Principles of Mechanical Measurements
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We have seen under temperature measurement, thermometers using the properties of the physical dimension changing. Secondly we have seen the electrical property that is thermal EMF, thermocouple junctions and their properties and different pairs of thermocouples. Now we are going to see radiation in resistance thermometer. First we will see resistance thermometer and then we will see radiation thermometers or radiometers. So we know all metals follow the rule similar to our temperature coefficient of linear expansion. We also have for metals temperature coefficient for resistance so the resistance increases as temperature increases for any metallic material. So that is the property what is made use of, so when temperature change the resistance change and that is made use of to measure the particular temperature.

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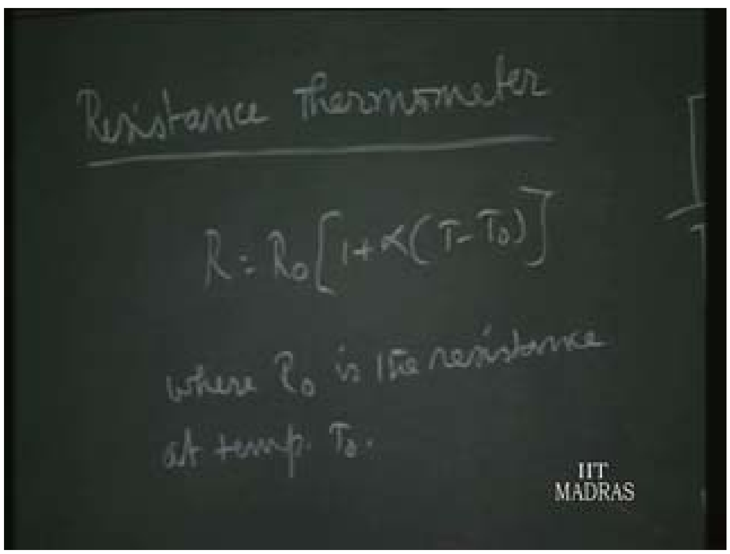

Now that is resistance is changed according to this formula R is equal to R_0 into 1 plus alfa, alfa is the temperature coefficient of resistance into T minus T_0 where R_0 is resistance at temperature T_0. So R is the resistance at unknown temperature T so by using this equation, we get the relation between increased resistance from a known resistance for a given temperatures, for any unknown resistance we can get it. So this is the physical property what is made use of, so when we subject a resistance into a temperature path its resistance is changing. So how to convert this resistance change into voltage change? This you already learnt under strain gauge. So when strain gauge is pasted on any stressed member due to strain the resistance will be changed. The resistance is changed into voltage by using wheat stone bridge or AC Bridge.

Similarly here it's a resistance element so the resistance of the thermometer is connected as one of the arms of a forearm wheat stone bridge. Previously we can balance a bridge and for any other temperature it is going to change, resistance will change, one of the forearms will change. Hence the imbalance will be there and the imbalance voltage you can measure it or in another way we also have to measure, this is what we are going to learn. There is basic difference between strain gauge and the strain gauge resistance change and the thermometer resistance change. There strain is of the order of microns and also the corresponding change in the resistance also is very less. So from 120 it may become 119.5 or 120.5 or 120.6 are very small change only is there in resistance of the strain gauge resistance. Whereas the resistance used for the thermo I mean temperature change there is large change of resistance is there in this thermometer and I mean the thermometer using the resistance is called resistance thermometer and you have got under these two groups, one is conducting material another is semiconductor material.

The semiconductor material there is negative change, coefficient is negative and it is very large more than 10 times. So in the thermometer the resistance change is large when you compare thermometer resistance, the resistance change is very large compared to resistance change in strain gauge. There we have derived an equation for imbalance voltage of a bridge when we use a strain gauge assuming the resistance change is very small, we neglected dR term and higher terms we have neglected and then we have derived an equation imbalance voltage e is equal to EGE epsilon by 4, 1 by 4 for a quarter bridge this is equation, E is the excitation voltage, G is the gauge factor, epsilon is a strain.

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That is imbalance output voltage. This is valid under the condition dR the resistance change in the resistance is very small. Then only the G into epsilon, you can also write a delta R by R that is G into epsilon we can write this. So under condition delta R is very small, delta R by R is small this is valid that means e will be proportional to delta R. Since all other things are constants excitation voltage constants, original resistance is constants. So output voltage, imbalance volt is proportional to delta R that is what you have derived. Under the assumption delta R is very small but here in the resistance in the resistance thermometer the delta R is not small one, hence it is no more valid.

So no linearity in this equation so the bridge there for strain gauge it is operated in deflection mode of operation, this is the bridge network for strain gauges they are used in deflection mode of operations. Hence imbalance voltage is proportional to delta R but here since the output volt is not proportional to delta R we cannot operate it in deflection mode of operation thus we operated only in null mode of operation. This is what is written here null mode of operation.

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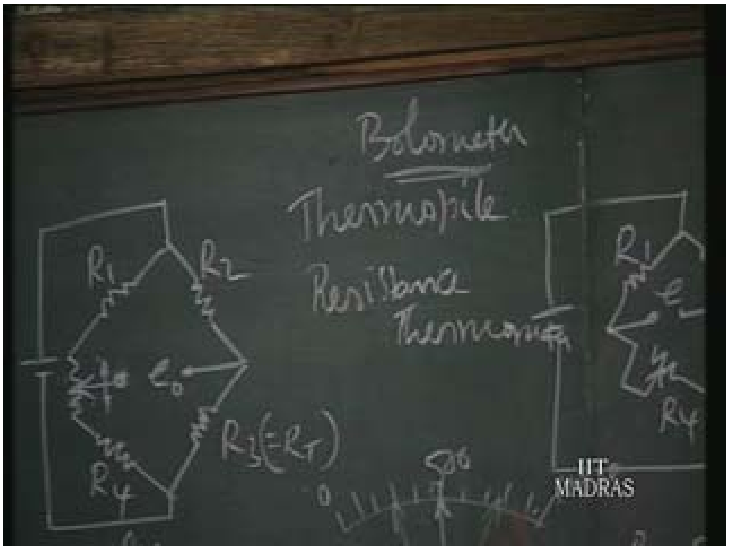

So what is null mode of operation that is what is depicted in diagram a, we find 4 resistances are there and R_3 let us call it as resistance of the thermometer which will be subjected to different temperatures. Now when originally we balance it to zero and in subject to any temperature then we find some voltage will develop here, imbalance voltage. To bring it to zero adjust R_4 so that e_o is brought to zero. Now how much adjustment is required in R_4 to bring the balance back is called the null mode of operation that is here deflection is zero, that is called null mode. You will have the reading zero, to bring it zero reading how much resistance you have to change and the amount of change required is a measure of the temperature of this arm. That is the null mode of operation but the drawback here in this null mode of operation is when we change this resistance the wiper or the contact point is moving over a resistance. When it moves at different position of the coil, it may how different contact resistance.

So that will form fourth arm of the stone bridge say any changing resistance will be also, we included which is not due to the temperature change in R_3. So that contact resistance will be an error source for this type of instrumentation. How to avoid this varying contact resistance? For that we go for circuit b. Now since contact resistance in the fourth arm it is included in the loss of in the loss of the bridge or balancing whereas if you put a potentiometer somewhat like this, against which we operate this contact, then we find the contact resistance is no more in the one of the arms. This is a path where under balance condition, zero current. So the contact resistance will be in zero current path and hence it will not affect this balancing. That is when R_3 is changed then we move this contact up and down so that the balance is brought back and how much motion is required is a measure of the temperature where R_3 or R_T is immersed.

Now here you find for a given motion suppose we move just above that means R_4 is increased R_1 is decreased to the same extent. So balancing will be quicker than in this case. Here suppose we have to move say 4 mm for a given resistance change to balance it, here half of it is sufficient because here it is increased, here decreased both the effect will bring the balance quicker. So half the travel is more than sufficient. anyhow the problem what we had earlier, the contact resistance in influencing the reading is no more there and the resistance is distributed against R_1 and R_4 and contact resistance is along the zero current path. So this circuit is better than the circuit so more accurate reading but in actual practice we will find there is some difference in this circuit.

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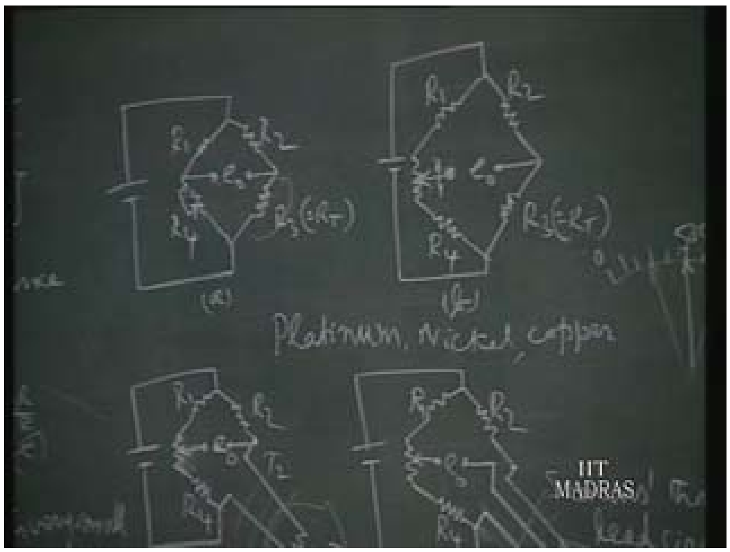

So we take R_3 to a distance place from the say control room. So the lead wires are brought to the control room for building the bridge there then you will find, this lead wires may be subjected to, this is one temperature T_1 this may be another temperature T_2. So you will find due to temperature T_2 the resistance of these lead wires also may change that forms part of the R_3 arm of the bridge. So that will affect the balancing of the bridge and that is not due to temperature in R_3 so this is an error source. Whenever the lead wires are subjected to different temperatures, accordingly the resistance change and that resistance also is to be interfering into the signal of the instrument or for that also we are adjusting here that is not the temperature where R_3 is subjected. So it is an error source, to avoid this Siemens introduce this so called Siemens three lead circuit where you find the zero current, this is a output. Zero current line also that is this line also brought to the furnace. So this is which may be the furnace where we are measuring the temperature. So you find the third arm lead wire is there and zero current wire also is taken there and then this wire is coming. So at any cross section we will find, there are 3 wires this is called three lead wire circuit.

So due to any temperature now this may be T_1 and suppose you have some other temperature T_2 what is the effect. T_2 is affecting all the three wires and two wires, the end two wires this wire forms part of R_3 and the other extreme wire forms part of R_2 that point is brought here. So two adjacent arms wires are affected in the same way so same change in adjacent arms of Wheatstone bridge has no effect in the imbalance voltage, this is we have learnt already.

Only opposite effect in adjacent terms will give rise to voltage but here the two end wires which are in adjacent arms are subjected to the same temperature. So the same resistance change, it will not give rise to any voltage output due to imbalance of the bridge. Similarly you will find the middle wire under balance condition is zero current line where the resistance increases or decrease, it does not matter. So you find the error introduced here in the circuit C is nullified by having three lead wire. What is done is this common point this junction is again brought to the same chamber. So that you have three wires and two wires are adjacent arms and similar changes giving rise to no imbalance. So that's how the engineers design was done, nowadays this is what is adopted. So finally D is the circuit for the null mode of operation so the resistance thermometers are used in this way and if you want to use the resistance thermometer in the deflection mode of operation, the nonlinearity say we told it's no more linear. Since delta R is very large it's no more linear but if you want to use again in deflection mode then nonlinearity should be reduced.

So here is a circuit where we can reduce this non linearity of the deflection mode of operation. For this is the circuit more or less similar but you find the resistance ratios are taken somewhat like this as per Dublin, R_1 is equal to R_2 is equal to 10 times R_3 and 10 times R_4. So R_1 and R_2 will be 10 times the value of the thermometer resistance and then R_4 arm but one more thing what is done is, this is also an engineers' design. Nonlinearity for a given range, suppose this instrument is used for measuring zero to say 1000 degree centigrade then subject this at middle of that range so it will be put at 500 degrees centigrade. So the thermometer resistance will put at 500 degree centigrade and now adjust arm R_4 so that e will be zero, the voltmeter connected to read the imbalance voltage, the voltage will be zero.

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So this is the reading so this may be zero degree, this may be 1000 degree and at 500 degree the voltage read is zero. This is actually zero voltage so the graduations are like that so wherever the pointer stops you write it as 500 volt, it is 0 volt but it is corresponding to 500 degree centigrade. Now any increase in temperature, pointer will move this direction and decrease in temperature, the pointer will move the other direction. So you find the nonlinearity is between 500 to 0 and 500 to 1000. So nonlinearity is reduced nearly to half the total nonlinearity by this design.

That is having made adjustment in R_4 so that balance is obtained for the middle of the range, we reduce the total nonlinearity into half. Previously for plus or minus 5 % nonlinearity, now by this design we can reduce to 2.5% of nonlinearity by this method. Having zero voltage for middle of the reading and later on the minus voltage or this plus voltage accordingly, it will reduce the total nonlinearity for the full range, this is the design what is done. That is for the conducting material, suppose mostly we find the resistance thermometer, the wire is made up of platinum, nickel and copper. These are the commonly used material for this resistance thermometer and that coefficient for resistance you can refer to books, it is around 0.0039 and this is double that value nearly 0.0065 and this is around 0.0043 something like this. So this is the coefficient that is we find nickel will be having much more sensitivity than the other two things for a given temperature change and the other one is called thermistor. When we use the semiconductor material for the resistance then it is called thermistor. Resistance thermometer and these are thermistors thermistors used in semiconductor element as resistance element.

As I told they have got very large negative coefficients, as temperature increase the resistance falls down and also it is very steep more than 10 times, temperature coefficient is 10 times than that of conducting materials or metals. Since you find it is often used to measure temperatures between 60 Kelvin to 1000 degree Kelvin, this is a normal range where semiconductors are used and below 60 Kelvin people are using carbon resistors below that is cryogenic temperatures are measured by using carbon resistors, silicon crystal and germanium crystal, they are used for cryogenic temperature measurements. That is regarding this resistance thermometers and thermistors and now we go to radiation thermometers.

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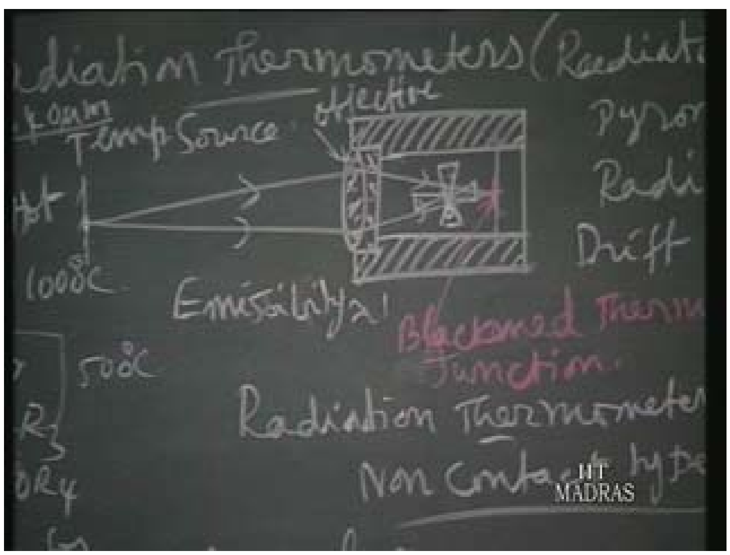

As we have already pointed out earlier this is one of the properties of materials that radiating capabilities is changing with temperature. So that is what is made use of in this type of thermometers and all those thermometers using this radiation are called radiation thermometers, also called radiation pyrometer or simply radiometer. This is also called radiometer. Thermometer is using the radiation of the hot bodies, they are called by these different names and the physical principal is any body above zero Kelvin radiates that is the basic principal, anybody above zero Kelvin that is all bodies or some temperature or the other, they give out radiations.

This radiation is picked up by this instrument and the amount of radiation gives rise to brightness and it is being made use of those intensities, made use of in identifying the temperature of the hot body. Now in collecting this radiation there are some error sources and another thing this radiation thermometer is a non-conducting and this is very important. So far all the thermometers what we have learnt have to bring the thermometer in contact with the body whose temperature is being measured, whereas in the radiation thermometer we only focus it towards the hot body. Hence you find these radiation thermometers are used to find the temperatures of distant bodies that is heavenly bodies or any moving object. We can stand in one place and we can find the temperature of ejection of a moving body, gas output of the moving body for example when missile missile is on the flight, you can trace it by collecting the radiation from the exhaust of the missile.

So it's an essentially non contact type but when we use this radiometers or radian thermometers for measuring the temperature of the heavenly bodies, the radiation is passing through the atmospheric conditions. There some of the radiations get lost or reflected so it gets absorbed. For example carbon dioxide moisture, dust presence of all these material is absorbing the radiation and then the amount of radiation received by the thermometer by the objective lens is reduced. This is one drawback in this radiation thermometer.

Second drawback is the radiation thermometers are calibrated by having a blackbody which gives the maximum amount of radiation for any given temperature with that it is being calibrated where for a blackbody the emissivity is nearly one but when we use the same calibration for some other bodies say heavenly bodies or distant objects then we should know the emissivity, many times emissivity is guessed. For example I mean it is because emissivity is a function of the surface shape and density, surface roughness and the angle at which we collect the radiation all these affect the emissivity of the body.

In gauging the emissivity we made some error hence you will find in calibration also they there may be some error. These are the two error sources and what is done in this radiometer is a set of radiation is collected from distant body and it is made to converge by having this objective lens. This is the radiation going and it is made to converge at focal point of a lens system but at that place where it converges the radiation is to be detected then we should have so called radiation detectors. These radiation detectors we have got two types, one is thermal type and then photo cell or based upon photon.

These are the two principles, the thermal type is nothing but a blackbody. We have a blackbody that is written here so its blackened surface will be there, they will be absorbing all the radiations falling on it and if the blackbody temperature is raised, since radiation is falling temperature is raised, at the same time the blackbody will give heat to the atmosphere and it attains one temperature for one type of collection of the radiation and that temperature is measured by so called thermopile. By thermopile or resistance thermometer, set of thermopile we know is a set of thermocouples 4 or 5 thermocouples in series or it is called bolometer

Bolometer is nothing but it is one made up of thermopile or resistance thermometer, a set of resistance thermometer. The bolometer name because it will be having a very less time constant, it will be very quickly respond to the radiations that is bolometer but it is nothing but thermopile where the mass is very small. When mass is small then it is timeout, time constant is very small, time response is small so it is called bolometer.

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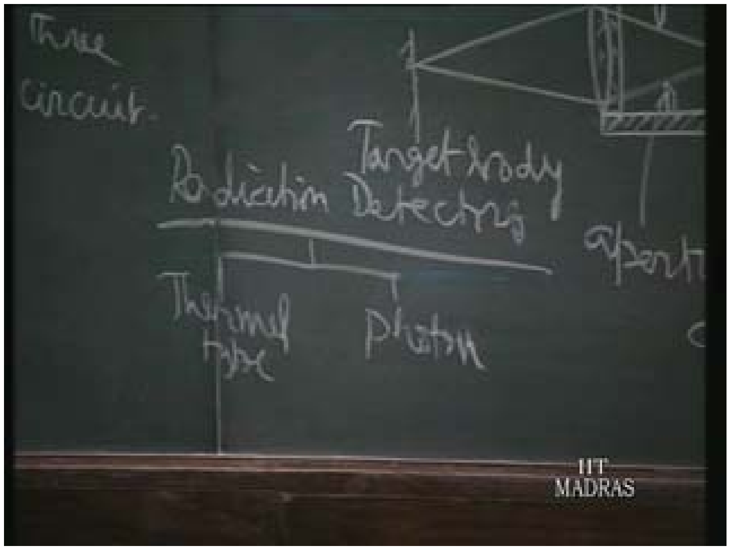

So such a temperature sensing device is put to embedded in this blackened body and from that the temperature source is measured that is the thermal type. Thermal type of radiation detector is based upon blackbody but whereas in photon we have got again three principles photo conductive and I will write it here photo conductive, photo cell and photo electromagnetic cell. So these are the three types under photon detectors, first one is as the radiation falls on this photo conductive cell it’s resistance is changed that is photo conductive principle and then amount of resistance change is sensed and that will tell about the amount of radiation it has received. That photo cell when it receives the radiation it develops a voltage and the photo electromagnetic cell is kept in a strong electromagnetic field and when it receives any radiation then the voltage is developed. These are the three principles under which the photon detector is made use of to detect the amount of radiation collected by the thermometer but there is some basic difference between the thermal type and photon type.

Thermal type is sensitive to the total amount of radiation, it is no more function of the wave length of the radiation and before that what is the wave length for this radiation thermometer. It is 0.3 micron to 40 micron. This is the normal wave length range in which all these radiation thermometers are functioning. We know the visible light is 0.3 to 0.72 micron this is the wave length of the visible light, white light. It is having the wave length in this range. So it is beyond this visible light as well as from 0.72 to 1000 it's called infrared rays.

The electromagnetic waves their wave length and how they are distributed, you can just see it here 0.3 to 0.72 micron wave length of electromagnetic waves represents our visible light region where we have got vibgyor, all these colors are put together looks like white color that is the range of the wave length and for infrared rays wave length is 0.72 to 1000 micron, 1000 micrometer is 1 millimeter so 0.72 to 1 millimeter wave length electromagnetic waves that represents infrared that is below the infrared region and for radiation thermometers what we are using is 0.3 to 40 microns this is the wave length of the electromagnetic waves made use of in the radiation thermometers. Now you find that is it contains both the visible region as well as infrared region and the ordinary glass. Normally what we use for the white light or the visible light they are opaque for the infrared rays. Hence the lens for this radiometers what I have drawn there are made up of Pyrex glass, it’s not ordinary glass.

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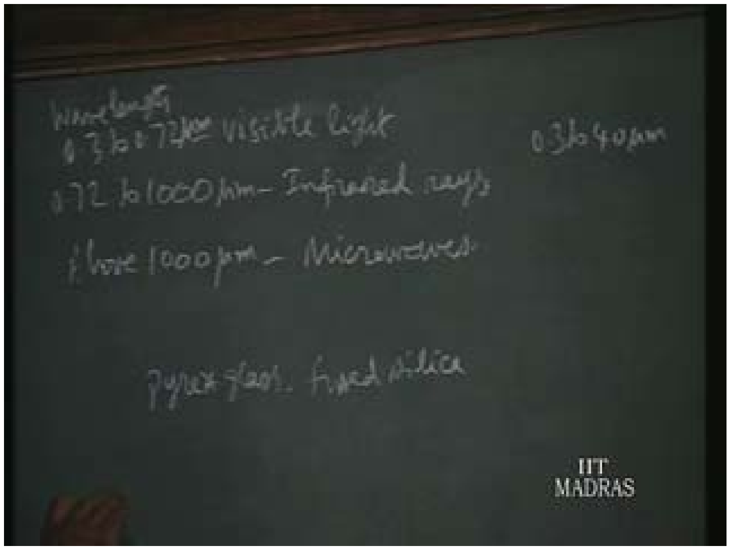

It’s a Pyrex glass fused with silica and calcium fluoride something like that, these are the special glasses which can transmit the infrared rays. So all radiometers glasses are made from this material, it’s not an ordinary glass since ordinary is opaque and above 1000 micron it is microwaves. Now we were seeing the radiation detectors, thermal detector it is insensitive to wave length say whatever the wave length it receives correspondingly it gives signal whereas the photon detector it is sensitive for the wave length. So the amount of resistance change for example if it is a photoconductive cell, the amount of resistance change depends also on the wave length of the radiation it has received because in certain wave lengths it gives more output, in certain other wave lengths for the same amount of radiation it gives less resistance change.

Hence you find photon detectors can be used only for a certain wave lengths alone, it will not respond for other wave lengths of radiation hence you find the thermal detectors are often used but the problem with thermal detector is it doesn’t change with the change in radiation its temperature it’s a slow process. That is the only thing, photon detectors are very quick to respond to radiation whereas thermal detectors they are read as like this, that is the drawback. Now we see the construction of one such radiation, it is the construction what is given here of an ordinary radiation thermometer, this is ordinary radiation where we have got the hot body. This is hot body and from here the radiation received by this object, the lens nearer to the objectives is called objective lens in optics. So objective it collects the radiation and converges to the blackened to focal point where the thermocouple junction itself blackened to have the small mass that is blackened, junction itself mass or body and that thermocouple will be connected in series where it will be calibrated in terms of temperature.

So there the output will be in DC, if magnifying DC we have problem of drift, this we have learnt in amplifier drift, to avoid the drift what they do this incoming radiation it is being chopped. So you will have the number of blades rotating in the path. What I have drawn, it will be perpendicular to the board it will be rotating, it will be somewhat here the two blades. So probably it will be here and the blades are coming like this. So you find for certain duration that is the gap between two blades the radiation will fall on the detector and when the blade is obstructing then no radiation will fall on it.

So alternatively blade and the gap will be coming as it rotates at different speeds, so now you find previously the voltage output was like this. Suppose the output voltage from the thermopile or bolometer is e versus time, now same thing is made into waves. So here when there is gap the full voltage will be developed by thermopile and that is between blades it is cut or now we can also say the blade also has certain radiations.

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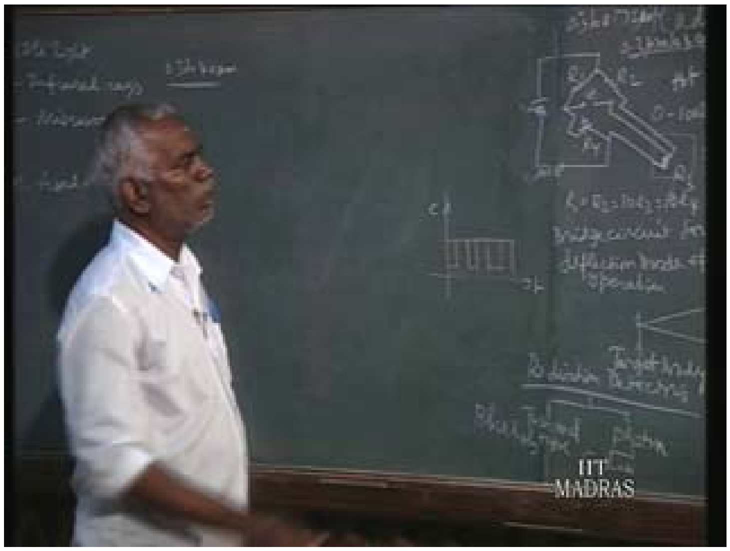

So you can find that is alternatively blade, so the detector is exposed to alternative to source as well as blade, blade also is certain temperature, it also radiates. That radiation also is picked up with the blackened thermopile junction and you can calibrate it, by having a blackbody you can calibrate this temperature and for any unknown body temperature you can use these calibrations and detect it. So by having this rotating blade or so called chopper and we can convert this DC voltage developed in thermopile into AC and later on we can amplify it and amplify voltage we can read conveniently in any other voltmeter and you can calibrate the voltmeter in terms of temperature.

Another version of the radiation thermometer is optical pyrometer this is optical pyrometer. This is also often used in finding the furnace temperature of different height. What is temperature of furnace and you find this is used above 700 degree centigrade because a manual observation is there that is possible only when temperature is above 700 degree centigrade. This type of thermometer the radiation thermometer read up to say 2000 degree centigrade up to that we are used, here this optical pyrometer up to 4000 degree centigrade this is the range of this instrument. Here the principle is to look an object so it is a white object we require a black background then only you can see this object. Suppose if background also is white, this is also white then the chalk piece disappears we say, since we don’t have any background the object disappears that is background also same colour it disappears. So it is called disappearing filament thermometer. Sometimes it is called disappearing filament thermometer also because you see here is a filament through which current is passed through this battery by adjusting the resistance. So when the current flows through these filaments it glows and that intensity brightness when it coincides with the brightness of the radiation.

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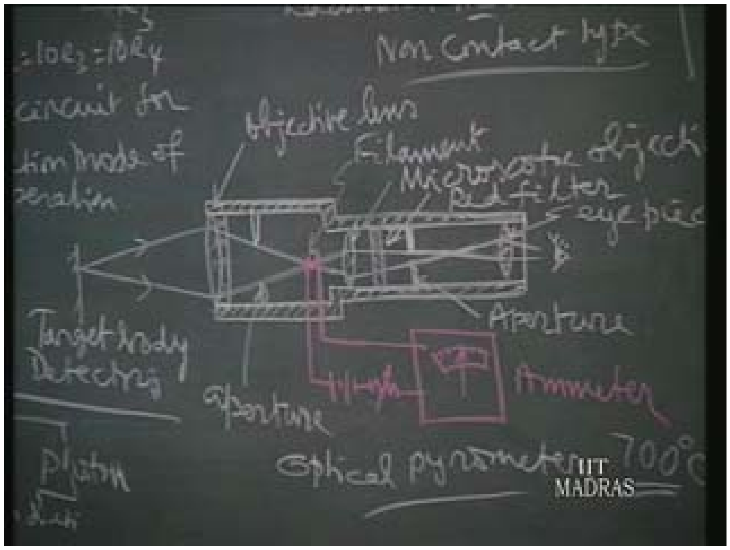

The radiation is received from the distant object; it is made to fall at the filament. Filament at the focal point of this objective lens. So when it falls the target is made here with its own intensity and brightness, when the filament brightness and the brightness of this both match and then filament temperature is assumed to be same as the object temperature. So what is done is we will be observing, this will be an object for this. This is a microscopic construction in combination with this objective, which is done. It will be a microscopic construction that we can see from here. So we have got a red filter that is only one color that is red color alone is made use of that is red filter made use of for this operation.

Now after we focus to a distant body then you can see the filament, now current is not sent and switch on the circuit and adjust this current, adjust this resistance so that current is increased and at one current flow that glowing of this will be matching the intensity of this radiation, at that time it will disappear and that is the current which is read in this ammeter which is calibrated in terms of that is to make it disappear you have to send so much current and at that temperature of the filament or the temperature of the body is identical and that is what is calibrated. That ampere is calibrated in terms of the temperature of the body that is how this is made use of, all the other things are constructions aperture amount of radiation is can be controlled.

Here also we have got microscope also on aperture, this is eye piece so by looking at it by adjusting a knob you can change resistance and make it to disappear at that time whatever current required is the amount of brightness is proportional to the current and that is proportional to temperature. So temperature is written in the ammeter. So that is how it is made use of, since we require some visible I mean some brightness already to sense this filament that is there only above 700 degree centigrade. So above this it is made use of, this you have to find the temperature by a manual adjustment. Then the last one is so called digital temperature sensor, the last sensor what you are going to learn under the temperature measurement is digital temperature sensor.

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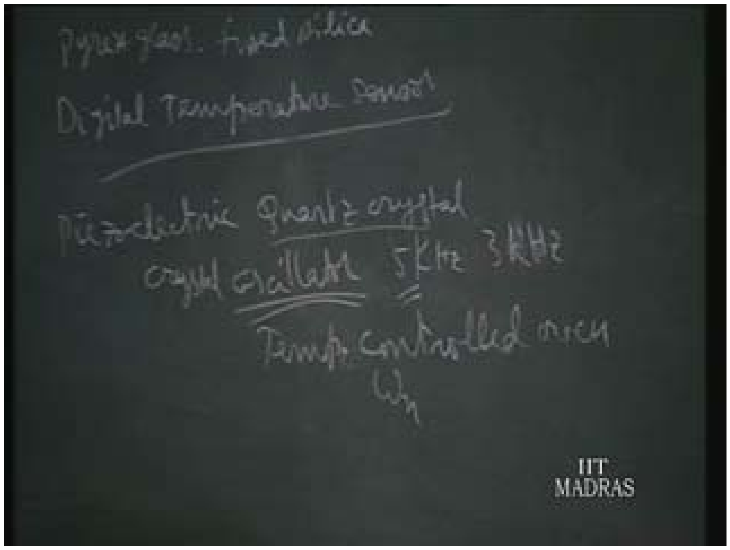

It may be remembered that we have learnt one method for measuring force by digital means. Sensing the force itself by digital for that we are using one string that is fixing a string and when you apply a force this ring vibrates at different frequency depending upon the force and by connecting a permanent magnet we convert this force into frequency and that frequency is picked up by the magnet and forming other circuits, we have sensed the force in terms of digital signal itself. Similarly for temperature also we have means by which they sensed by digital way itself directly so that it can be given to a computer and that is based on the property say piezoelectric quartz crystal, for example piezoelectric quartz crystal.

We know this quartz crystal is made use of in the oscillators, that oscillator is one where we can produce signal at different frequencies and we have also got so called crystal oscillators. There you will have a quartz crystal as means to have that particular frequency. They will have only fixed frequency either 5 kilohertz or 3 kilohertz normally used for this instrumentation purpose. It is for one frequency only, one crystal oscillator will be there and that depends upon the crystal dimensions, by controlling the crystal dimension we can get these 5 kilohertz or 3 kilohertz whatever it is. So it will be forming part of the so called the oscillator circuit. We know the property of quartz crystal is when temperature is changed that natural frequency of quartz crystal is changed. So by having that particular thickness we can change the frequency of the oscillator.

So in oscillator what happens quartz crystal is kept in temperature controlled oven. So that quartz crystal is at a given temperature so that its natural frequency doesn't change that is omega$_n$ of that crystal is not changing then only you will have the constant output frequency from the oscillator. That is the oscillator circuit I am not drawing the oscillator circuit, we can get any electronic books, a standard books but I am telling only the principle. Instead of keeping the quartz crystal in the temperature controlled oven, you put the quartz crystal in the probe tip and then connect in the same circuit. We will have the same circuit of the oscillator but instead of keeping the quartz crystal in the temperature controlled oven, we keep it at the probe tip where probe tip is immersed in a furnace whose temperature we are interested to measure.

So now as temperature is changed the frequency of the output of the oscillator will change. previously crystal oscillator as crystal oscillator we had one frequency but now as a digital temperature sensor its output frequency will be a function of the temperature of the furnace where we put the quartz crystal at the probe tip. So now the output of this oscillator circuit will be given will be read in a universal electronic counter where the frequency can be read or it can be stepped up or stepped down. So that we get the reading corresponding to the temperature, this is the principle. That is when we read this frequency output in a universal electronic counter and later we can have circuit there itself to step down the reading or step up the reading until we get a number corresponding temperature. this is what is extra it is done otherwise it is same circuit as the oscillator circuit but instead of keeping the quartz crystal in the temperature controlled oven it is put in a probe tip and the probe tip is put in an oven. Hence we by using the same oscillator circuit and measuring the frequency and stepping down the frequency to have the same reading, we achieved the digital temperature sense that is the principle of it. With this the temperature measurement comes to an end.