Metal Additive Manufacturing
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Lecture 36
Non-Destructive Testing (Part 1 of 2)

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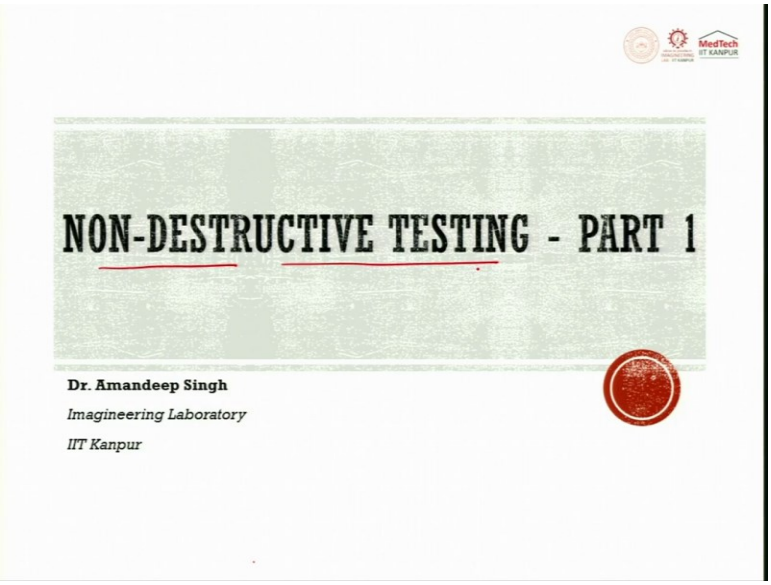

Welcome to the next lecture in the course Metal Additive Manufacturing on Non-Destructive Testing. Non-destructive testing methods are quite close to what we studied in reverse engineering.

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There are contact and non-contact methods. What is non-destructive testing, we will talk about this. The contact and non-contact methods, the technologies, and the construction of the systems and what are the application, advantages, and the demerits of these, we will discuss. A quick light on ultrasonic testing, eddy current testing, magnetic testing, penetrate testing, acoustic testing, which are contact methods. And for the non-contact, radiography, thermographic testing, visual inspection, X-Ray CT scanning, it is computer tomographic scanning, would be taken in this lecture.

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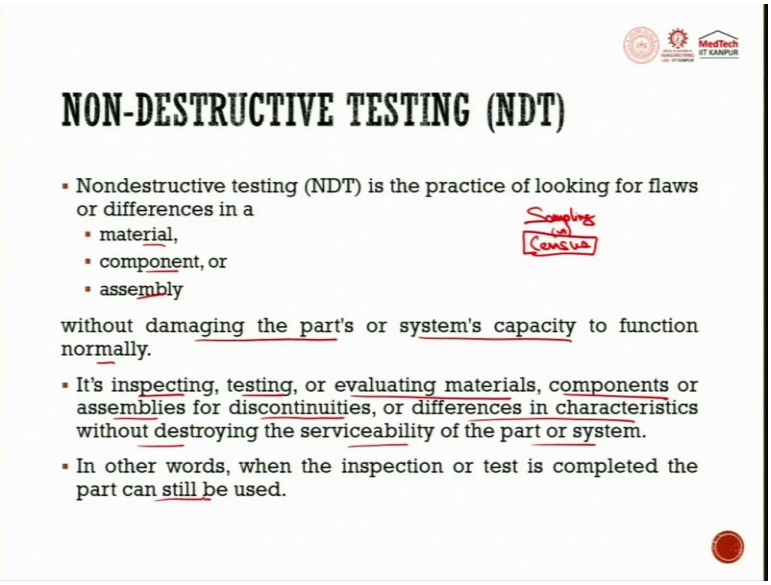

Now, non-destructive testing as definition is a practice of looking the flaws or differences in a material or a component or assembly without damaging the parts or system's capacity to function normally. So, it is a process of inspecting, testing, evaluating the components assembly materials, any discontinuities without destroying/ putting any harm to the component.

So, when the inspection test is completed, the part can still be used. So, in contrast to non-destructive testing, there are tests which are destructive in nature. For example, there are the strength test, the test for the tensile stress, for the compression tests for the component that is produced. We try to produce a specimen of that or sometimes we must try to break the component. But in that case, the component cannot be reused.

So, there are two kinds of the inspections or testing that take place in industry. Number 1 is sampling inspection and the second one is census inspection. Sampling means, we take out some samples because if we must break the system or break the sample or component, we cannot test all, say 10,000 components which are produced in a day.

Out of the 10,000 samples, sample must be collected based upon a systematic way, that could be random sampling, stratified, cluster based, it depends upon the process, how it goes. Census testing is when all, that is, every component is testing for example each component could have been tested at least visually while looking at whether the color of the component is coming correct or not.

So, the two kinds of testing are sampling and census. So, non-destructive testing is always there when we have census inspection. So, these methods use the technologies which are used in manufacturing fabrication or the in-service inspections to ensure that a product integrity, its reliability, its control or in manufacturing process and the cost, everything is maintained at a uniform level.

So, it is to make sure that the quality of the material and joining processes during the fabrication and during the election phases, during the build up phases of metal additive manufacturing or post metal additive manufacturing, testing or the inspection of the dimensions, it is quite useful. So, to identify the damages or to identify the faults in the components or the prints that we have got, these tests are also especially useful. So, how are these useful, what kind of technologies are

there how are their technologies used in different fields in contact and non-contact areas, this we will see.

So, it is inspecting testing or evaluating the materials, components or assemblies for discontinuities or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed, the part can still be used. This is what is NDT.

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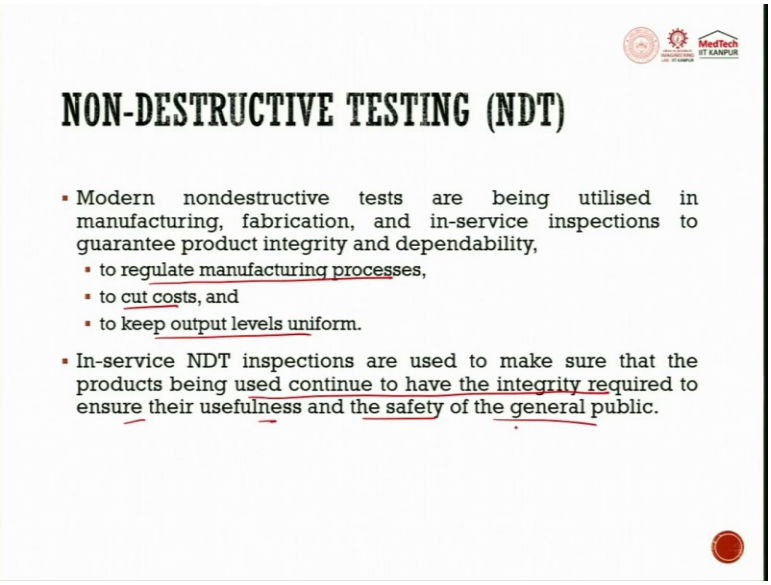

Now, modern non-destructive tests are being utilized in manufacturing, fabrication and in-service inspections and guarantee product integrity and dependability. This is to regulate the manufacturing process, to cut costs, to keep output levels uniform. So, in-service non-destructive testing inspections are used to make sure that the products are being used to continue to have the integrity required, to ensure their usefulness and safety of the general public.

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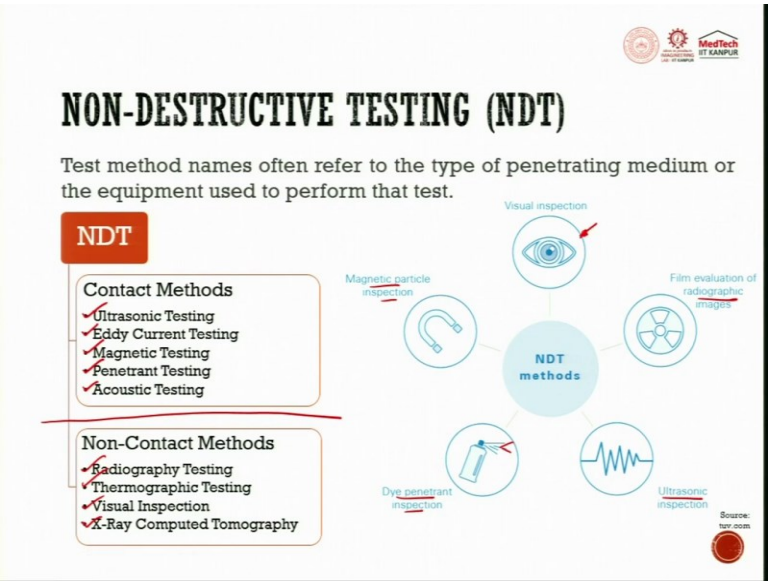

So, this graphics represent the non-destructive testing, the major of the tests in detail. So, we have the methods, that would be visual inspections, that is just by naked eye, without using any

passive or active method, if we try to visualize whether the product or the component we have taken maintains or meets the conformance or not.

Then film evaluation of radiographic images is there, ultrasonic inspection is there, dye penetrant inspection is there, magnetic particle inspection is there. Now, in dye penetrant inspection, you could see this penetrant, this spray or the liquid, whatsoever will try to make to penetrate the component would definitely contact it. So, visual inspection could be, we are only trying to see, we are not contacting physically to the component.

So, we can now divide them into two major segments, contact and non-contact method. In the contact methods, when the probe has to touch the component for ultrasonic, for providing the ultrasonic pulses, that is the ultrasonic testing as a contact method. Eddy current, the wires the end connectors must connect. Similarly, in magnetic, they must pass the magnetic field to the contact has to be there.

In acoustic also we need to have the vibrations. In penetrant testing, the liquid or the spray or the aerosols that would like to penetrate to the component, would contact them. The non-contact method means we try to let the radio waves, or we try to see the thermal images or visual inspection, or we try to only have X-Ray, images CT images of them. So, let us try to have a look on them one by one.

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Contact methods.

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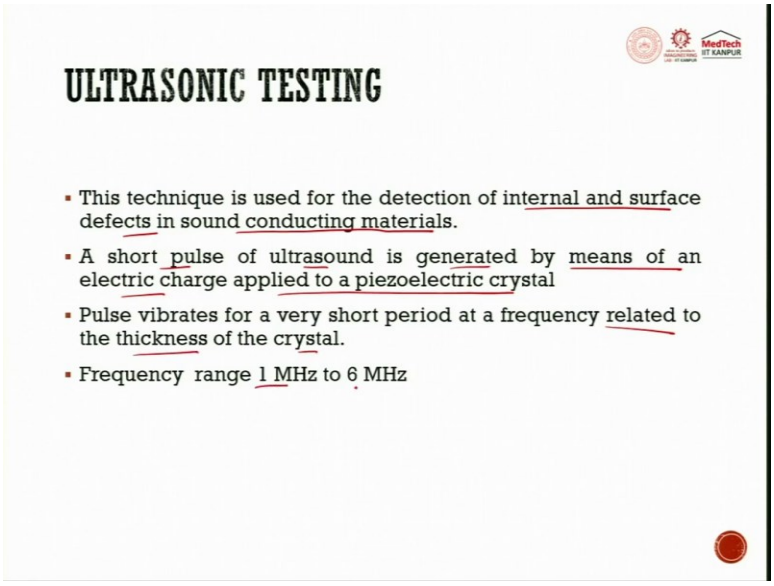

Ultrasonic testing- This technique is used for detection of internal and surface defects in sound conducting materials. Short pulse of ultrasound is generated by means of an electric charge applied to the piezoelectric crystal. Pulse vibrates for a short period at a frequency related to the thickness of the crystal. The frequency range varies from 1 to 6 megahertz.

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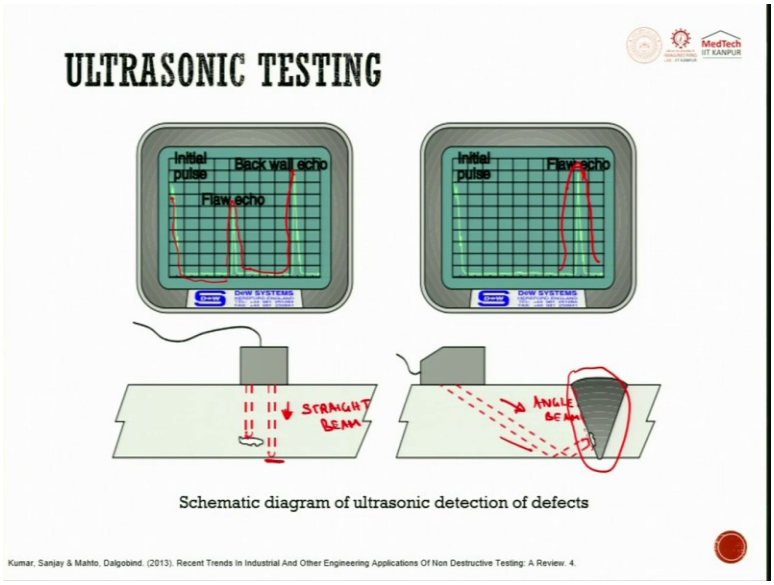

So, in ultrasonic testing, this is a setup that shows how ultrasonic system could help us to give the flaw, and it also test where, at what point the flaw is located. So, in ultrasonic testing, you can see initial pulses. So, it is showing, it is all going uniform. Now here, it shows that there is a spike. Through a spike it shows that there is something not conducive here, that means there is a flaw.

It ignores this flaw, then it still starts going, it open, so the wall-wall echo could also happen in between. So, similarly, the flaw, sometimes the ultrasonic pulse is made to follow a pattern. Then it reaches the flaw while coming at an angle. So, this flaw echo is because of this reason. At the end, it comes at this angle.

So, in this ultrasonic testing, this is a straight beam, this is an angle beam. Straight beam, and we have angle beam. So, in straight beam inspection, we use longitudinal waves which interrogate the test piece as it is shown here. And it, if the sound hits the internal refractor, the sound from the reflector will be reflected to the transducer faster and the sound coming back from the back wall of the part due to the shorter distance from a transducer, this results in the screen display.

So, back wall echo is there from back wall, and it gives this echo here. It goes and hits the back wall here, this is the back wall, and gives us an echo that is high. Now, back wall echo is when it hits the back wall and returns. Now, we have the angle beam as well in which the beam is mounted in such a way that it is angled, or it is wedged and it is designed to transmit the sound beam at a known angle.

This angle could be any, maybe 45^0, 60^0, 70^0, or so. So, with the angle being calculated to make sure that the line transforms the thickness tries to have the information from the whole surface that is under the test. This whole surface is to be tested. So, in angle mean inspection, the transducer in the wedge combination, that is moved back and forth so that the test, the flaw, or the fault that is there, that is recorded back there, and the flaw echo is generated here. You can see an echo is generated here. So, there could be straight beam, there could be angled beam, then sometimes, it is also immersed in water.

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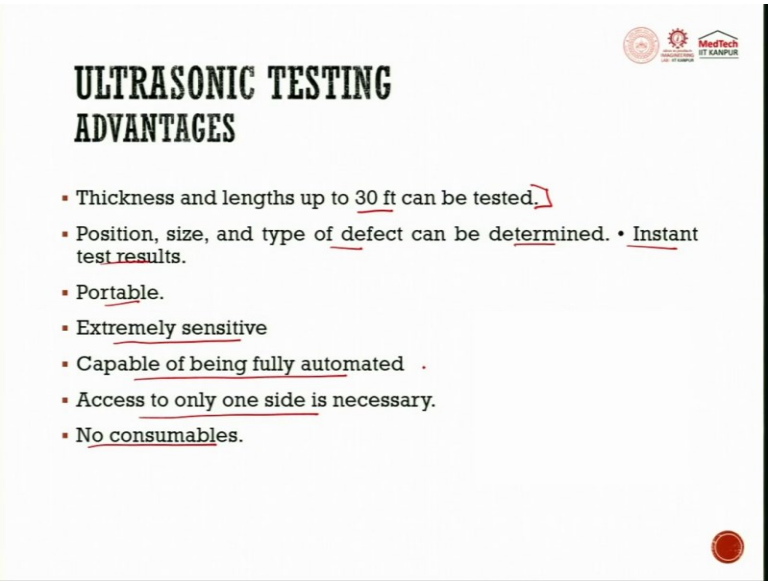

So, there are certain advantages of the ultrasonic testing, that are thickness and lens up to 30 feet can even be tested. See how thick it can even go. So, then, the position, size and type of defect can also be determined, that is, we get instant test results. It is a portable system. It is extremely sensitive, that is, we get the test result immediately. And it is sensitive to the small faults even.

It is capable of being fully automated, it accesses to only one side is necessary, we only need to have access on one side of the surface, and there are no consumables in this. So, there are certain other advanced steps in the ultrasonic systems itself like immersion testing. In the immersion test, the tank of water is there. And the water tank has a coupling medium that allows the sound beam to travel through them.

So, this ultrasonic machine is mounted on the movable platform on a bridge side of the tank and it can travel down the length of the tank. So, there are subtle ways also that we do, and through transmission also happens. So, that is, the transmitter in the receiver try to understand what the test beam or the sound beam is trying to see. So, we are talking about the ultrasonic testing from the viewpoint of the vibration and the sound beam as well.

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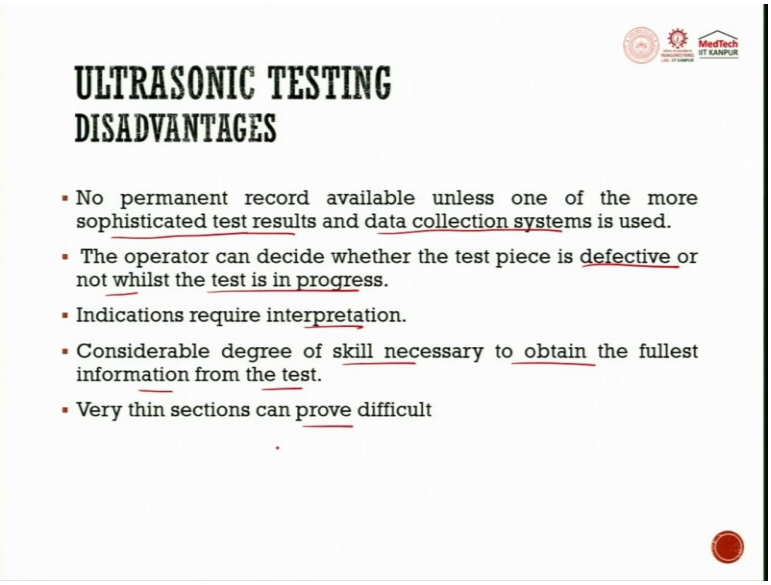

So, there are certain disadvantages of the ultrasonic testing as well. For example, no permanent record is available unless one of the more sophisticated test results and data collection system is used. So, it only gives the results, try to give you echo. If you record the echo, if you try to have the printout of it or if we have the image record of that, that is fine. Otherwise, that is, the data collection system must be installed.

The operator can decide whether the test piece is defective or not whilst test is in progress. So, indications require interpretation. Interpretation from the, one is the operator, second is the machine itself. So, there is an exception of digital wall thickness gauges which will take the interpretation by themselves.

So, considerable degree of skill is necessary to obtain the fullest information from the test. In this case as well, like in reverse engineering we studied, the tests are conducted in a battery of the series. Battery of the series means number of tests are conducted, then only the best results are taken. So, very thin sections can be proved difficult to be tested using this.

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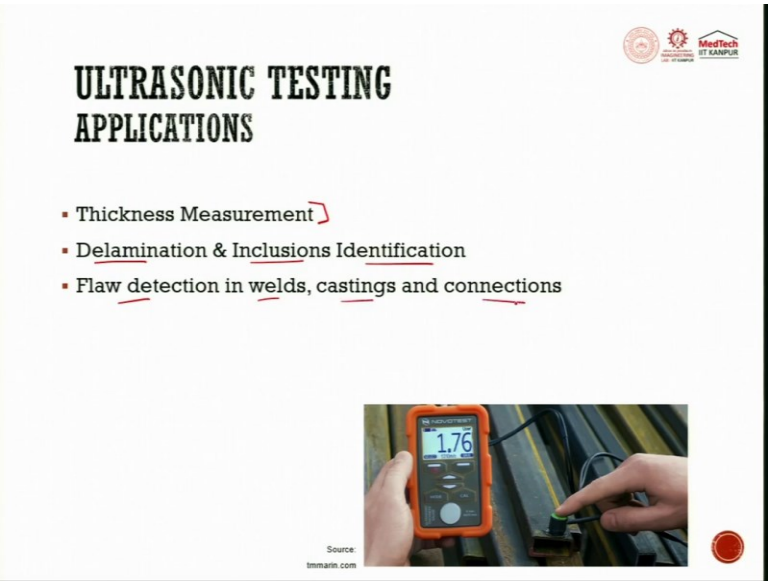

The applications for ultrasonic testing are when thickness measurement is there, when delamination and inclusions identification is required, when flaw detection in welds, castings and connections are required.

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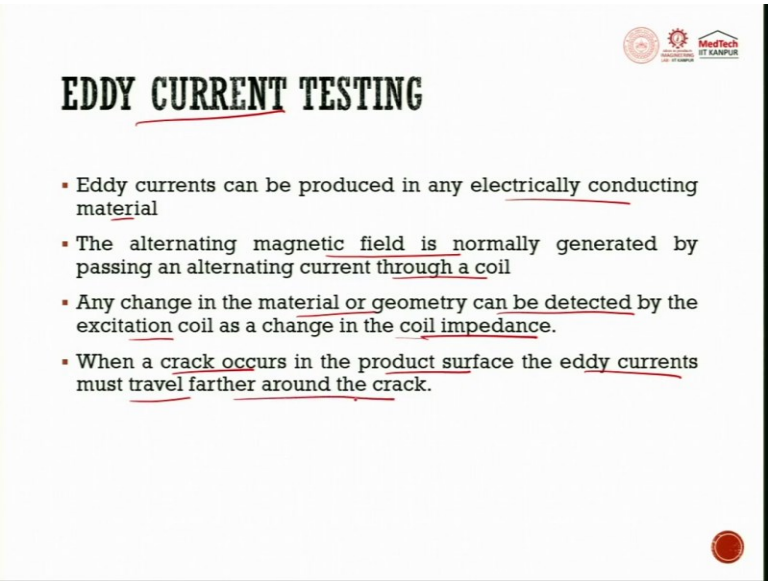

Next kind of the contact method that we have is eddy current testing. Eddy currents can be produced in any electrically conducting material. The alternating magnetic field is normally generated by passing an alternating current through a coil. Any change in the material or geometry can be detected by excitation coil as a change in the coil impedance. So, when a crack

occurs or a flaw is there or a fault is there in the product, the eddy currents must travel further around the crack.

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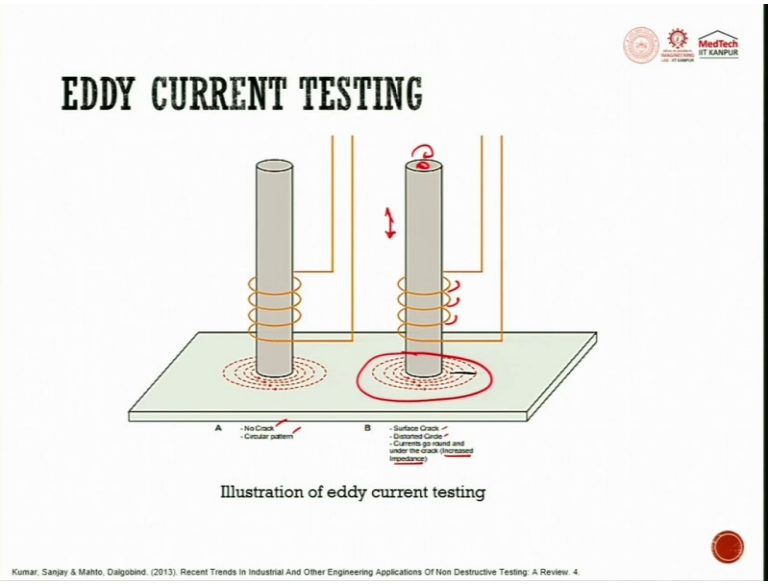

So, in the eddy current, you can see in this illustration, that impedance change is there when the crack is there. So, there is a change in impedance. See, there is an increase in impedance when the crack is there, here the crack is here. There, is no crack, the pattern is completely circular. So, in this case, the current is passed, the surface crack is there, the circle is distorted.

So, because the circle is distorted, currents go round and under the crack, so, the increase of impedance is there. So, that is what an eddy currents suggests us that the change in the impedance, that is recorded as an electrical signal gives us the information on the current or on the effect that is there. So, in eddy current testing, this uses the flux field. This is the flux field. And any change in the flux field is terms of impedance change that is recorded. So, the flow pattern of the secondary current here is the eddy current. Eddy current means the secondary current.

So, the encircling coils which are here are to be used to test tubular or bar shaped surfaces majorly. These coils are used. Now, the product can travel in between, this product can go up and down and encircling coil is there. So, eddy currents could also be given here within the product itself. Here also the eddy currents could be given. So, it depends upon the kind of the testing and kind of the shape of the product that we have.

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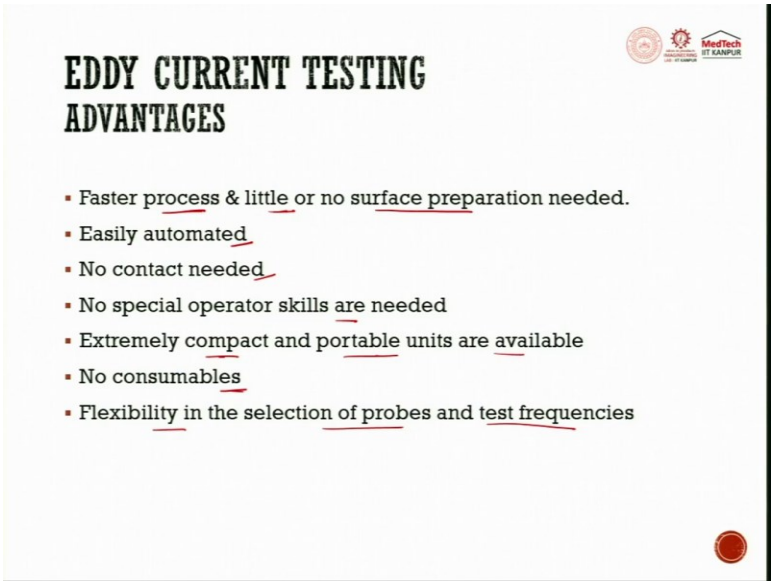

So, advantages for it would be, it is faster process and little or no surface preparation is needed. It is easily automated, no contact is needed, no special operator skills are required, extremely compact and portable units are available. So, there are no consumables as well other than sometimes the probes are there which are to be repaired again. We have flexibility in the selection of probes and test frequencies in the eddy current testing. This flexibility is to suit the different applications to different shapes of the components that we are trying to test.

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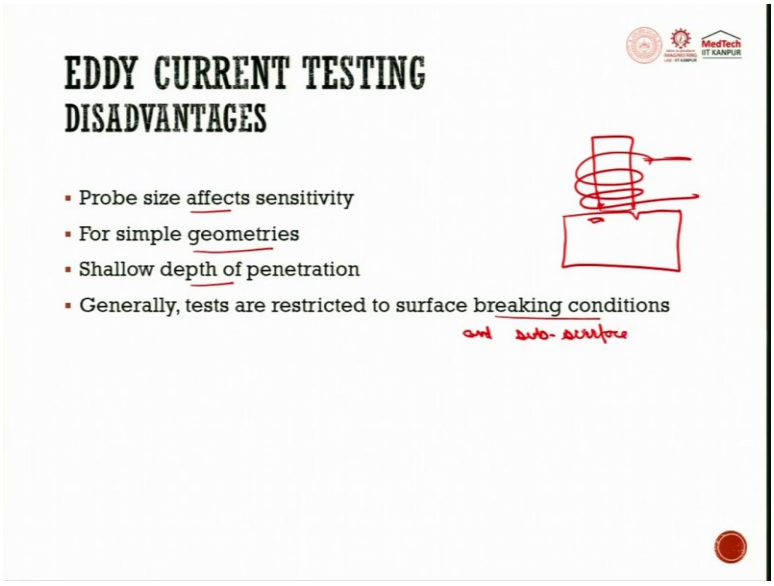

Disadvantages would be the probe size effects sensitivity. That is why the probes are repaired and again so that we try to fix it to the sample as close as possible. For simple geometries only, this test could be taken. We cannot take test for the complex geometry. For example, the fins of an impeller, the components of a carburetor, it will be tough. Only these circular geometries straight geometries could only be tested.

There is a shallow depth of penetration, that is, we cannot go as deep as we could go in the ultrasonic testing. We could go up to 30 feet, it was given there. So, generally, tests are restricted to surface breaking conditions only. So, and slightly sub surface loss could also be taken. So, if the flaw is here on a surface, that is fine. Slightly subsurface flaw, for example, if it is here, very slightly, that could also be seen using the ultrasonic testing. So, for example, if it is here, and we have a coil here. So, surface and subsurface both. I will put and subsurface, that is, very close to surface.

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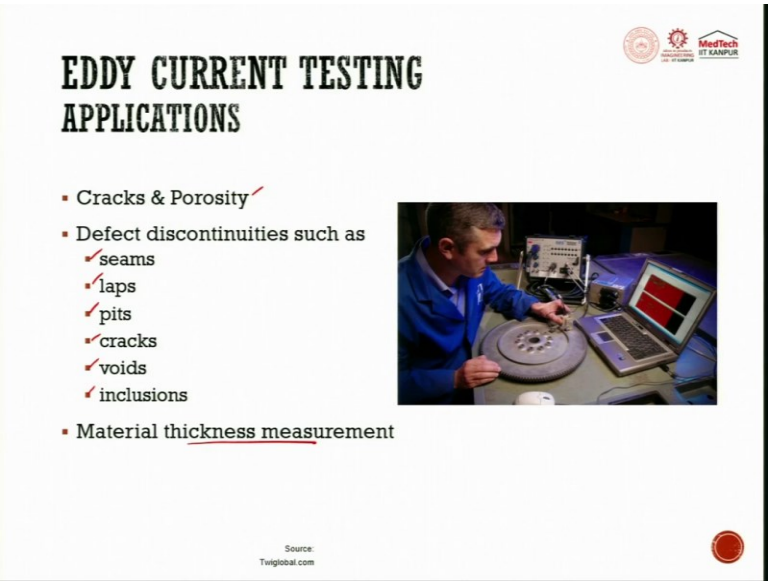

The application would be cracks and porosity, determination or identification, defects continuous, defect discontinuities such as if seams are there, laps or there, small pits have been developed, cracks are generated, voids exist there, inclusions need to be identified. Then material thickness measurement also, to some extent, can be taken through the eddy current applications.

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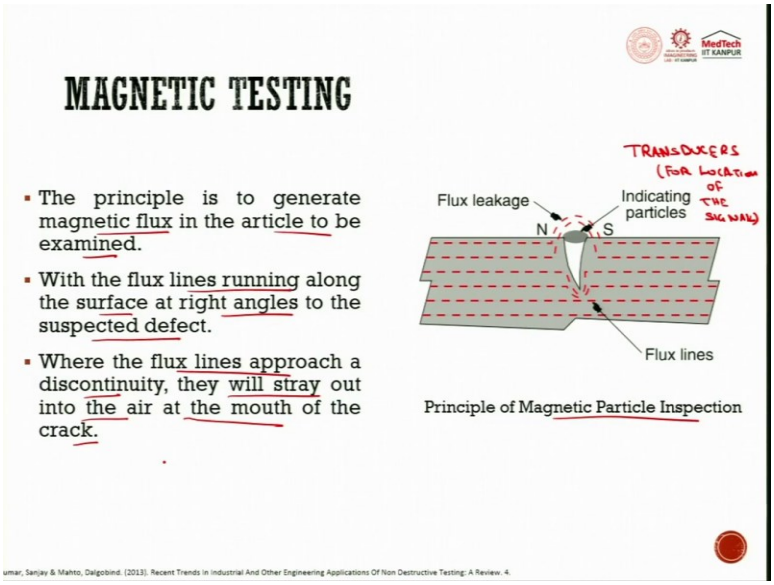

Now next comes the other contact method, that is, the magnetic testing. The magnetic testing has a principle that is to generate magnetic flux in the article to be examined. With the flux lines running along the surface at right angles to the suspected defect, where the flux lines approach a discontinuity, they will stray out into the air at the mouth of the crack.

So, flux lines are generated, so the flux leakage is there, so this indicate that some particle is there, or the flux lines are distorted here. The principle of magnetic particle inspection is given here. In magnetic particle inspection, the flux leakages detect the anomalies in the normal flux patterns.

So, this is discontinuities. So, in ferrous material, this is quite applicable. So, this is used for piping, tubing inspection, then tank floor inspection and other applications are also there. For example, in tubular applications, the inspection at contained is made up of drive and sensor coils and the position transducer, those are connected by cables or some power source or so.

So, this head is placed around the pipe or the tube which is to be inspected and drive call is energized. The location of signal that is sent by the position of transducer here, so transducers are used for location of signal. Now, tank floor inspection applies the same principle, but it uses a series of magnetic field generations, that is, bridges of magnetic fields are generated here. So, in tank floor inspection as well, the, because the area is more, more systems, more bigger bridges

are generated of the magnetic field, which helps us to understand the test, the discontinuity, growth if it is there, it tries to monitor that.

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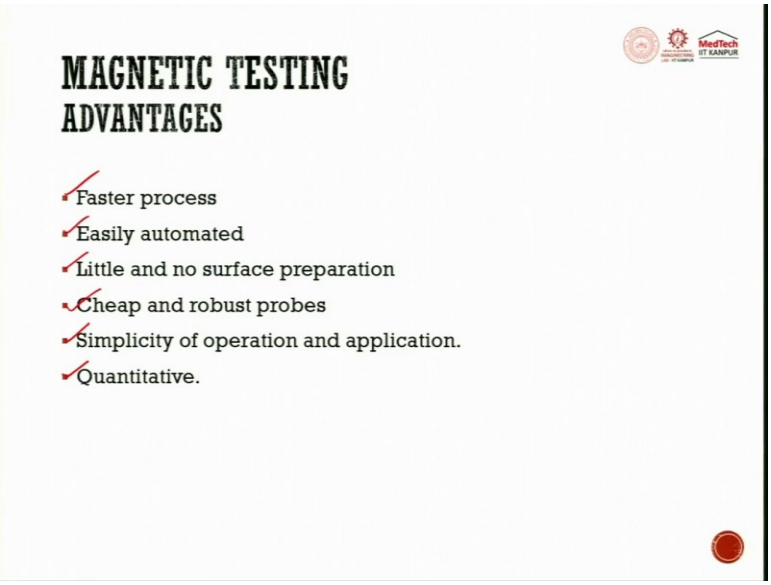

So, it is a faster process, it can be easily automated, little and no surface preparation is required. It is cheap and robust probes could be used here. The simplicity in the operation and the application is always there with magnetic testing techniques. It is a quantitative technique, that is, we get the results in the units of the magnetic field that is Tesla, and it can be quantified because with data that we get is a continuous data here.

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The disadvantage attributed to this kind of the test is, it is restricted to only ferromagnetic materials. It is also restricted to the surface or the subsurface or near-surface flaws just like eddy currents. So, each component needs to be tested twice because we need to confirm the test and from both the directions. The diagonal defects are difficult to detect here.

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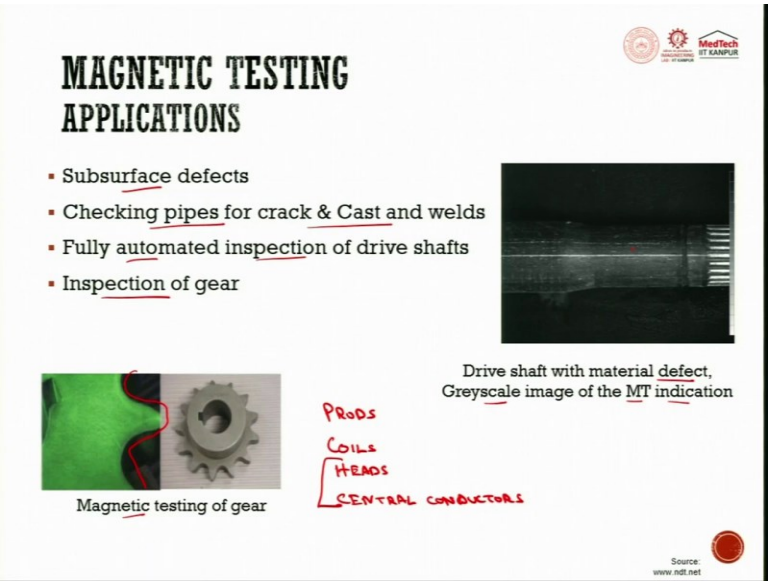

The applications are the sub surface defects, checking pipes for crack and cast and welds, fully automated inspection of drive shafts could be taken, inspection of gears in general is taken, is

carried out by the magnetic testing process. So, drive shafts with material defect, then grayscale image of the magnetic testing indication is here.

Then magnetic testing of a gear, how does it look like, how does the field flow, it is showing here. So, to get this image of the magnetic testing of gear, certain parts of magnetic testing system, I could just name them, for example prods are required. So, prods use direct induction. So, when current runs through the path or circular magnetic field, it is generated around the legs of the prods here. So, then, the flux lines are generated, and it tries to indicate wherever the distortion is there. Then, we can also use coils even. So, why coils, because electric coils are used to generate a longitude of magnetic field only.

And when this is energized, the current creates magnetic field, and the wires which make up the coils result in the flux lines which are oriented through the coil and because of the longitudinal field, the indication in the parts placed in the coil are oriented in the traverse to the longitudinal field so we get the direction, so we get the exact information regarding that.

Also, we have heads, movable heads as well. Heads means horizontal worth bath machines are there, which is a magnetic testing setup, in which the heads are moved. It is just a movable head like a grinding machine setup or so. Then, we have central conductors. Central conductors could be something equivalent to the coils, which I just talked about. But these can be placed between the heads of the part and between the bars. So, there are always, these two can work in unison to get the output image and about the magnetic field information.

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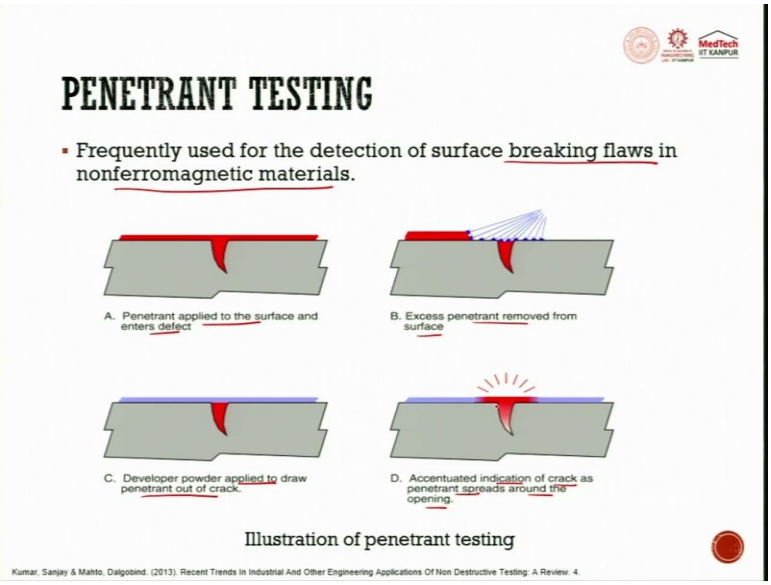

Another test is penetrant test. The penetrant test means a medium must penetrate the material that is to be tested. It is frequently used for the detection of surface breaking flaws in non-ferromagnetic materials where the magnetic tests are not applicable because of their non-ferromagnetic nature. So, penetrants are applied to the surface and enters the defect.

Then, the excess penetrants are removed from the surface. The developer powder applies to draw penetrant out of the crack, then accentuated indication of crack as penetrant spreads around the opening. So, we get the information about the crack, the amount of paint that is spread, and how powder tries to draw. So, this amount of the penetrant and the shape of the penetrant also tells us what is the crack behavior, what is the crack shape.

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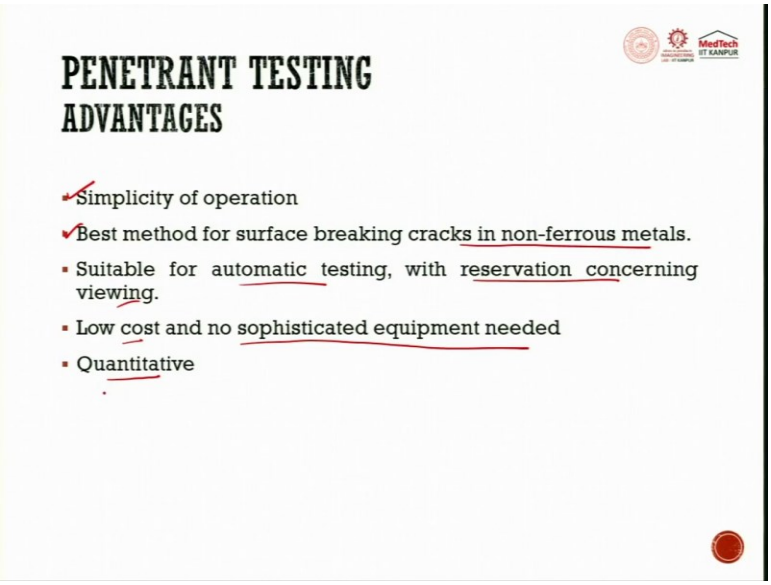

So, it is again simple to operate. It is the best method for surface breaking cracks in non-ferrous metals. It is suitable for automatic testing with reservation concerning viewing. It is a low cost, low sophisticated equipment required, and again it is a quantitative method because we can get the information in millimeter, in grams and we can quantify the information, once again.

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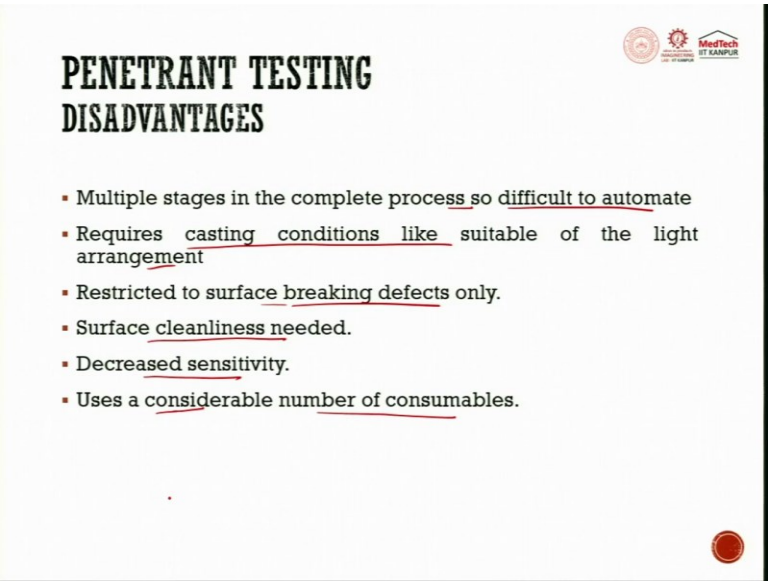

The cons would be multiple stages in the complete process, so it is difficult to automate the system. It requires casting conditions like suitable light arrangement. This is restricted to surface breaking defects only. Surface cleanliness is required, sensitivity is lesser, it uses a considerable

number of consumables because for developer penetrant everything goes waste, and these are all consumables only.

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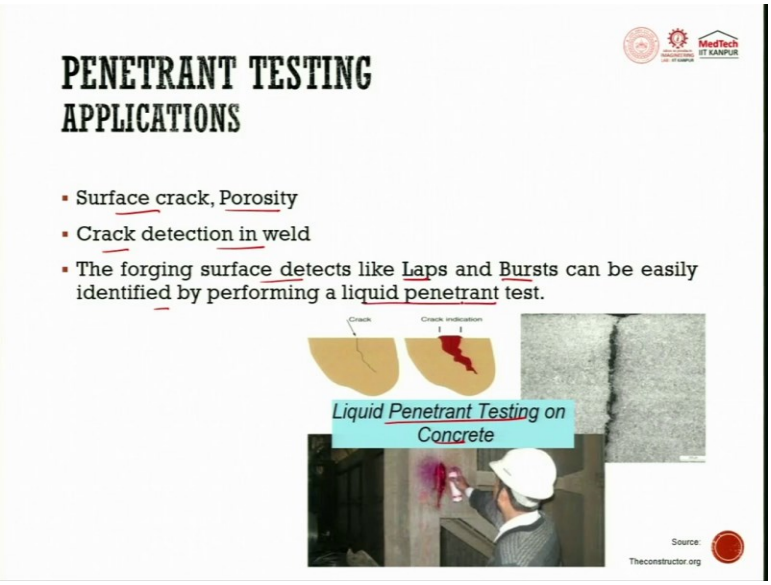

The applications definitely are there where the small portion is there and the full machine cannot reach, but still, we need to have the information of the crack. For example, this is liquid penetrant testing on the concrete. So, to test the shape of the crack and the type of the crack, the liquid is penetrated in this, then it is taken out using a developer.

While taking out of the system, we try to see how the pattern of that test, how the crack has been developed and what is the shape, what is the size of that, what volume of liquid has gone in it. So, surface crack or porosity can be determined or can be identified using this. Crack detection in weld could be taken care using these kinds of test. The forging surface detects like laps, bursts can be easily identified by performing a liquid penetrant test.

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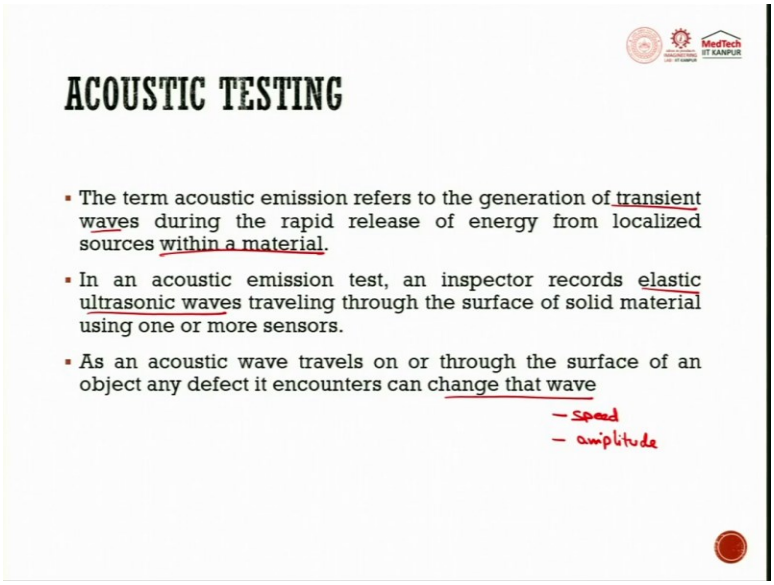

So, next is another contact method, that is, acoustic testing. The term acoustic emission refers to the generation of transient waves during the rapid release of energy from a localized surface within a material. In an acoustic emission test, an inspector records elastic ultrasonic waves traveling through the surface of solid material using one or more sensors.

So, we have elastic ultrasonic waves here, which travel through surface of the solid material. Sensors are there. What this sensor recalls, we will just see. As an acoustic wave travels on or through the surface of an object, any defect it encounters, can change that wave. So, this change in wave must be now captured. So, this change in waves happens in the terms of the speed of the wave or in the terms of the amplitude of it. So, this must be recorded.

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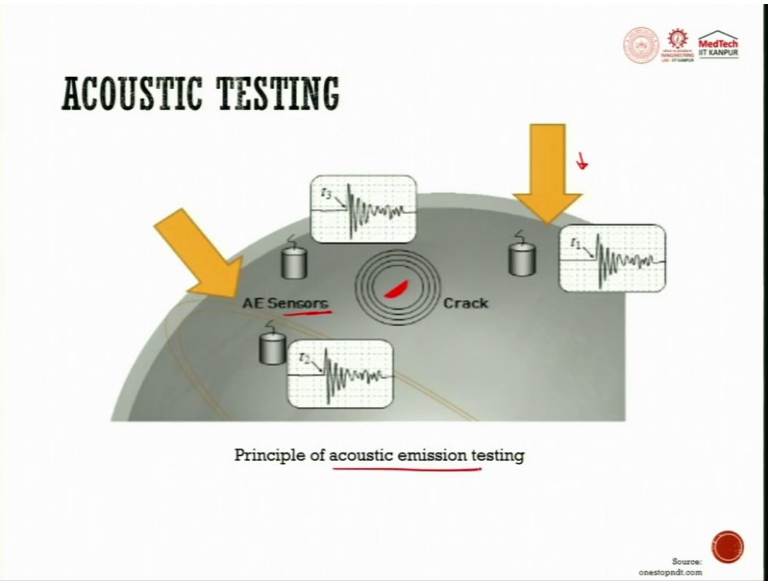

So, in the acoustic testing, it is performed by applying localized external force such as an abrupt mechanical load. So, then, a rapid temperature or pressure change happens, the resulting stress waves in turn generate a shockwave or high frequency elastic waves, which are in the form of a small material displacement. So, this small material displacement is recorded here using sensors. So, it is detected by sensors. When multiple sensors are used, the resulting data can be evaluated to locate discontinuities in the part. So, this is how it works, this is the principle of acoustic emission testing.

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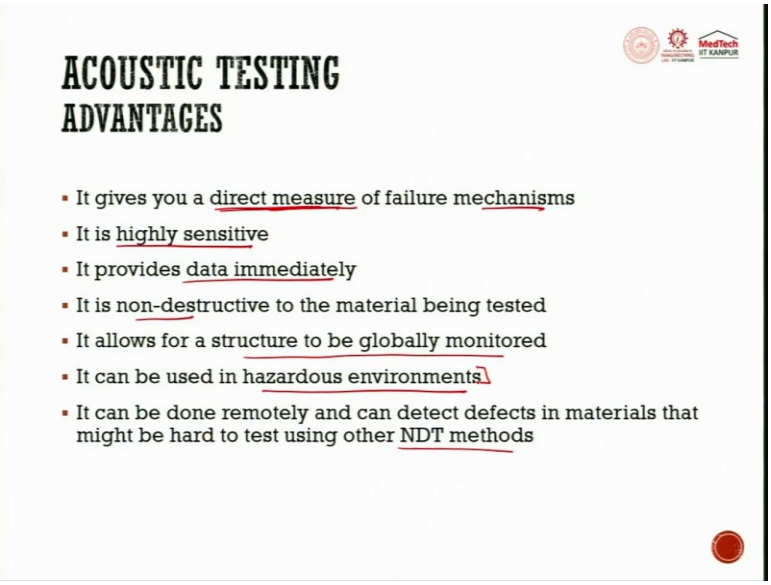

It has an advantage that it gives you direct measure of failure mechanisms. It is again, sensitive. Even small cracks or small defects could be identified using this. It provides data immediately or instant readings could be taken. It is a non-destructive test to the material being tested. It allows for a structure to be globally monitored. It can be used in hazardous environments as well. It can be done remotely and can detect defects in materials that might be hard to test using other non-destructive testing methods because it can be used in the hazardous environments as well.

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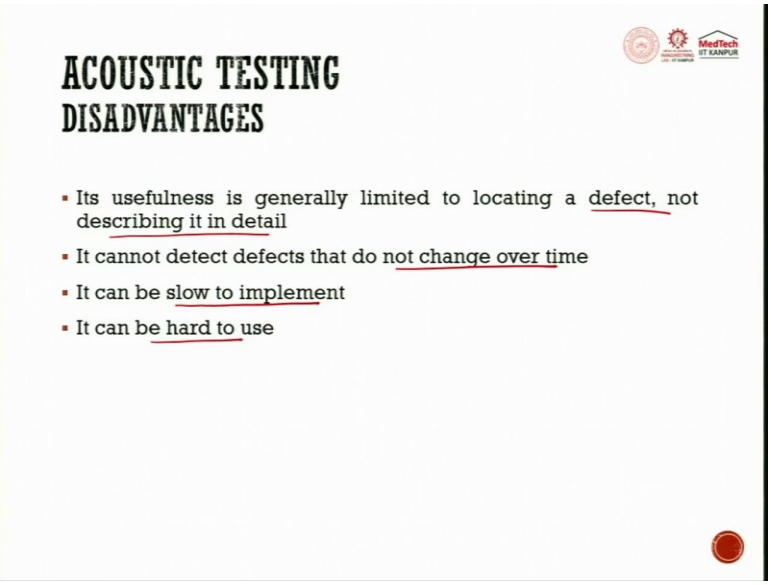

So, the disadvantages are that its usefulness is generally limited to locating a defect, not describing the defect in detail. It only gives you the signal, yes, the defect is there, there is a change in wave, but what is the size, shape, the measurement, quantitative techniques cannot be applied on it. So, this means that commercial acoustic testing systems can only provide qualitative estimates only. That is, test is there or not, yes, no. It cannot give you test of this quantity, this measure is there. It cannot detect the defects that do not change over time. It is slow to implement.

It can be hard to use. Acoustic signals are very weak, so there is lot of noise and signal discrimination, what is the signal exactly, do we measure, what is the noise, is the unwanted readings, unwanted output. So, differentiating between them, sometimes becomes difficult. So, it is not quite simple test.

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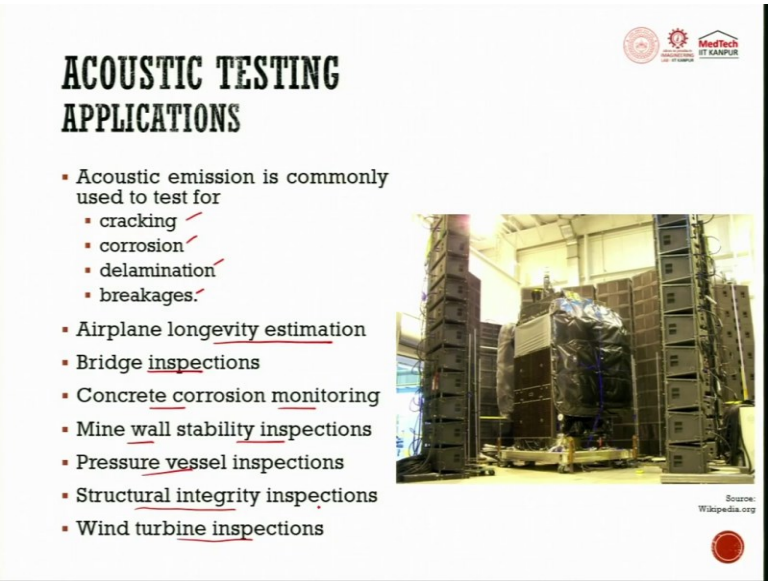

But still, it has an applications to test for the cracking, corrosions, delamination and breakages. Airplane longevity estimation is taken care by applying the acoustic testing methods. Then bridge applications are there, concrete corrosion monitoring is there, mine wall stability, pressure vessels, structural Integrity inspections, wind turbine inspections are taken care by the acoustic testing methods.

So, with this, the part one of the lecture on Non-Destructive Testing is completed, where we have discussed the contact methods only to have the non-destructive tests on the materials and the components. We will meet in the next part, we will discuss on the non-contact methods. Thank you.