Metal Additive Manufacturing
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Lecture 37
Non-Destructive Testing (Part 2 of 2)

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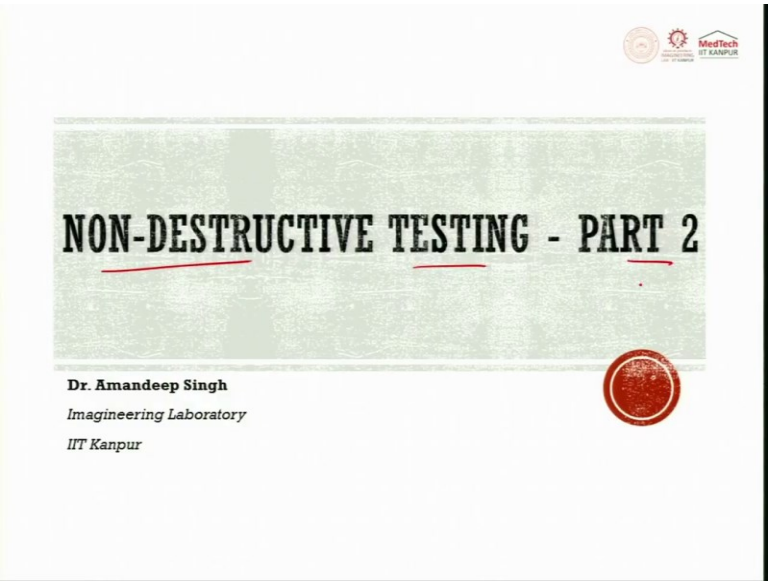

This is part 2 of the lecture series on Non-Destructive Testing, in which we will discuss about the noncontact methods.

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That is, the radiographic, thermographic, visual and X-ray computed tomographic tests.

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Non-contact, methods just like we studied in reverse engineering, would not have direct contact with the system.

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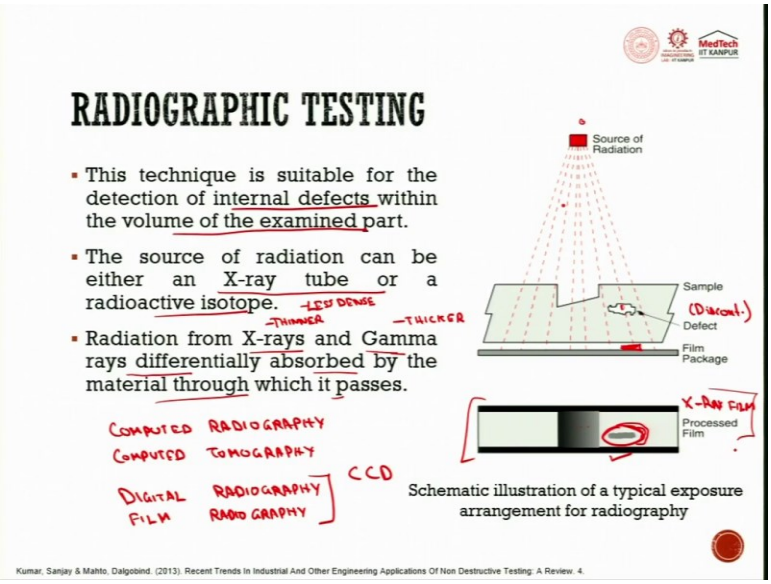

So, there are certain non-contact methods. The first one is radiographic testing. As the name itself says, it sends the radio signals, that is, it sends the sonar signals and its tries to see what the defect is, what is the flaw in the part under inspection. So, there is a radiation source, so radiography involves a technique that is suitable for the detection of internal defects within the volume of the examined part.

The source of radiation can be either an X-ray tube or a radioactive isotope. Radiation from X-rays and gamma rays are differentially absorbed by the material through which it passes. So, a source of radiation is there, that falls on the material or the surface under inspection, and if the defect is there, it shows the discontinuity, the defect is there. So, it reports this as a discontinuity. So, this is how it is tested.

So, this is a processed field, it is showing that, ok, this is something, the signals are different because the distance is different, but there is a discontinuity here. So, this is how it determines the flaw in the pieces or the test piece under its inspection. For thinner or less dense materials such as aluminum, electrically generated X-rays that is the X radiation are commonly used. And for thicker and denser materials, the gamma radiation is used.

So, this is for X-rays of the thinner material, thinner or less dense. So, gamma is used for the thicker material. The gamma radiation is given off by decaying radioactive materials with the most common sources may be iridium or cobalt. That is, iridium 192 variant and cobalt 60 is also

there. The recording media can be an industrial X-ray system or X-ray system film only, or it could be one of the sides of the digital radiation detectors.

So, this could be an X-ray film right or it might be for the gamma radiations and could be other digital relation detectors. So, with both, radiation passing through a test object exposes the media. So, any defect having the darker area that is shown here gives us that there is a flaw. The area becomes dark in color, and this represents that there is a void or defect in the part.

So, more radiation passes through causes a darker image on the film or the detector. So, because radiation passes more, the film here receives more radiation, so this area becomes darker here. So, this is the basic principle. So, there are certain different types of the radiography.

These are computed radiography, computed radiography means this CR technique which is a transition technology, where the film and a digital radiography are both partially involved. This uses a reusable or flexible photo simulator phosphor. This phosphor plate is available which is loaded into a cassette and exposed into a manner, like the traditional radiography film.

Similarly, we have the common way, that is CT, the computed tomography. What we generally call, in the medical sciences as well, the CT scan. This involves a computer to reconstruct an image of a cross-sectional plane of an object as opposed to the conventional radiograph. So, this is also one of the ways.

Then we have digital radiography and film radiography. In the digital system, it digitizes the radiation that passes through the object directly into an image, that is displayed on a computer monitor. So, the device is just like in reverse engineering, could be CCD which are charged coupled devices.

And it has amorphous silicon in it. So, it could also use other, similar methods like CMOS system. These images are available for viewing and analysis. Then film radiography uses this film, this kind of frame that is shown here. The film radiography uses the transparent plastic-coated film, that is, fine layer of this silver bromide. So, one or both sides of the plastic is used here. So, film radiography uses a film. And digital radiography uses a digital, directly on computer images of the test results which are equivalent to what we get in the film. So, the consumables are reduced here.

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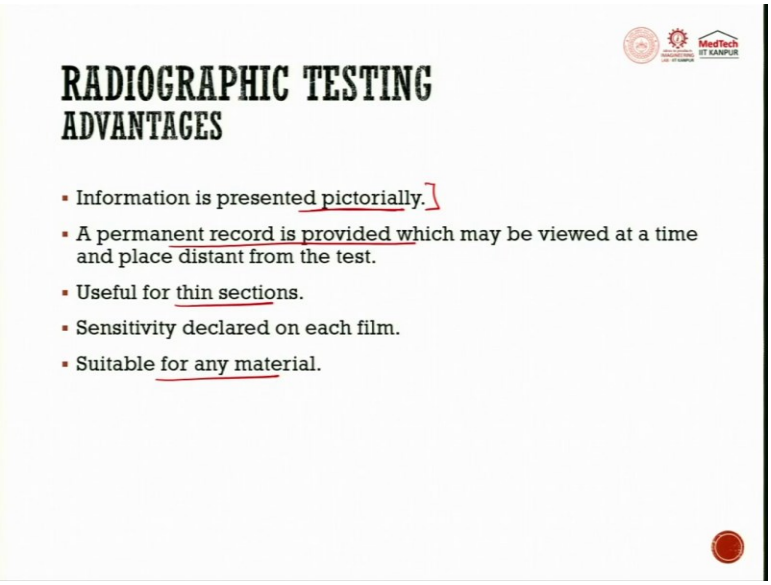

The advantages of this are the information is presented pictorially. The visual inspection then comes into play after this to understand the picture of the image. The permanent record is provided which may be viewed at a time and placed distant from the test. It is useful for thin sections. So, sensitivity is declared on each film. It is suitable for any material irrespective of ferromagnetic, paramagnetic, or so, or non-ferromagnetic, plastic. It can be applied to any material.

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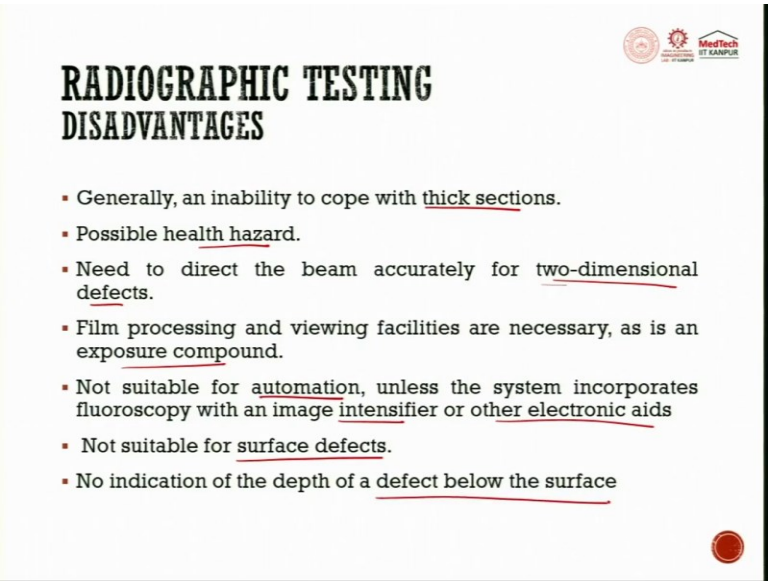

But still, there are certain disadvantages, that is, it has an inability to cope up with the thick sections. Due to possible health hazards, the operators must wear the protective suitings and gloves, the spectacles, everything to keep themselves safe.

Needs to direct the beam accurately for 2-dimensional defects only. So, the film processing and viewing facilities are necessary as is an exposure compound. It is not suitable for automation unless the system incorporates fluoroscopy with an image intensifier or other electronic aids. It is not suitable for surface defects in general. No indication of the depth of a defect below the surface is there.

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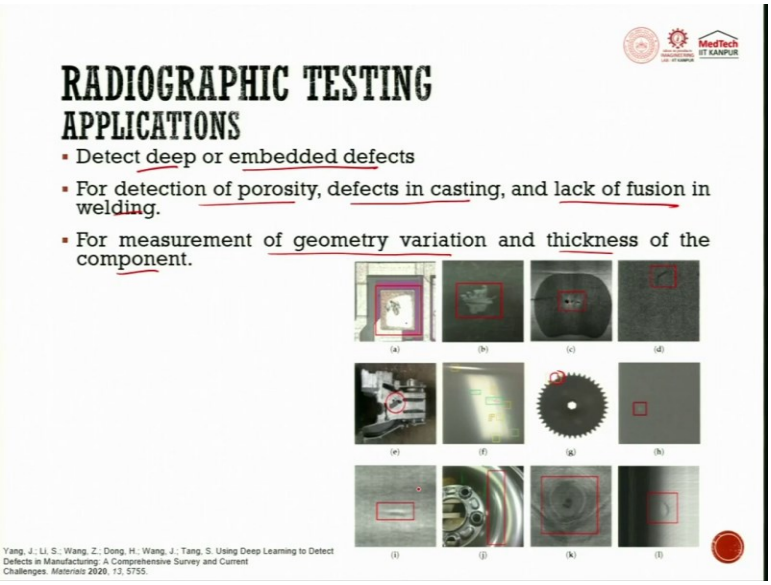

Now, its applications are overwhelming. It detects deep or embedded defects, for detection of porosity, defects in casting and lack of fusion in welding, for measurement of geometric variation and thickness of the component. It has multiple applications. You can see different applications for the radiographic test which are given. The surface that is small, pores here. The small cracks here, the broken gear, so many applications are here.

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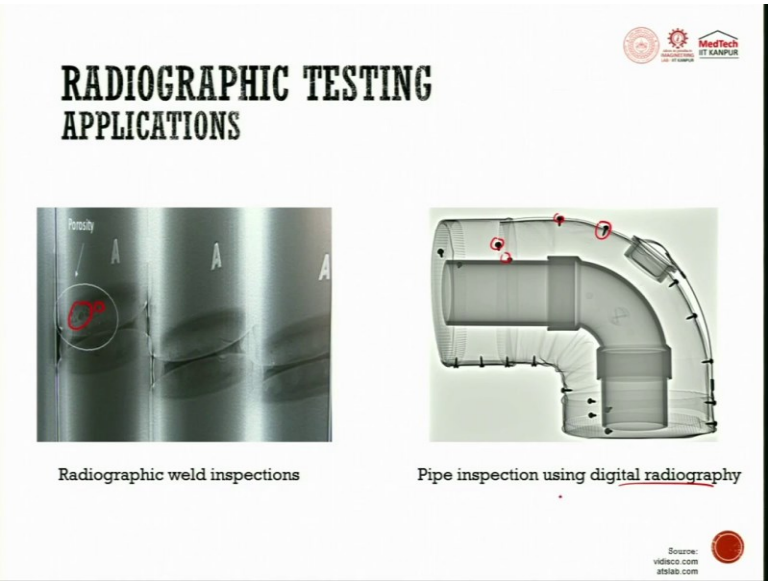

One of the other applications which is given here is the porosity in the weld inspections. You can see the film has recorded the area which are darker, which determines, or which reflects the

porosity, the small and big pores are there. So, this is the recorded data in the frame. Another, you can see in the pipe inspection, a digital radiography, the image is gotten only in the computer and it is telling us how the pipe is connected, where are all the screws in the pipes. So, this is the digital radiography in which no film is used.

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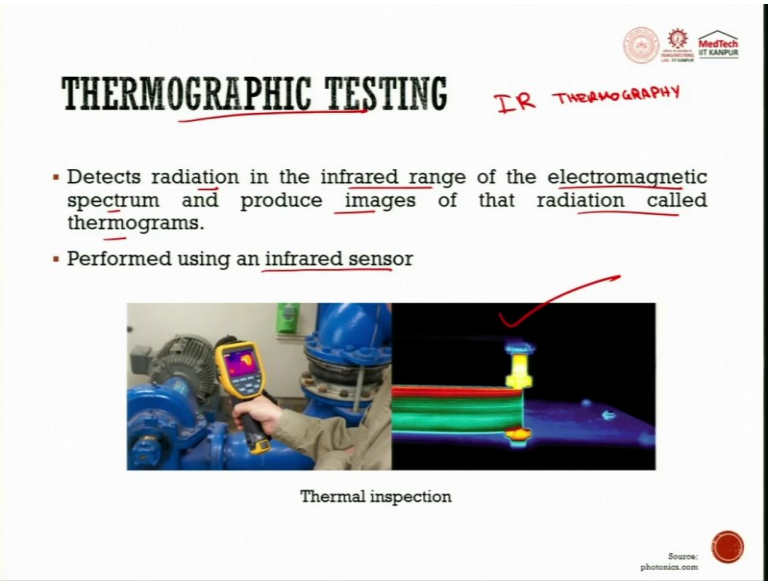

Next is the thermographic testing. Thermograph testing is having plethora of application. For example, in machine tool cutting itself, whenever the temperature is to be measured, temperature measurement instruments or temperature sensors are available from -25^0 to 2000^0, and the temperatures could be measured to identify the kinds of the temperature change, how drastically the temperature is changing.

It is also known as IR thermography, that is, infrared thermography. So, this is useful, and it detects radiation in the infrared range of the electromagnetic spectrum and produce images of that radiation which are called thermograms. These are here. These are performed using an infrared sensor.

So, the infrared thermography or the thermographic testing is used to measure or map surface temperature based upon the infrared radiation, which is given of by an object or as the heat flows through them. Heat flows to or from the object, the cameras, the thermal cameras could measure it. So, the accurate infrared testing of the parts is investigated and should be done in direct line of sight with the camera.

So, the camera must directly focus on where we need to measure the temperature. That means it should not be done with any panel covers or any canopy or any distortion, or any hurdle in between. Otherwise, this will diffuse the heat and results would give you not the correct readings. So that the thermal imaging can be determined or taken to detect the corrosion damage, delamination, voids, inclusions or any other detrimental defects that we have.

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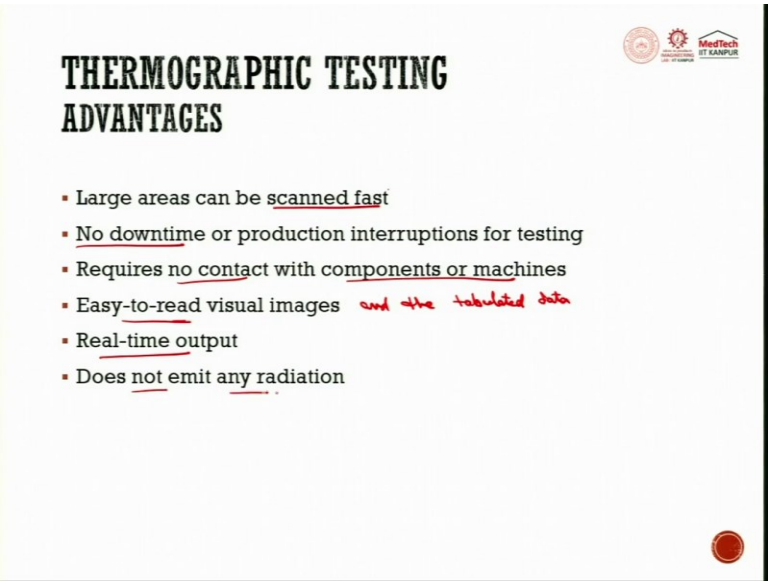

So, there are certain advantages of this. For example, large areas can be scanned fast. No downtime or production interruptions for testing. Directly, we can get the thermal images. Also, the temperature along with the images can be gotten in the directly quantitative form. So, we can get the quantitative data, temperature is varying from time A to time B, for example from 0 to 60 seconds, the temperature has risen from 10^0 to 30^0, if we are heating something very rapidly or so.

So, this can give the quantitative data. For how long, in the annealing, the temperature is being maintained to 700 or 730^0. So, this could also be measured. So, to have the quantitative outputs, this is extremely useful. It requires no contact with components or machines. It is easy to read visual images, and I would say, the tabulated data. The tabulated data means that the data is available in the tabular form with the time, the image could be mapped with it, and the temperature. It is a real time output that we can get out of it. The thermographic testing does not emit any radiation.

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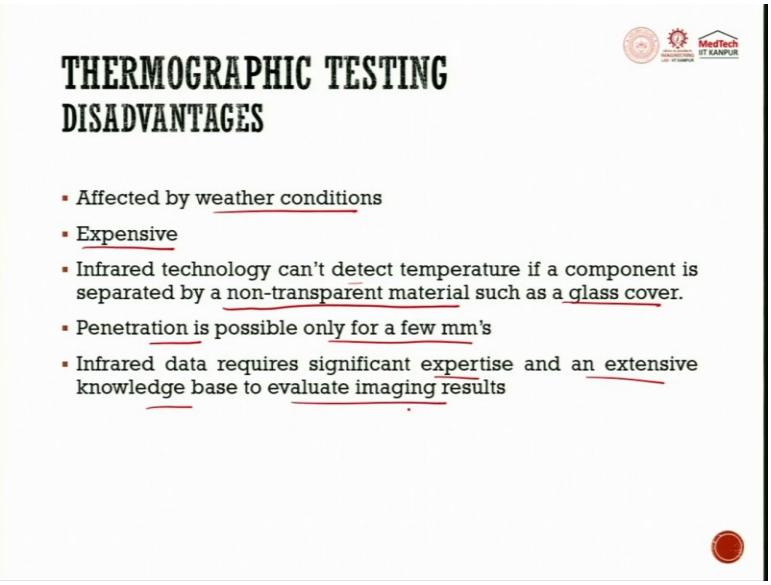

The demerits would be, it is affected by weather conditions or environmental conditions, the cameras are expensive. A simple thermal camera that is having a range up to 700^0, that we have gotten here in IIT Kanpur is costing 3,60,000 rupees. So, it is not very economical technology to be used by everyone.

Infrared technology cannot detect temperature if a component is separated by a non-transparent material such as glass cover. I said the canopy, the in between hurdles, any material in between affects the overall results. The penetration is possible only for a few millimeters. The infrared data requires significant expertise and an extensive knowledge base to evaluate imaging results.

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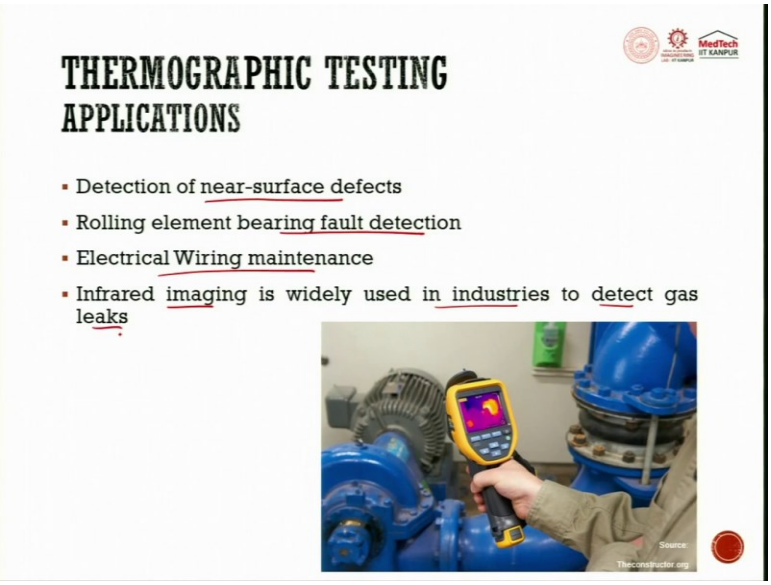

The applications of thermographic techniques in testing are, it detects the near-surface defects, the rolling element bearing fault detection could be taken using the thermal cameras. The electrical wiring maintenance, wherever the connections are weak, the wires would heat because the current is passing through, and there is a thermal flux that is coming out of it or leaking out of it. Infrared Imaging is widely used in industry to detect gas leaks as well.

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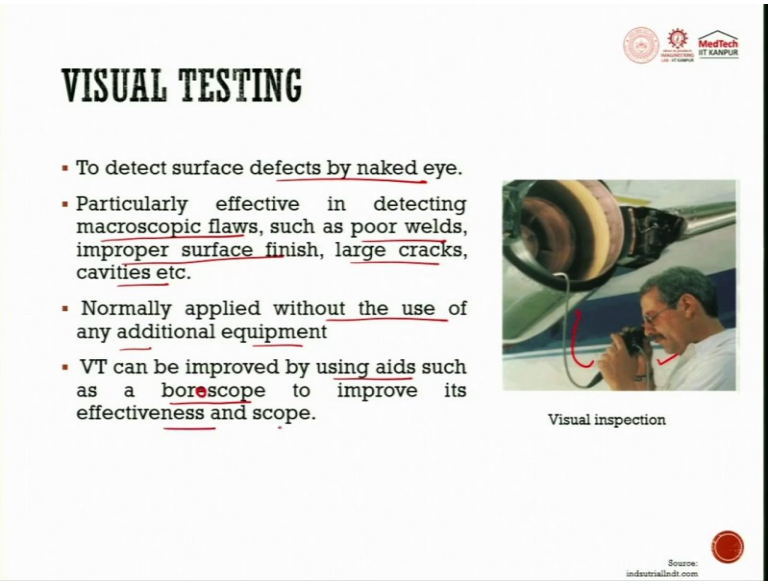

Next is visual testing. As you can see here, just by visualizing, an experienced operator, an experienced engineer could test that how is my material behaving, how is my system behaving.

So, here, an engineer is trying to test the propeller of an aircraft. So, visual testing is used to detect surface defects by naked eye.

By naked eye, that means it would definitely be used, but its also use the camera, or sometimes also the CCD, the charge coupled devices to get the images. So, particularly effective in detecting macroscopic flaws such as poor welds, improper surface finish, large cracks cavities. Like visual testing is most used in testing industry because visual test is the first test that you try to employ on any of the systems that you have. Like visually, it is not looking correct, it is general.

Because most of the test methods require that the operator look at the surface of the part being inspected, visual inspection becomes an inherent of most of the other test methods. The visual observation of the surface helps us to determine whether the discontinuities are there or not. So, this might be direct viewing using a naked eye or using a line-of-sight vision. For example, this person is using a line-of-sight vision to see what is the defect inside the propeller where the naked eye could not reach directly. It may be enhanced using the optical instruments.

Like magnifying glasses or mirrors or flexible wires are there, which are also magnifying an optical image, then we have a charge coupled devices, computer assistant viewing, cameras. Corrosion, misalignment of parts, physical damage, cracks are some kinds of the flaws that could be seen using the visual inspection. So, visual inspection can be improved by using aids such as a boroscope to improve its effectiveness and scope.

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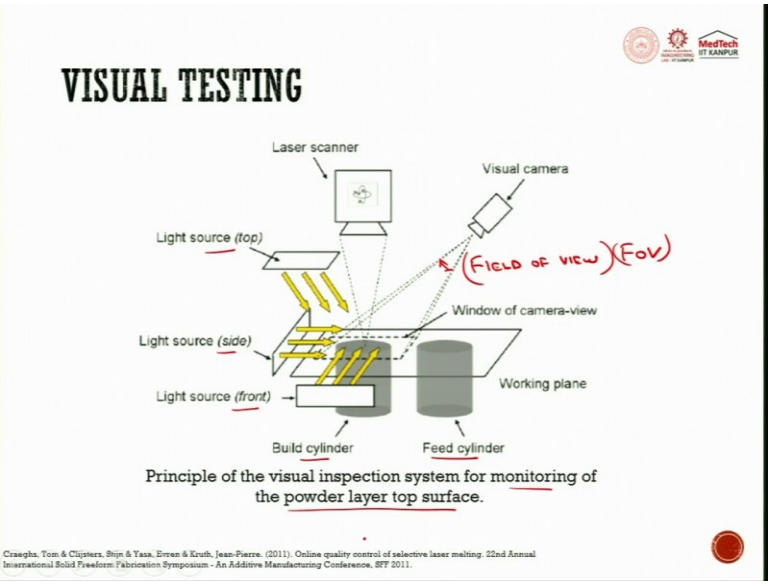

So, this is a visual inspection system, that has camera and laser scanner as well to identify, to monitor the powder layer of the top surface in metal additive manufacturing. So, it is a visual camera. This is the window of the camera, or I would say, the Field of View the FoV, it is also called FoV of the camera.

Now, this helps us to give the information about how the system is working and how the powder layer of the top surface is looking like, whether the powder is completely dispersing properly or not. So, this is a light source. Yes, in the visual inspection, light is a major source and light has to be properly illuminated.

This would come as one of the basic requirements because we need to find the things only by looking at it. So, light source from the top, at the sides, and in the front. So, that the visual inspection is not hindered. So, there is a build cylinder, this is a feed cylinder, this is the general metal additive manufacturing setup that you could see here, in which vision inspection is being employed.

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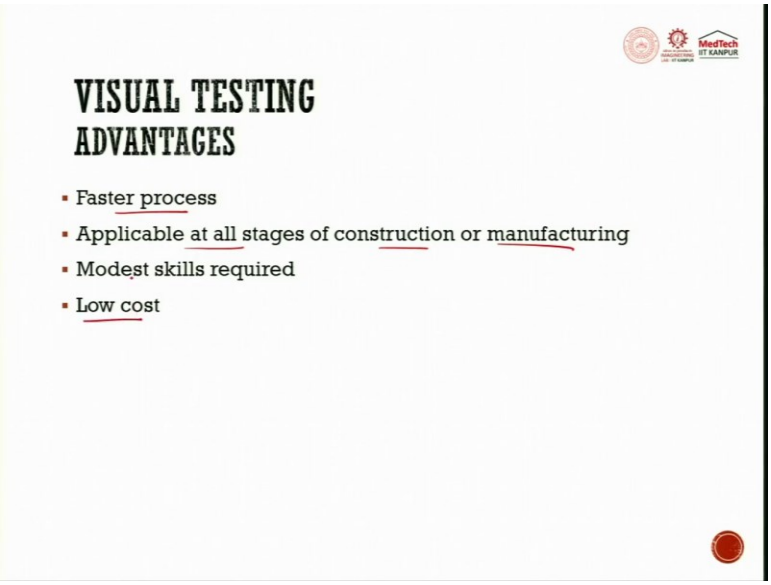

Advantages are, it is a faster process, it is applicable to all the stages of construction or manufacturing, modest skills are required, that is, very few skills are required, at least to have the retrieval information. So, it is a faster process. It does not require any sophisticated apparatus, and it is very inexpensive method, low cost.

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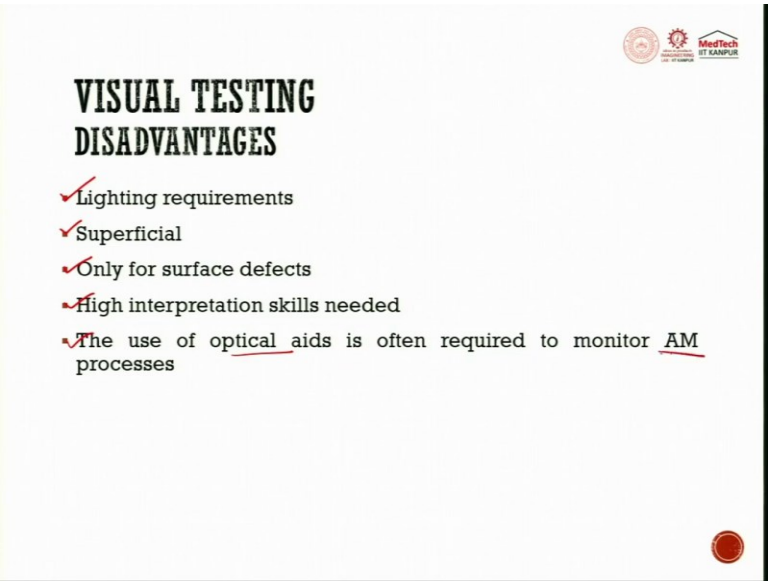

Disadvantages are, I showed you illumination or the lighting requirements that are always there. It is always a superficial test, which means, just by looking at surface, the information we are

trying to put on an inference is based upon the experience only. Which is at times correct, based upon the package of experience of the engineers working upon.

But most of the time, mechanical and electrical tests are also conducted to confirm whether what is being inspected visually, what is being reported while having visual test is correct or not. So, it is only for surface defects. The internal defects, because your eyes cannot reach there or some instruments, even the optical instruments cannot reach there, so it can only determine that could only been seen. High interpretation skills are required. Engineers must have long or intensive skills. The use of optical aids is often required to monitor the additive manufacturing processes.

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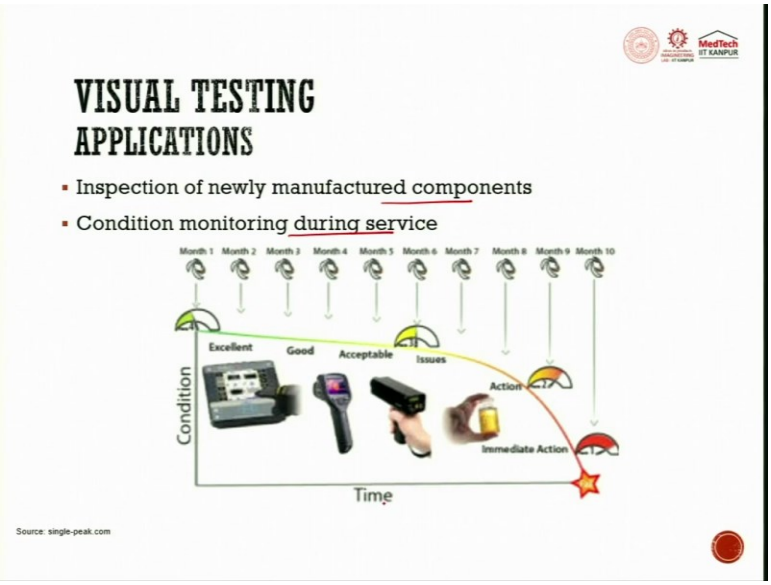

The applications of the visual testing are generally in the areas where instruction of newly manufactured components is to be taken, and condition monitoring during service. For example, whether the condition is excellent, good, acceptable in each, while the month of the year keeps on going. It is by trying to tell us using the visual inspection only, whether to accept the condition of the system or not. So, condition monitoring during service.

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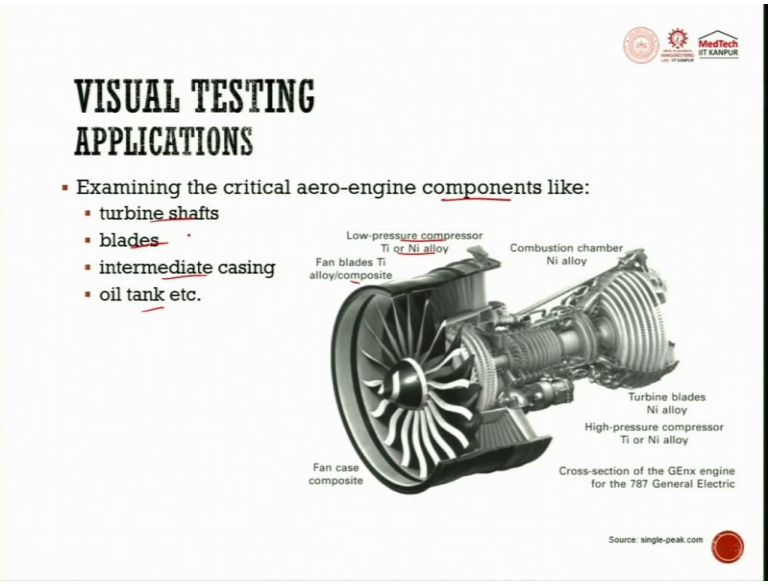

Also examining the critical aero-engine components, for example, turbine shafts, blades, intermediate casing, oil tank, low pressure compressor, titanium alloy, so this all, from outside, whatever we could look. The intermediate casing, the oil tank, turbine, and this is generally visually inspected.

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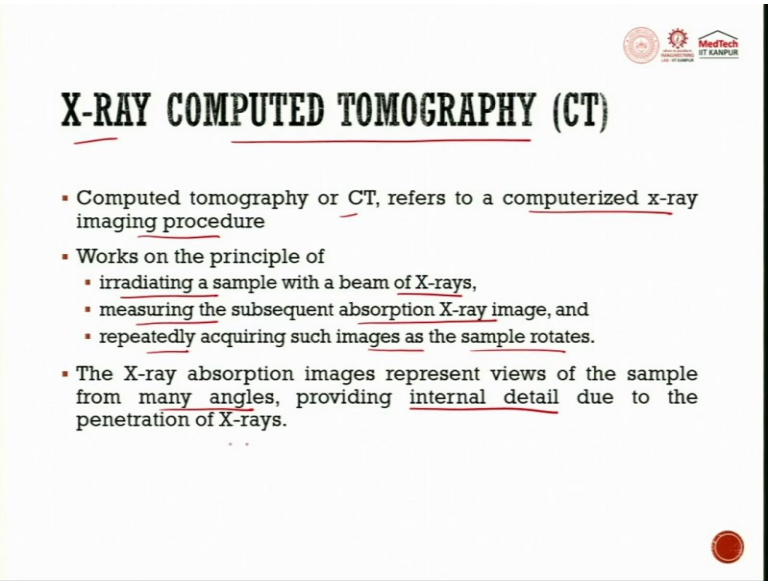

Next, and the last technique in this lecture series on non-destructive testing to be discussed is X-ray computed tomography. Computed tomography or CT refers to computerized X-ray imaging procedure. It works on the principal, that is irradiating a sample with a beam of X-rays,

measuring the subsequent absorption of X-ray images. Irradiating a sample, measuring the image, then repeatedly acquiring such images as the sample rotates. So, X-ray absorption images represent views of the sample from many angles providing the internal detail due to the penetration of the X-rays.

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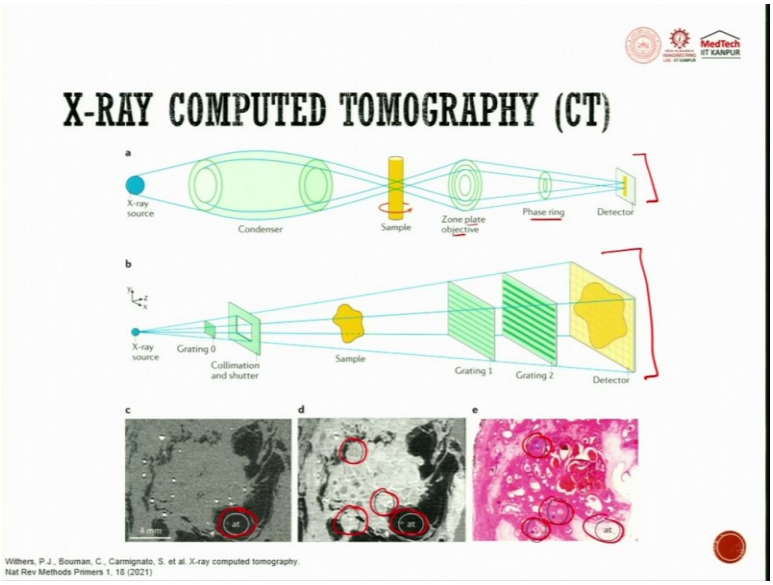

So, this is a schematic here. X-ray source is there, there is a condenser, and this is a sample. Sample is rotating from each side. The images are being captured by the detector, which lets the image of the ray to pass through a zone plate, that is, the objective, then a phase ring.

So, this helps us to capture the image here. This is one way, the sample is rotating, this is another way when directly X-ray source is there and through the grating itself, we are getting the image. So, using the CT technology, we can get the flaws at certain points. You can see the microstructures and the flaw images that we have got here.

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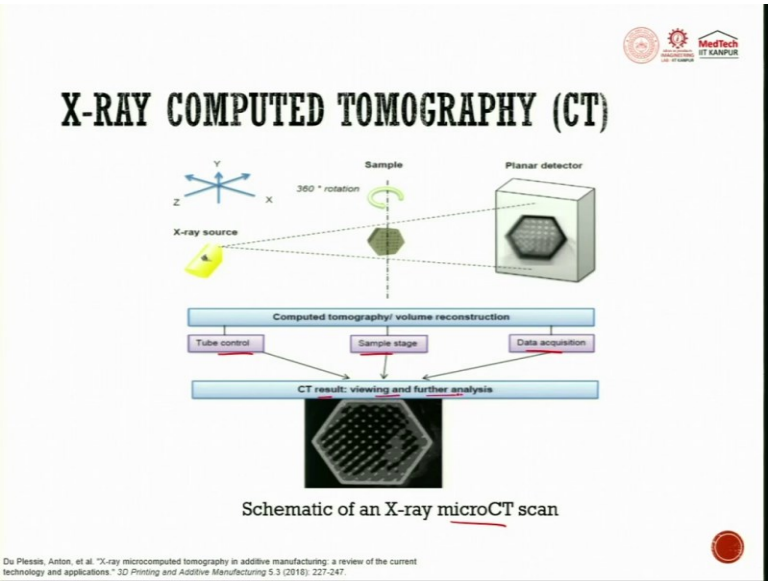

So, this is again a schematic of an X-ray micro-CT scan, that has a planar detector. So, it is a tube control sample stage and data acquisition that helps us to get the CT result that is viewed and further analyzed.

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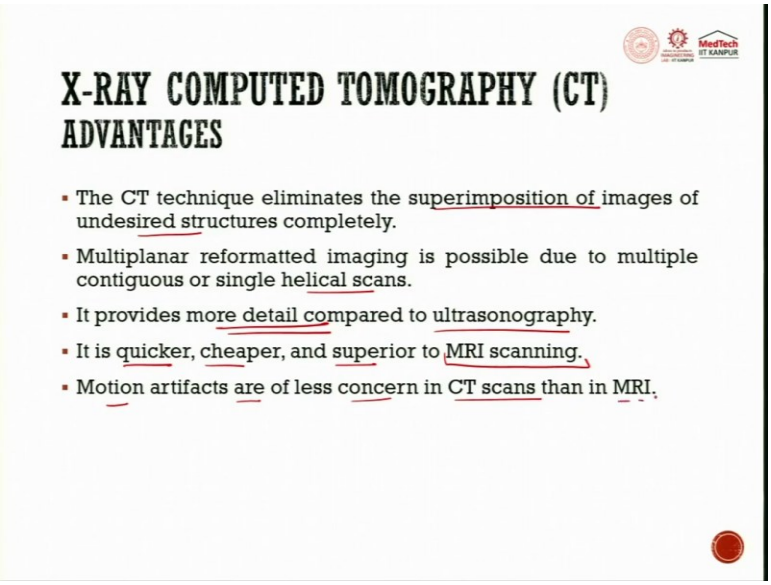

The advantages of the CT technique are that it eliminates the superimposition of images of undesired structures completely, multi-planar reformatted imaging is possible due to multiple continuous and single helical scans. It provides more detail compared to the ultrasonography, more details are there. It is quicker, cheaper, and superior to MRI scanning. Otherwise, CT

scanning requires high cost, but in comparison to magnetic resonance imaging, it is quite cheaper. Motion artifacts are of less concern in CT scans than in magnetic resonance imaging.

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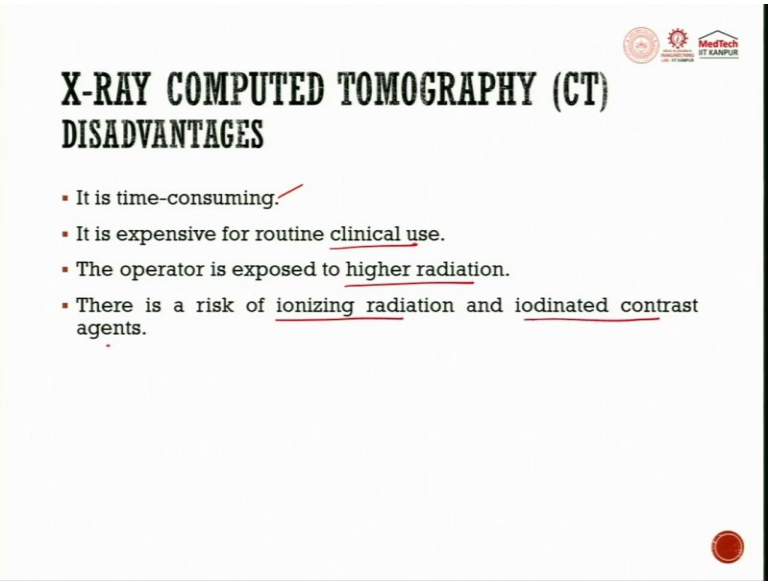

The disadvantages would be, it is time consuming because multiple images are to be taken and the body or the component is to be rotated sometimes. It is expensive for routine clinical use. The operator is exposed to higher radiation. There is a risk of ionizing radiation and the iodinated contrast agents. Whatever it is, the X-ray CT technology provides higher resolution. That is, it can distinguish the tissue having differences of less than 1 % of their physical densities.

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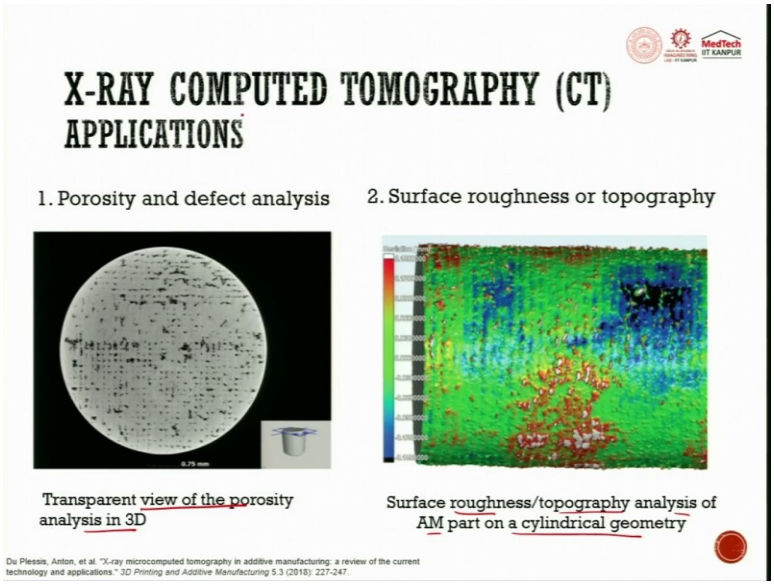

So, it has certain advantages. That is, the quality of the images that we get is useful in having the feel of the defect in the color form, in the shape. The porosity and effect analysis, you can see transparent view of the porosity, analysis in a 3D form. Then surface roughness topography analysis of an additive manufactured part on a cylindrical geometry using the topography and using the X-ray computed tomography.

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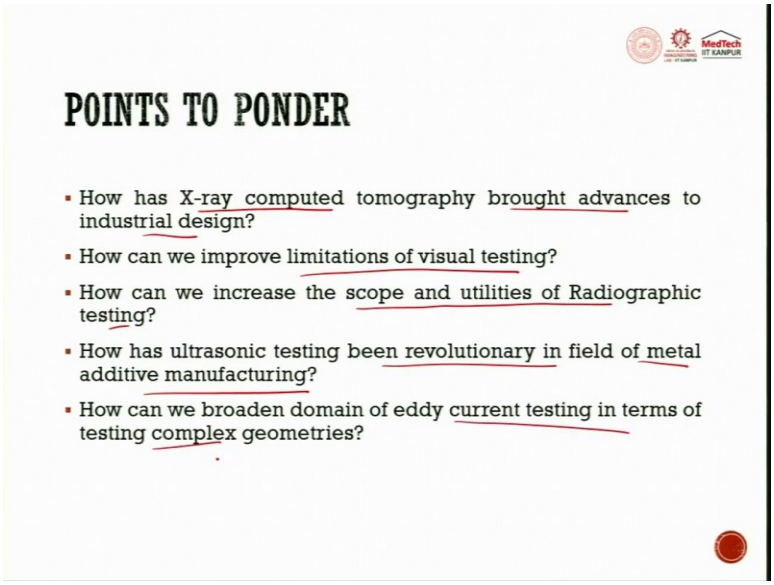

So, with, this the discussion on the contact and the non-contact methods is completed. So, it was just a broad introduction to what techniques exist. Each of the techniques has its own

background, the science, and the physics, which you can definitely study. We will provide the links in the reference of the slide's notes of the lecture, where you can go and try to study about each of the tests separately.

Now, for the points to ponder from this lecture, you can please try to see how X-ray Computed Tomography has brought advances in industrial design, try to see what the applications are, and can we improve the limitations of visual testing, by what aids can we try to improve those?

How can we increase the scope and utilities of the radiographic testing? So, has the ultrasonic testing been revolutionary in the field of metal additive manufacturing? Please try to see and try to have the answer to this. How can we broaden domain of eddy current testing in terms of testing complex geometries?

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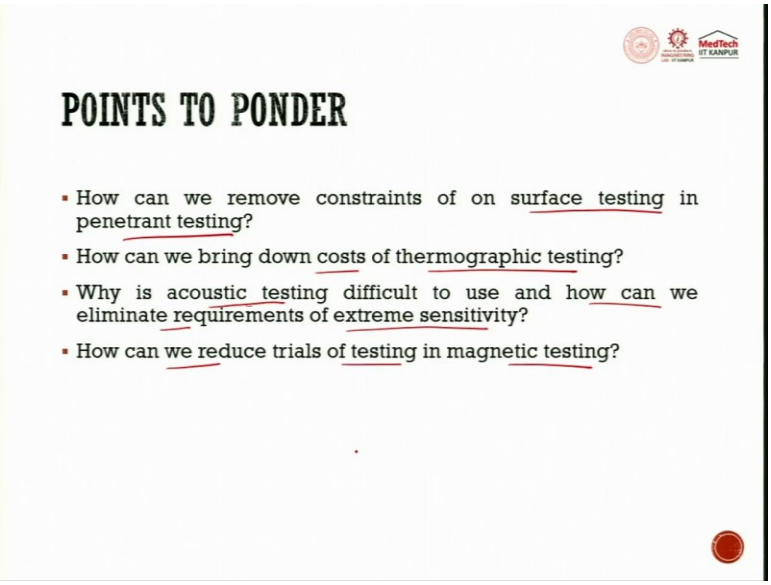

Then, can we remove the constraints, how can we remove the constraints on the surface testing in penetrant testing? There are certain constraints, as we said. The test is only limited to the subsurface or the top surface only. So, how deep could we go, what kind of penetrants are used for this? How can you bring down the costs of the thermographic testing, what is acoustic testing or why is acoustic testing difficult to use, and how can we eliminate requirements of extreme sensitivity? How can we reduce trials of testing in magnetics testing? With this, the lecture on non-destructive testing is complete. And we will again meet to discuss more on metal additive manufacturing. Thank you.