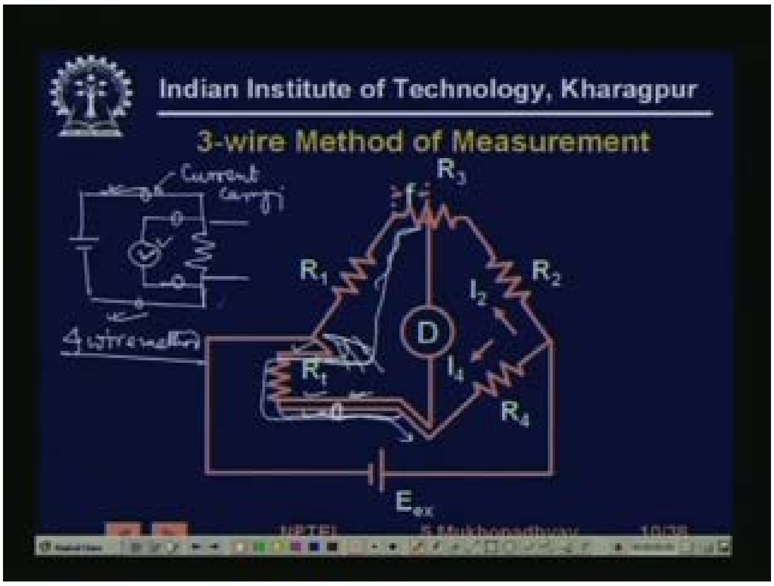

So, to prevent this, the standard strategy is to, is to go for a 3 wire method of measurement, you can go for a either a 3 wire method or you can go for a 4 wire method. In a 3 wire method, the principle is simple, the principle is that see you have 4 wires this, this and this, so actually what happens is that the current look at the current flow path the current flow path is through this path. So, that flows through this one, while the detector actually senses the voltage across these two.

So, what happens is that this lead resistance this lead resistance is variation that is if there is a variation across this lead resistance that does not affect it. So, similarly you could have 3 wires or you could have 4 wires RTD where you could again run another piece of wire from here you knows. So, now if you could if you have if you have 4 wire RTD then you could have a very simple circuit that is you have a battery and you have an RTD here, so you have 4 wires and you have 2 wires, here you have the voltage.

So, you see that through these wire, these wires are also long these wires are also long, but they are the current carrying wires. So, these are also long, but they do not carry current because this is the voltmeter, so it is a high impedance thing. So, therefore, you actually sense the potential across the resistive element only and not on the leads. So, if you have a four wire RTD then you can use this circuit this is the 4 wire method, so by these methods you can actually take care of the lead wire problem.

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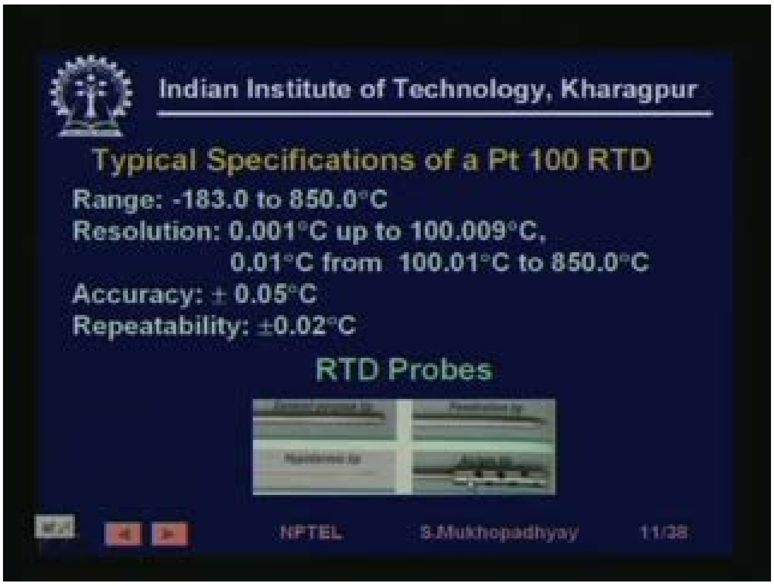

Let us look at a typical specification of platinum RTD, this is just to show, this is just to show that you can get, you can get a very accurate sensor. See, the error is plus minus 0.05 degree centigrade over this range and the repeatability is 0.02 centigrade. This is, this is another very great thing about platinum is that it is a noble metal it is not, it is not degraded easily and it is possible to obtain it in very high purity and it is interchangeable.

That is if you take ten readings you will get the same readings and even if you replace the sensor by another so called identical sensor you will really get an identical performance. So, that is very important thing in the industry for which it is used just to give you an idea the RTD are, actually these resistance are actually put inside probes and we will show how they are put inside probes.

So, these are various kinds of probes are available, s you should, so you know if you have, if you want to measure temperature of air or gas then you need to ensure that the flow fluctuations do not cause temperature fluctuation. So, you actually put the probe, I mean outside you put a, you put another cylinder with some holes such that the, such that the fluid inside it which whose temperature is actually sensed that is not so much effected by the flowing fluid.

So, that is why you have when you are trying to measure the temperature of air or gas you have these kind of probes. If sometimes you like to penetrate the probe into something and measure the temperature inside or you could have a general purpose tip which is just fixed to the medium.

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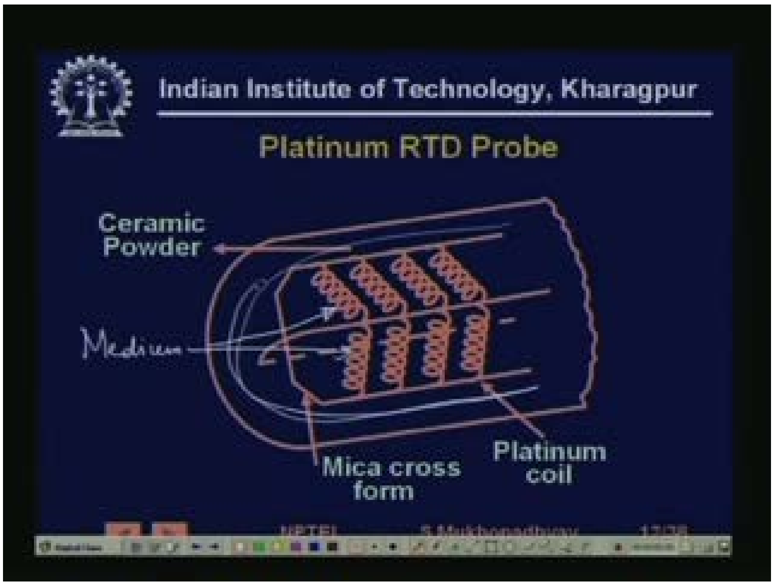

Inside the probe the arrangement is like this that you see you need have you need to increase the resistance right to about 100 ohms. So, you need to have very thin wires and you need to have very long wires, so the thin and long wires are actually arranged like this, so they are coiled coils. So, there is a, there is a, there is a former which is like this, so on that this thin coiled coil is wound and it is and the important that it is not, it is not stressed because if it is stressed then it may tear.

So, stress it is neither stressed by expansion etcetera and then you need to ensure that you have very good conductivity between this is here is the medium. So, the heat must flow through this space and then reach these elements, so for that you need to fill this element with good conducting material sometimes you use ceramic powder. So, this is how it looks like inside, so this is about the RTD it is a very simple instrument, the next one is the thermistor.

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The thermistor is a, is actually a temperature sensitive semiconductor resistor, so they typically have negative temperature coefficient which is interesting. Although, there are positive temperature coefficient thermistors are also available, but they are less used the advantage of thermistor is that the resistance change is very large. So, you get great sensitivity, but it works in a small range after that you know semiconductor material, so cannot, so withstand too much temperature it is also very non linear that is it, that is a drawback.

But, it has very small size and, therefore it has very small thermal inertia, so it can measure very quick temperature fluctuations and can reach various you know small places. So, that for that it is used it is generally made of oxides of manganese nickel cobalt kind of materials and it is available its actually you know you make a paste kind of thing. Then on a piece of wire you connect you make lumps of that paste and then you connect it on the wires and then you, then you center, so if you center it then this piece of material on the 2 wires they actually form the thermistor.

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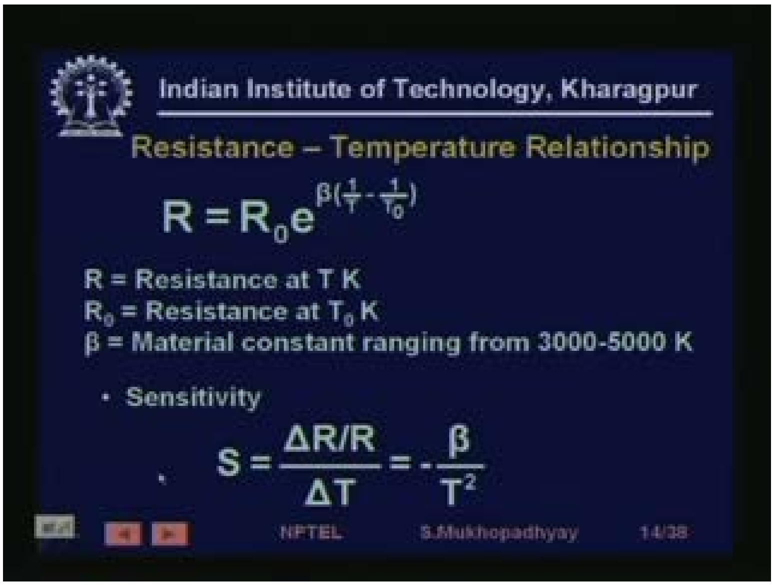

So, if you see the resistance temperature relationship it is highly non linear, as you can see it is an, it is an it is an exponential relationship and R is again resistance and some T, degree T degree Kelvin R 0 is resistance at some T 0 degree Kelvin. Therefore, this is denoted like this and beta is called the thermocouple material constant varies with from 3000 to 5000, we generally take it as 4000.

If you differentiate this that is find delta R by R divided by delta T that is percentage change in the resistance for unit change in the temperature. You get this expression which shows that the sensitivity changes drastically with temperature, so at low temperature it has very sensitivity which quickly comes down and becomes flat.

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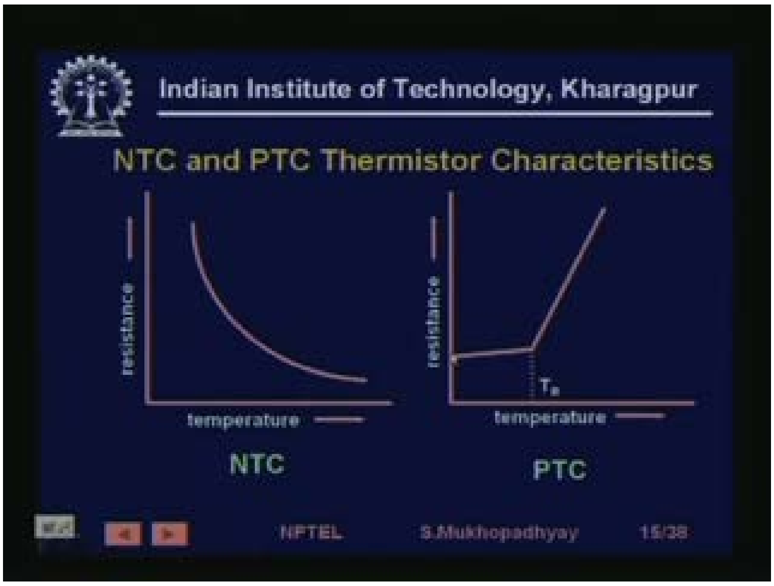

So, here you have the sensitive characteristics are shown, so the resistance temperature characteristic this is just a form we are not drawn into scale. So, for negative temperature coefficient with temperature the resistance comes down and for PTC or positive temperature coefficients to some temperature it stays at a lower value. Then suddenly increases, PTC are generally used for you know for switching applications they generally not used for measurement, since it is a resistance it can be again put in the Wheatstone's bridge and it turns out that.

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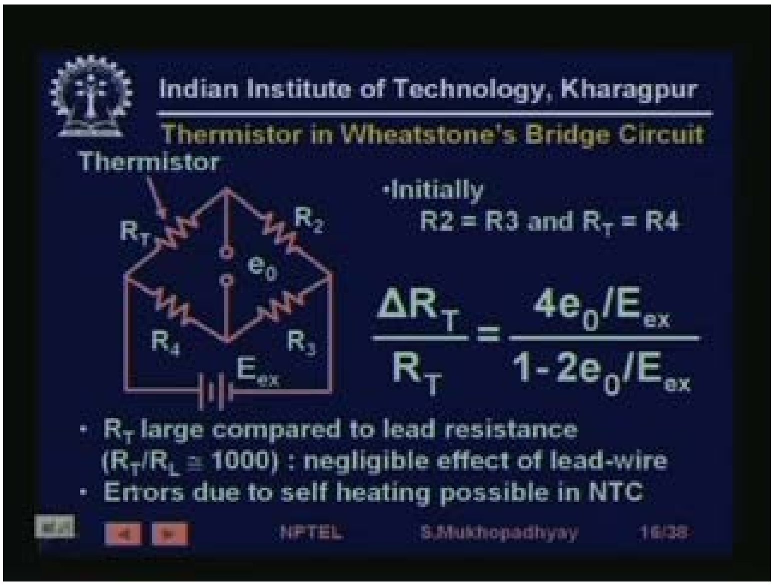

You can derive this expression delta T by R T which is the percentage change in the resistance is given by 4 e 0 by ex in to 1 minus 2 e 0 by ex, so if you get e 0 these are all constants. So, what happens is that, now you know that you know the beta by T square, so from here, so this is what you can sense. So, from e 0 you can sense this delta R T by R T and then based on the based on your sensitivity you can, you have to find out what is the temperature for small ranges.

That is when the overall temperature T does not change too much minus beta by T square can be assumed to be constant then that case the percentage change in resistance is proportional to the temperature. In this case, there are certain advantages, for example the resistance the resistance itself is much larger compared to the lead resistance and its change is also quite large. So, therefore the effect of lead wire resistance variation is not very is very negligible here not as significant as in RTD.

But, on the other hand there could be self heating error you see self heating error typically occurs much more in negative temperature coefficient thermistors because when current flows through this. If a, if a significant amount of current flows through this it will cause heating, now as it will heat that will bring its resistance lower when its resistance becomes lower then more current flows and more heat is generated.

Now, this situation can actually run away and continuously the temperature of the thermistor will increase, so you will get a much erroneous temperature. Then, finally the device may burn, so it is needed to ensure that the current does not go beyond a certain level in the N T C thermistors.

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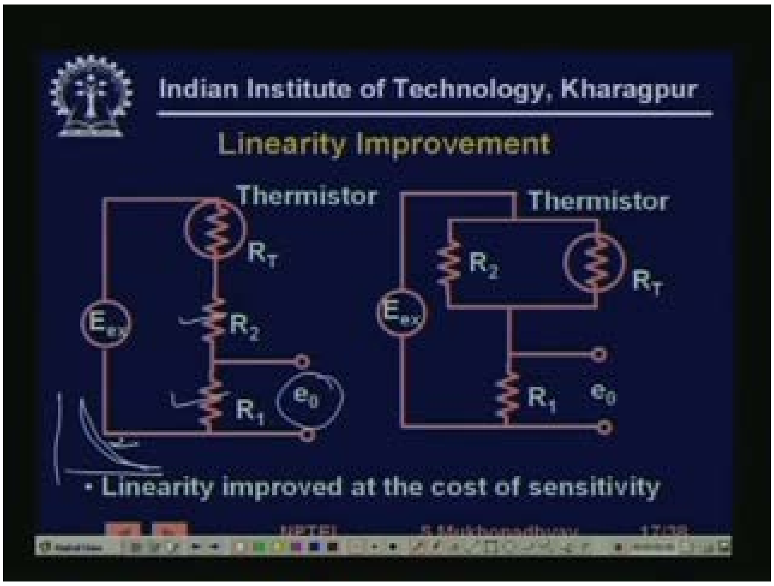

There are certain, you can actually connect certain amounts of resistances in you know circuits like this which are called linearizing circuits and then tune this R 1 R 2 values such that over a range this combination resistance. That is, this e 0 will be, e 0 is going to be linear with T, so you basically, you in this in this equation you have RT is known I mean the variation of R T. So, you have R 1 and R 2 unknown, so you based on linear variation you try to ensure you choose that the values of R 1 R 2 such that you get the e 0 values on a, on a, on a linear curve for this thermistor.

So, there are if you put that then over that range it is it will it is expected to be roughly linear. So, linearity is, but at the same time you must remember that linearity improvement is at the cost of sensitivity. This you can easily check by simply putting a resistance R across R T fixed resistance R across R T you will find that the that the short variation of that the short variation of fall of resistance will become much more linear. But, you will also feel no that the, that the sensitivity has changed, now for unit temperature change the resistance does not change by so much, so you are you could you can gain some improved linearity at the cost of degraded sensitivity.

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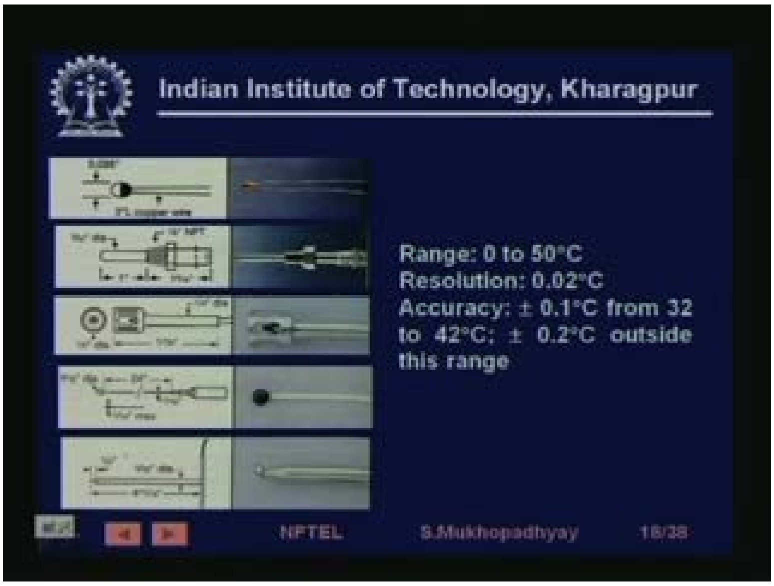

These are you know some of the RTD probes thermistor probes, so you can see again same thing, a gas probe again with a head and these are you know, these are, these are exposed RTD beat thermistor beat. You can have various kinds of you know probes, here you will find that the if you if you compare these values then you will find that. Firstly, you will find that the range is much smaller the resolution is good very much, but the accuracy is much degraded compared to the RTD, so these are the characterizing features of a thermistor.

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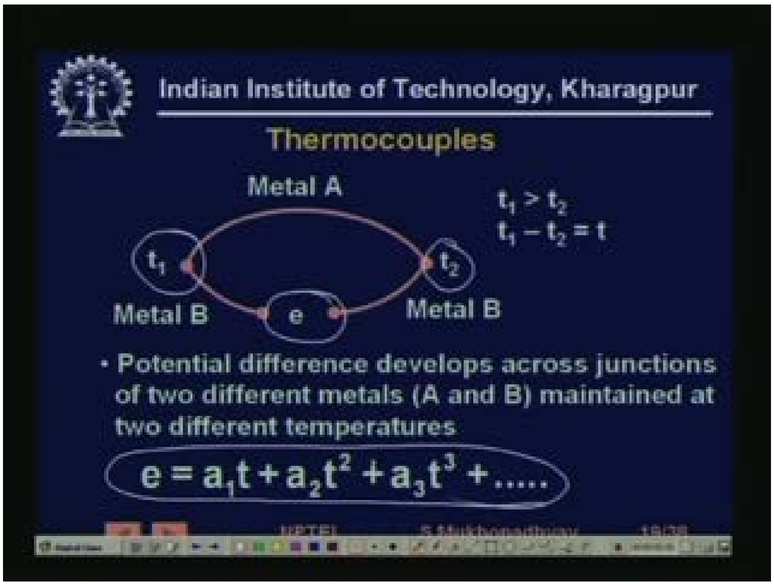

So, here are these two resistive sensors, one is metal resistor another is semiconductor resistor and you basically use Wheatstone bridge and they have, you know they have trade off regarding sensitivity linearity range etcetera. After that, we come to thermocouples, which are based on the principle that if two metals, so you have metal A and metal B. If they are joined at these two points and if these junctions are maintained at and if the, and if the, and if the junctions are maintained at temperature t 1 and t 2 then what happens is that here you will get an E M F.

This effect is called the Seebeck effect and this E M F that is generated can be related by some polynomial like this and people use seventh degree, eighth degree polynomials to catch this resistance variation. This E M F variation this is called a thermoelectric E M F or thermo E M F, so you see by sensing this E M F you can actually sense the temperature the advantage of these I am sorry.

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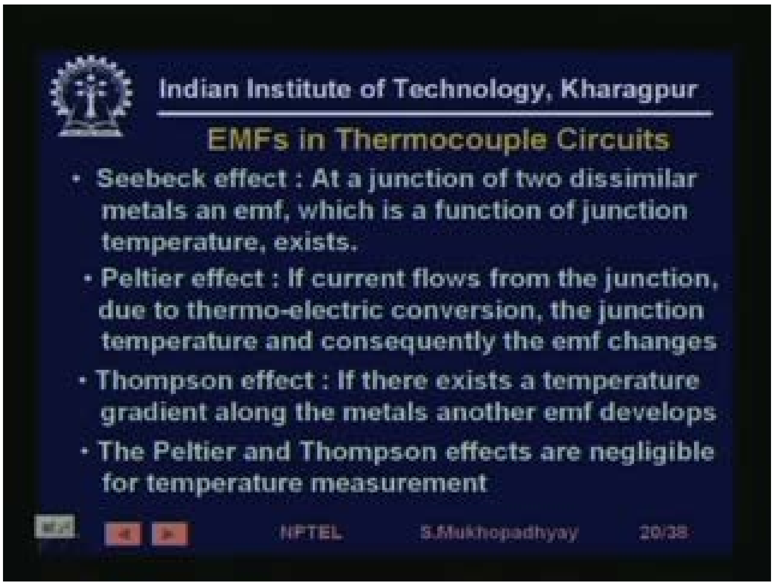

There are actually there are three kinds of E M F strictly speaking from a, from a, from a physics point of view. There is one called the Seebeck effect which is the basic effect which is used in the temperature measurement, which says that at the junction of two dissimilar metals and EMF which is function of the junction temperature difference actually exists. It is a function of junction temperature, so now if you have two junctions at two dissimilar temperatures then there will be two different valued EMF. So, there will be a potential difference across these two points, so this is the idea, but there are two other effects associated.

One is called a Peltier effect which it comes in to play when the current flows through the junctions and do the thermoelectric conversion process. The junction temperature may get changed slightly and because the junction temperature changes slightly again by due to the Seebeck effect the E M F can change slightly. So, the Peltier effect can affect the measurement although it does negligibly because hardly any current flows through a temperature measurement junction because they are usually connected to very high impedance point on a meter.

So, Peltier effect is generally negligible, similarly you have Thompson effect which comes into play if there exists a temperature gradient along the metals. Then if you have then you have another E M F which is developing, but this is also not so important. So, therefore for the case of temperature measurements Seebeck effect is the, is the main effect which we are going to look at.

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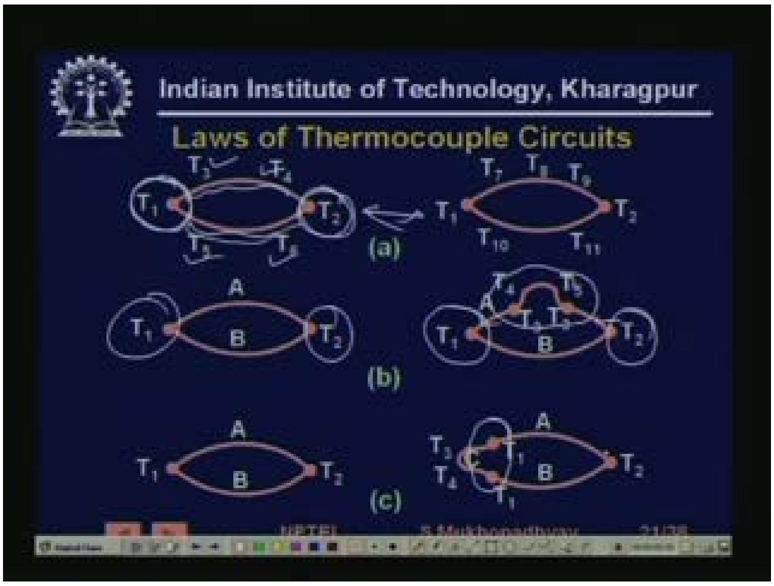

There are various laws of the thermocouple circuits which make the thermocouple a very useful instrument. For example, the first three says that it is only dependent on the junction temperature for T 1 and T 2 even if there is T 3 here T 4, T 5. Here, this arbitrary temperatures can exist here as long as the junctions are at T 1 and T 2 then the E M F is going to be the same, so these two cases will give same E M F. Similarly, it says that even if you connect a third metal here and the temperature here can be here anything, but still if you have here.

If you have A here if you have A and this is B and if you maintain them at the same temperatures T 1 and T 2 then you get the same E M F across the loop that is also another point. The third point says that third point is basically a similar thing only thing is that you are now opening out the junction itself, so rather than having a junction you can have an extended junction. So, you can call this one as the junction though it is not a physical junction is actually through another metal arbitrary metal even then the EMF is the same.

So, the insertion of an, of a, of a metal and we need to bother about as long as we keep the junction temperatures the same. We also need not bother about the temperature gradient across the wires we only need to bother about the temperatures at the junction points. So, that makes measurement much easier because if we had to maintain the temperature all across the wire then it would have much more cumbersome.

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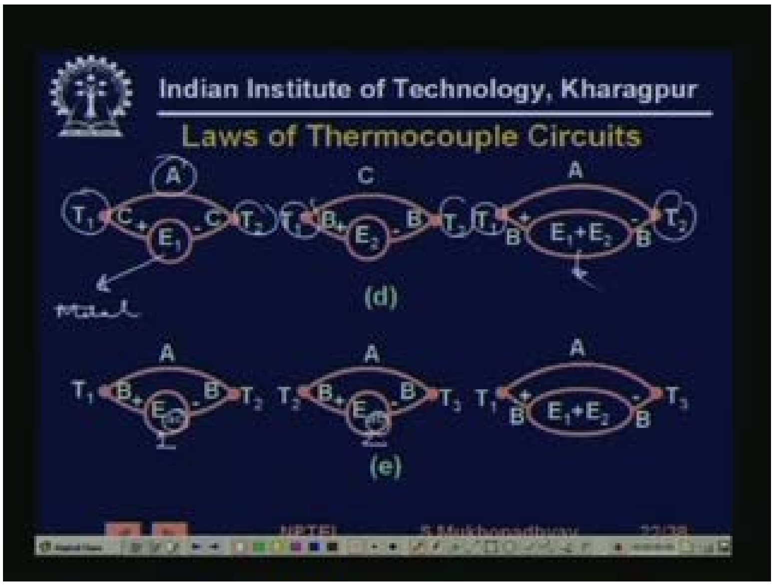

Next say that the measurements are, so you have two rules one is called the law of intermittent intermediate metal and the, and the law of intermediate temperature. So, it says that if you have between A and C when you maintain them see three cases, you have the same temperature T 1, T 2, T 1, T 2 and T 1, T 2. But, temperature difference is the same, now between if you connect A and C you get a E M F, E 1 when you connect C and B you get E 2. So, it says that if you connect A and B you will get E 1 plus E 2, so which means that you can connect, so which means that each one of them, the E M F can be calibrated with respect to a particular metal.

Then we can make arbitrarily combinations of these and then using this law we can find out what is going to be the EMF generated, so that is a, that is a big advantage in standardization. Similarly, it says that this is super position holds here with respect to temperature also, so between to the, to same metals if you have T 1 T 2 junction temperatures then you will get the first one if you have T 2 T 3 you get the second one. So, if you have actually this should have been E 1 and this should have been E 2, so if you now maintain T 1 T 3 then you will get E 1 plus. So, this adds up and is very linear and it is very easy to measure the temperature, so you can have there are various kinds of thermocouples.

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Type	K	T
Positive	Chromel	Copper
Negative	Alumel	Constantan
Range	700-1200°C	-200 to 350°C
Sensitivity	40.95μV/°C	30-50μV/°C

They are typically called you know called by some industrial type names like you know J K T S. So, K type thermocouple is a, is a popular one it is called chromel Alumel it is got a good sensitivity and a descent range, so it generally measures in this range. Similarly, you can, you can have copper constantan which is, which is, which has the only problem is that the range is lower. Basically, because of the fact that copper gets you know oxidized and corroded beyond this. Then there is also some variation in the sensitivity, so the sensitivity is not, so that means that that there is some amount of non linearity there.

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Similarly, you can have iron constantan which is type J see that large range and the good sensitivity. The type S is the most stable it has the highest range which is platinum 10 percent and rhodium is one wire and pure platinum is another wire. This is very stable has can measure temperature up to 1400, 1500 degree centigrade, but has very low sensitivity, so this is just to, you know give you some examples, some typical thermocouples.

Now, yes now the point is that we are not interested as we, as we have seen that the thermocouple can measure the temperature difference between the junctions. Now, we are not interested in measuring the difference we are interested in measuring the temperature of the measuring junction. So, one of the ways, this needs to go back, I am not, so I think I am missing one slide that is why I am I am wondering, so anyway.

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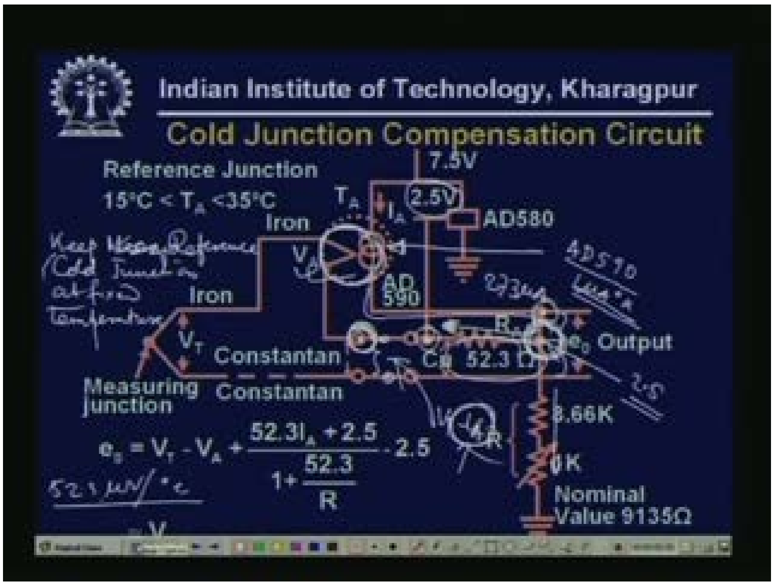

So, you see there are, there are basically two strategies if you want to get them, if you get the, get the temperature of the measuring junction. One strategy is that keep measuring junction at 0 degree, keep reference junction, one of those junctions is called the reference or sometimes called the cold junction at fixed temperature that what that is one way. But, then that is cumbersome, because you need to how do you maintain temperature there, so you would either have to put it in a small oven or you have to create some you know ice bath in which you will do you are going dip it, so that is cumbersome.

So, therefore what people try is that the voltage drop which occurs due to the ambient suppose you keep the reference junction in just open. So, the temperature in the ambient is going to vary and that is, that will cause some error. So, what you should do is that you must compensate for the ambient temperature variation using electronics. By measuring the ambient temperature variation that is a, that is the, you know smart way to do things which is also much easier.

So, what happens here is that you see, if you, if you, if you look at this circuit what happens is that this voltage actually becomes V T minus V A. So, it is not V T because of this is the ambient, so this becomes V T minus V A, so basically what we are trying to do is that at the output we are trying to add this V A, basically that is what we are trying to do. So, how is that being achieved see we have put a sensor which is called A D 590 sensor it has a 1 microampere per degree Kelvin sensitivity.

So, it delivers current 1 microampere per degree Kelvin, so and this is 2.5 volt, so at 0 degree centigrade it is going to develop put 273 microampere. That will drop though this potential will become 2.5 and this is also 2.5, so you see that the, so this is also 2.5. So, this potential is the same as this potential, so therefore e 0 is normal, but now as this temperature rises the potential at this point will change by how much. For iron and constantan it will change by something like you know 52.3 volt per degree centigrade microvolt per degree centigrade.

So, we have to compensate this, so that is why a 52.3 ohms resistance is put, so that every additional microampere will now drive through this. So, what is going to happen is that the, this point will be at a higher potential compared to by exactly 52.3. So, as this potential falls this potential is going to rise by the same amount, so the e 0 will not be effected by the change in this V, this is what is cold junction compensation.

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So, there are various advantages of thermocouples, for example here the can work over long range and give relatively large thermal E M F. They are, they can precisely calibrate and they are generally resistance to corrosion and oxidation and they are interchangeable. So, these are basically advantages of using thermocouples in an industrial situation similarly if you connect many thermocouples in series.

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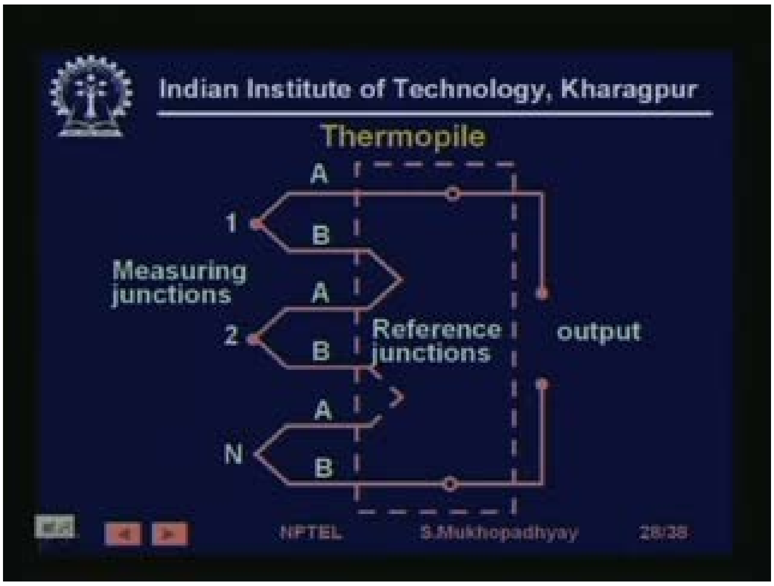

You can, you can, you can further increase the sensitivity of the thermocouples and say if you put many N number of measuring junctions. Then this voltage will be N times the voltage that you are you can get from a single thermocouple, so that is called a thermopile.

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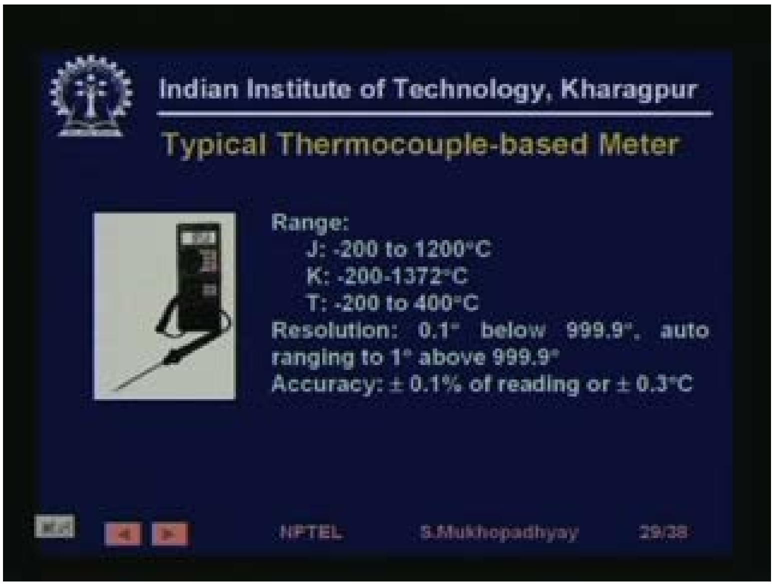

This is the picture of a typical thermocouple based meter, it is the probe and these meters are constructed. Either you can connect various types of thermocouple J K T you get pretty good accuracy which is 0.1 percent of reading over this range, 0.1 percent of reading or plus minus 0.3 degree centigrade.

So, you can have various other electronic features also, so these are very, you know popular instruments which are used in the industry, so having see these are the these are the main types of sensors which are used. So, apart from this there are very there are very well temperature sensors, but we are putting we are not going to put much stress on that because of the fact that there are not. So, much used in automation as such they are generally used for indication purposes, so for example we know that the well know liquid in glass thermometer.

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So, here is a liquid in glass thermometer which is which is shown in a sort of an industrial casing you know. So, liquid in glass thermometers you have to have there are, there are very precise markings available and which are, and there are immersion points marked that you have various kinds. You have, you have, you have the total immersion type you have the partial immersion type, you use mostly, you use mercury sometimes. You can use ethyl alcohol etcetera, which are much higher expansive expansion coefficient. So, you get you get better sensitivity.

But, they are all generally, they are all of manual reading types although there are some versions where you know you can, you try to sense the that are, there are mercury column is rising. You put slight light float in the fluid which also rises and then you can use some proximity detection principle you can automatically detect the temperature. But, generally these are manual reading types and, so therefore we are not going to cover them in too much detail.

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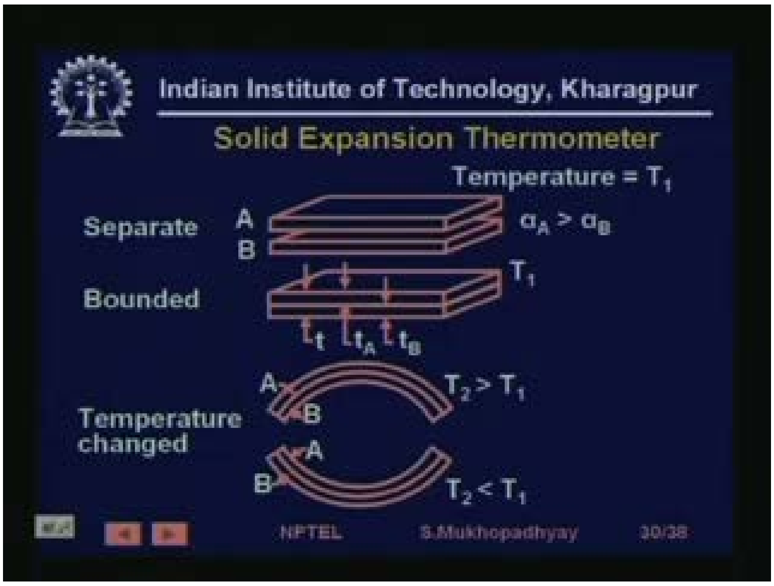

So, these are all these are based on the, you know expansion of solid liquid gas under temperature principle, so the liquid expansion thermometer the most common. So, we told that first then you have solid expansion thermometer which are basically you know bimetallic strips. So, based, so that depends on the fact that the expansion coefficients of the two solids are actually different, so therefore if temperature is increases at one temperature they are, they have no stress among they have, they are bounded together.

So, if temperature decreases it will turn one way, if temperature increases it will turn the other way, so therefore from this motion we can measure temperature. There are, there are industrial sensors, which actually utilize this kind of bimetallic sensor they are, they are sometimes also used for temperature switches and sometimes you know they have, they are used as bimetallic springs. So, as the temperature rises then the spring rotates and it can be connected to a something like a dial, similarly you can have gas expansion and vapor expansion thermometers.

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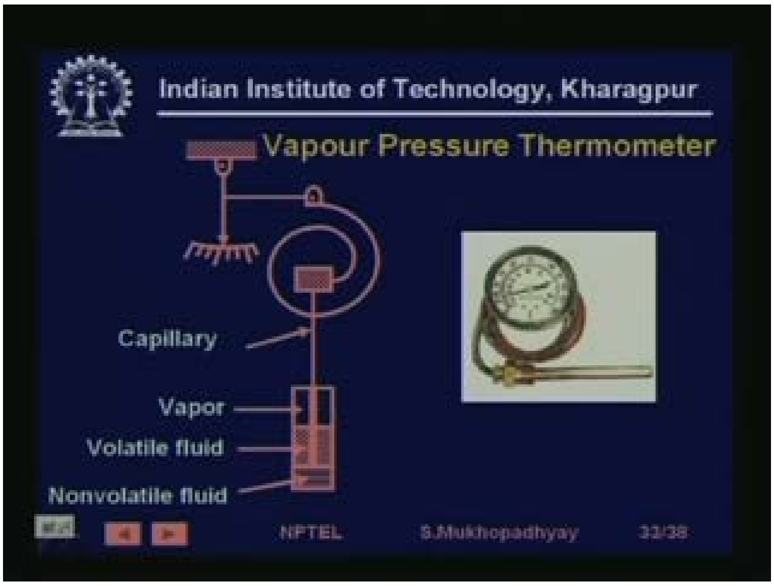

So, this relies on the fact that the vapor pressure of a liquid depends on the temperature, so this pressure is actually sensed by a pressure sensing device in this case we have shown a shown a capillary and then a bourdon gauge kind of thing. So, as this vapor pressure increases this spring will turn and then the then that will create a, create an indication.

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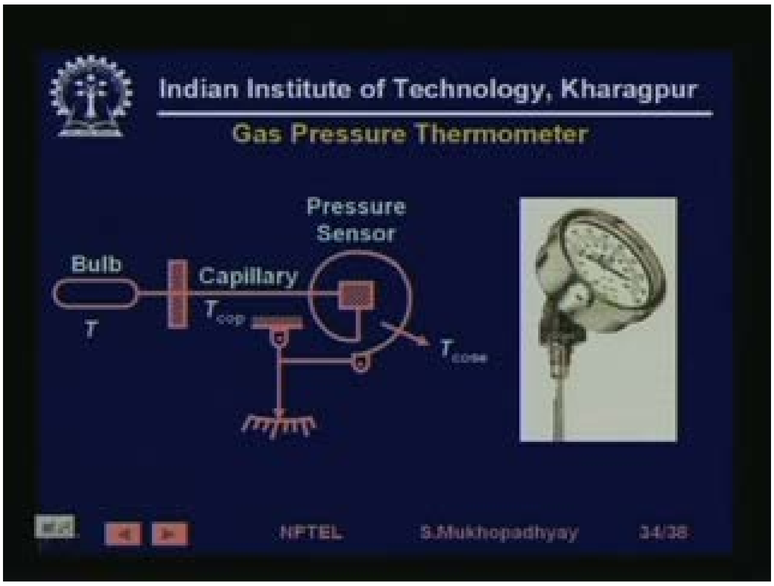

Similarly, for a gas pressure thermometer, so here you have a bulb, which is essentially a constant volume case because the capillary volume you can, you can neglect. So, as you, so the pressure increases linearly with temperature and this pressure is again sensed by a pressure sensor in the same way and you have this is the, this is the picture of an industrial sensor.

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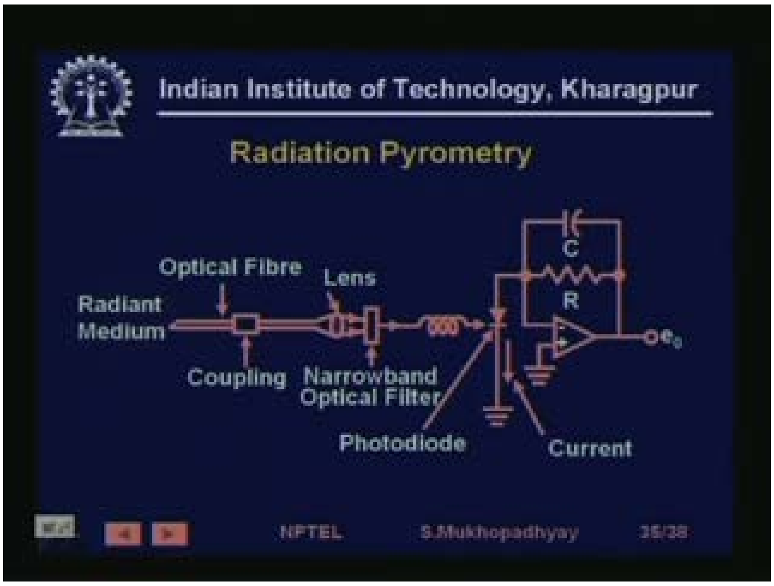

One of the non contact methods which is which is interesting and used in used in many cases, especially when you need to measure temperature from a distance or when the temperature is too high like in like. You want to measure the temperature of you know interiors of furnaces where even putting a thermocouple can be very difficult or you want to measure temperature of molten steel.

Then if you dip a thermocouple it will get, it will give a reading what it will get immediately destroyed, in fact thermocouples are used in such cases. But, modern techniques of measurements are trying to utilize the fact that a heated body gives out radiation, so let us go to the theory first and just find out the idea.

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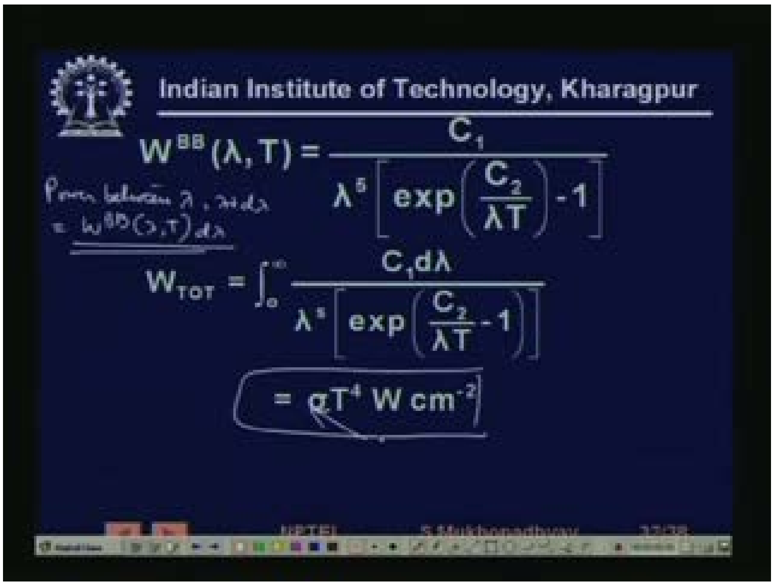

So, the idea is that a heated body gives out radiation and this radiation depends on two things that are the radiation is actually spread over the radiation frequencies of the wavelength. So, you have a, so what is known as a power spectral density at a given temperature which is given by this formula. So, if you, so this is the, you can say that W B B, B B for black body, so this is a sort of an ideal idealization.

So, a black body at wavelength lambda and temperature T gives a radiation between lambda and lambda d plus lambda it will give a power which is this 1 in to d lambda. So, the power between lambda and lambda plus d lambda is equal to WBB lambda T d lambda, so if you want to find out the total power then you have to integrate this lambda from 0 to infinity. So, that is what it has been done here and you get it only as a function of temperature which is you know Boltzmann’s law, so this is a Stefan Boltzmann constant.

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So, it now the, now the what it turns out that ideal real black, a real radiating body they are not black body black body is idealization physics. So, there the body could be I mean, I mean you need, you need to apply some kind of a correction factor to the, to the, to the black body radiation to get the actual radiation from that body. So, that correction factor is called the emissivity, so the emissivity of a given body A is the ratio between its actual things and the, and the theoretical black body power spectral density. So, if you take the black body power spectral density, and if you multiply it by its emissivity then you get the real power or in other words the black body 1 can be obtained by taking the real power and then dividing by the emissivity.

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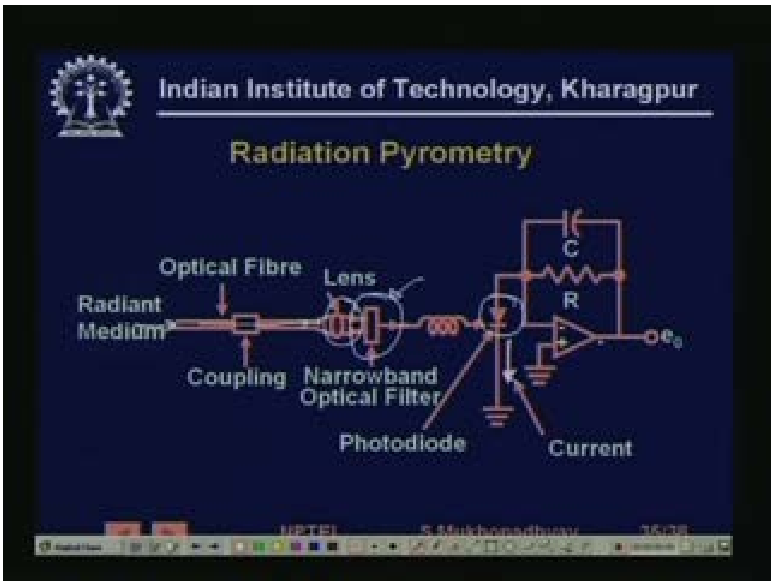

So, now let us see how we actually collect that radiation, so what we do is, for example if you suppose you have a radiant medium here. So, the radiation in this case we are using an optical fiber, this is a, this is a, this is a particular case you have various kinds of radiation parameters you have you have optical radiation parameters you have. So, basic idea is that you collect a radiation and then focus it on to a, on to a sensor, so if you focus it on to a sensor then the temperature of that sensor is going to go high.

Then you use such sensors are generally conventional sensors, so they could be, they could be you know black coated particular, you know strips of metal which are called bolometer or they could be thermopiles. In this case, this is the, this is the case which has a slight slightly modern case where you are actually collecting the radiation from a long distance choosing an optical fiber. So, the radiation gets in to the fiber here and it gets into the fiber here and then goes travels through the fiber and then, finally comes to a lens.

Now, this lens will focus this power and then you here you have a monochromatic filter which actually will take a particular lambda. So, only a, only a particular lambda will actually pass through it and then this radiation will fall on this diode. So, the current through the diode because this radiation is going to cause some free electrons in to that in the diode and therefore, the current through the diode will increase. Now, this current has been amplified using an op amp.

So, that will give rise to a voltage, so this is the principle of measurements of radiation pyrometer and there are a number of variations possible. So, that is about we have we are we have come nearly to the end of the lecture and so this we have seen, so this is, then the next one is emissivity.

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You have very good, you know this is, this is a picture shows an shows an infrared thermometer. So, you basically you have something like a, in this case you do not have optical fiber, but you actually directly point this gun, you often may come in the form of pistols. So, you just point the pistol towards the object and the radiation from that side of the object will be sensed and if you keep it in certain known distance. Then it will give you the, give you the temperature sometimes it is used to, it is in many cases it is used to also detect.

You know places where there is you know steam leak or there could be some in some electrical power panel there is some current related heating is being generated. So, you just, if you take the instrument and just rotate the gun you will know that where you are getting hot spots. So, that is sometimes useful in especially in maintenance and other related activities, so we have come to the end of this lesson before we close we should we need to review it.

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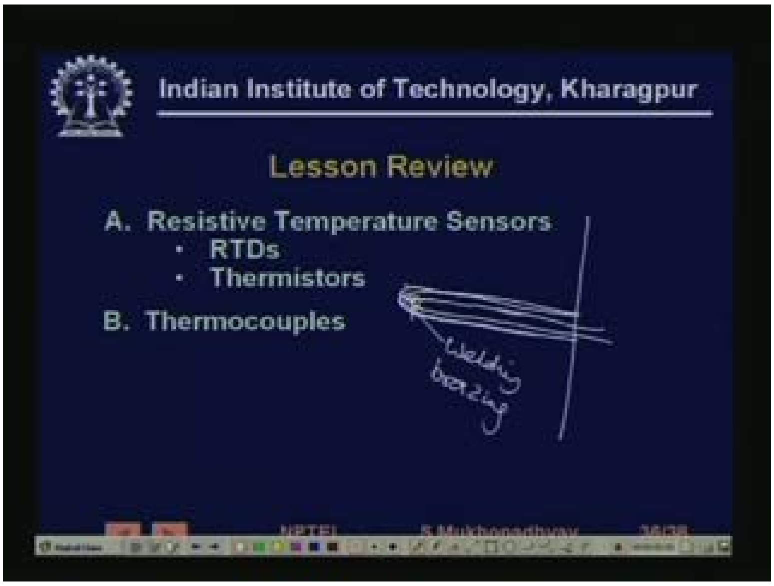

So, we have looked at temperature measurement briefly of course and we have basically looked in some depth on resistive temperature sensors of two kinds. Firstly, we had looked at RTD, which operate at longer ranges and are very stable and lead give rise to accurate instruments, but, their sensitivity is not that high. On the other hand, we have seen the thermistors that have semiconductor resistances the quite non linear.

So, therefore can be effectively used in low temperature ranges, but is, but is highly sensitive and with a very low thermal time constant, so therefore quick and rapid temperature variations can be sensed. So, apart from, so these two, apart from these two we have seen the, so RTD and thermistors, apart from these two we have seen the thermocouples which are in which are a sense of you know which are active sensors.

So, active sensors means that with an even without power they generate some source while this RTD is actually a passive sensor because to be able to generate a voltage or a current it requires a power supply. So, we have seen various kinds of thermocouples are also very stable and operate across a large temperature range they are also pretty accurate, so therefore they are actually widely used in the industry. One of those there are, there are, there are some problems associated with thermocouples especially when you have you know long lead wires.

You know this thermocouple wires, they are sometime suffer from electromagnetic interference electromagnetic as well as electrostatic interference. So, they have to be you know properly shield and sometimes yes, so sometimes for a better generally thermocouples are you know wires, so they are not mechanically very strong thing, so they are sometimes put inside thermo wells. So, you actually have, so suppose this is a structure you actually have a thermo well and then inside the thermo well as you have seen in the case RTD, so you have a protective material, I mean inside you put the you actually put the thermocouple wire.

Now, this thermocouple wire, so sometimes you can keep it like this, so here you form the junction is generally is formed by welding or by brazing and sometimes you want for better heat conduction you sometimes ground this. So, you can have grounded junction type thermocouples or you can have un-grounded junction type of a thermocouples accordingly you will have to. When you interface it with an, with an amplifier thermocouple voltage it essentially has to amplified there is no other signal condition is needed. So, some filtering and some amplification is needed standard filtering and amplification apart from the thermocouples we have seen.

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The expansion thermometers though all kinds although they are not so much important for industrial automation, and finally we have seen what is basically a radiation pyrometer.

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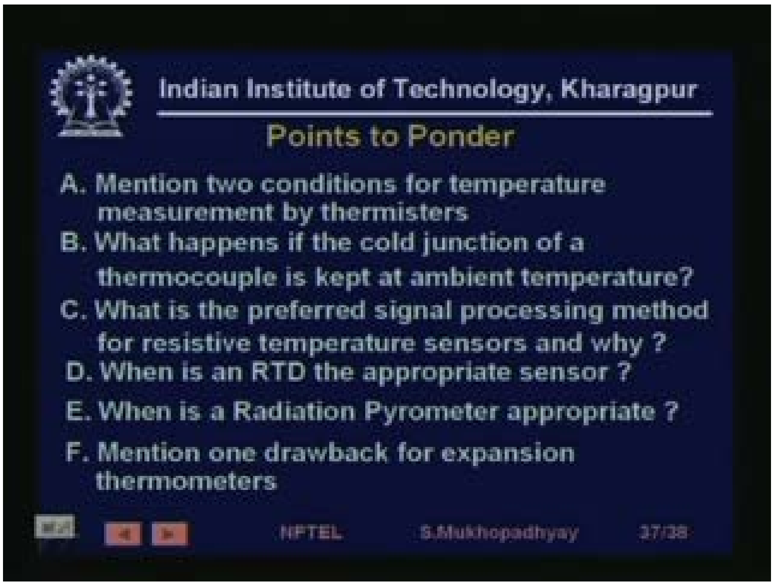

So, points to ponder you can mention two conditions for temperature measurement by thermistors under what condition we have told it many times during the lecture what happens if the cold junction of a thermocouple is kept at ambient temperature. So, why do you do cold junction temperature compensation at all, what is the preferred signal conditioning method for resistive temperature sensors and why always Wheatstone's bridge what is the basic advantage of Wheatstone's bridge.

When it is an RTD the appropriate sensor when is a radiation pyrometer appropriate and, finally can you, if you can mention one drawback of expansion thermometer. So, you can ponder over these answers are generally available in books and also in this lecture, thank you very much. Welcome to lesson 5 of the course on industrial automation and control, today we are going to talk about pressure force and torque sensors. These sensors are used in variety of contexts both for the process industry as well as the manufacturing industry, so let us look at the instructional objectives as is the practice first.

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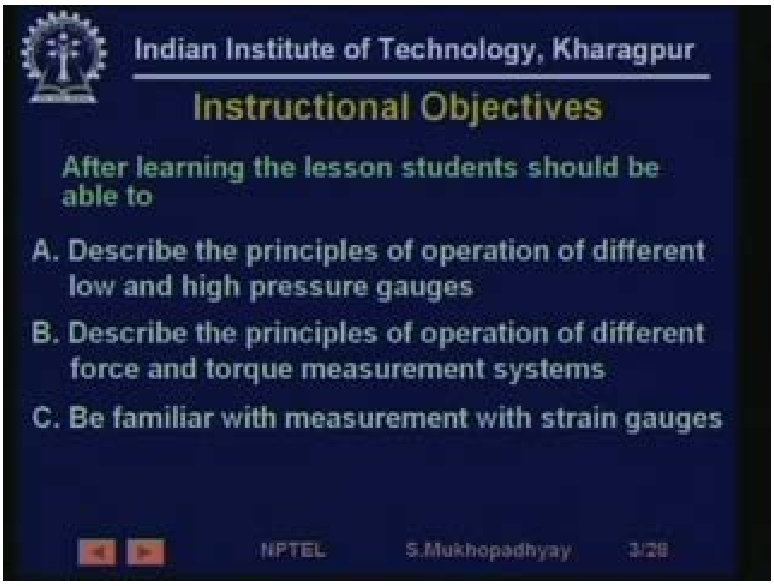

So, the instructional objectives are the following number 1 to understand the basic principles of operation of various pressure gauges which work in various pressure ranges. To describe the principles of operation of different force and torque measurement systems and most of them use many of them use the so called strain gauges, so to understand the basic principle of measurement with strain gauges. So, it turns as we have learnt earlier that when we want to get the value of the physical variable from 1, form to an electrical form which is convenient to sense to process to display this.

So, this transformation from the variable that we want to actually measure and its electrical form actually goes to a number of stages as we have learnt. So, it gets transformed to some intermediate forms and these transformations each of them in turn are sometimes achieved through sensors. So, in an in an in an overall measurement system you often find that there are a number of sensors.