Machinery fault diagnosis and signal processing
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Module No # 08
Lecture No # 36
Thermography

This lecture is on thermography, this is in the last module on NDT techniques which are used in machinery condition monitoring. So we will be covering this NDT technique in about the next four lectures. If I was to list down the NDT techniques which are used

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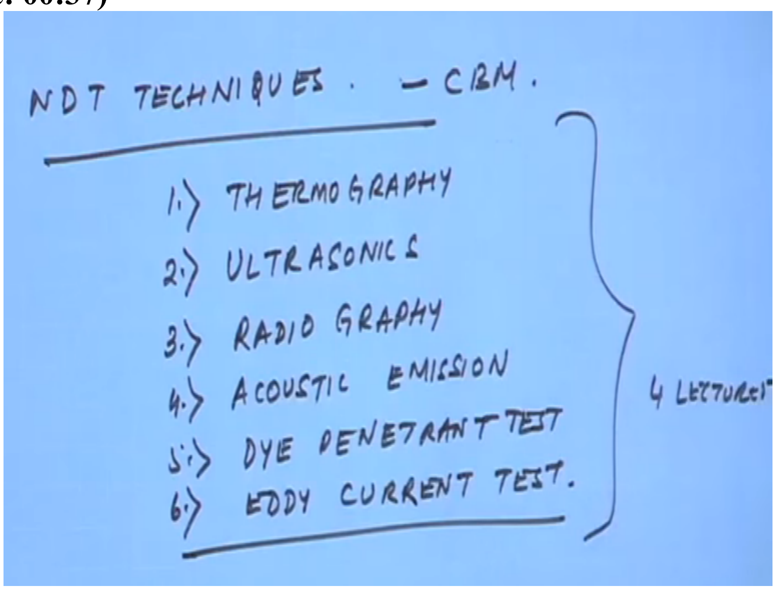

For MC or CBM thermo, so for CBM has to less than one is thermography. Then next is the ultrasonic, then we have radiography, acoustic emission and few other techniques like dye penetrant test and eddy current. So in this NDT technique what is known as non distractive test techniques? About 10% of the condition based maintenance which is done throughout the world almost like in this area and if I just recollect our memory about in the whole world.

About 70% of the CBM techniques is by vision based followed by 20% being where debris analysis and then I was just mentioning that a new technique of the motor current signature analysis is also becoming very prevalent and another 10%. But out of this 10%, lot of this are also the NDT techniques.

So in the last module on this course where we have four lectures. We will be covering mostly thermography, ultrasonic, radiography, acoustic emission and also dye penetrant and eddy current test. In about four lectures no thermography is such a technique which essentially there is on.

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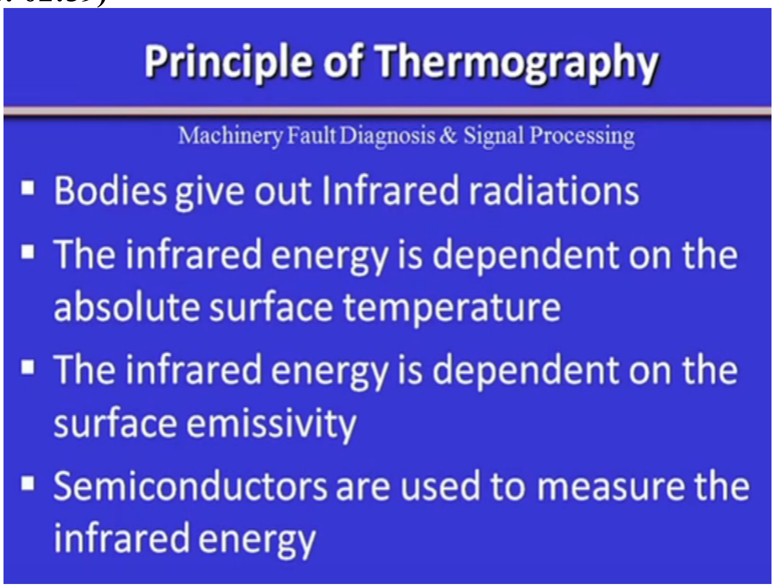

Principle that any body gives out infrared radiations and these radiations are a function of the bodies. Absolute temperature in the Kelvin scale and the energy which is radiated by this infrared from the body is dependent on factor known as the surface emissivity and somehow this energy can be captured. One can get a good clue about the temperature of the body in fact if you think for body.

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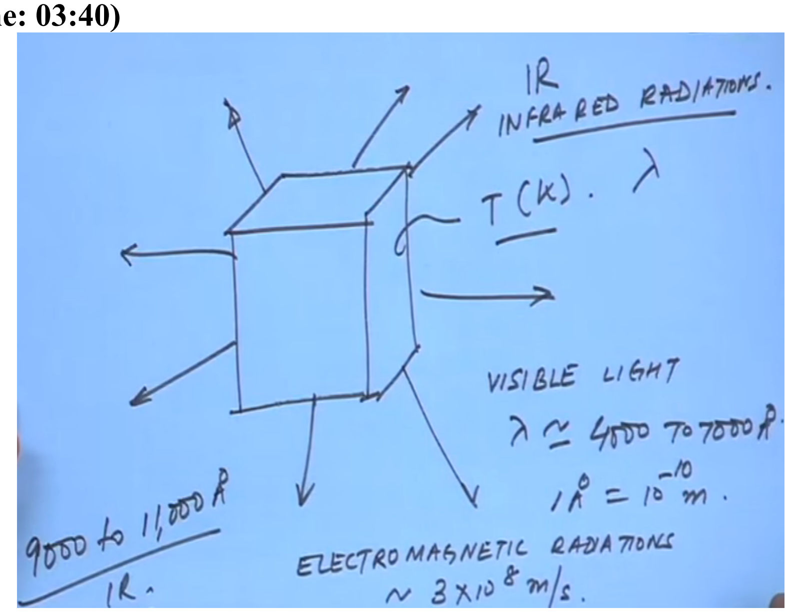

A three dimensional body at a certain temperature in Kelvin, so it gives out infrared radiations. IR or infrared radiations basically this infrared radiations are electromagnet radiations and it travel at the speed of light. But this wavelength of the infrared radiation is the visible light the wavelength is somewhere from 4000 TP.

About 7000 angstrom where one angstrom is 10 to power - 10 meters. So the infrared is somewhere from may be nine thousand to eleven thousand angstrom to the IR. So just beyond the visible light the wavelength of the infrared is from nine thousand to eleven thousand angstrom and these infrared radiations give out from the body, have some

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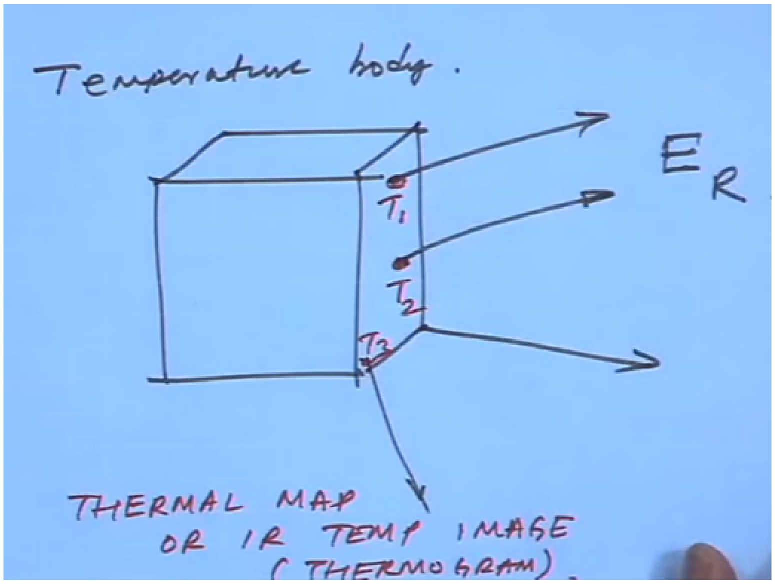

Clue as to the temperature of the body. Now there are devices which can measure the energy radiated from every location and then give us some indication. What is the temperature at these locations? May be T1, T2, T3 so then we can get what is known as the thermal map or IR temperature image or a thermogram. So before we go in details about this infrared. Let us see what are the governing expressions and what is the.

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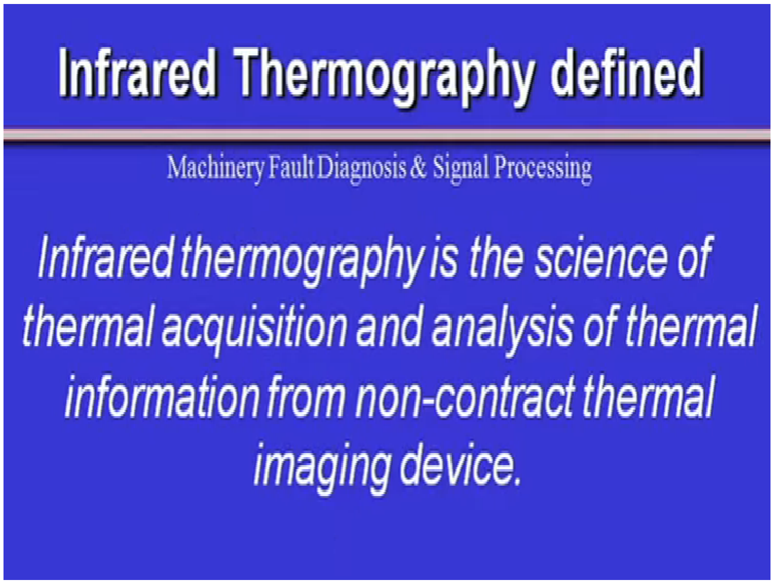

Theory of this temperature radiation and how the heat energy is getting transferred and so on. So if I was to define thermography, so infrared thermography is the science of thermal acquisition and analysis of thermal information from non contract thermal imaging device.

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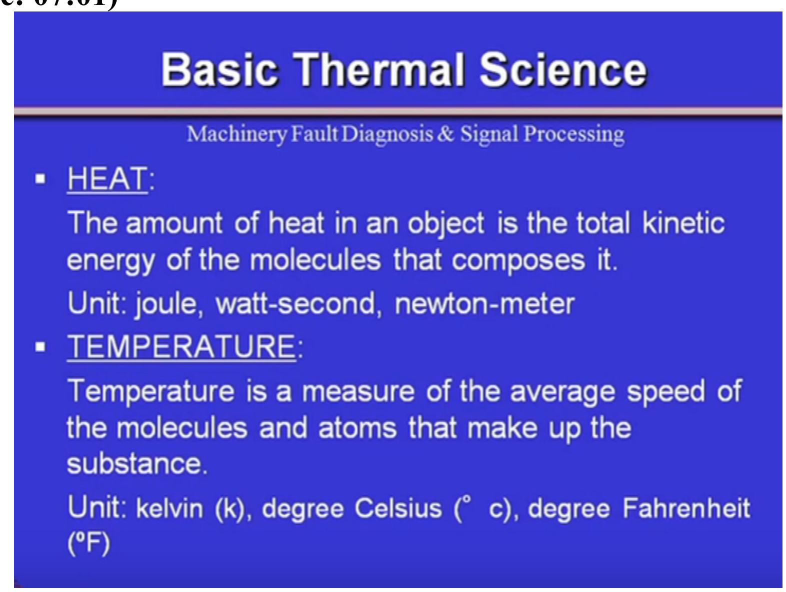

So some basic about this thermal sciences well these are basic textbook definitions like the, amount of heat in an object is the total kinetic energy of the molecules that composes it and the temperature is a measure of the average speed of the molecules and atoms that take up substance.

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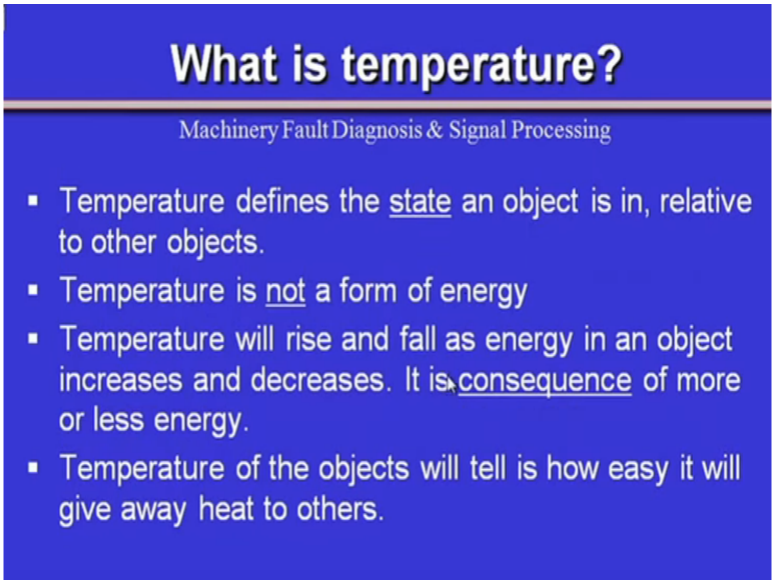

So temperature defines this state an object is in relative to other objects. Temperature is not a form of energy. But temperature is an index of the amount of energy in the body. Temperature will rise and fall as energy in an object increases and decreases it is consequences of more or less energy. So temperature of the objects will tell us how easy it is for a body to give heat to others or take heat from others. So now certain basics of heat transfer, suppose I have

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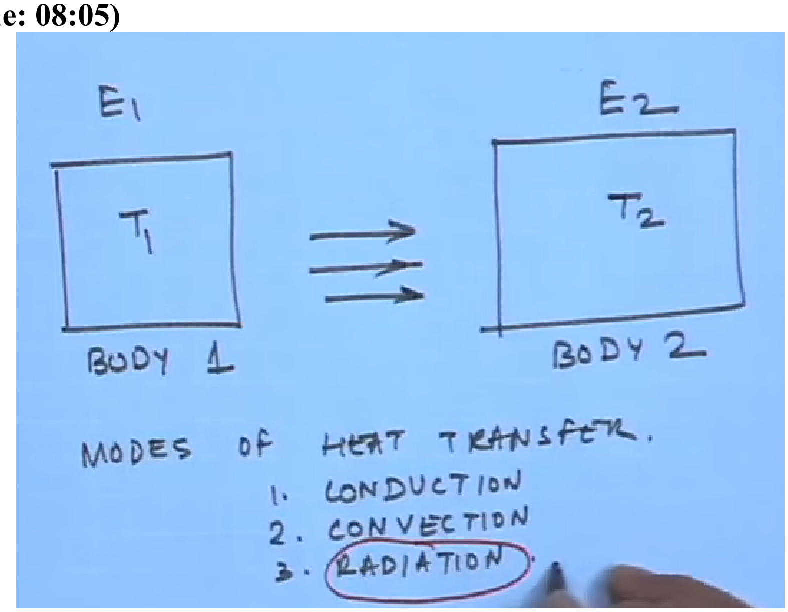

One body here, another body two there are many modes of heat transfer. If this is at some temperature T one this is at some temperature T2 may be the energy is in an higher energy than this some sort of energy transfer occurs. So that this body are in thermal equilibrium, so the modes of heat transfer between bodies as you all know is conduction convection and radiation. So this radiation mode of heat transfer which comes to use in thermography .

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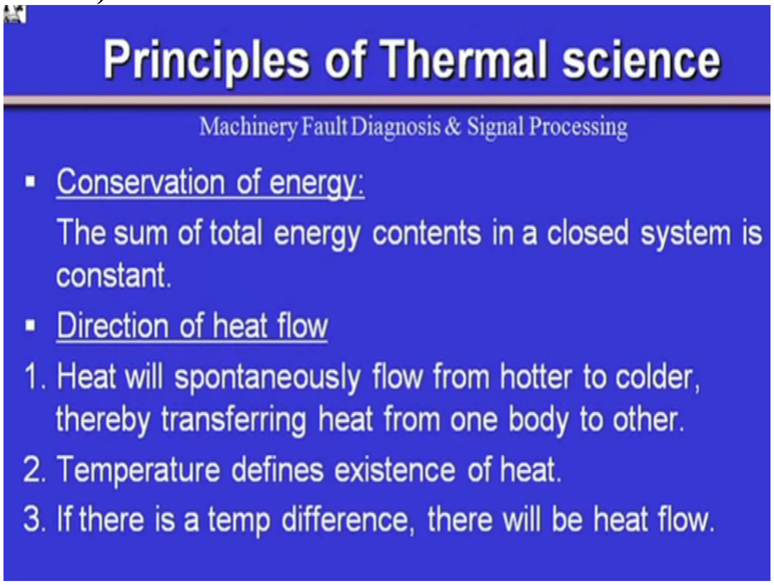

So the principles of thermal science tell us that the conservation of energy the sum total energy contents in a closed system is constant. So there has to be thermal equilibrium. So heat will spontaneously flow from hotter to colder. Therefore transfer of heat from one body to other will occur. So temperature will define the existence of heat and when bodies are in thermal equilibrium there will be no heat transfer.

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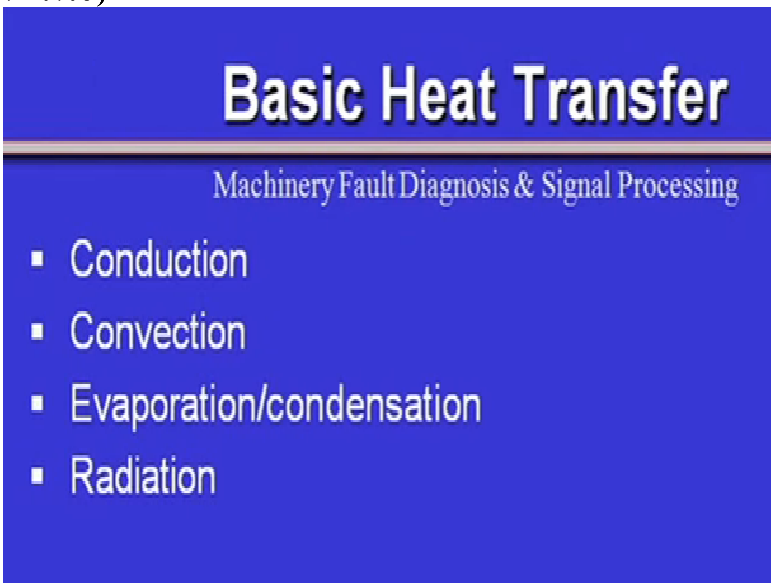

So we just mention about conduction, convection, radiation.

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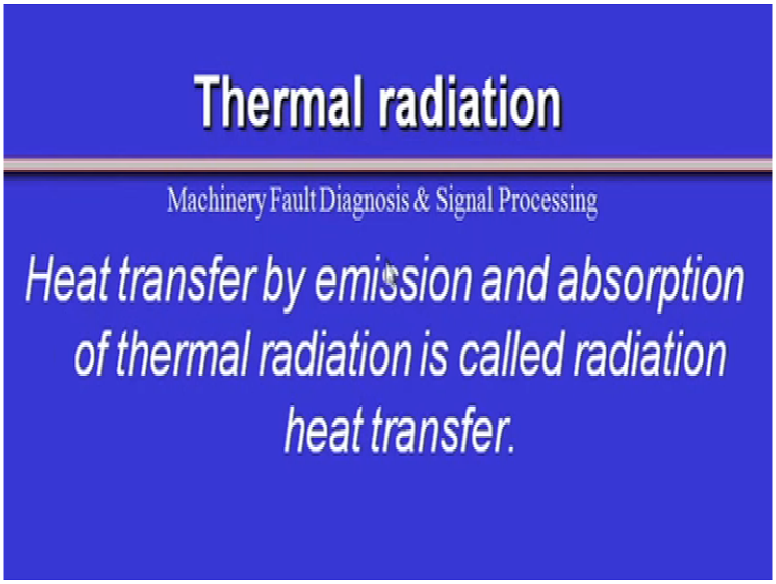

So heat transfer by emission and absorption of thermal radiation is called radiation heat transfer and I was telling you radiation heat transfer is what we are going to take help of to estimate the temperature of the bodies by thermography.

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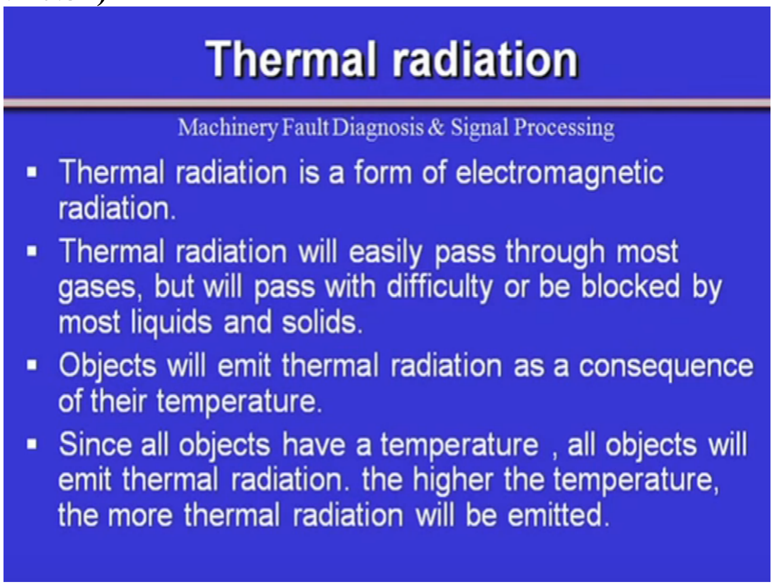

So thermal radiation is a form of electromagnetic radiation we just mention to you these are

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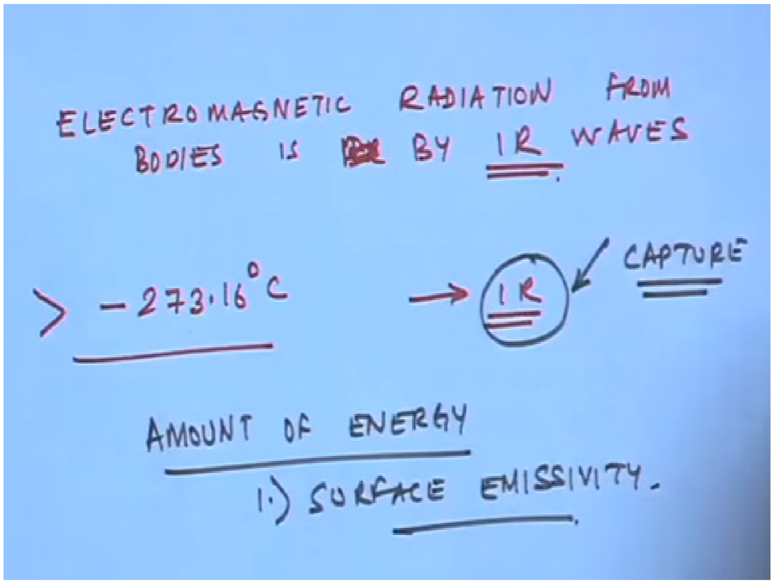

In the form of this electromagnetic radiation from bodies is used by IR waves. So this thermal radiation will easily pass through most gases but will pass with difficulty or be blocked by most liquids and solids. So very easily an object will emit thermal radiation as a consequence of their temperature. Since all objects have a temperature all objects will emit thermal radiation the higher the temperature the more thermal radiation will be emitted.

So in fact anybody it is more than the absolute. If any body temperature is more than the absolute 0 it is going to emit IR but other than that in thermography. We have to find out the way to capture this IR but it is not so simply said that nobody will radiate heat by IR that is fine. But the amount of energy which is emitted depends on few other things like surface emissivity. We will define what this and so on.

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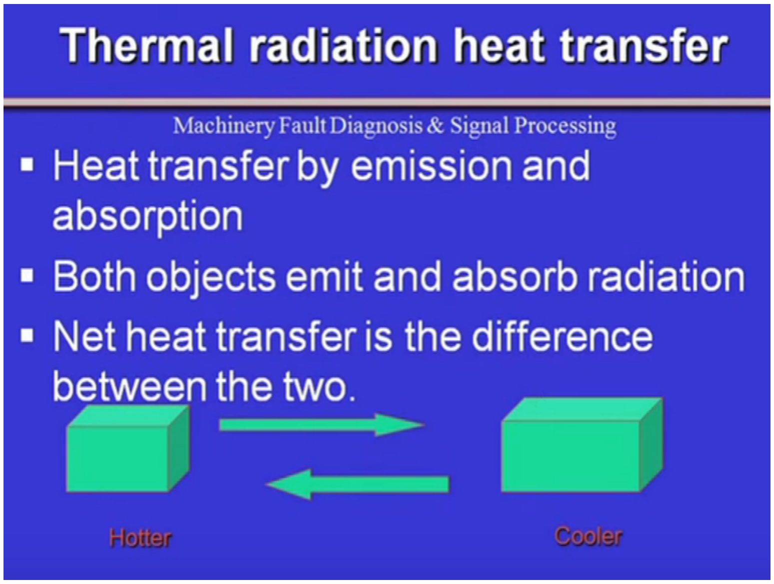

So there is actually I will come to the law later. But so heat transfer by emission and absorption both edge object emit and absorb radiation net heat transfer is the difference between the two.

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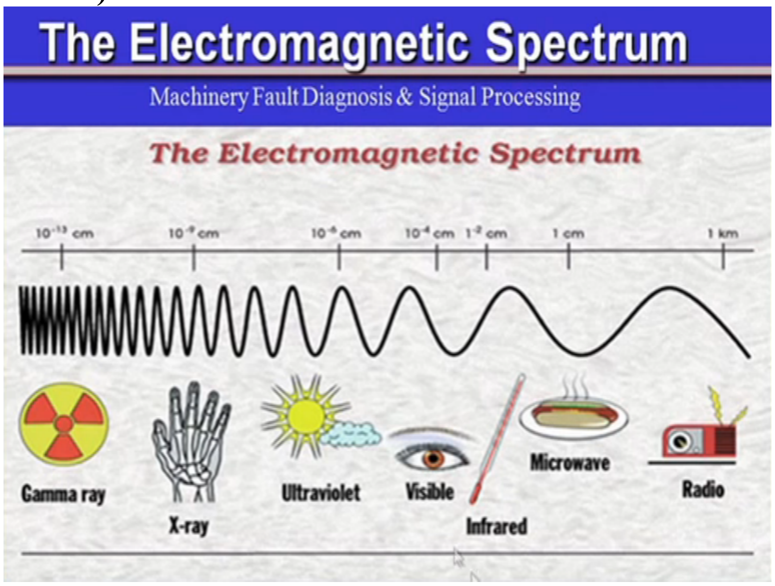

I have just to give you an idea regarding the electromagnetic spectrum. I just mentioned to you about the visible range somewhere from 4000 to 9000 angstrom and then somewhere is the infrared wavelength and the higher the wavelength it will get microwave and radio.

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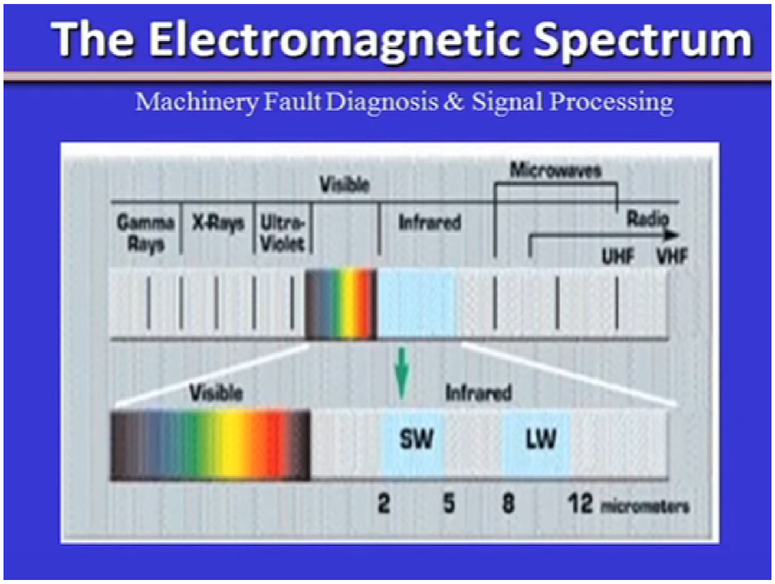

So we are talking beyond the visible is the infrared and this band is where we are taking advantage of it this thermal radiation measurement.

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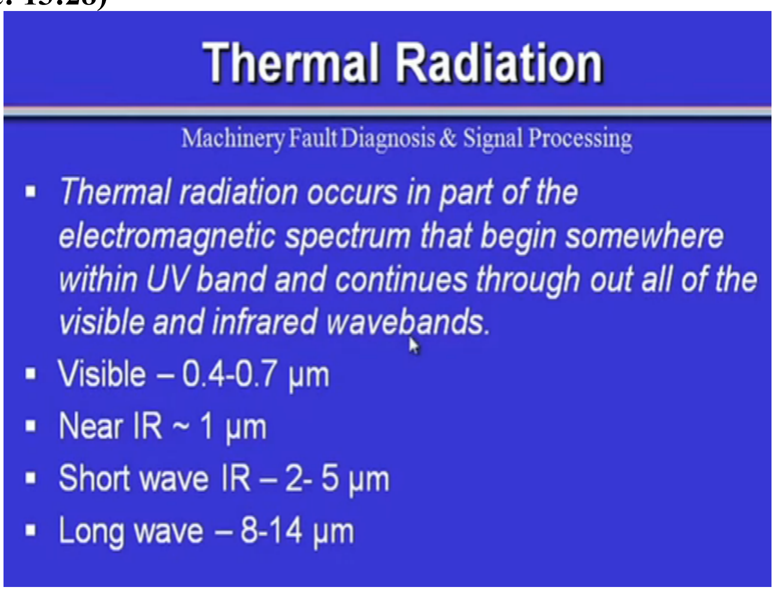

So thermal radiation occurs in part of the electromagnetic spectrum that begins somewhere within UV band and continuous visible infrared wavebands visible is about 4000 to seven thousand angstrom, near IR, short wave IR and long wave IR. So this is the ranges of the wavelength of the infrared waves which are emitted from the body.

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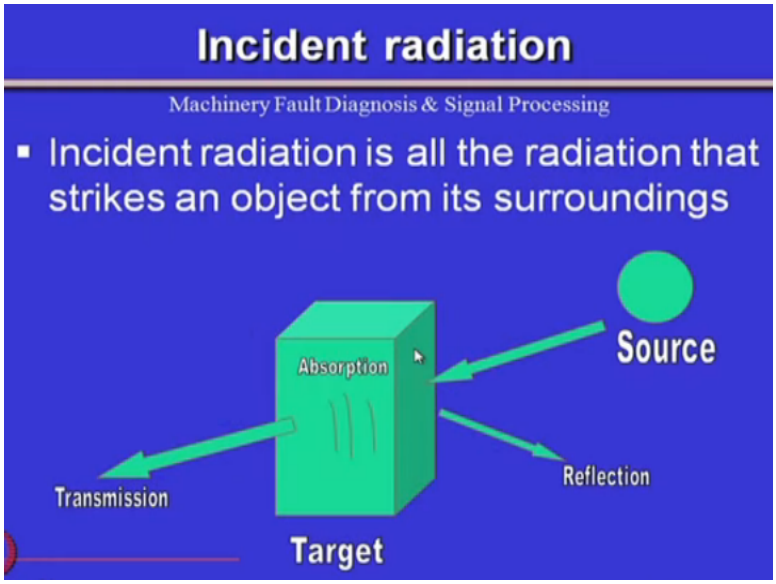

Now infrared radiation is incident on a body from a source. Some of it will get absorbed some will get reflected. Some will get transmitted, now this reflection transmission and absorption depend on the body type, the surface type and so on.

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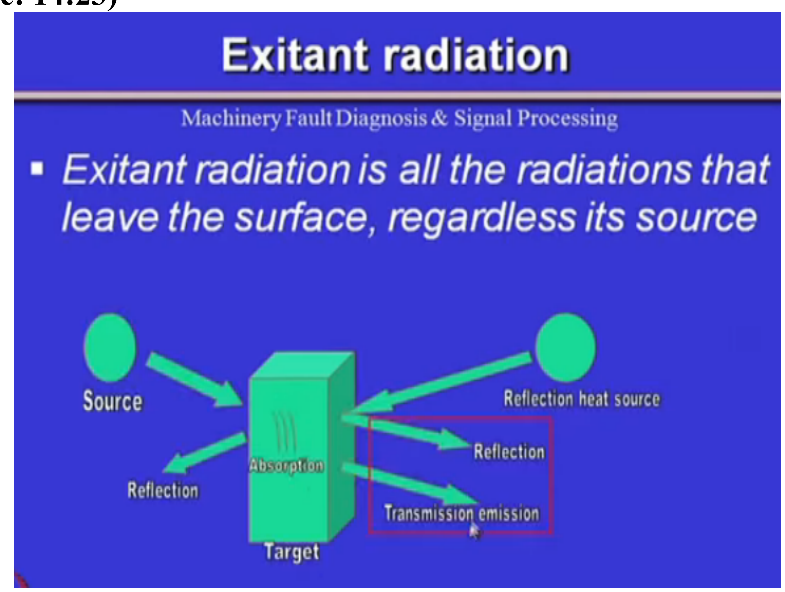

So this reflection which is coming out of the body is what we are going to measure.

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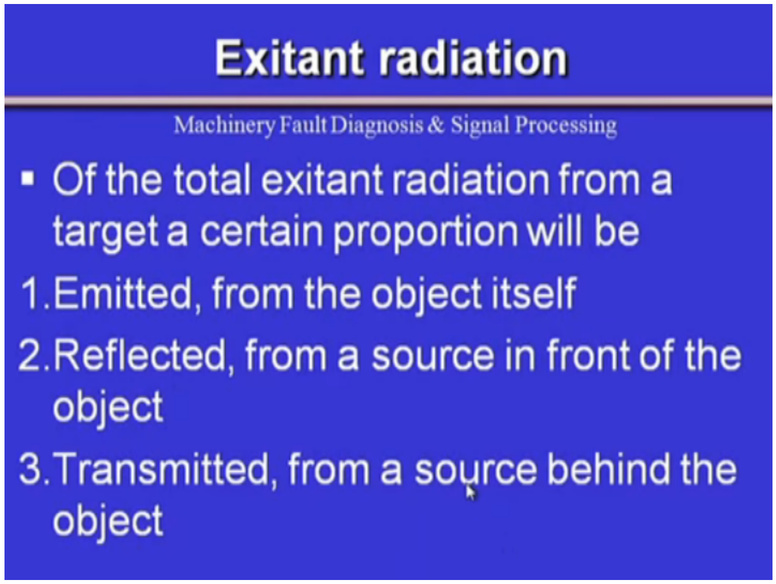

So of the total exitant radiation from a target a certain portion will be, emitted from the object itself. Reflected from a source in front of the object. Transmitted from a source behind the object. So one has to be careful that are we able to capture the right kind of wave.

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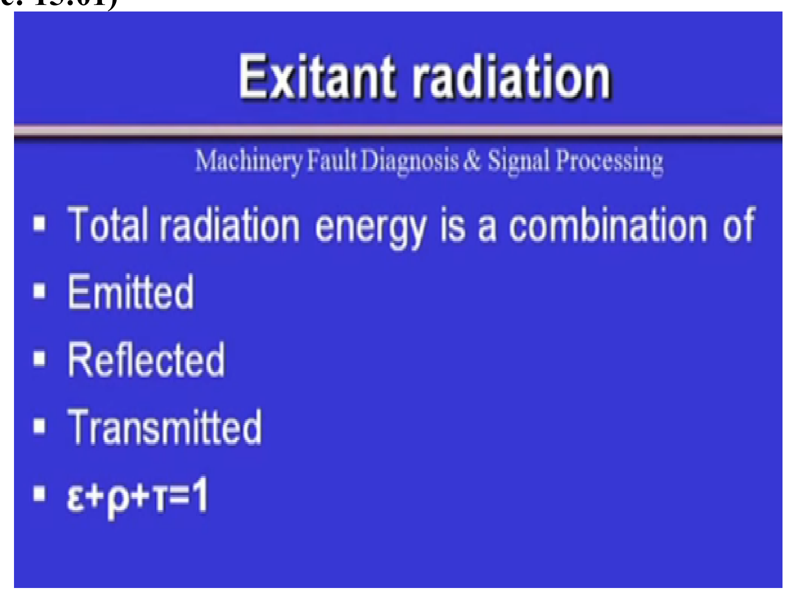

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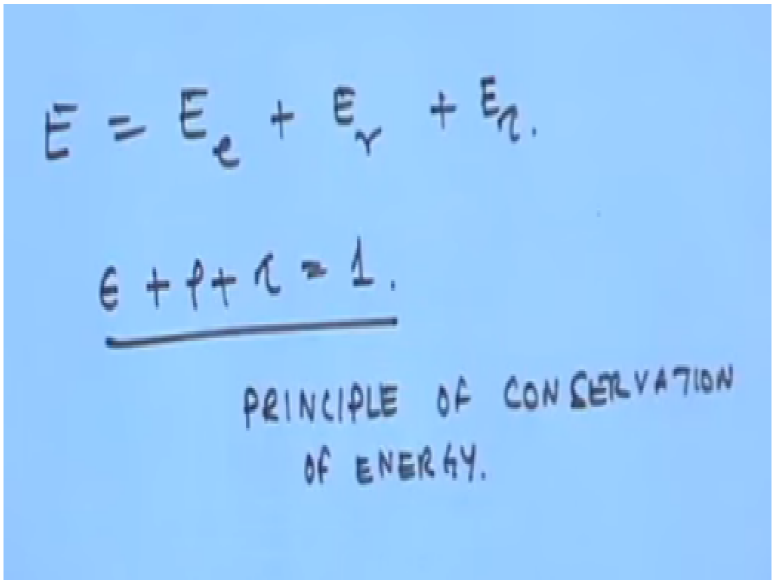

So certain things I will be telling you later on as to the total energy is some of them is emitted, some of them is reflected, some of them is transmitted. So if I take the ratios, they are given by term should be equal one and this expression is always true from the principle of conservation of energy.

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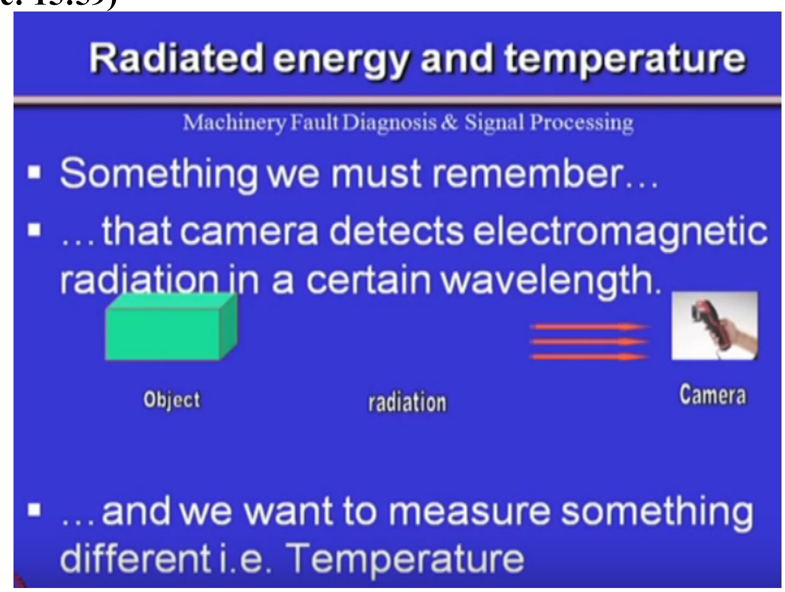

So now if the object or the body is giving out radiation can have a device which can capture this radiation and then try to get a sense as to what the temperature is and that is the essence of principle behind this thermal radiation or thermography principle. Now let us see that is the certain physical law.

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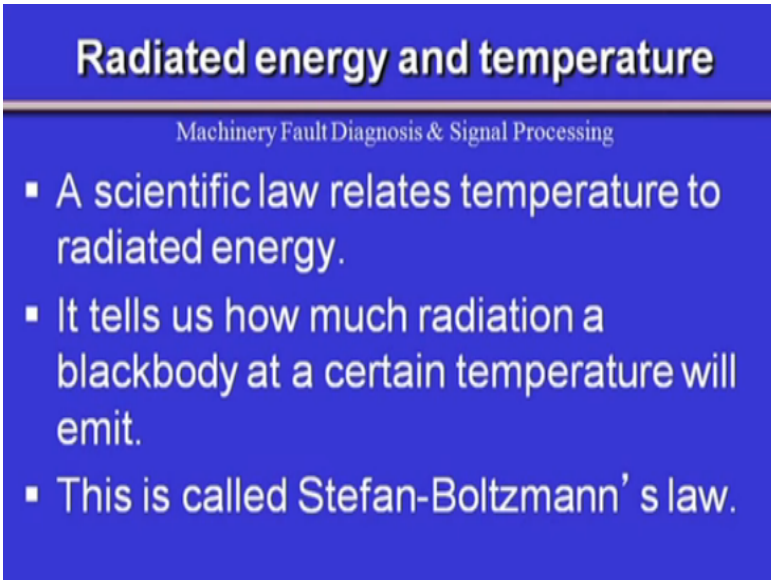

There is an scientific law relates to the temperature to the radiated energy and this tells us how much radiation a black body at a certain temperature will emit and this is called as the Stefan boltzman law. So based on the Stefan boltzman law the amount of energy which is getting emitted can be estimated.

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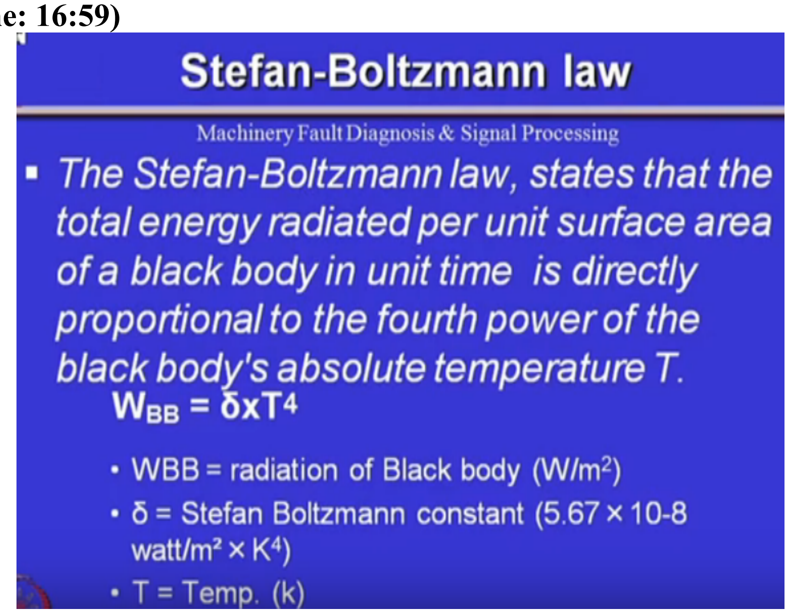

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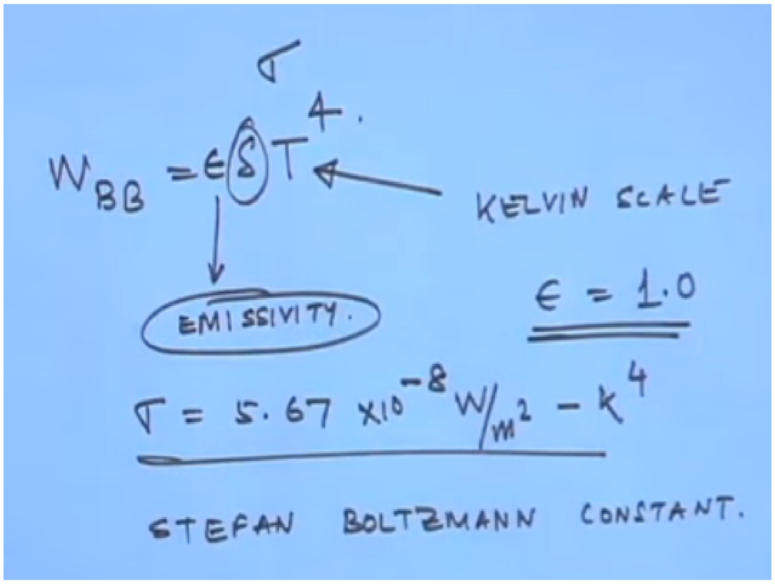

And for a perfect black body that means which only the energy given out is given here I will give an expression here. This is one of the emissivity and when you there like this is delta or sigma. So this temperature is in the Kelvin scale and value of the Stefan boltzman constant is 5.67. It is not ten to the power minus eight.

So this value is 5.67 into 10 to the power - 8 watt per meter square Kelvin to the power 4 Stefan boltzman constant. So anybody which radiates heat energy can be estimated by this expression where this is the parameter for black body this happens to be one for other bodies will see what the values are.

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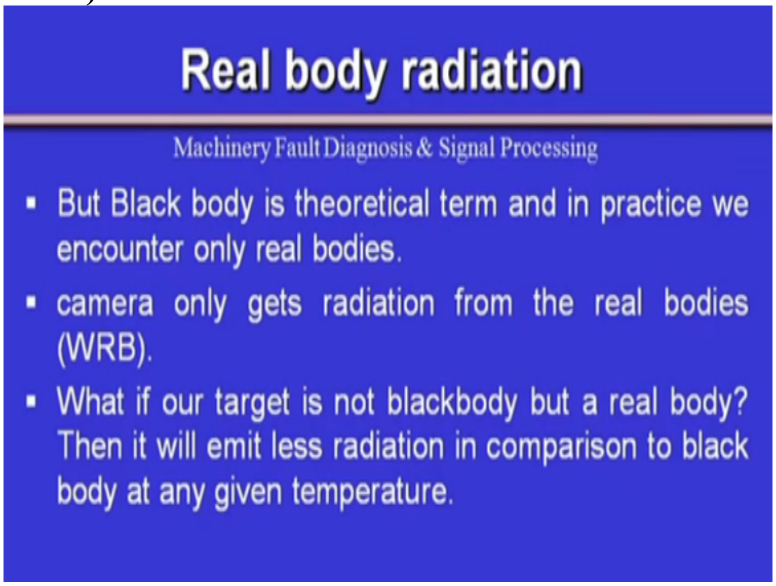

So body is a theoretical term and in practice we encounter only real bodies. So these are known as camera only gets radiation from the real bodies. So what if our target is not black body but a real body then it will emit less radiation emissivity of not black bodies or real bodies reflection is less than 1.0 where keep that in mind for every material if this emissivity is known to us. Then we can plug in the emissivity value and then we can because of the temperature.

But many times what happens the emissivity is not known but sometimes this can be found out by simple calibration and I will explain you how this calibration particularly for infrared imaging is done and that is very handy concept which is to be used in the field because if I have a thermal camera how do I believe that whatever temperature it is given is correct. So that calls for incentive field calibration.

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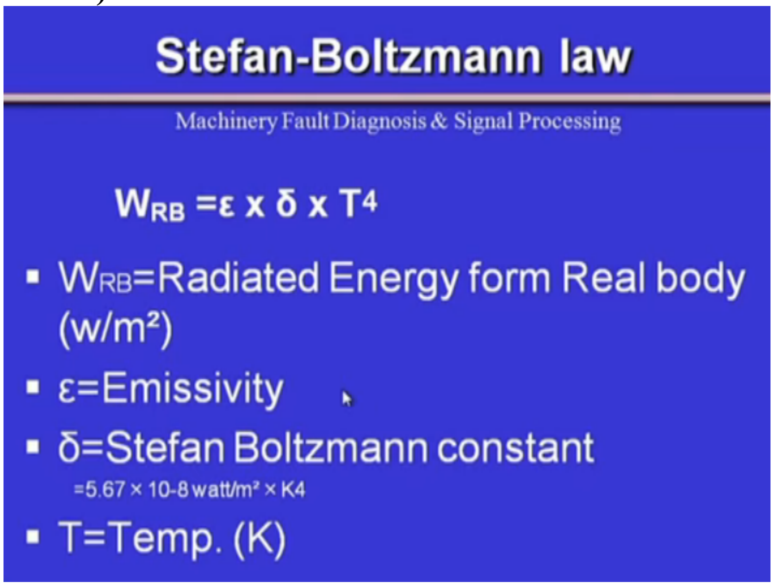

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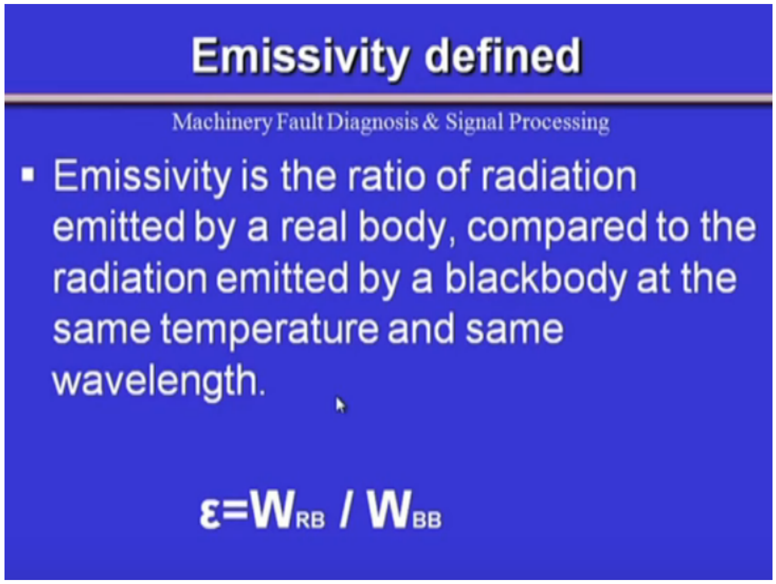

So this is the Stefan boltzman law so emissivity is the ratio of radiation emitted by a real body compared to the radiation emitted by a black body at the same wavelength and same temperature.

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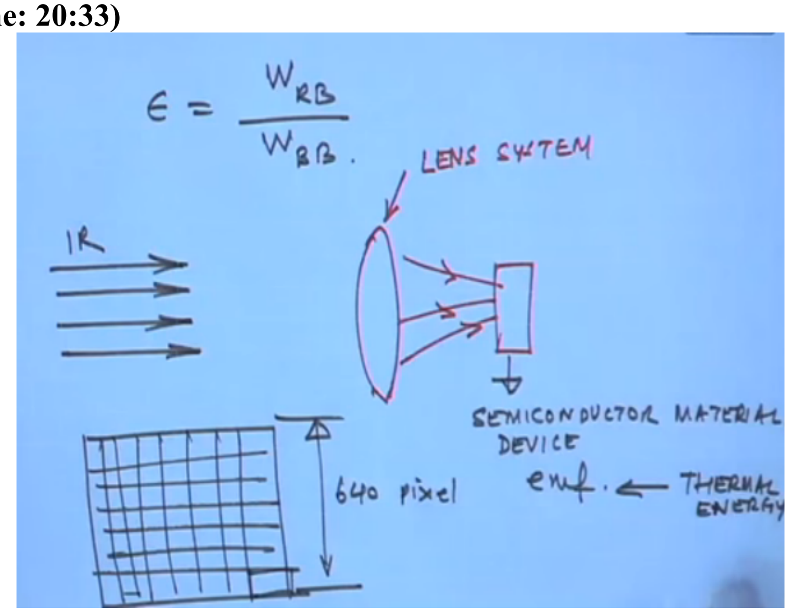

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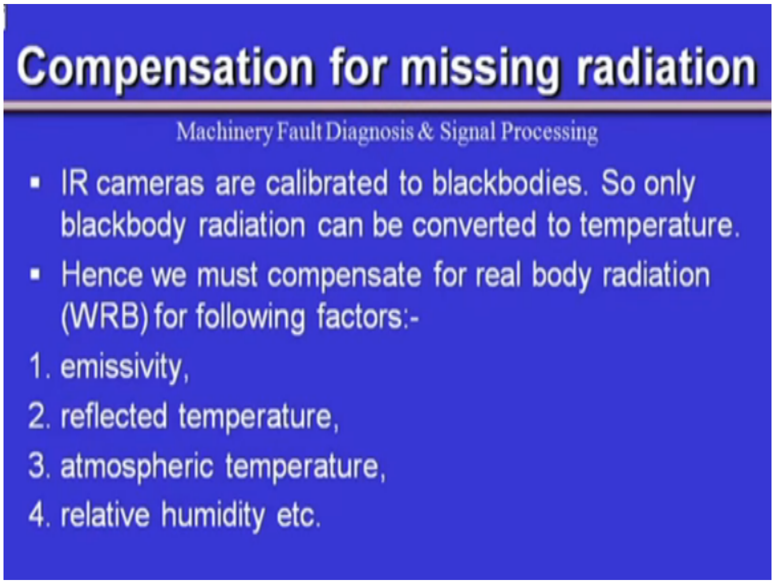

Real body black body now some times this IR cameras before I go into this let me tell you what this IR cameras are actually. So now I know that some IR waves are incident. So what I can have less system which will make this IR waves convert converge on a semi conductor device and which gives us certain EMF based on the thermal energy incident.

So this is essential semi conductor material and you can think of them as a grade and they will be pixel of the pixel. So this could some pixel 320, 640 depending on. So many pixels can be there depending on the resolution each of this pixels will gill give us an EMF. So if I have a body,

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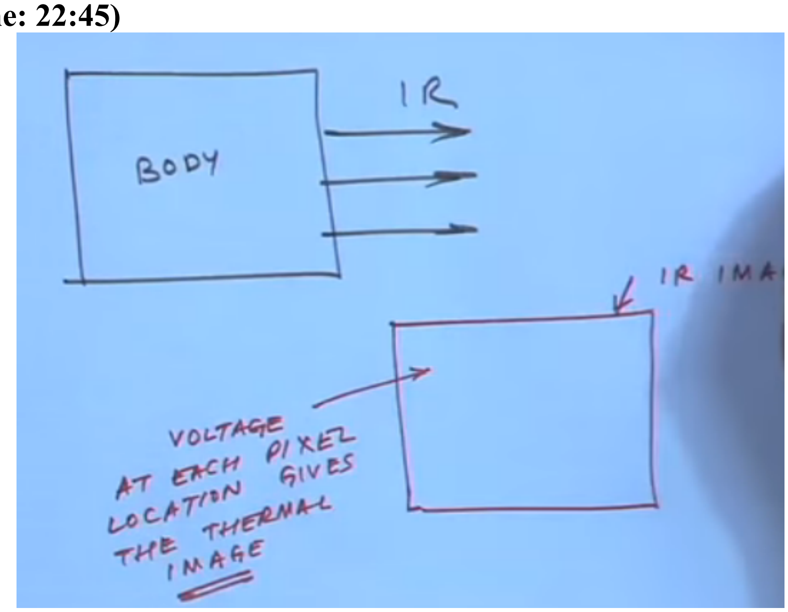

Which is giving out IR waves I can have a camera system and which will essentially an IR image on the camera where depending on the temperature the voltage at each pixel location gives the thermal image. That is something we have to keep in mind, so depending on the body I will be showing you examples where in this thermography, how it is useful in condition monitoring or quick measurements of the surface temperatures of large bodies.

These are very handy imagine in many times to measure temperature we normally use thermocouples RTDs thermometer even for that matter but imagine a large body say for example the wall of a blast furnace. We will like to find out if the blast furnace refracted lining in the inside has weaken or got damaged. So that the blast furnace wall temperature at that point would increase to do to find out such places. We can do a quick survey so coming to the application of this technique.

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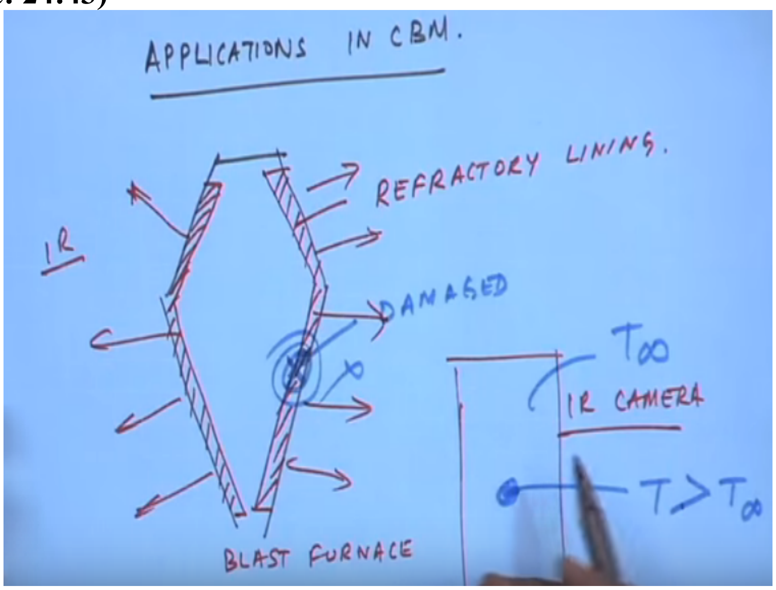

So that we appreciate that why at all we are using this technique in CBM. Let us talk about blast furnace. Some sort of a furnace when there is the refractory lining and this is the blast furnace wall. So if there is some place where this has got damaged. So I can shoot and I might all this are everything giving out IR waves. So if I have a IR camera it is going to capture this IR waves and then it will give us a picture that if you look at the side view, this blast furnace maybe this is the area.

Because this got damaged the temperature has shot up this temperature is much higher than the normal temperature and this gives us quick way to find out that this area in the blast furnace is damaged. So this would normally would not have been possible by conventional temperature measuring imagine a large blast furnace about 20 meters height, 4 meters in diameter. Imagine I mean just cannot put thermocouples and keep measuring these are some of the areas and another example I will tell you how this has helped us in CBM for example you know in electrical circuits.

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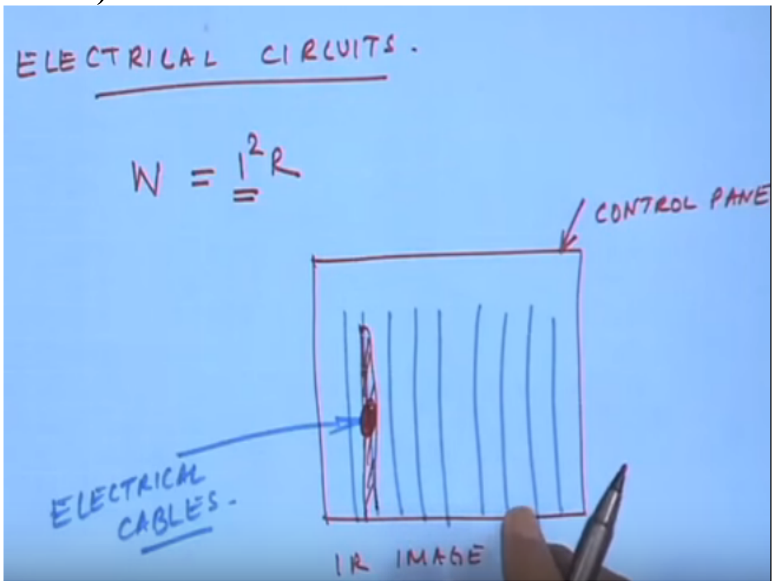

The heat radiation is I square R and the current increases the heating effect the current produces the temperature and imagine you have a control panel particularly in ships. This is used so this is the control panel and behind it there are lot of electrical cables which are going around. These are all electrical, so if the one particular cable is carrying high current for some reason it may be a higher increase in the lower or something.

This temperature has increased or the entire cable the temperature has increased. So what can happen by an IR image it can quickly find out that where is the source of the increase in temperature. So these are the places where the thermography is applicable in CBM if I was to briefly say it is used for a quick.

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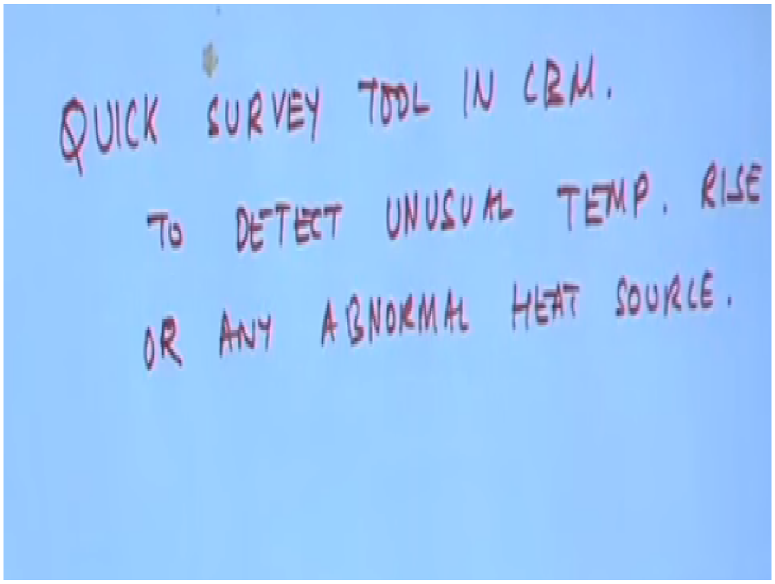

Survey tool in CBM to detect unusual temperature rise or any abnormal heat source. This is where CBM is of use. Now this IR cameras,

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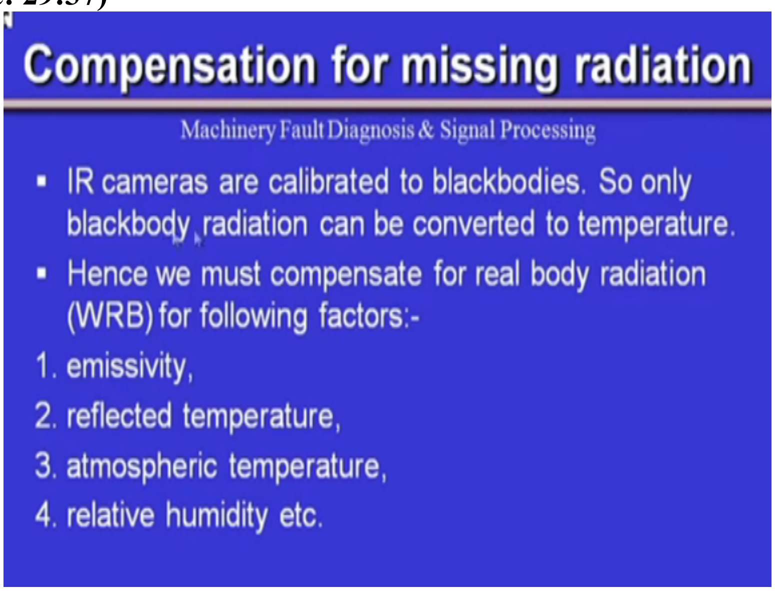

Are calibrated to black body. So only black body radiation can be converted to temperature. Hence we must compensate for real body radiation by the most important is the emissivity, reflected temperature, it will left you with humidity, atmospheric temperature because these factors will affect the infrared waves which are incident which are being emitted from the body but most importantly let us look into this emissivity.

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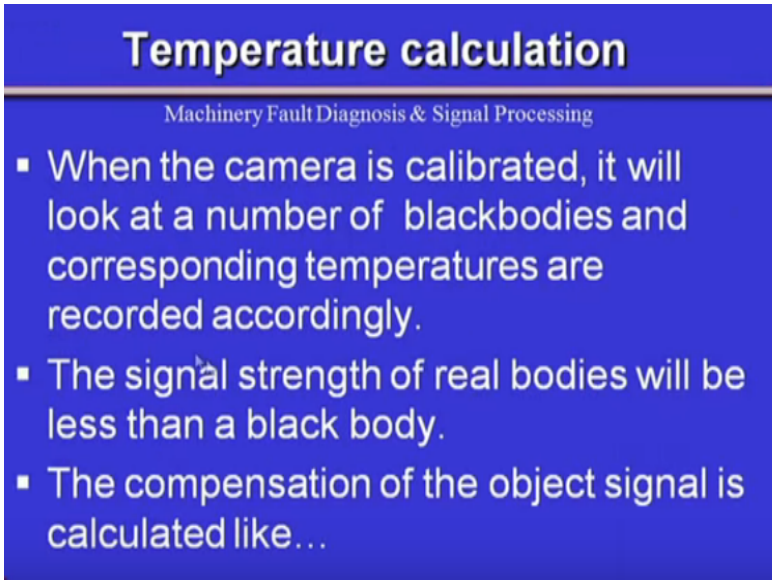

So when the camera is calibrated it will look at a number of black body and corresponding temperatures are recorded accordingly. The signal strength of real bodies will be less than a black body. The compensation of the signal is calculated like.

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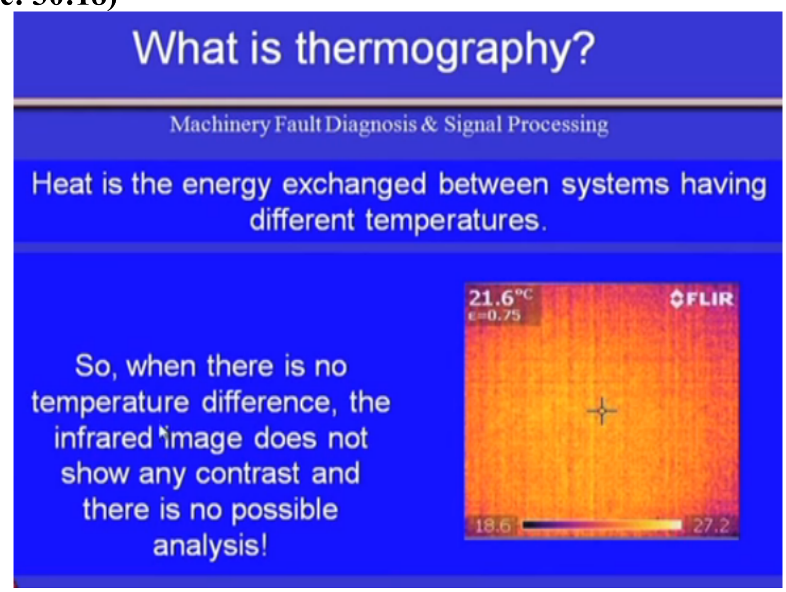

Heat is the energy exchanged between systems having different temperatures. So when there is temperature difference the infrared image does not show any contrast and there is no possible analysis. So if there is no temperature difference I cannot find out any contrast and thus I cannot possibly do thermography. So there has to be a temperature difference to find out, any

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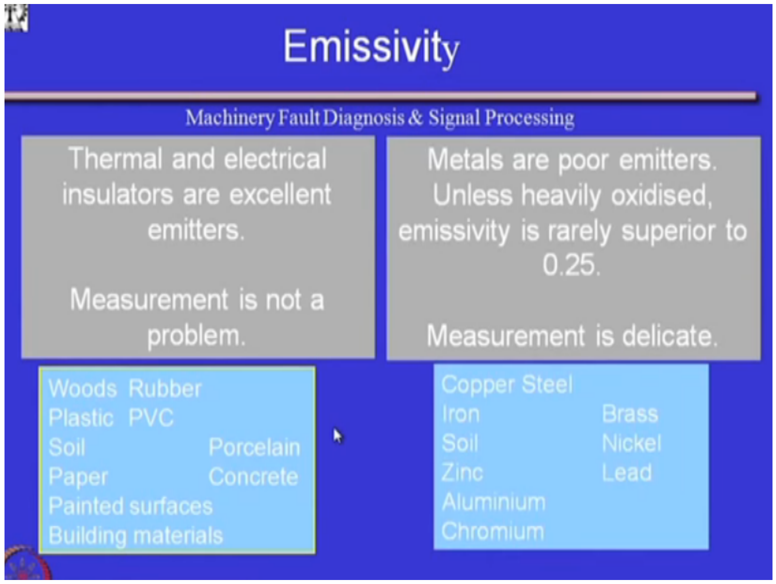

Significant information. So something about this emissivity, so thermal and electrical insulators are excellent emitters. Measurement is not a problem like on woods, plastic, soil, paper, painted surface, building material, porcelain, concrete but metals are poor emitters unless heavily oxidized.

Emissivity is rare superior to only point two five. Measurement is difficult when we have lot of metals copper, steel, iron, iron coil zinc, aluminum, chromium, brass, nickel, lead extra. Now how do I know while we are doing calibration? How do I know that I am doing right kind of measurements? So what typically people do is,

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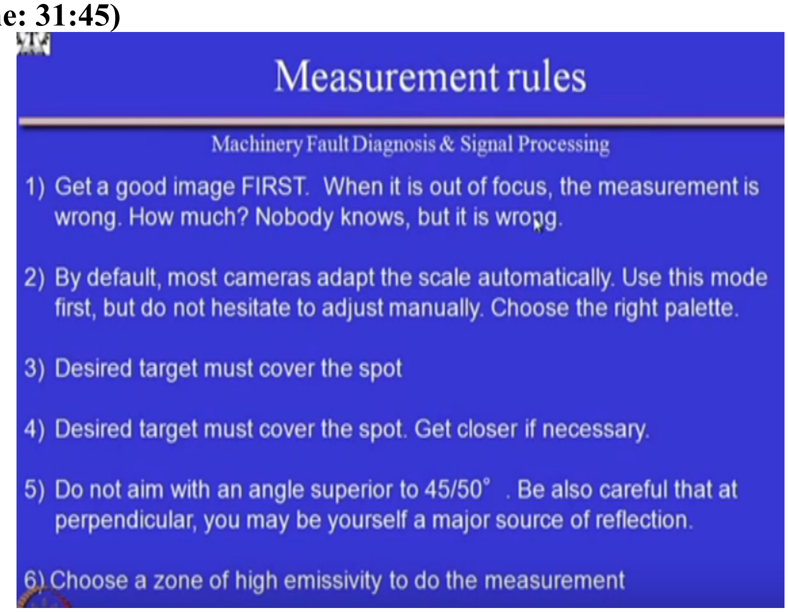

Some of the rules which we will follow, but a good thermal imaging procedure requires that I first capture a good image. When it is out of focus the measurement is wrong how much nobody knows but it is wrong. So first thing is we have to focus. Sometimes these IR cameras if you can think of these IR cameras are little sophisticated than your normal video cameras. Or you can say sophisticated IR cameras can be still bar.

You can record them in a video mode but the most important characteristics of this IR camera is we have a semi conductor backing or focusing plane which gives out voltage. Sometimes laser are provided on such IR cameras to focus on a particular desired target must cover the spot and that is why sometimes we have to use a laser and do not aim with an angle greater than 45, 5 degree.

But sometimes you know what happens if you are perpendicular to the body you may also be refracting and choose a zone of high emissivity to do the measurement. So these are some of the things you have to keep in mind. Say for example whenever you are measuring on a shiny metal.

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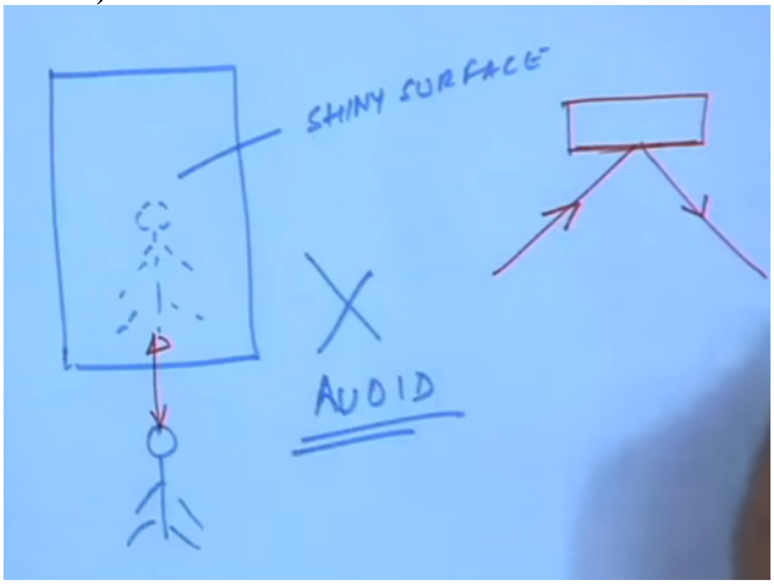

An example where we had a refrigerator and I was trying to measure. This is the shiny surface and if you are measuring front of it, so your reflections is going to come across. So this is to be avoided. This kind of a scenario and never be perpendicular, if you are perpendicular always stand at angle and this angle is usually between 40 to 50 degrees.

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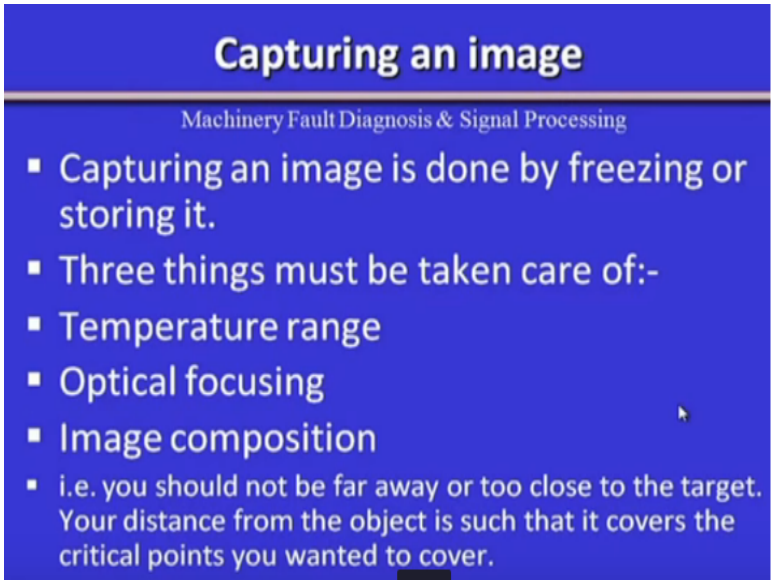

So essentially three things must be taken care of while doing an thermography. One is the temperature range, focusing and the image composition. So you should not be far away or too close to the target. Your distance from the object is such that it covers the critical points you wanted to cover. So it depends on the

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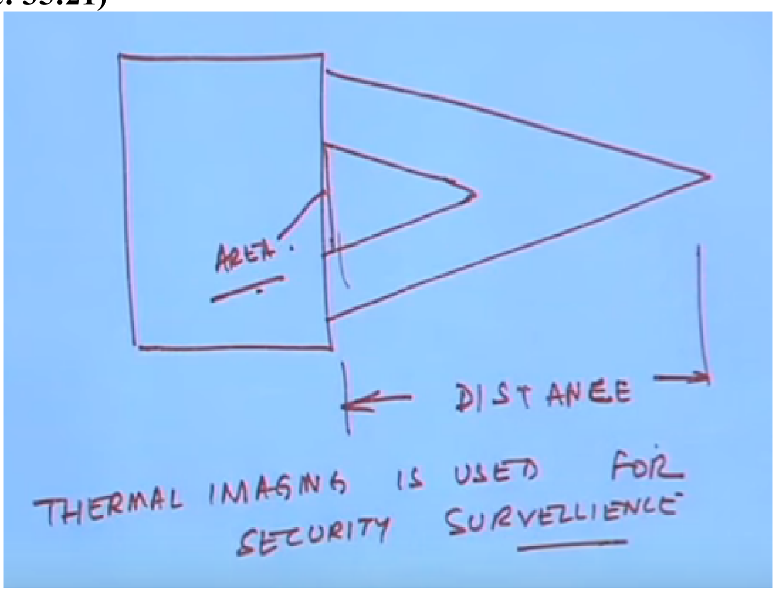

Focusing area and the depth of coverage. If you are close by you can only get this, if you are far off like then depending on the distance and this area and of course there is no end to this distance. For example I will just give you an example many times you know you have seen thermal imaging is used for security surveillance.

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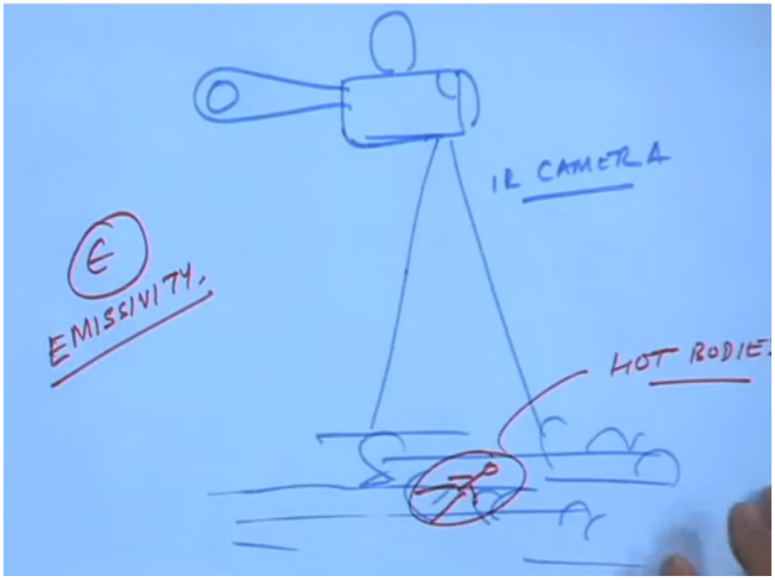

So what happens, suppose there are shafts and there is a intruder. So you must have seen this from above or maybe from a helicopter. You can shoot an IR camera, so you can identify a hot body that is depth of coverage will depend on how high, up from the ground you are and there is no end to the length. You can cover and of course with more the length, area of coverage will increase.

But most important factor which you have to keep in mind is this emissivity. Now all this cameras have a microprocessor based circuit.

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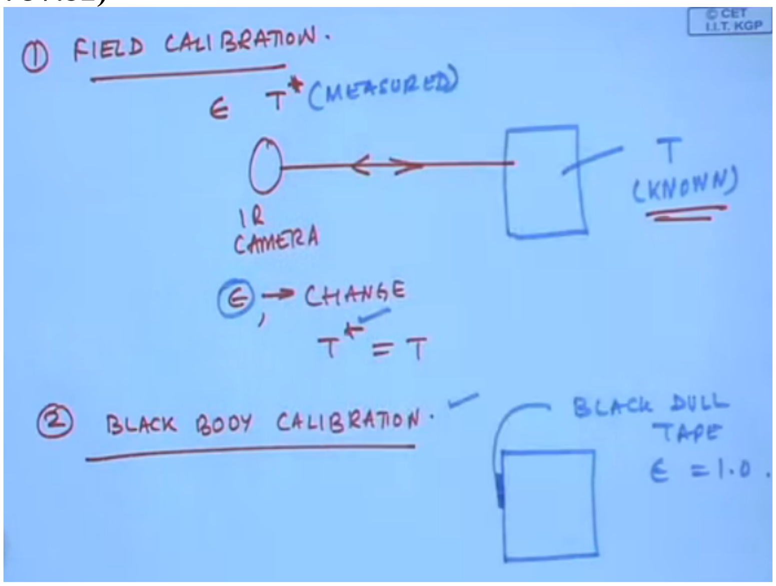

So for example one quick rule of calibration people do is suppose this known temperature T and they will try to shoot from an IR camera and suppose they measure a temperature T star with a particular emissivity. So in this camera there is an option to change emissivity, some of these handled cameras. So you can change the value of emissivity. So that T star equals to T provided T is known and you can do that with couple of temperature and that is a very quick way you can do field calibration that is one.

Next is you can do a black body calibration in the sense I will make a body and I will put some black patch, black tape, black dull tape. So that emissivity becomes one and then because the emissivity of this IR camera is set to one I will measure the temperature accurately. So this is one but in the field it is always good to change emissivity. So that your known temperature is equal to whatever you are measuring by T star by the camera. This is something you have to keep in mind.

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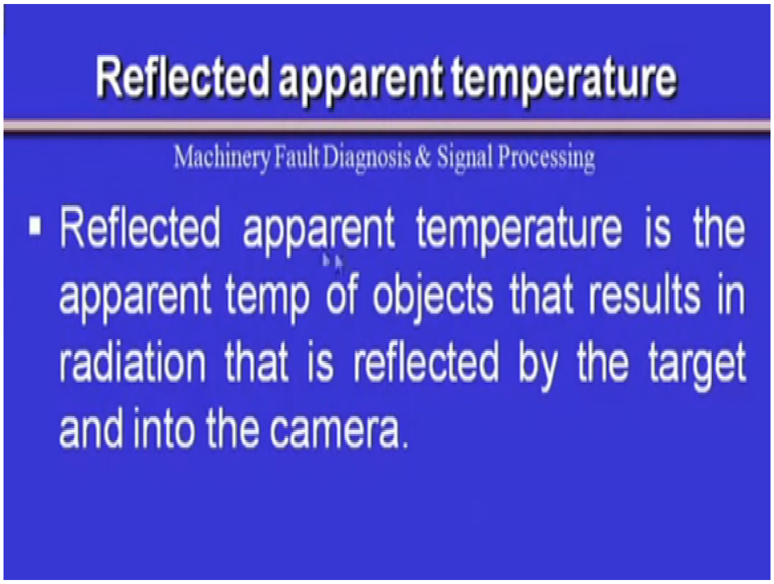

So the reflected temperature is a problem while doing IR measurement. So reflected apparent temperature is the, apparent temperature of objects that results in radiation that is reflected by the target and into the camera to avoid reflection. We should not be right in front of the camera and we should be little away from it.

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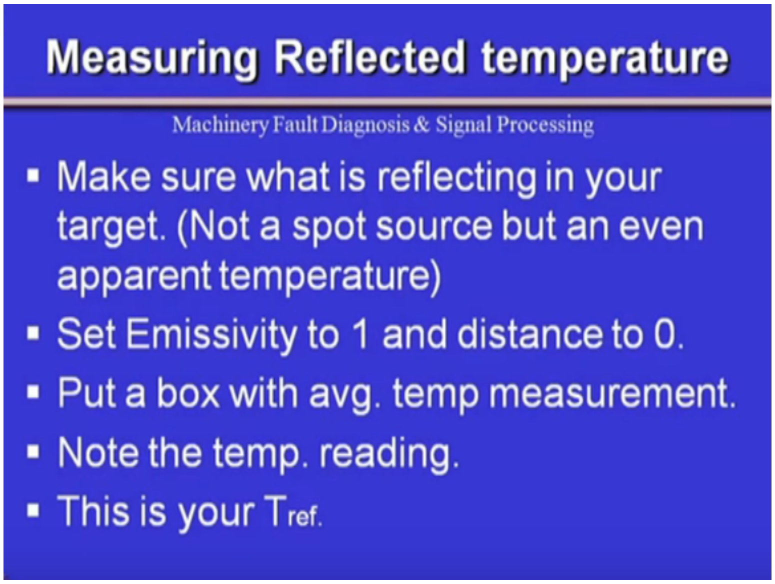

So make sure that what is reflecting in your target not a spot source but or an even apparent temperature set emissivity to one and then you can find out the average temperature.

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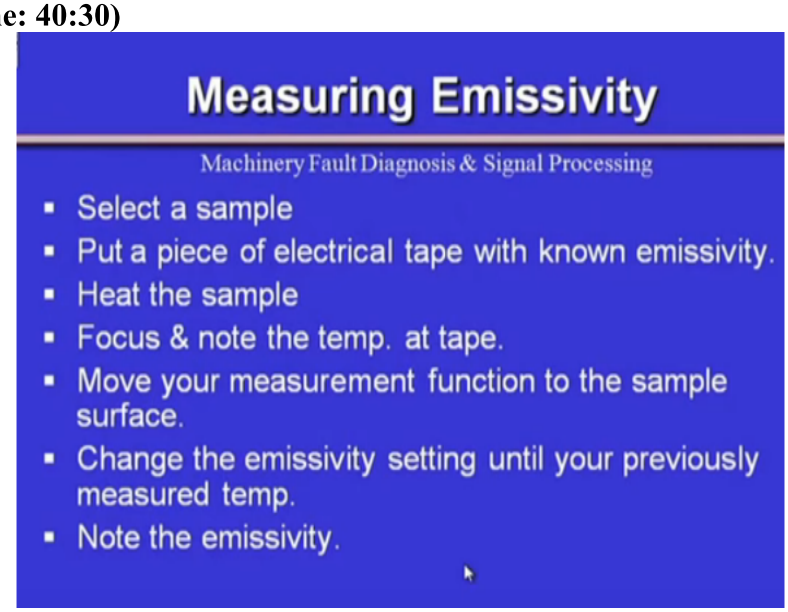

So one way to measure emissivity select a sample put a place of electrical tape with known emissivity. Heat the sample, focus and note the temperature at tape, move your measurement function to the sample surface, change the emissivity setting and then till you get the previous. So you can change the emissivity till you get the right temperature that is what people follow in the field.

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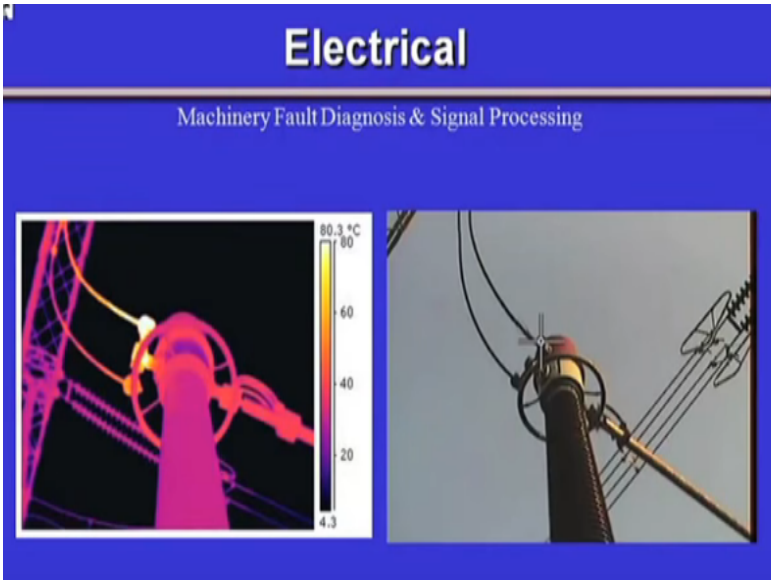

Now these are some examples which I am going to show you. Example, many times in this switch gear these are because of loose contact. You can find out by thermal imaging that how this kind of temperature can be measured and which is not possible.

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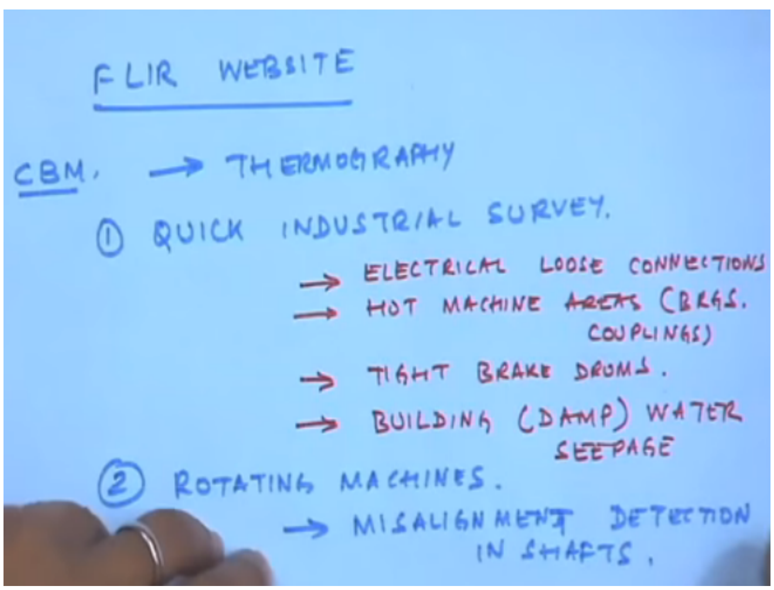

Imagine a high voltage circuit it is not humanly possible for them to monitor it temperature by the way some of this images from the are from the FLIR website. In fact you know in laboratory we have an FLIR camera and I will be showing that to you.

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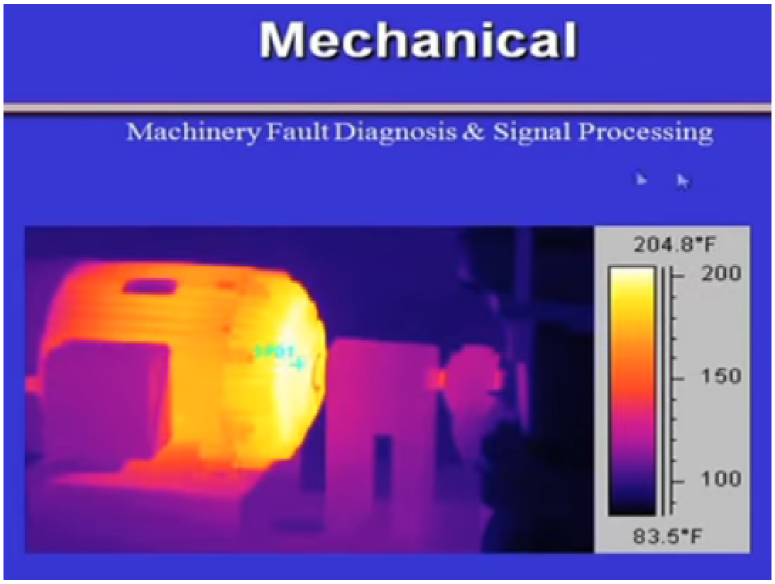

And this is particularly in electrical motor. Again a thermal image this is near the bearing of the electrical motor.

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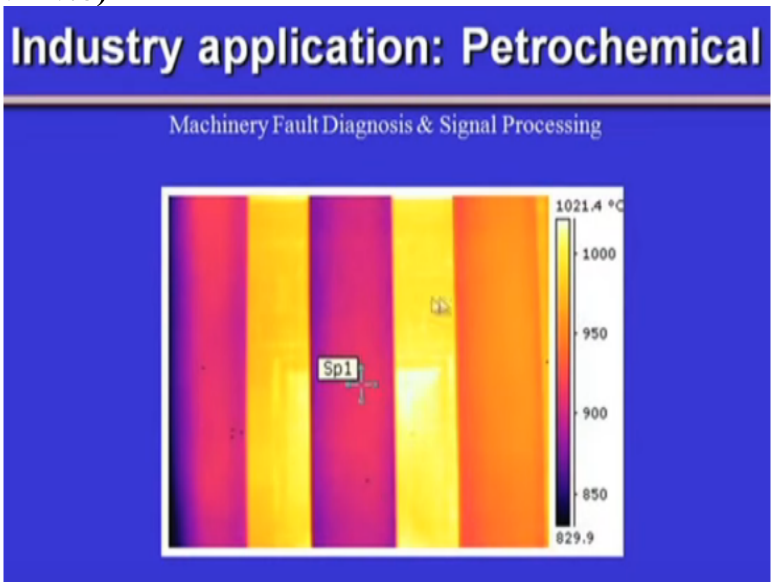

You can see how the temperature has increased particularly in few petrochemical applications.

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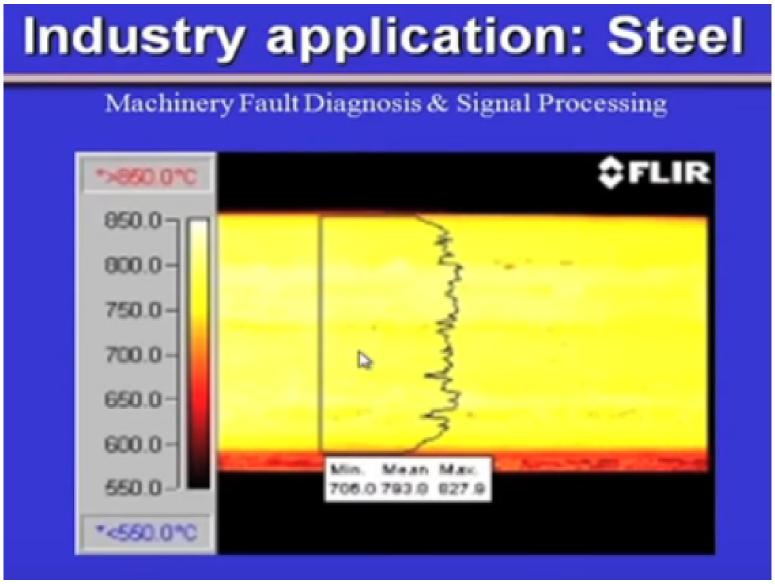

This is in this steel meal measuring temperature difference a very high temperature rotating of jets. We cannot possibly measure the thermography or temperature measurements. So in CBM the applications of thermography are for quick industrial survey, lot of energy audits are done using thermography like you can find out electrical loose connections, hot machine, areas like bearings couplings, tight brake drums.

Particularly automobiles building if building has become damped or water seepage. So these are few industrial surveys but if was to go down to rotating machines in our laboratory in fact we have been able to find out detect misalignments, detection in shafts.

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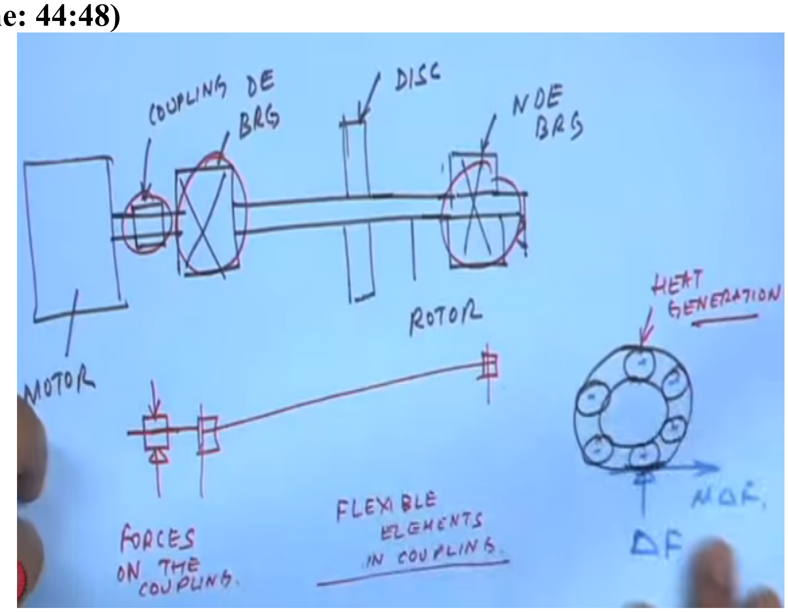

I will tell you how this happens for example, we have a bearing we may be driven by a motor and then I have a disc on the shaft and then another bearing and there is a complaint between the motor and the shaft. So this is the coupling, motor bearing, driven bearing, ND non driven bearing, rotor and this is the disc. So if this shafts where mishandle some extent what happens they will be forces on the coupling forces on the coupling.

Then what happens because of the forces of the couplings these bearings the rolling elements and there are certain clearances between them and they are allowed to move. So there will be some sort of an extra force I am writing them as Delta force and because of this force there will be increase in refraction. Refraction force will increase and this is going to be the source of heat generation.

So once and while they are rotating and there will be lubricants. So heat will be generated in the bearings because of such forces and sometimes these couplings also have some flexible elements. So flexible elements in coupling will also get heated up because there is a sliding of flexible elements in the coupling because of the forces and heat is being generated. So couplings will become hot couplings and when a machine is rotating by noticing the change in the coupling temperature, I went to measure the coupling temperature that is a difficult thing because a rotating device.

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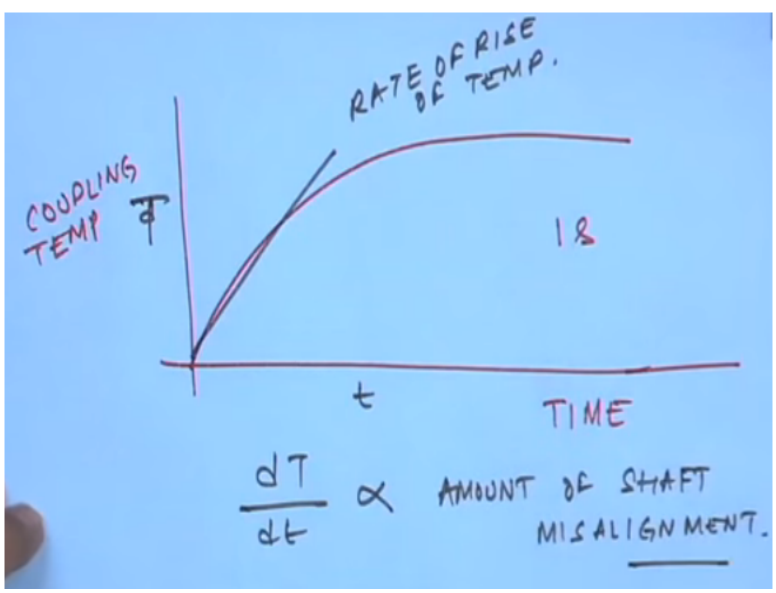

So if somehow by IR image I can record the coupling temperature and so for a exponential curve being a first order system the rate of rise of this temperature is going to be capital T. So DT by will be proportional to amount of shaft misalignment and so this has to be measured by an infrared thermal imaging camera where we have to sample them at temperatures at intervals of maybe every one second. So this cameras also have the provision to capture image frame you know depending on the,

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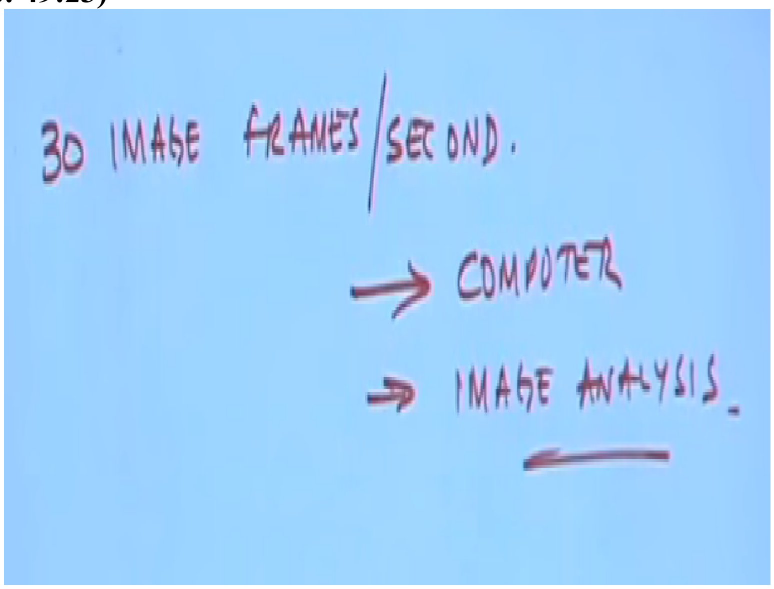

Format maybe 30 image frames per second and then store it with computer where you can do further image analysis. So all those kind of things can be done with thermal imaging.

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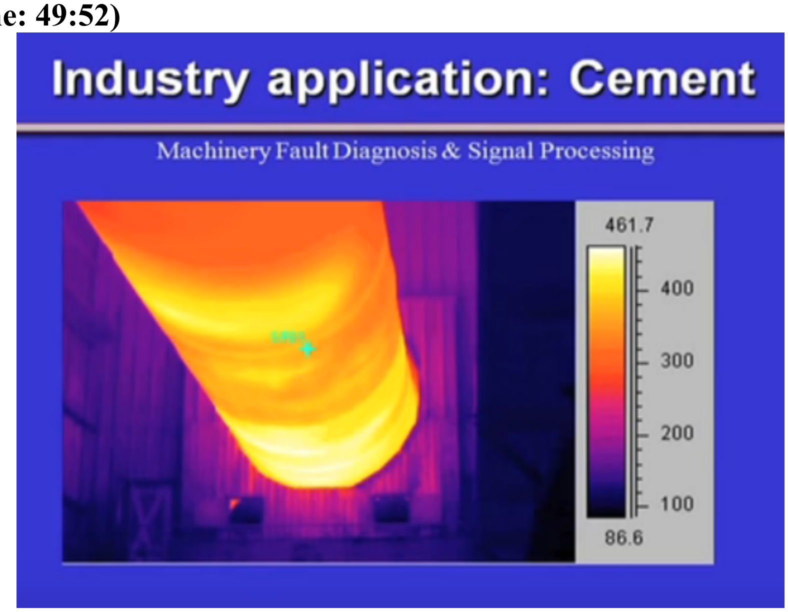

And this is another example where in a cement plant, you can see the thin becoming hot.
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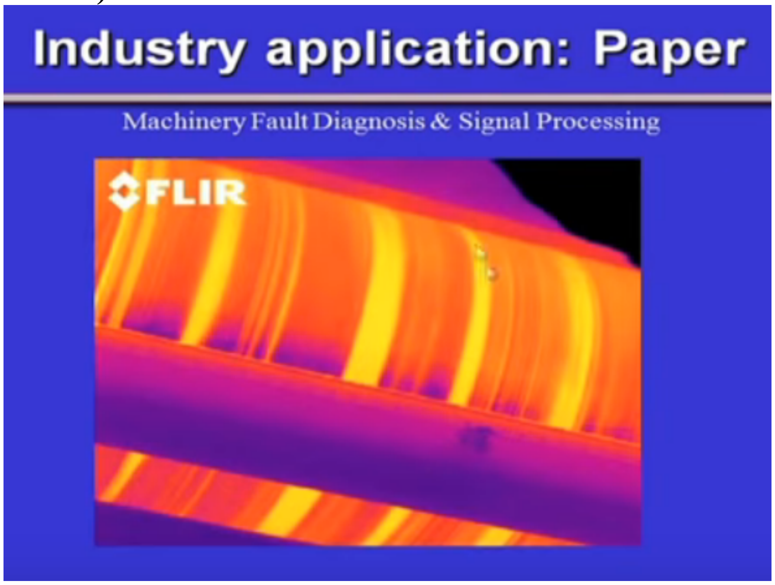

In paper belt you can see the rolls getting hot.
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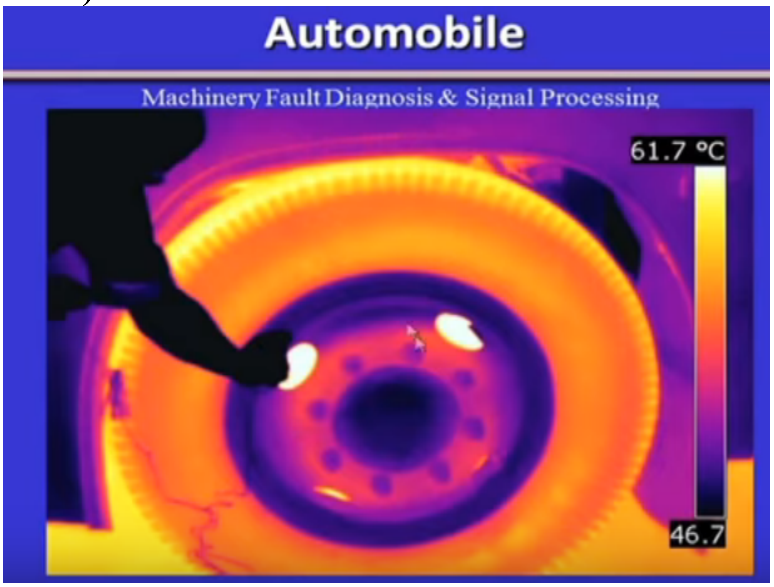

This is the big drums, this has become hot.
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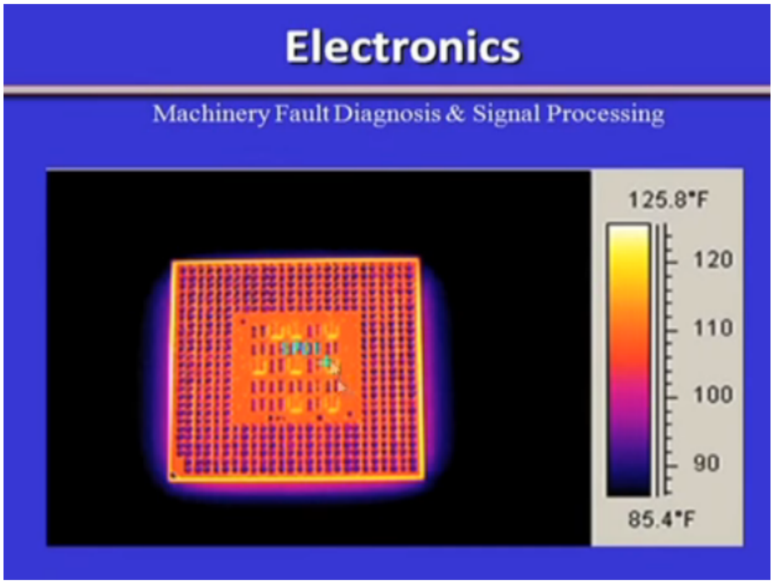

This from the electronics you can see IC going hot.

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Defence, these are some of this figures are from the FLIR website as I have mentioned to you.

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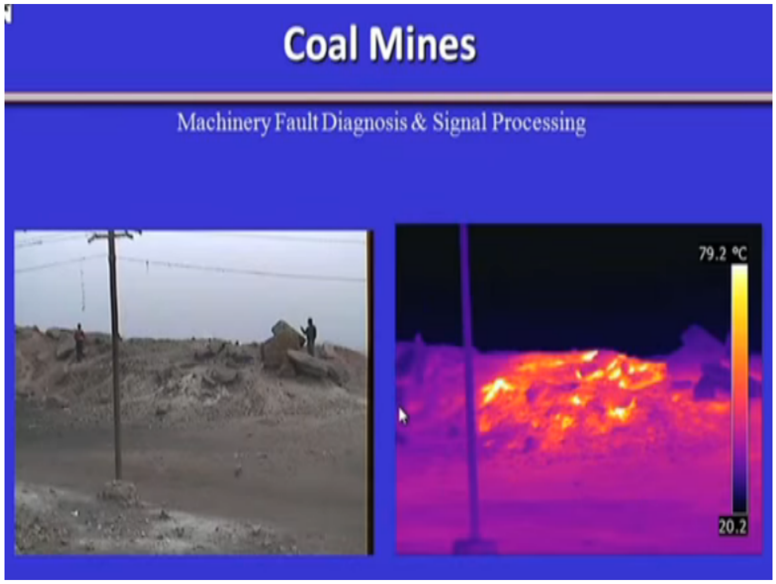

Coal mines.

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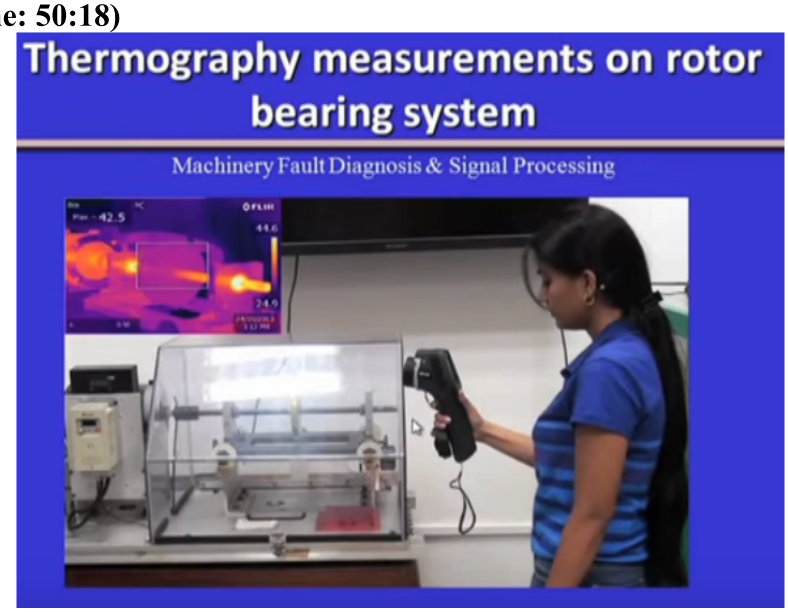

And this is what I was telling you regarding the infrared imaging or laboratory. This student holding this FLIR camera and have the bearings, coupling. So the rate of temperature rise we can artificially introduce misalignment in this system. This is the coupling, driven bearing, non driven bearing, motor behind it. So this is the flexible element coupling. So through IR imaging we can see the temperature rise.

This is single stationary shot but this can be put in a tripod and the samples can be taken at 30 image frames per second and such videos can be made and they can be stored on a computer where you can do image analysis and looking at the rate of temperature rise, you can find out the

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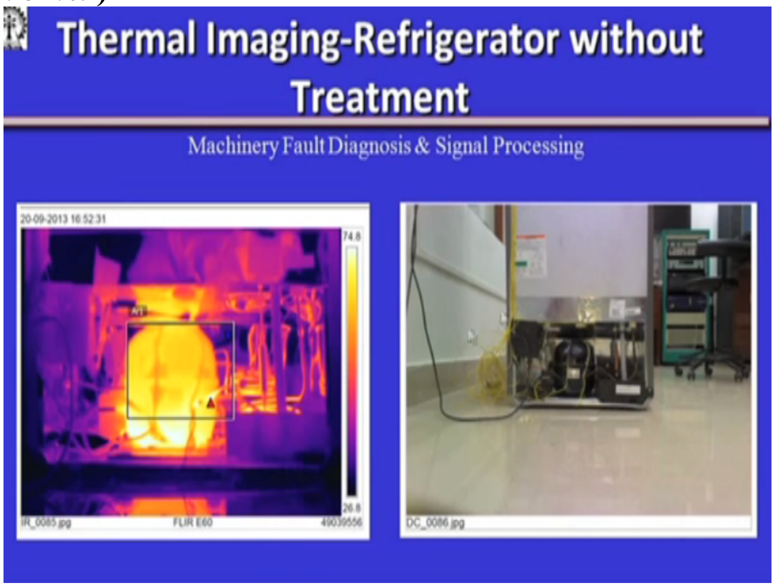

Temperature and this is a another example in laboratory where we have refrigerator and this is the compressor of the refrigerator. Just to correlate we can see this yellow cables, they are actually all thermocouples put on the compressor. The refrigerator is in our laboratory this shiny metal surface, though this a black dull surface.

So thermal imaging you can see the temperature of the refrigerator compressor and this we are doing because we are trying to reduce the noise of this refrigerator through some treatment and then we do not want the compressor temperature to rise abnormally and that is why we took the advantage of this thermogram thermal imaging. So that in one go we can get a quick image. We can see these are the thermocouple cables, these lines are thermocouple cable.

So quickly in one single shot we can get the view of image. So this is the video image, this is the thermal image. So as I was telling the thermography has lot of application in engineering particularly in condition based maintenance for a quick survey which can be done to find out the areas which have hot spots and then you can do a detailed analysis on the thermal imaging depending on the interest or depending on the severity of the problem and this is quick, very fast and not only qualitative but also you get a quantitative estimate of the temperature rise. Thank you.