Inspection and Quality Control In Manufacturing
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Lecture – 14
Thermographic Nondestructive Testing

Hello my friends so now we are going to start our new chapter that is a thermographic nondestructive testing. So, it is also a one kind of nondestructive testing but here just through some image or maybe through some temperatures accumulations on maybe by temperature difference then we are going to detect that what kind of problems or maybe the defects is occurring into the materials during manufacturing process.

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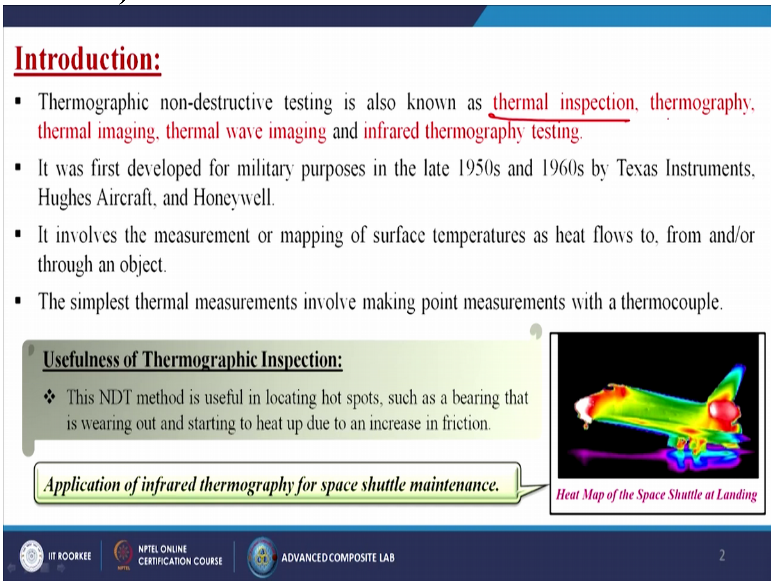

So, what is the thermo graphic non-destructive testing. so, basically the thermographic non-destructive testing is also known as thermal inspection or maybe thermography whatever I have told already thermal imaging, thermal wave imaging and infrared thermography testing. It was first developed for the military purposes in the late 1950s and 1960s by Texas Instruments, Hodges aircraft and Honeywell. It involves the measurement or mapping of surface temperatures as heat flows to form and or through an object that already I have told you.

The simplest thermal measurements involved making point measurements with a thermo couple. Usefulness of thermographic inspections that means what is the advantage generally we are getting. This non-destructive testing method is useful in locating the hot spots such as a bearing that is wearing out and starting to heat up due to an increase in friction. So, that means from that particular definitions or may be the example you can understand that we are doing the online monitoring of that particular parts.

So, applications of the infrared thermography for Space Shuttle maintenance so generally we are getting the thermographic image. Now you can so in this particular image there are so many colors and all the colors is having different meanings say suppose if I can see it through the mechanical point of view. So, maybe the red in color is getting the maximum stress or maybe the string if I see it through the thermal point of view then red in color is maybe the maximum heat is generating at that particular point.

And then how the stress and strain is passing through that particular materials or maybe how it is acting inside the materials or maybe that temperature how it is moving inside the materials so I can get the heat map or maybe the stress-strain map from particular space shuttle's at landing.

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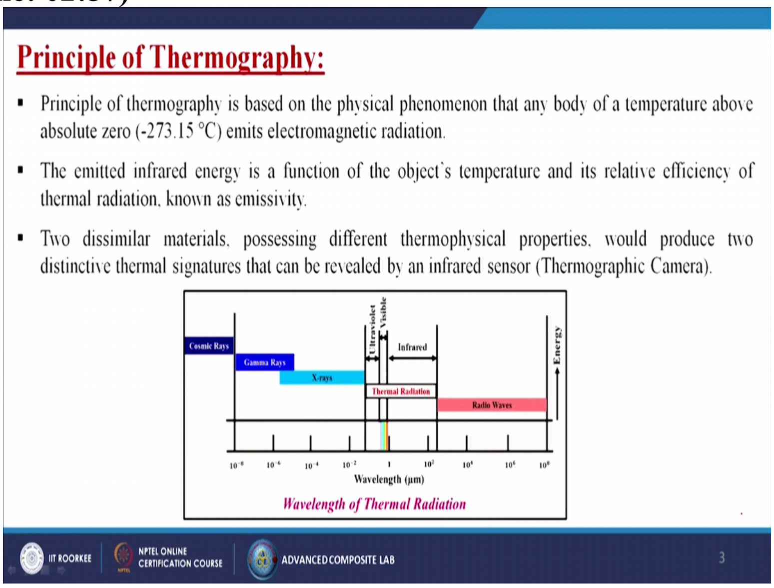

So, now what are the principles of thermography so generally the principle of thermography is best on the physical phenomena that anybody up a temperature above absolute zero what is that -273.15 degree centigrade emits the electromagnetic radiation. The emitted infrared energy is a function of the object's temperature and its relative efficiency of thermal radiations known as emissivity. Two dissimilar materials possessing different thermo physical properties would produce two distinctive made thermal signatures that can be revealed by an infrared sensor that is called a thermographic camera.

So, in this particular case now you can see that what is the wavelength of these kind of thermal radiations. So, when you are talking about the cosmic rays it is beyond the 10 to the power -8 micrometer. When we are talking about the gamma rays it is little bit overlapping with the x-rays also so generally it is 10 to the power -8 to in between maybe 10 to the power -5 micrometer. Then our x-rays are coming is around 10 to the power -1 or something then after that the ultraviolet ray is coming and then we are having the visible region.

Now from this particular you can understand that our visible region is very, very narrow then after that it is coming infrared and after infrared we are getting the radio waves and you can see that it is having a very long range.

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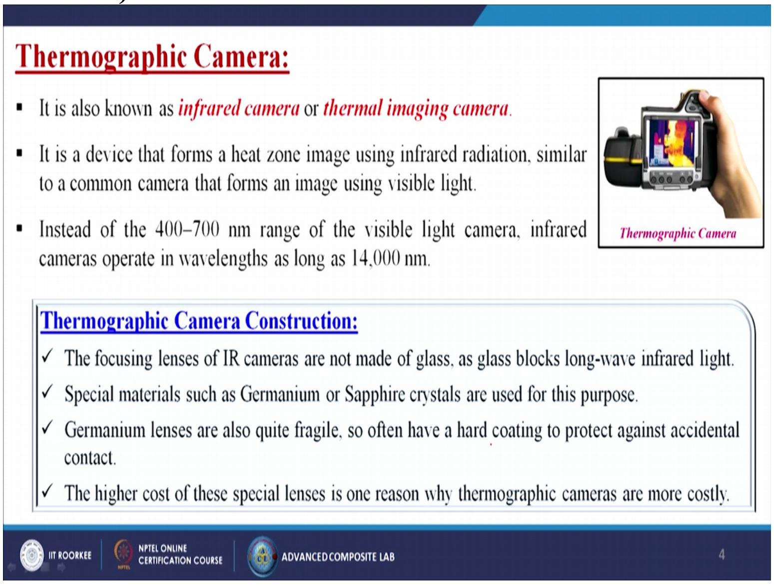

So, now what is thermographic camera so it is also known as infrared camera or maybe the thermal imaging camera. It is a device that forms a heat zone image using infrared radiation similar to a common camera that forms an image using visible light. Instead of the 400 to 700 nanometer range of the visible light camera infrared cameras operate in wavelengths as long as 14,000 nanometer.

So, now you can see that basically it is actually acting in this particular zone itself after our visible limit. So, thermographic camera constructions the focusing lenses of IR cameras are not made of glass as glass blocks long wave infrared light then what materials we are using? Special materials such as germanium or maybe the sapphire crystals are used for these particular purposes.

Germanium lenses are also quite fragile so often have a hard coating to protect against accidental contact the highest cost of these special lenses is one reason why thermographic cameras are so costly in the market. So, this is the example of the thermographic camera.

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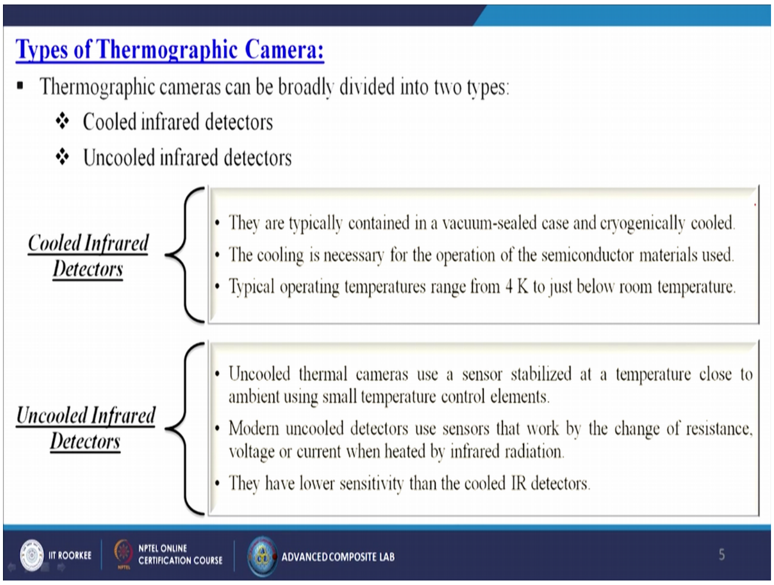

Now there are several types of thermographic cameras are available what are those? One is called the cooled infrared detectors another one is called the uncooled infrared detectors. When you are talking about the cooled infrared detectors so basically they are typically contained in a vacuum sealed case and cryogenically cooled that means you can understand either we are using some kind of liquid nitrogen kind of things to make it cool.

The cooling is necessary for the operations of the semiconductor materials used because when you are using it for the thermal imaging. So, automatically my camera is going to be heated up and then whatever the materials we are going to use for imaging or maybe for capturing that particular image so that time if that material will be heated up so what will happen it will lose its own properties so material will be changed so camera will be out of order.

So, in that case to make that material stable and it can work into that with high temperature outside we are putting on cooling jackets by which we are cooling down or maybe lowering down its temperature so that inside material can be stable. Typical operating temperature ranges from 4 Kelvin to just below room temperature. Next we are having that uncooled infrared detectors and cold thermal cameras use a sensor stabilized at a temperature close to ambient using small temperature control elements.

Modern and cold detectors use sensors that work by the change of resistance voltage or current when heated by infrared radiation they have lower sensitivity than the cold IR detectors.

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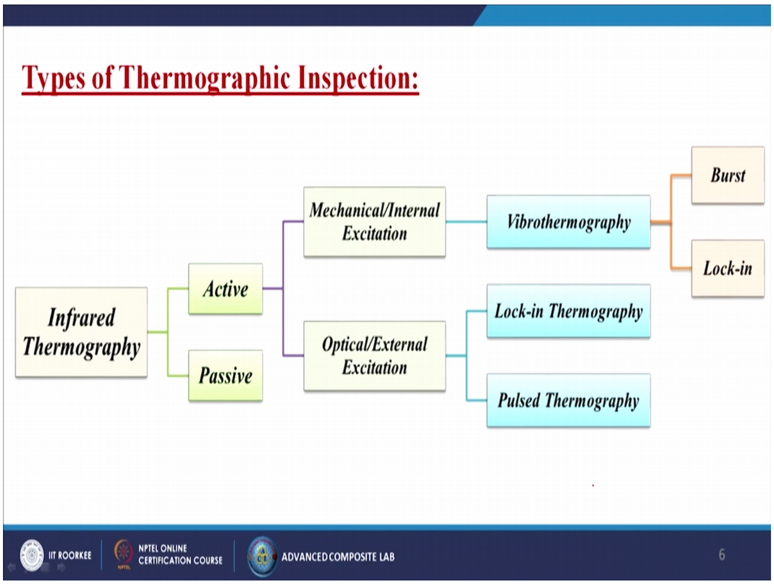

Now types of the thermographic inspections so when we are talking about the infrared thermography it is divided into two parts one is called the active another one is called the passive. When you are talking about the active part so it is divided into also into two parts one is called the mechanical or maybe the internal excitations another one is the optical or maybe the external excitations.

Then mechanical or internal excitations is divided into vibrothermography and then after that the vibrothermography is divided into two parts one is called the burst another one is called the locking. And if we see about optical and external excitations it is also divided into two parts one is called the lock-in thermography another one is called the pulsed thermography.

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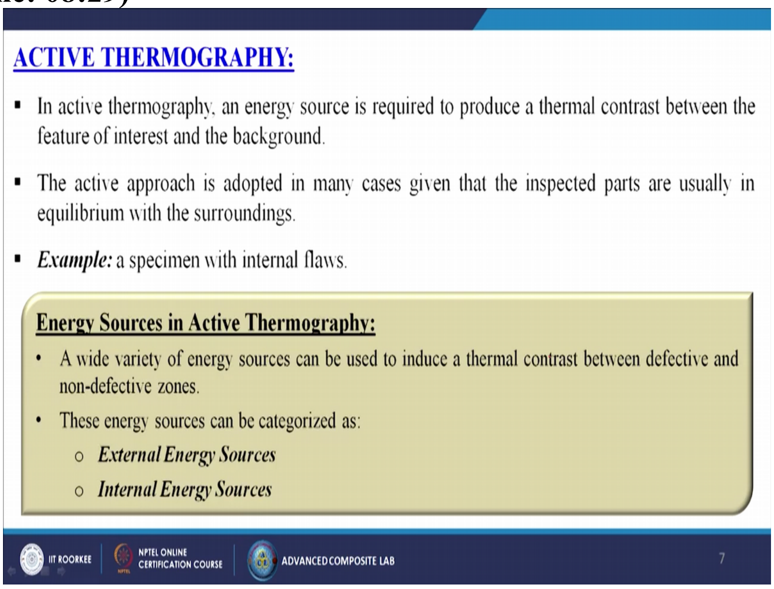

Then what is active thermography in active thermography and energy source is required to produce a thermal contrast between the feature of interest and the background. The active approach is adopted in many cases given that the inspected parts are usually in equilibrium with the surroundings example a specimen with internal flaws. Energy sources in active thermography a wide variety of energy sources can be used to induce a thermal contrast between defective and non-defective zones.

So, what are those first one is called the external energy sources and the second one is the internal energy sources.

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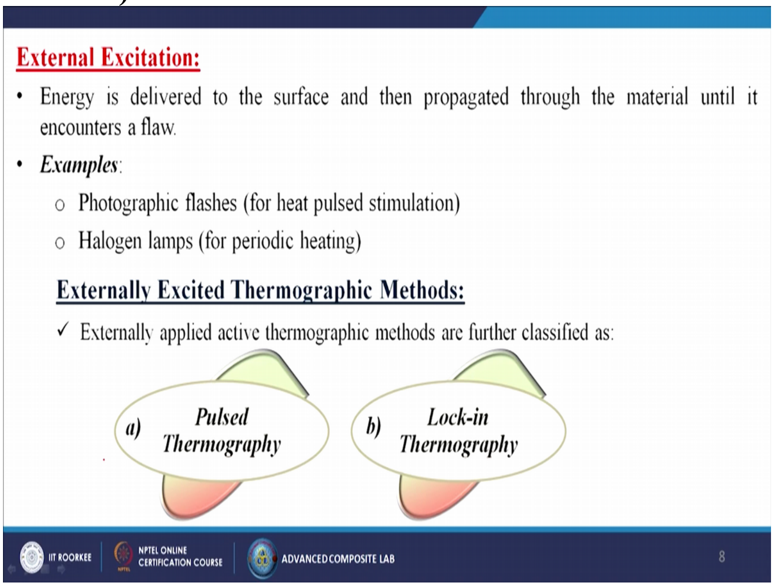

So, when we are talking about the external excitations or may be the external energy says so generally this energy is delivered to the surface and then propagated through the material until it encounters flaw examples photographic classes for heat pulsed simulations, halogen lamps for periodic heating. So, generally externally excited thermographic methods, externally applied active thermographic methods are further classified as one is called the pulsed thermography of a and second one is called the locked in or may be the lock-in thermography.

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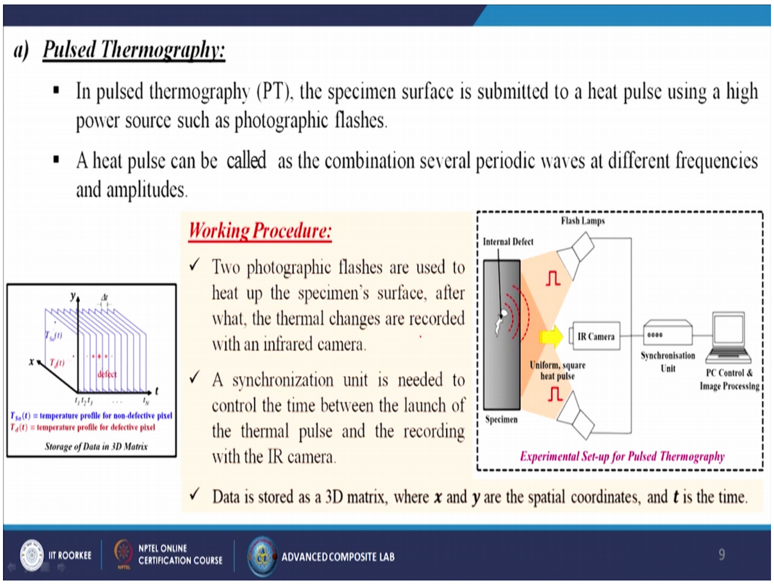

So, what is pulsed thermography? In pulsed thermography in short generally we are calling it as a PT the specimen surface is submitted to heat pulse using a high power source such as photographic flashes. A heat pulse can be called as the combination several periodic OF's at different frequencies and amplitude. So, pulse means you can easily understand there is certain of time and on time so it is not the continuous one we are going to use.

So, working procedure two photographic flashes are used to heat up the specimen surface after what the thermal changes are recorded with an infrared camera. So, you can see that we are using two flash lamps over there we are hitting our materials our specimens and then after that we are using that IR camera to proper imaging of these particular defects. A synchronization unit is needed to control the time between the launch of the thermal pulse and the recording with the IR camera.

Data is stored as a 3d matrix where x and y are the spatial coordinates and P is the time. So, directly from the IR camera the data is going into the computer and we are getting the 3d image along with the exact locations of that particular defect inside the specimen.

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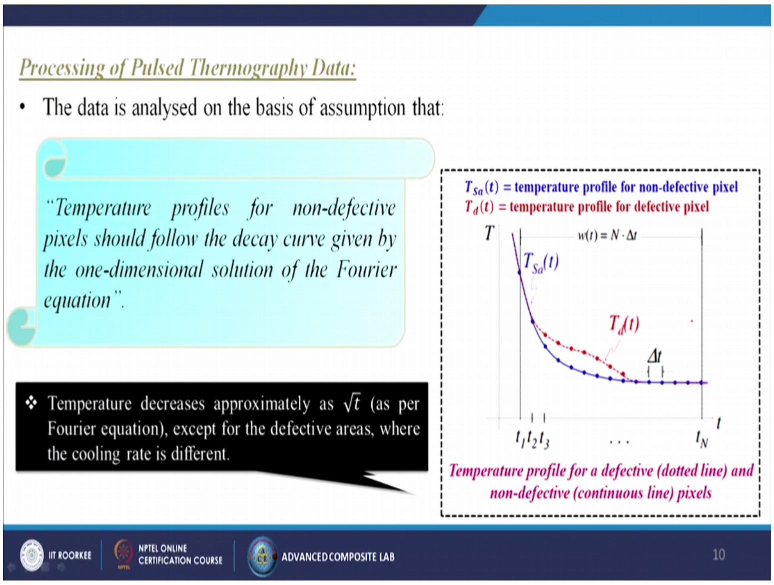

So, now processing of the pulsed thermography data so that data is analyzed on the basis of assumption that the temperature profiles for non-defective pixels should follow that DK curve given by the one-dimensional solution of the Fourier equations so in this particular case you can see that TSA T is the temperature profile for non-defective pixels and TDT is the temperature profile for defective pixels.

So, from this where if there is no such kind of defects are available so the line will follow this particular path but when there is certain kind of ambiguity are present inside the material so that time that curve will deflect with the normal one so by this way we can simply get the information's of our non destructive materials. Temperature decreases approximately as root over T as per for your equations except for the defective areas where the cooling rate is totally different.

So, in this particular case in the x axis we are putting T 1, T 2, T 3 up to T n, so this is the T time basically we are going to give. So, temperature profile for a defective dotted line and the non detective continuous line pixels.

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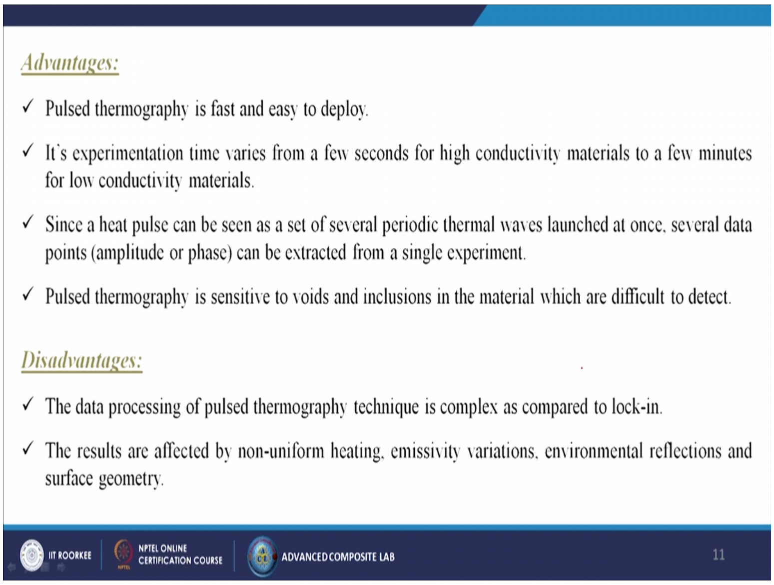

Then what are the advantages so pulse thermography is fast and easy to deploy, its experimentation time varies from a few seconds for high conductivity materials to a few minutes for low conductivity materials. So, it is having a very wide range of applications in terms of material physical properties. Since the heat pulse can be seen as a set of several periodic thermal waves launched at once several data points can be extracted from a single experiment.

Next pulsed thermography is sensitive to voids and inclusions in the material which are difficult to detect. Then what are the disadvantages the data processing of post thermography techniques is complex as compared to lock in. The results are affected by non-uniform hitting emissivity variations, environmental reflections and the surface geometry.

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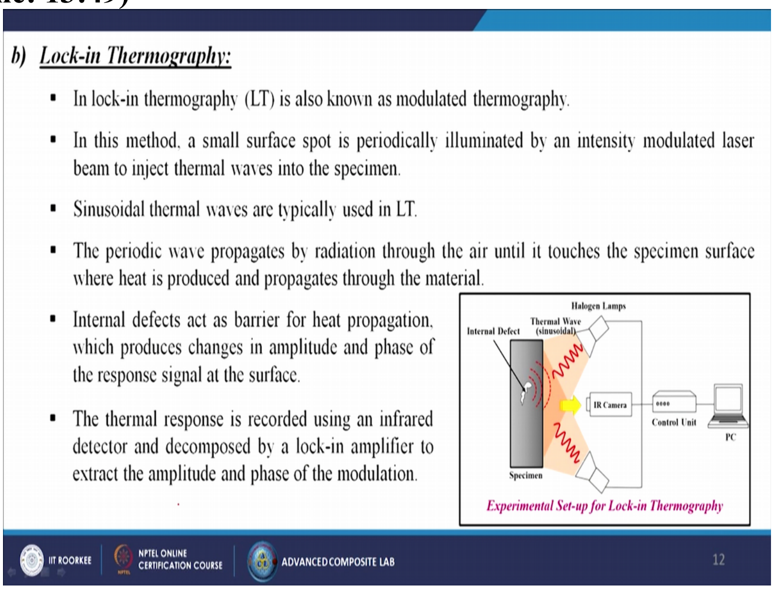

Then come to the lock-in thermography so in lock-in thermography is also known as modulated thermography. In this particular method a small surface spot is periodically illuminated by an intensity modulated laser beam to inject thermal waves into the specimen. Sinusoidal thermal waves are typically used in LT, LT is nothing but the lock-in thermography.

The periodic wave propagates by radiation through the air until it touches the specimen surface where heat is produced and propagates through the material. Internal defects acts as barrier for heat propagation which produces changes in amplitude and phase of the response signals at the surface. The thermal response is recorded using an infrared detector and decomposed by a lock-in amplifier to extract the amplitude and phase of the modulations.

So, simple what I am doing just after getting the information's where the Boyd's or the cracks are present I am putting one laser directly at that particular point to propagate to intensify the results and then after that we are capturing that particular results. Selection of working frequency for inspection of different materials the rate of decay of the thermal wave as it penetrates through the material depends upon the thermal diffusion length that is nothing but the Mu.

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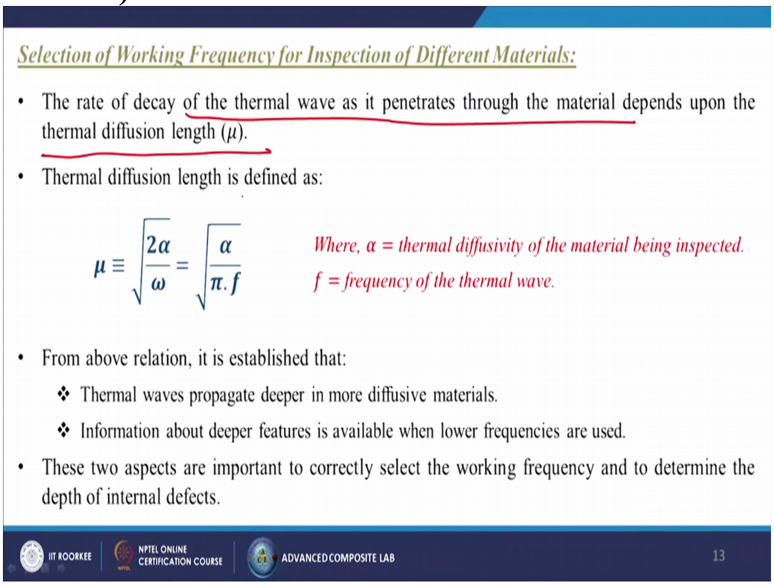

Thermal diffusion length is defined as mu = root over 2 alpha by Omega = root over alpha by PI f where alpha is the thermal diffusivity of material being inspected f is the frequency of the thermal wave. So, by applying these equations we can easily calculate the thermal diffusion length. From above relation it is established that thermal waves propagate deeper in more diffusive materials.

Information about deeper fee is available when lower frequencies are used. These two aspects are important to correctly select the working frequency and to determine the depth of internal defects.

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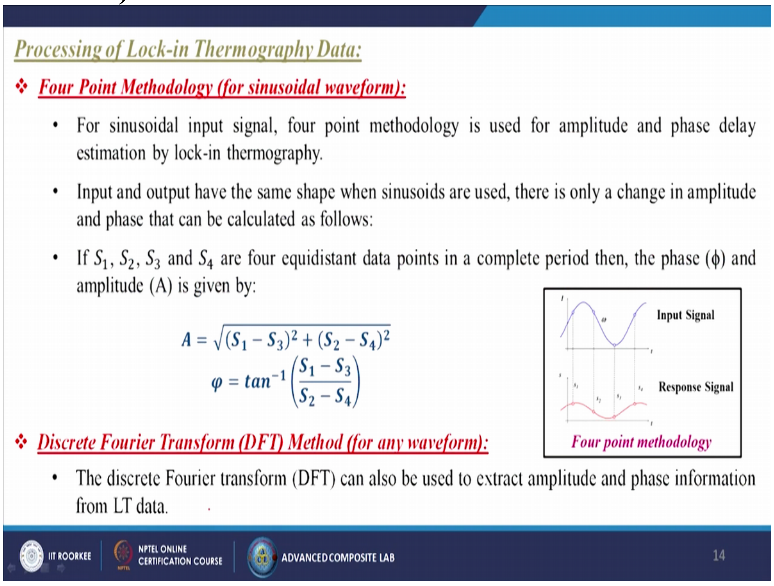

Next processing up lock-in thermography data, 4 point methodology for the sinusoidal waveform, so, for sinusoidal input signal for point methodology is used for amplitude and phase delay estimations by lock-in thermography. Input and output have the same shape when sinusoids are used there is only a change in amplitude and phase that can be calculated as follows.

If S 1, S 2, S 3 and S 4 are for equidistance data points in a complete period then the phase Phi and the amplitude a is given as A = root over s 1 - S 3 square + S 2 - S 4 square so Phi is nothing but the tan inverse S 1 - S 3 by S 2 - S 4 so that is our input signals and that is our response signals so simple we are getting S 1, S 2, S 3 and S 4 and the t from here. So, now if we are talking about the discrete Fourier transform DFT method for any waveform that discrete Fourier transform can also be used to extract the amplitude and phase information's from the lock-in thermography.

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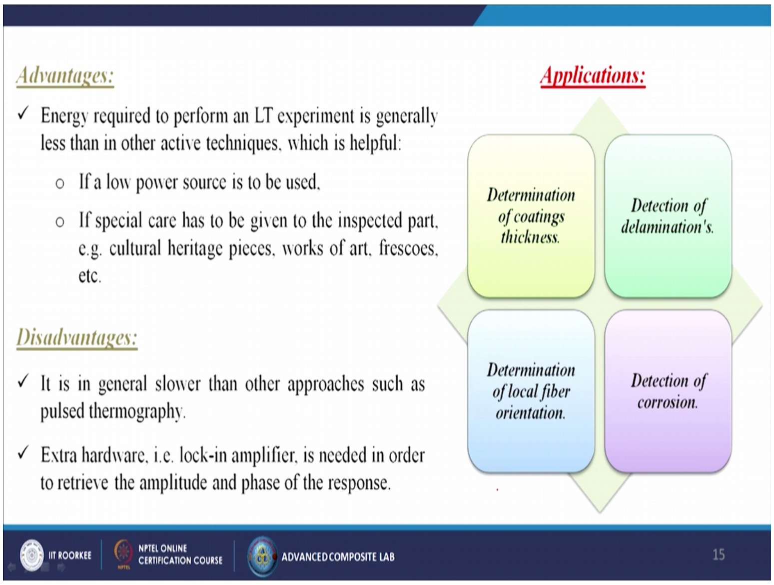

What are the advantages of these particular methods so generally the energy required to perform an LT experiment is generally less than in other active techniques which is very, very helpful. So, if a low power source is to be used and if special care has to be given to the inspected part that is cultural heritage pieces works of art Frisco's etcetera that means where we need a very delicate data.

Then if we are talking about the disadvantages it is in general slower than other approaches such as pulsed thermal effects. Extra hardware that is where that is lock-in amplifier is needed in order to retrieve the amplitude and phase of the response. Now come to the applications so generally the determination of coating thickness we are using this LT technology detection of delaminations, detection of corrosion, determination of local fiber orientations.

So, now you can understand all these applications we are getting a very low signals or maybe very minute imaging or maybe the minor data we are going to fetch from that particular materials so that's why this technology is very, very useful for a over range of application.

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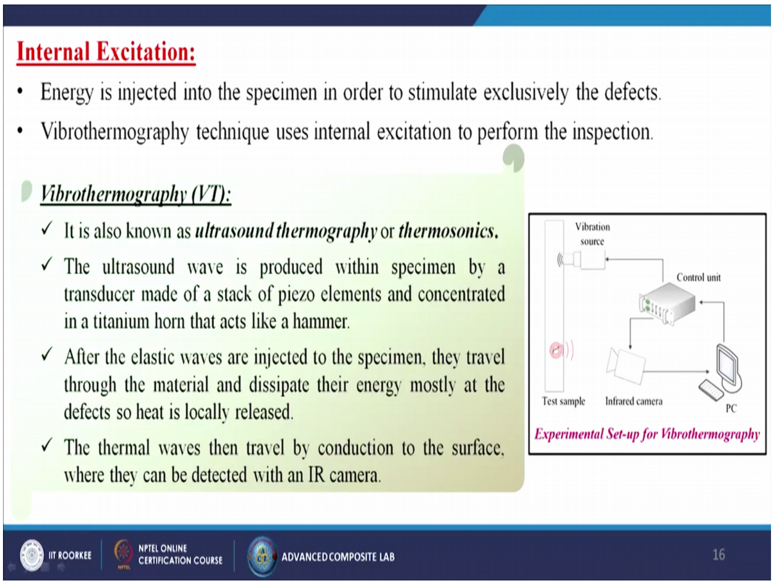

Now we are talking about the internal excitations so generally the energy is injected into the specimen in order to stimulate exclusively the defects. A Vibrothermography technique uses internal excitations to perform the inspections. What is vibrothermography? In short generally we are calling it as a VT it is also known as ultrasound thermography or maybe the thermosonics.

The ultrasound wave is produced within specimen by a transducer made of a stack of Piezo elements and concentrated in a titanium horn that acts like a hammer. After the elastic waves are injected to the specimen they travel through the material and dissipate their energy mostly at the defects. So, heat is locally released. The thermal waves then travel by conduction to the surface where they can be detected with an IR camera.

So, simple we are giving the vibrations so these vibrations is going that is actually accumulating at the defect points and the defect points is getting heated up and then we are having that infrared camera by which we are doing the thermal imaging and we are exactly locating that where the defects is actually present.

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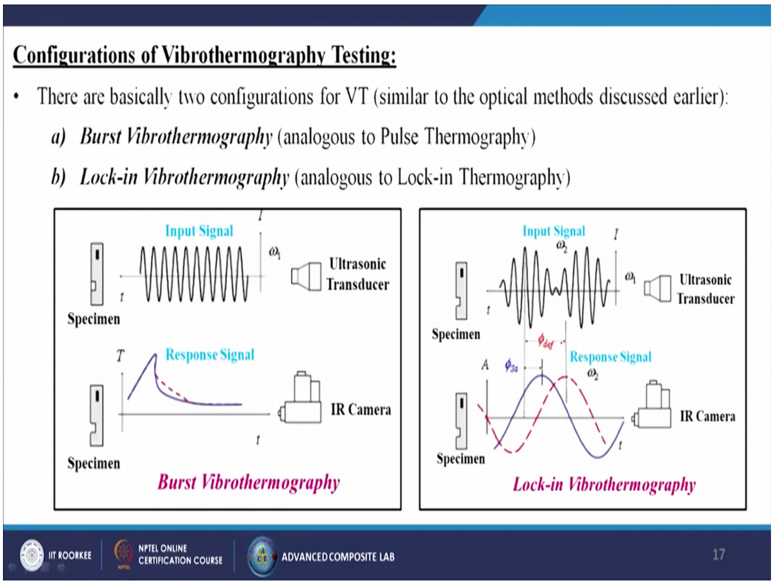

What are the configurations of the vibrothermography testing there are basically two configurations for VT similar to the optical methods discussed earlier what are those? First one is called the burst vibrothermography which nothing but the analog has two pulse, thermography and the second one is also the lock-in vibrothermography that means it is the analogous to lock-in thermography.

So now we are having two images or maybe you can say two groups of one is the burst vibrothermography another one is the lock-in vibrothermography. So, in this particular case you see that we are having that specimen we are giving the input signals by the ultrasonic transducers and the maximum peak for this is same that means we are not going to change the amplitude or maybe the frequency. And then we are getting the response signals looking like this of these particular defects.

Now when you are talking about the lock-in vibrothermography so you can see that there is a change in the amplitude and also in the frequency level and then we are going to get two different graphs over there by which we are going to get the exact locations that means the logic is same for both but these sites lock-in vibrothermography is giving the more accurate results than the bursts vibrothermography.

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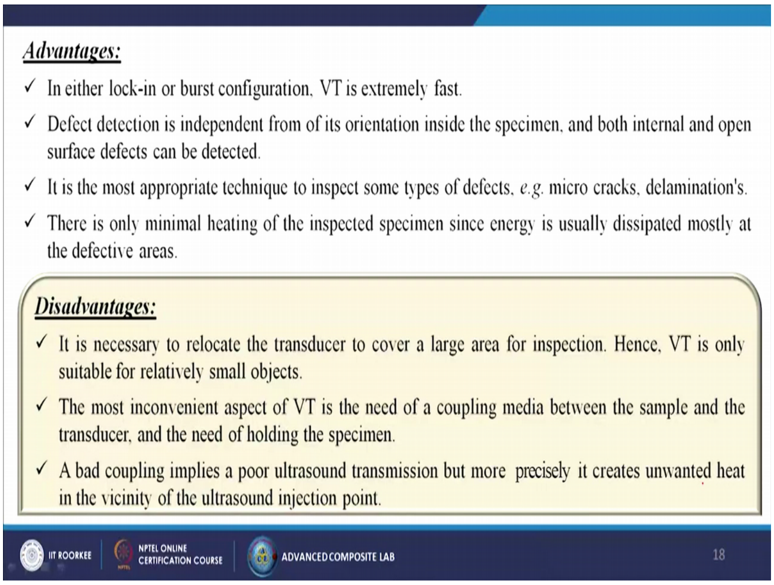

What are the advantages in either lock-in or burst configurations VT is extremely fast technique defect detections is independent from its orientations inside the specimen and both internal and often surface defects can be detected. It is the most appropriate techniques to inspect some types of defects like micro cracks delaminations etcetera. There is only minimal heating of the inspected specimen.

Since energy is usually dissipated mostly at the defective areas so that means this is more accurate more precise. What are the disadvantages it is necessary to relocate the transducer to cover a large area for inspections hence VT is only suitable for relatively small objects. The most inconvenient expect of VT is the need of a coupling media between the sample and the transducer and the need of holding the specimen itself.

A bad coupling in implies a poor ultrasound transmission but more precisely it creates unwanted heat in the vicinity of the ultrasound injection point that means your ultrasound horn should be clearly touched your sample there should not be any gap or maybe any kind of other problems. So, that exactly that ultrasound vibration can go inside the materials and then it can properly reach at the defective sides and then the defective sites can be heated up.

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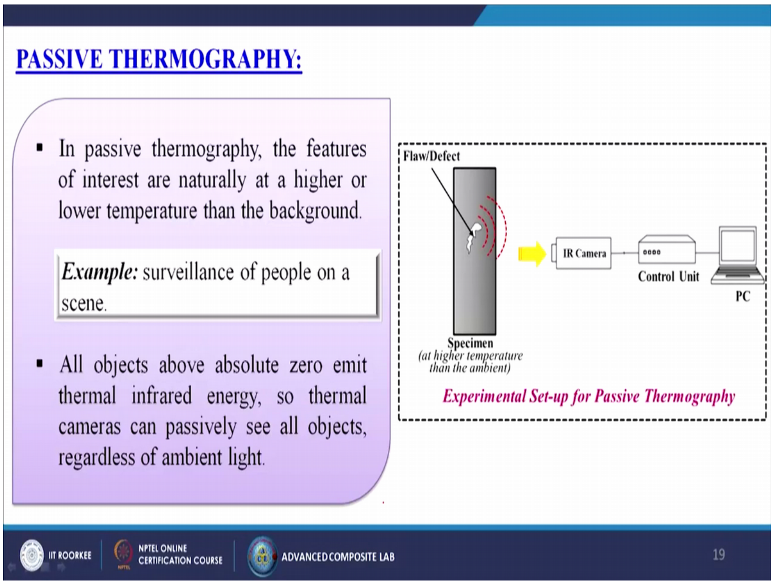

Next come to the passive thermography so in passive thermography the features of interest are naturally at a higher or lower temperature than the background example surveillance of people on a scene. All objects above absolute zero emit thermal infrared energy so thermal cameras can passively see all objects regardless of ambient light. So, simple we are having that specimen at higher temperature than the ambient conditions it is generating some kind of thermal vibrations and then IR camera is capturing that particular thermal detection or maybe the thermal emissions. So, this is the generally the experimental setup for the passive thermography.

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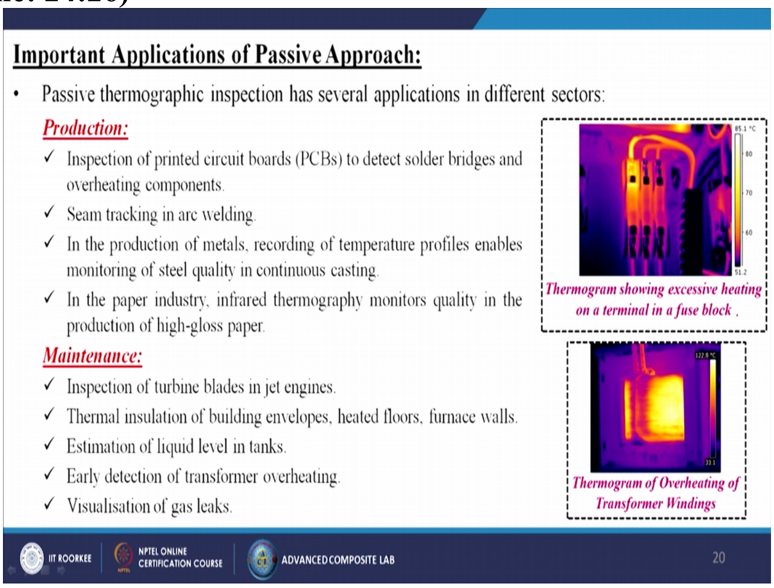

Important applications of the passive approach passive thermographic inspections has several applications in different sectors like production, inspection of printed circuit boards maybe the PCBs, to detect solder bridges and overheating components, seam tracking in arc welding in the production of metals recording of temperature profile enables monitoring of steel quality in continuous casting. In the paper industry infrared thermography monitors quality in the production of high gloss paper.

When you are talking about the maintenance point of view inspection of turbine blades in jet engines, thermal insulation of building envelopes, heated floors, furnace walls estimation of liquid levels in tanks early detection of transformer overheating, visualization of gas leaks so these all are the images that how we are getting the thermal image.

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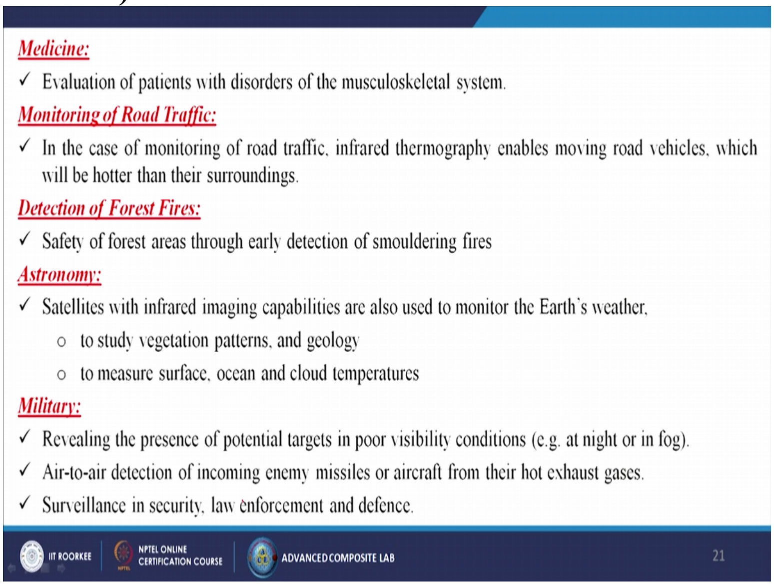

In terms of medicine or maybe the biomedical applications evaluation of patients with disorders of the musculoskeletal systems that means if we are having some kind of in our bones so we get the thermal image. In the case of monitoring of road traffic infrared thermography enables moving road vehicles which will be hotter than their surroundings. Detection of forest fires, safety of forest areas through early detection of small moldering fires, astronomy, satellites with infrared imaging capabilities are also used to monitor the Earth's weather to study vegetation patterns.

And the geology to measure surface ocean and cloud temperatures. In terms of defense military revealing the presence of potential targets in poor visibility conditions like at night or in fog. So, we are using some kind of thermal camera on their gun or maybe the sniper rifle kind of things so that in the dark night or maybe in the foggy weather systems also they can see properly their enemy.

Air to air detection of incoming enemy missiles or aircraft from their hot exhaust gases, surveillance in security, law enforcement and defense so now you can understand it is having a very wide range of applications.

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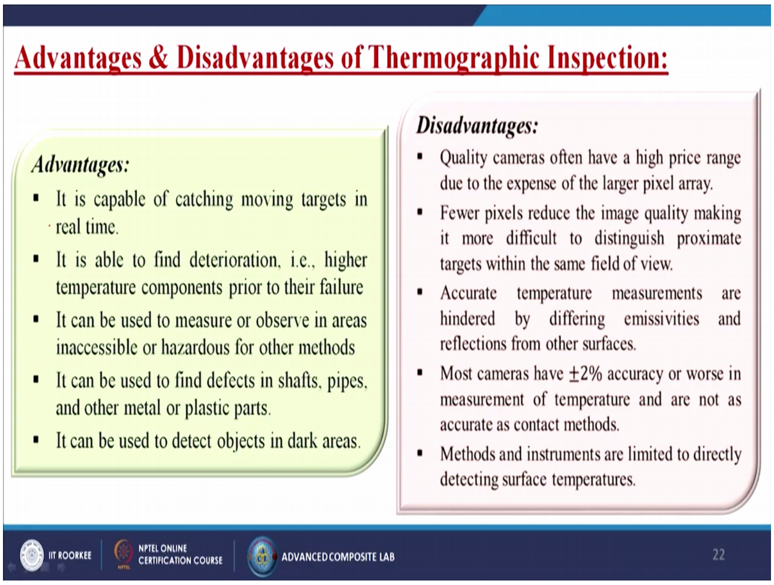

Now what are the advantages and disadvantages of thermographic inspection advantages it is capable of catching moving targets in real time. It is able to find deterioration like higher temperature components prior to their failure. It can be used to measure or observe in areas inaccessible or hazardous for other methods. It can be used to find defects in shafts pipes and other metal or plastic parts. It can be used to detect objects in dark areas.

Now of course these techniques is also having some disadvantages what are those? Quality cameras often have a high price range due to the expense of the larger pixel array. Fewer pixels reduce the image quality making it more difficult to distinguish proximate targets with the same field of view. Accurate temperature measurements are hindered by different differing emissivity's and reflections from other surfaces.

Most cameras have +- 2% accuracy or worse in measurement of temperature and are not as accurate as contact methods. And methods and instruments are limited to directly detecting surface temperatures.

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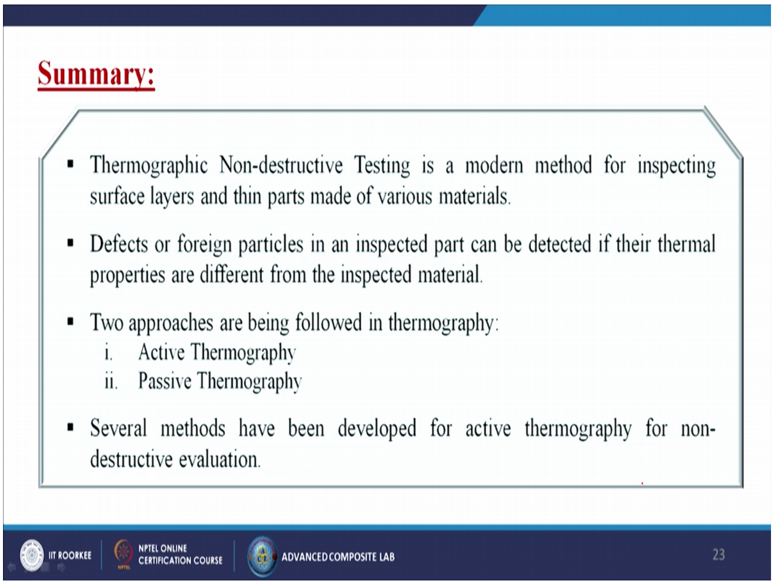

Now we have come to the last slide of this particular lecture. So, in summary we can say that thermographic non-destructive testing is a modern method for inspecting surface layers and themed parts made of various materials. Defects or foreign particles in an inspected part can be detected if their thermal properties are different from the inspected materials that means in terms of one reference frame we are capturing the image and then we are trying to see that what are the changes or maybe the what are the difference in between these images where one image is that where there is no defect another one is the defects are present.

Two approaches are being followed in the thermography one is called the active thermography another one is called the passive thermography. Several methods have been developed for active tomography for non-destructive evaluation, thank you.