Inspection and Quality Control In Manufacturing
Prof. Kaushik Pal
Department of Mechanical and Industrial Engineering
Indian Institute of Technology – Roorkee

Lecture - 09
Eddy Current Inspection

Hello my friends, now, we are going to discuss about our new chapter that is the, Eddy Current Inspections under the non-destructive testing. So first, let us know, the history behind it, so eddy current inspections has its own origins with the Michael Faraday's discovery of electromagnetic induction in the year of 1831. Its development as a non-destructive testing techniques for industrial applications was carried out during the World War II, in Germany.

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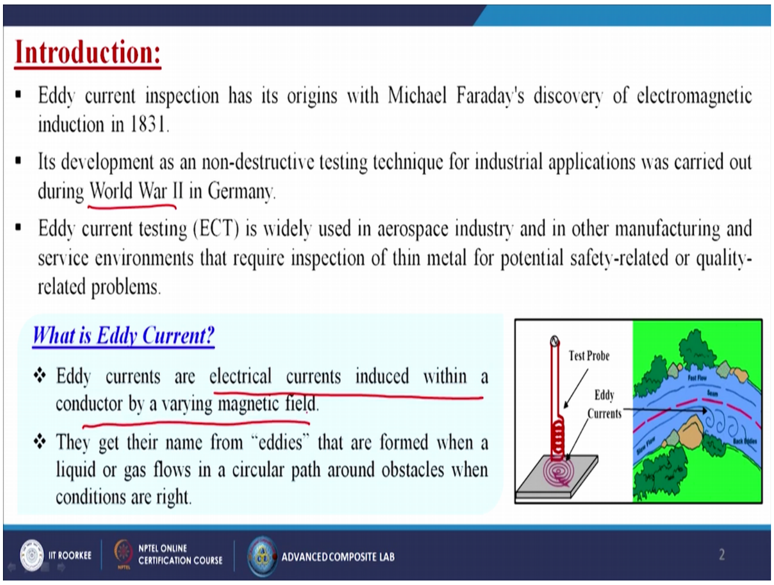

Eddy current testing sometimes we are calling it as ECT is widely used in aerospace industry and in other manufacturing and the service environments that require inspection of thin metal for potential safety related or quality related problems. What is Eddy current? Eddy currents are electrical currents that induced within a conductor by a varying magnetic field. So it is just the opposite of that magnetic particles inspection, they get either named from eddies that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right.

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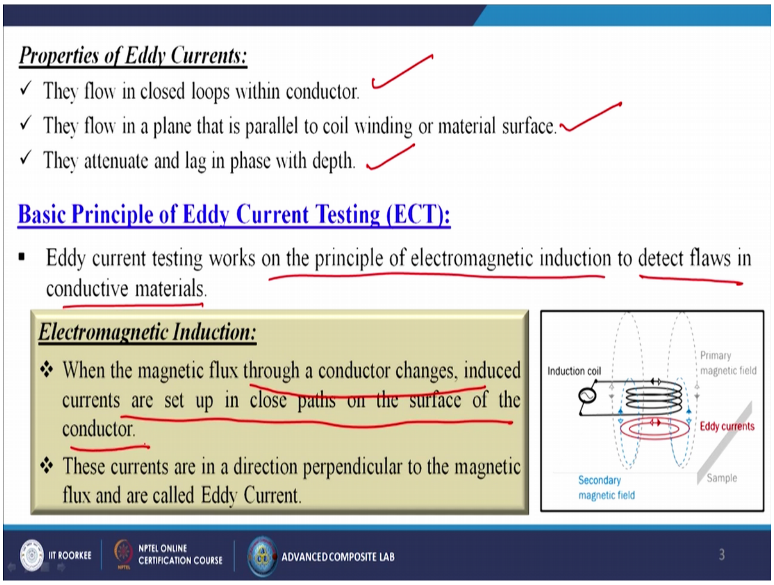

Properties of the Eddy Currents: They flow in closed loops with conductor. They flow in a plane that is parallel to coil winding or maybe the material surface. They attenuate and lag in phase with depth. Now what are the basic principles of the Eddy current testing? Eddy current testing works on the principle of electromagnetic induction to detect flaws in conductive materials.

Electromagnetic induction: When the magnetic flux through a conductor changes, induced currents are set up in closed paths or the surface of the conductor itself. So now, you can see that we are having that sample. So now we are having that induction coils and through that we are generating the magnetic field over there, and due to that magnetic field this reading color the eddy currents is generating on to our work or maybe the onto our sample. These currents are in direction of perpendicular to the magnetic flux and are called Eddy current.

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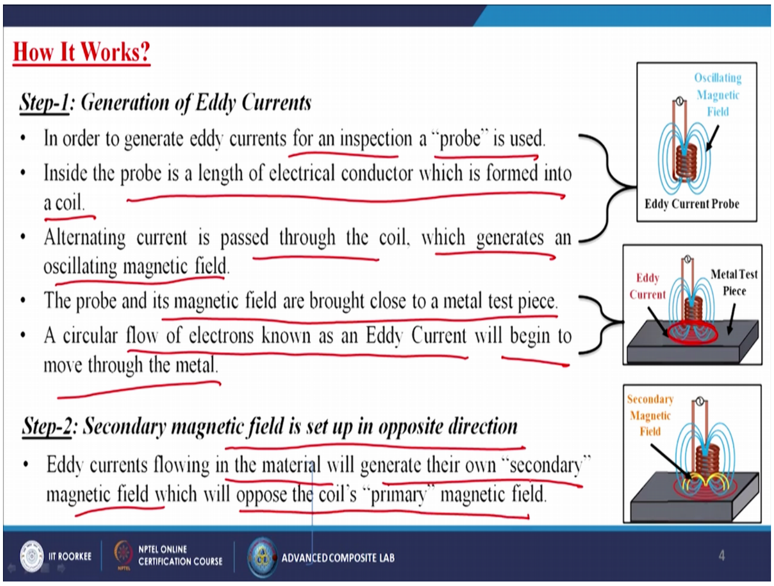

How it works? Step one, first is that the generation of Eddy currents. In order to generate the Eddy currents for an inspection, a probe is used. Inside the probe is a length of electrical conductor which is formed into a coil. So you can see that coil. Alternating current is passed through the coil which generates an oscillating magnetic field. The probe and its magnetic field are brought close to a metal test piece. A circular flow of electrons form known as Eddy current will begin to move through the metal itself that red in color. Second step, Secondary magnetic field is set up in opposite directions. Eddy currents flowing in the material will generate their own secondary magnetic field which will oppose the coil's primary magnetic field over there.

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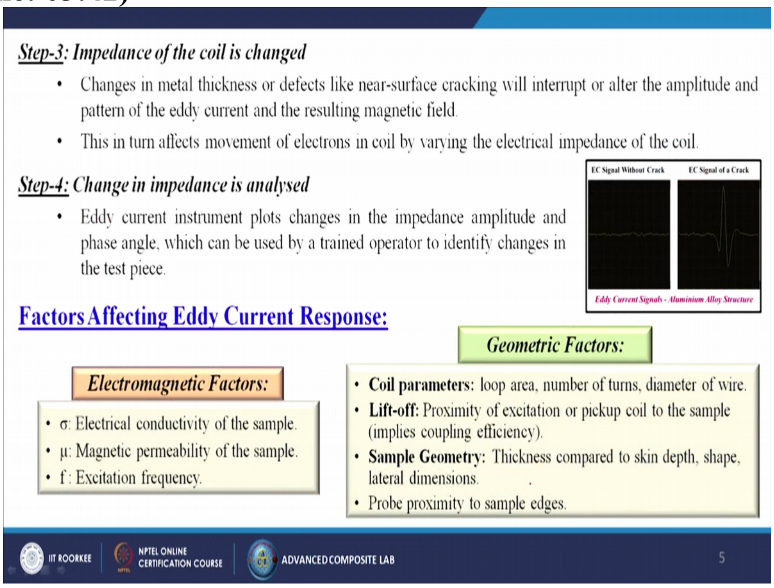

Step 3: Impedance of the coil is changed. Changes in metal thickness or defects like near surface cracking will interrupt or alter the amplitude and pattern of the eddy current and thus resulting the magnetic field. This in turn affects movement of electrons in coil by varying the electrical impedance of the coil itself. So now you can see from this particular image, that how we are getting the signals, EC signal without crack, so it is good in nature. But, when we are having some cracks we are getting some erratic signals over there, so now change in impedance is analyzed. Eddy current instrument plots changes in the impedance amplitude and phase angle, which can be used by a trained operator to identify changes in the taste piece.

Now what are the factors that affecting the Eddy current response, first one is called the electromagnetic factors, electrical conductivity of the sample, that is nothing but the Sigma, mu, magnetic permeability of the sample, and the small f that is the excitation frequency and next is that geometric factors, like coil parameters, loop area, number of turns, diameter of wire. Liftoff: Proximity of excitations or pickup coil to the sample implies coupling efficiency. Sample Geometry: Thickness compared to skin depth, shape and lateral dimensions probe proximity to sample edges.

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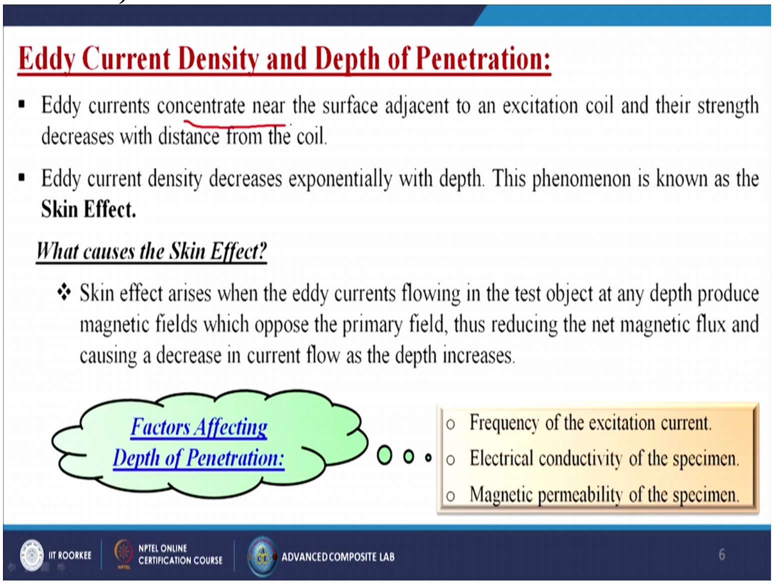

Next is Eddy Current Density and Depth of Penetration: Eddy currents concentrate near the surface adjacent to an excitation coil and their strength decreases with distance from the coil. So that means, a thin sample can be easily detected rather than the thick sample. Eddy current density decrease exponentially with the depth. This phenomenon is known as the Skin Effect.

What causes the Skin Effect? Skin effect arises when the eddy currents flowing in the test object at any depth produce magnetic fields which oppose the primary field thus reducing the net magnetic flux and causing a decrease in current flow as the depth increases. Factors affecting the depth of penetration: Frequency of the excitation current, Electrical conductivity of the specimen, Magnetic permeability of the specimen.

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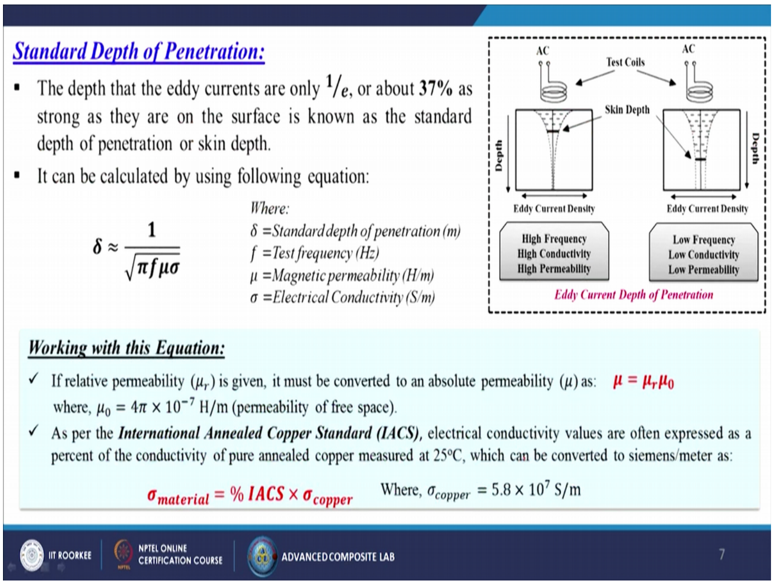

Now what are the Standard Depth of Penetrations? The depth that the eddy currents are only 1 by e or about 37% as strong as they are on the surface is known as the standard depth of penetration or maybe the skin depth it can be calculated by using the following equations that is Delta is more or less equal to 1 by root over PI F Mu Sigma, where Delta is the standard depth of penetrations in meter, F is the test frequency in hertz, mu is the magnetic permeability that is H by m and Sigma is the electrical conductivity that is S by m.

So working with this equations if relative permeability mu r is given, it must be converted to an absolute permeability mu as mu is equal to mu r into mu 0, where mu 0 is equal to 4 PI into 10 to the power minus 7, H by m, permeability of free space. As per the International Annealed Copper Standard IACS, electrical conductivity values are often expressed as a percent of the conductivity of pure annealed copper measured at 25 degree centigrade which can be converted to Siemens per meter, that means S by m or maybe S / m, as Sigma material is equal to percentage is IACS into Sigma copper, whereas Sigma copper is equal to 5 point 8 into 10 to the power 7 Siemens per meter.

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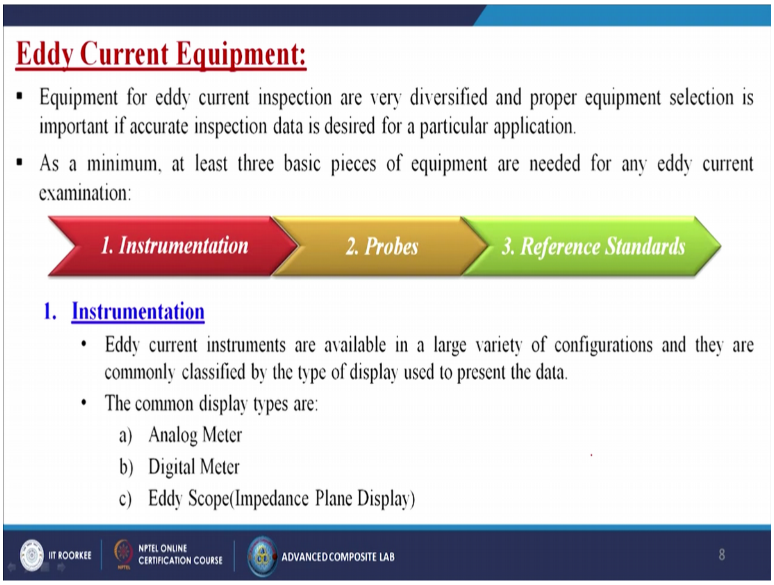

Now Eddy Current Equipment: Equipments for eddy current inspections are very diversified and proper equipment selection is important if accurate inspection data is desired for a particular application. As a minimum, at least three basic pieces of equipments are needed for any eddy current examination. What are those? First is that instrumentation, second is the Probes, Third is the Reference Standards. So when you are talking about the instrumentation, eddy current instruments are available in a large variety of configurations, and they are commonly classified by the types of display used to present the data. So first is called the Analog meter then Digital meter and the Eddy scope or maybe the Impedance plane display.

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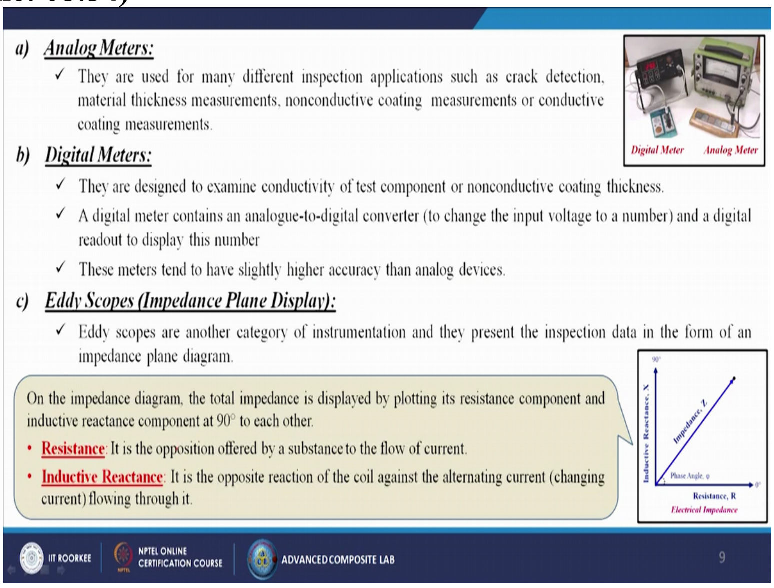

What is Analog Meter? They are used for many different inspection applications such as crack detection, material thickness measurements, non conductive coating measurements or maybe the conductive coating measurements. Next come to the digital meters, so here you can see, that digital meters, the value will come digitally and analog meter maybe some graph will be plotted, and from that, you have to calculate. When you are talking about the digital meters they are designed to examine conductivity of taste component or non conductive coating thickness.

A digital meter contains an analog to digital converter, to change the input voltage to a number, and a digital readout to display this number. These meters tend to have slightly higher accuracy than the analog devices, because it will give you the more precise value. Or third one is the Eddy scopes or sometimes we are calling it as a Impedance plane display. Eddy scopes are another category of instrumentations and they present in the inspections data in the form of an impedance plane diagram. On the impedance diagram the total impedance is displayed by plotting its resistance component and inductive reactance component at 90 degree to each other.

So here in the x-axis, we are drawing or maybe the plotting the resistance R and in y axis we are plotting the inductive reactance that is X and these the whole angle is the 90 degree. Now it is based on two resistances it is the opposition offered by a substance to the flow of current, and the inductive reactance it is the opposite reaction of the coil against the alternative current, changing current flowing through it.

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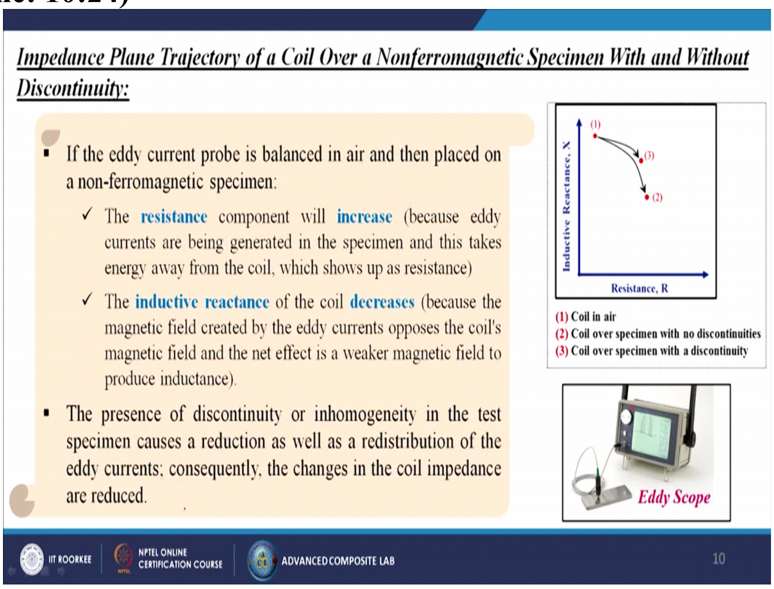

Now Impedance Plane Trajectory of a Coil over a Non ferromagnetic Specimen with and without the discontinuity. If the eddy current probe is balanced in air and then placed on a non ferromagnetic specimen, the resistance component will increase, because eddy currents are being generated in the specimen, and this takes energy away from the coil, which shows up as resistance.

So first you can see that number one points, that is the coiling air, number two coil over specimen with no discontinuities, no cracks. Now the inductive reactance of the coil decreases because the magnetic field created by the eddy currents, oppose the coils magnetic field and the net effect is a weaker magnetic field to produce the inductance. So that is the number three positions over here. So coil over specimen with a discontinuity.

The presence of discontinuity or maybe the in homogeneity in the test specimen causes a reduction as well as redistributions of the eddy currents. Consequently the changes in the coil impedance are reduced. So Eddy scope is generally looks like this.

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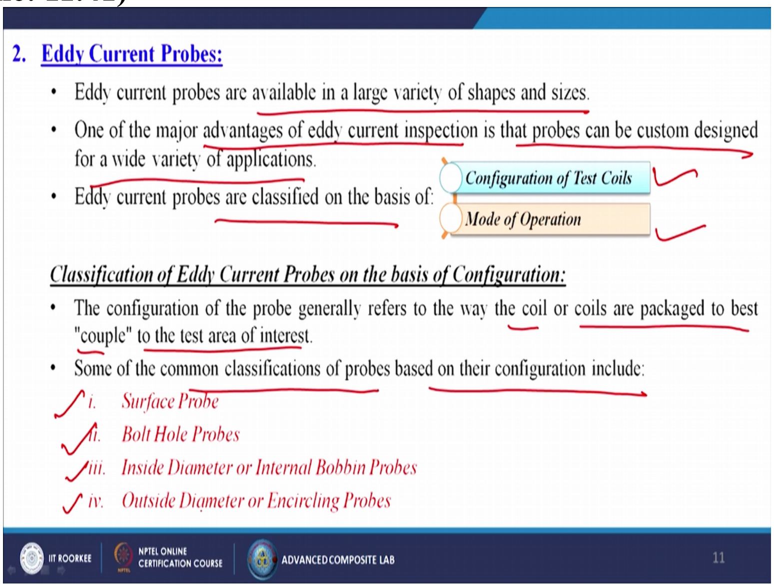

Second Eddy Current Probes: Eddy current probes are available in a large variety of shapes and size. One of the major advantages of eddy current inspection is that probes can be custom designed for a wide variety of applications. So depending upon the sample size, depending upon the material size, there are different types of probes are available. Eddy Current Probes are classified on the basis of configurations of the test coils and the mode of operation.

Classification of eddy current probes on the basis of configurations, the configuration of the probe generally refers to the way the coil or coils are packaged to best couple to the test area of interest. Some of the common classifications of probes based on their configuration include Surface probes, Bolt Hole probes, inside diameter or may be the Internal Bobbin probes and the Outside diameter or may be the Encircling probes.

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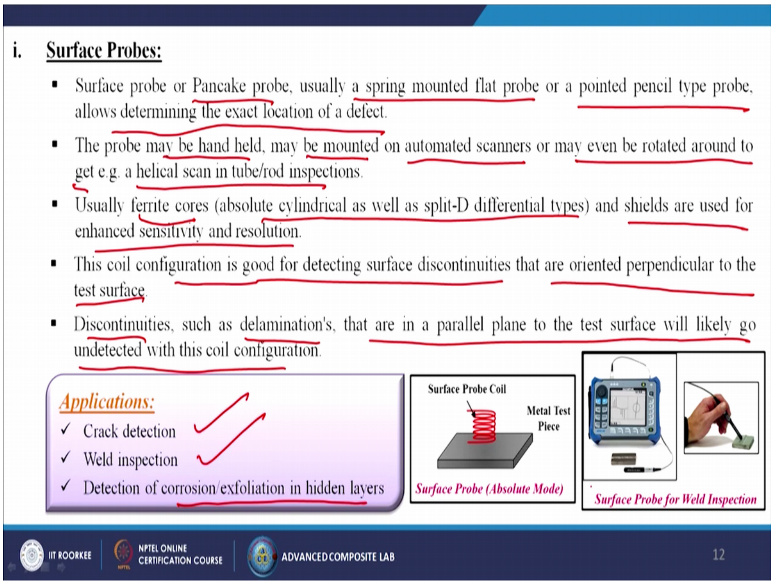

Now come to the Surface probes. Surface probes or sometimes we are calling it as a pancake probe usually a spring mounted flat probe or a pointed pencil type probe allows determining the exact locations of a defect. So this is the best example, it looks like this. The probe may be hand held, may be mounted, on automated scanners or may even be rotated around to get like helical scan in tube or maybe the rod inspections. Usually ferrite cores absolute cylindrical as well as split D differential types and shields are used for enhanced sensitivity and the resolution.

The coil configuration is good for detecting surface discontinuities that are oriented perpendicular to the test surface. Discontinuities such as delamination's that are in a parallel plane to the test surface will likely go undetected with the coil configuration. Applications generally crack detections, wield inspections, detection of corrosion or maybe the exfoliation in the hidden layers. So like this way, we are doing the testing.

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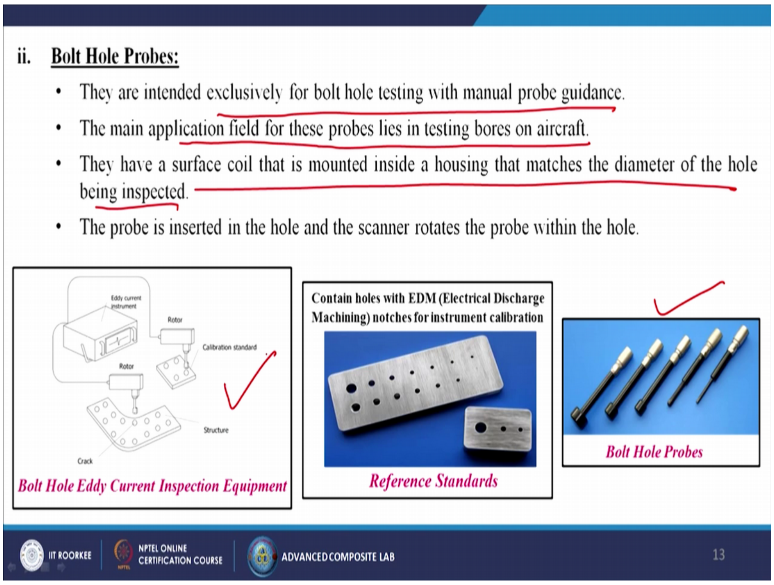

Now come to the Bolt-Hole Probes. They are intended exclusively for bolt-hole testing with manual probe guidance. The main applications field for these probes lies in testing bores on aircraft. They have a surface coil that is mounted inside a housing that matches the diameter of the hole being inspected. So here you can see just we are trying to inspect the inside of this particular hole. So we are having different bolt hole probes. So just we have to insert these probes inside this hole. So Bolt Hole Eddy-current inspection equipment is looks like this.

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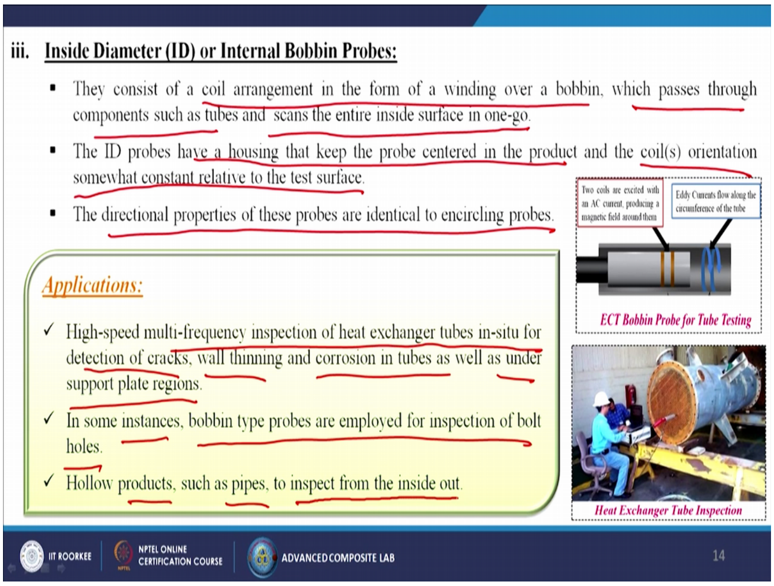

Third Inside Diameter or may be the Internal Bobbin Probes, they consist of a coil arrangement in the form of a winding over a bobbin, which passes through components such as tubes and scans the entire inside surface in one go. The ID probes have a housing that keeps the probe centered in the product and the coils orientation somewhat constant relative to the test surface.

The directional properties of these probes are identical to encircling the probes itself applications, High-speed multi frequency inspection of heat exchanger tubes in situ for detection of cracks, wall thinning and corrosion in tubes as well as under support plate regions. In some instances, bobbin types probes are employed for inspection of bolt holes, hollow products such as pipes, to inspect from the inside out.

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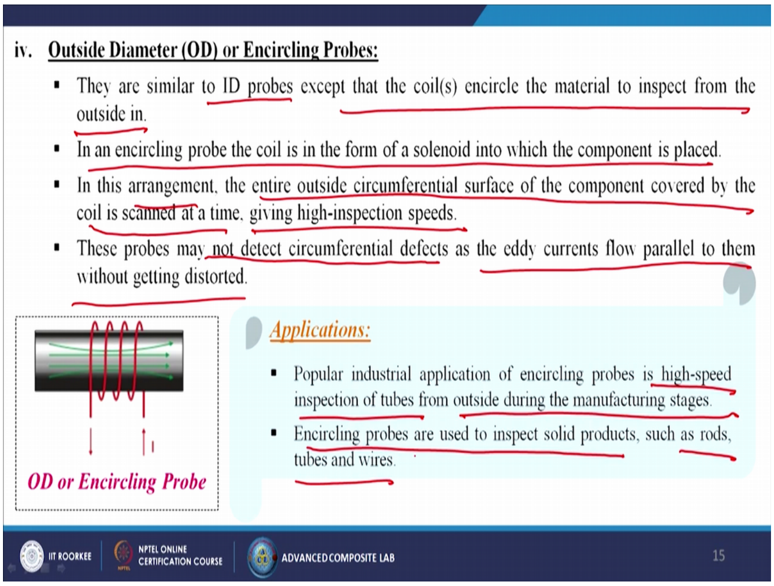

Next Outside Diameter or may be the Encircling Probes. They are similar to ID probes except that the coils encircle the material to inspect from the outside in. In an encircling probe the some oil is in the form of a solenoid into which component is placed. In this arrangement the entire outside circumferential surface of the component covered by the coil is scanned at a time giving high inspection speeds. So that means one is internally we are putting and one is externally we are putting.

These probes may not detect circumferential defects as the eddy currents flow parallel to them without getting distorted. What are the Applications? Popular industrial applications of encircling probes in high-speed inspection of tubes from outside during the manufacturing stages encircling probes are used to inspect solid products such as rods tubes and the wires.

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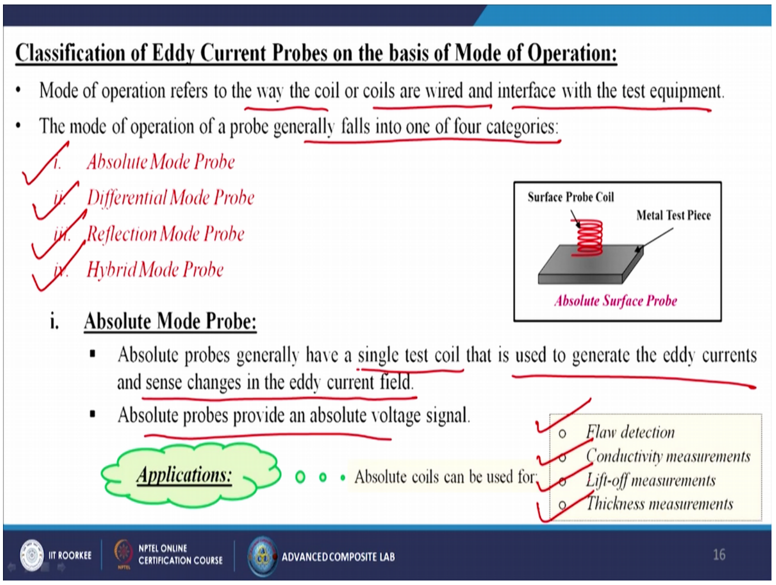

Classification of Eddy current probes on the basis of mode of operations: Mode of operations refers to the way the coil or coils are wired and interface with the test equipment. The mode of operation of a probe generally falls into one of four categories. What are those? Absolute mode probe, Differential mode probe, Reflection mode probe and the Hybrid mode probe. So now, first we are going to discuss about the, Absolute mode probe.

Absolute probes are generally have a single test coil that is used to generate the eddy currents and sense changes in the eddy current field. Absolute probes provide an absolute voltage signal. Absolute coils can be used for flaw detection, conductivity measurements, liftoff measurements, and the thickness measurements.

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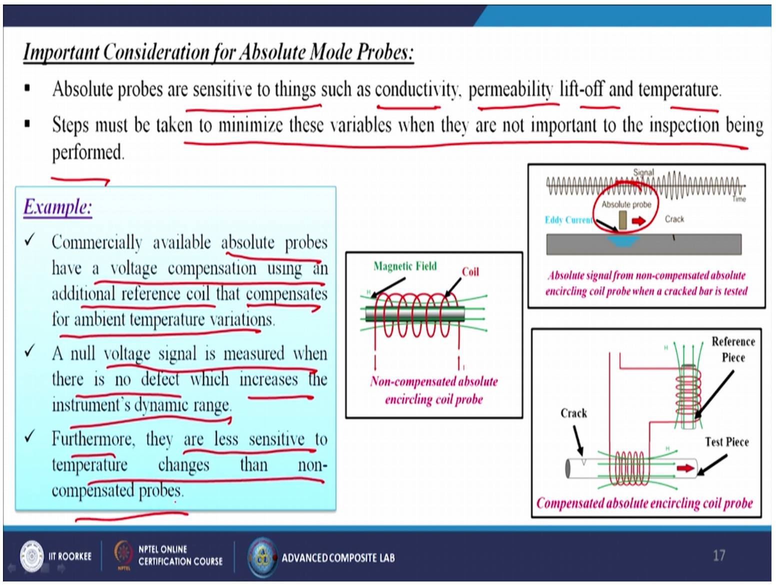

Important considerations for Absolute mode probes: Absolute probes are sensitive to things such as conductivity, permeability, liftoff and the temperature. Steps must be taken to minimize these variables, when they are not important to the inspection being performed. So basically the actual logic is that depending upon your shape and size and which area you are going to cover you have to take the different probes or maybe the different techniques.

What is the example? Commercially available absolute probes have a voltage compensation using an additional reference coil that compensates for ambient temperature variations. So this is the example of the absolute problem. A null voltage signal is measured when there is no defect which increases the instruments dynamic range. Furthermore they are less sensitive to temperature changes than non compensated probes.

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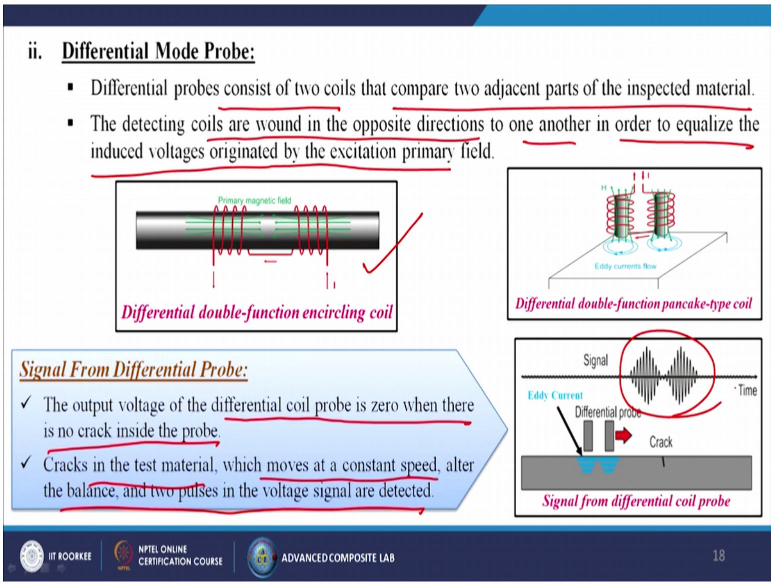

Next come to the Differential mode probe: Differential probes consist of two coils that compare two adjacent parts of the inspected materials. The detecting coils are wound in the opposite directions to one another in order to equalize the induced voltage originated by the excitation primary field. Now differential double functioning in circle coil is looking like this.

So here in this case, we are using the double function Pancake type coil. Signal from differential probe. The output voltage of the differential coil probe is zero when there is no crack inside the probe. Cracks in the test terminal which moves at a constant speed alter the balance and two pulses in the voltage signals are detected.

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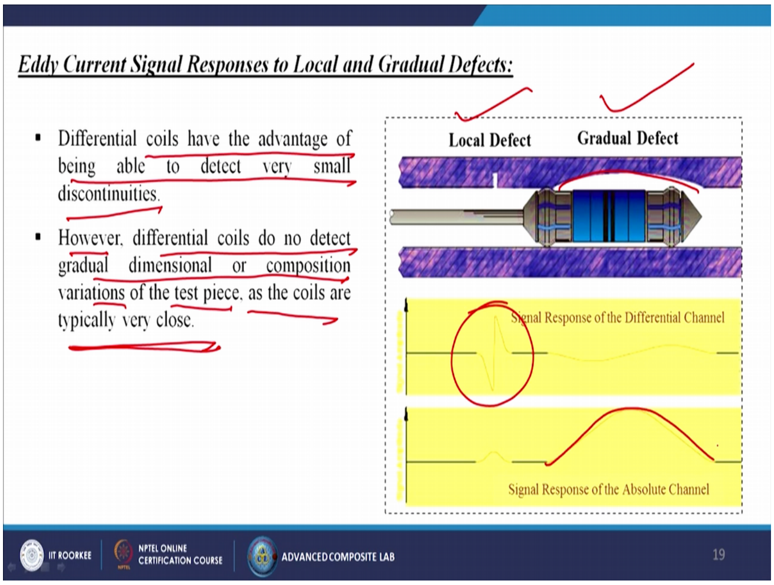

Eddy Current Signal Responses to Local and Gradual defects. Differential coils have the advantage of being able to detect very small discontinuities. However differential coils do no detect gradual dimension or composition variation of the test piece, as the coils are typically very close. So this is the local defect and this is the gradual defect is taking place over there. So for local defects we are getting a sharp edges signal response of the differential channel and when you are talking about the signal response of the absolute channel you can see only a hinged kind of thing.

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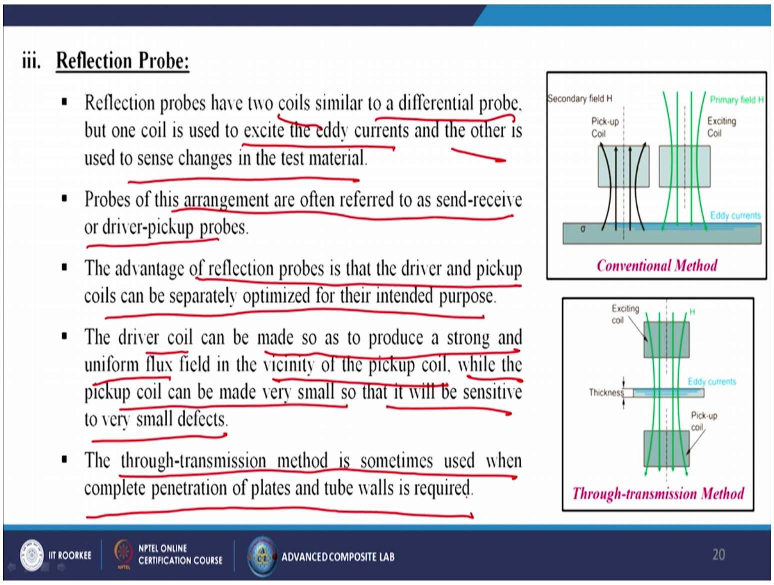

Next come to the third one that is called the Reflection Probe. Reflection probe have two coils similar to a differential probe but one coil is used to excite the eddy currents and the other is used to sense changes in the test material. Here not both the probes are, testing the samples. Probes of this arrangement are often referred as send receive or maybe the driver pickup probes.

The advantage of reflection probes is that the driver and pickup coils can be separately optimized for their intended purpose. The driver coil can be made, so as to produce a strong and uniform flux field in the vicinity of the pickup coil, while the pickup coil can be made very small, so that it will be sensitive to very small defects. So one will help for the eddy current generations and another one will just take the results. The through transmission methods is sometimes used when complete penetration of plates and tube wall is required.

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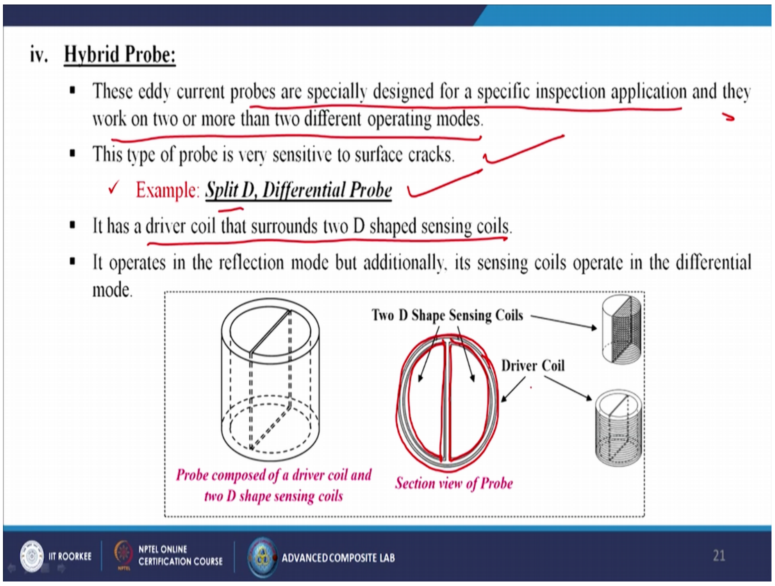

Next is called the Hybrid probe. These eddy current probes are specially designed for a specific inspection application and they work on two or more than two different operating modes. This type of probe is very sensitive to surface cracks. Example: Split D, Differential probe. It has a driver coil that surrounds two D shaped sensing coils here. So this is one D and this is another D and this is surrounded by the driver coil.

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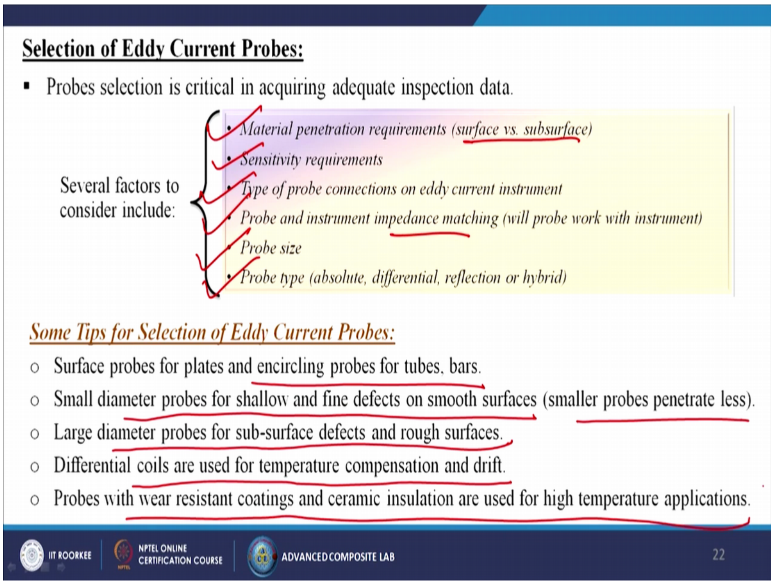

Now selection of Eddy current probes: Probe selection is critical in acquiring adequate inspection data. Several factors to consider include, material penetration requirements, surface versus subsurface, sensitivity requirements, types of probe connections on eddy current instrument, probe and instrument impedance matching will probe work with instrument, next is the probe size, and last one is the probe type whether it is absolute, differential, reflection or maybe the hybrid.

Some tips for selection of the Eddy current probes. Surface probes for plates and encircling probes for tubes and bars. Small diameter probes for shallow and fine defects on smooth surfaces, smaller probes penetrate less. Large diameter probes for subsurface defects and rough surfaces. Differential coils are used for temperature compensations and drift. Probes with wear resistant coating and ceramic insulation are used for high-temperature applications.

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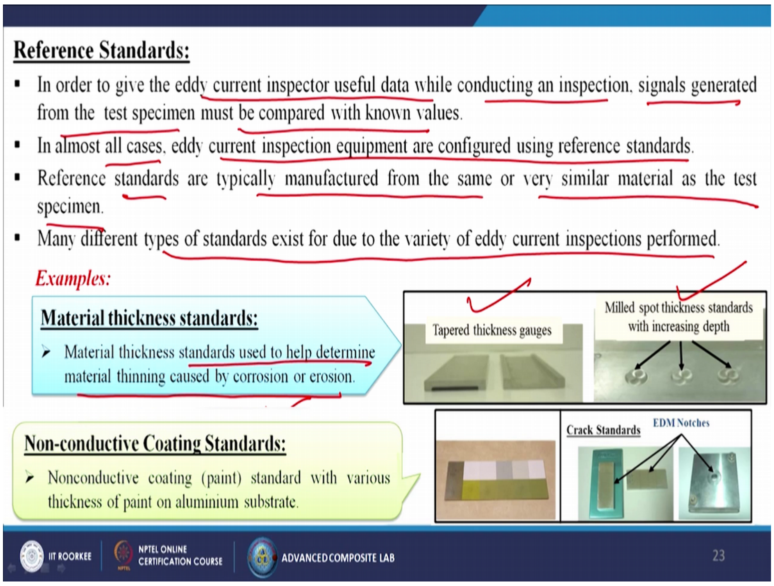

Now come to the Reference Standards. What is reference standards? In order to give the eddy current inspector useful data while conducting an inspection, signals generated from the test specimens must be compared with the known values. Yes of course, known values means, some standard values. In almost all cases eddy current inspection equipments are configured using reference standards. Reference standards are typically manufactured from the same or very similar material as the test specimen.

You can say this is a nothing but a dictionary. So it is having the data for same materials, different materials, different conditions, and then whatever the signals you are getting from your sample, simply it will try to match with the database, and then it will show you the result. Many different types of standards exist for due to the variety of eddy current inspections performed.

Examples: Material thickness standards, Material thickness standards used to help determine material thinning caused by corrosion or maybe the erosion. So taper thickness gauges, mild spot thickness standards use increasing depths. Crack standards some EDM notches. Non conductive coating standards, non conductive coating like paint standard with various thickness of paint on aluminum substrates. So this is the standards.

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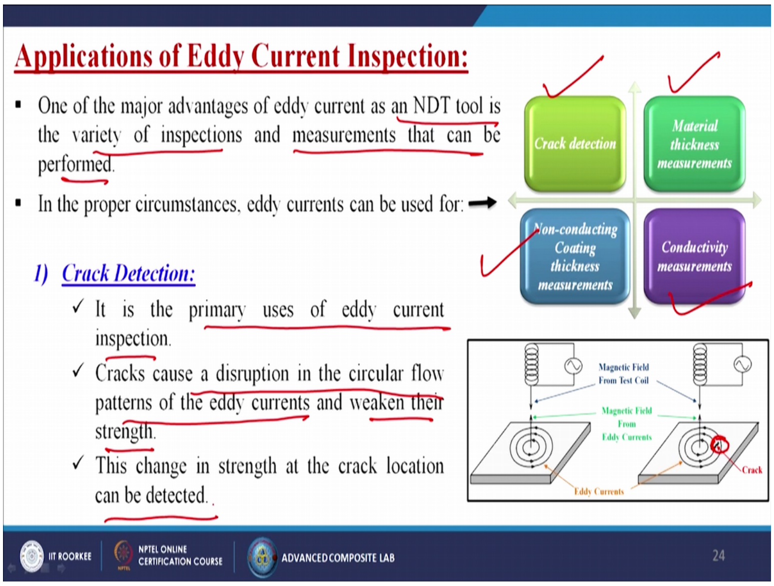

Now applications of the Eddy current inspection: One of the major advantages of eddy current as an NDT tool is to variety of inspections and measurements that can be performed. In the proper circumstances, eddy currents can be used for crack detection, material thickness measurements, conductivity measurements, non conducting coating thickness measurements. What is crack detection? It is the primary uses of eddy current inspections. Cracks cause a disruption in the circular flow patterns of eddy currents and weaken their strength, in this particular case, here. The cracks are present, so it has been weakens the signals. This change in strength as the crack location can be detected.

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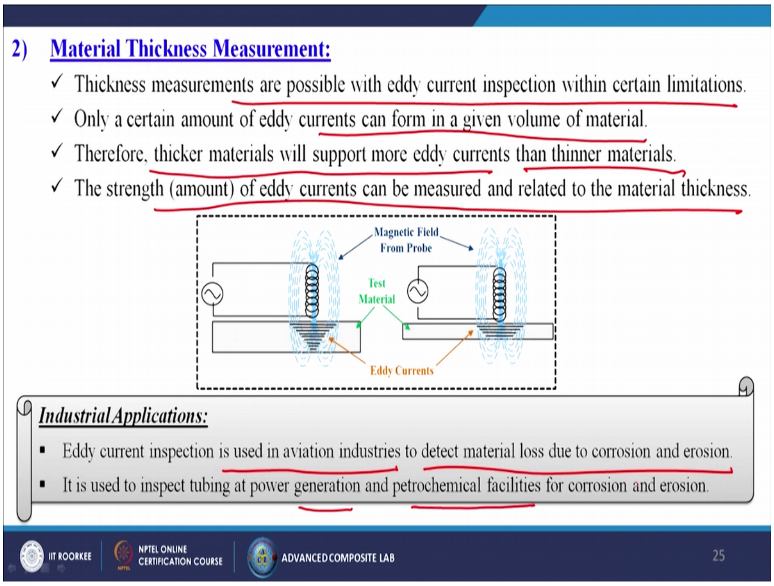

Material Thickness Measurement: Thickness measurements are possible with eddy current inspection with certain limitations. Only a certain amount of eddy currents can form in a given volume of material. Therefore, thicker materials will support more eddy currents than the thinner materials. The strength of eddy currents can be measured and related to the material thickness over there. Industrial applications: Eddy current inspection is used in aviation industries mainly aerospace industries to detect material loss due to corrosion and erosion. It is used to inspect tubing at power generations and petrochemical facilities for corrosion and the erosion testing.

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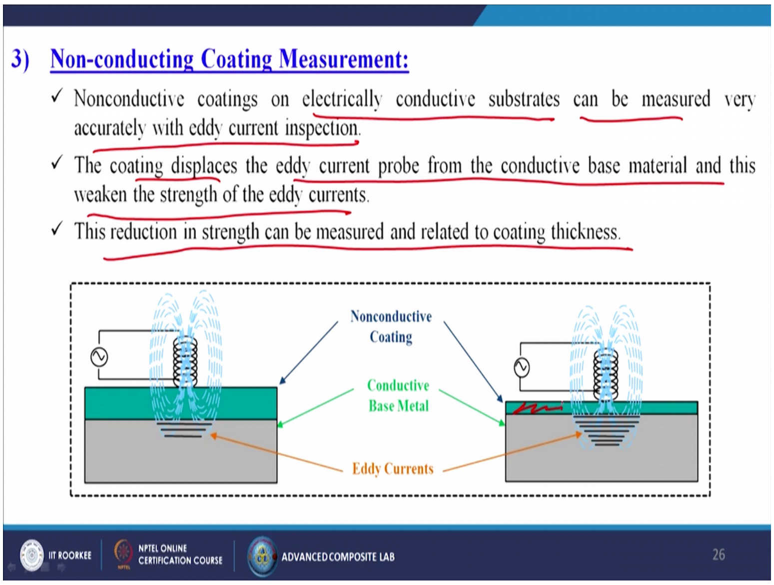

Non-conducting Coating Measurement, Non conductive coatings on electrically conductive substrates can be measured very accurately with eddy current inspections. The coating displaces the eddy current probe from the conductive base material and this weakens the strength of the eddy currents. This reduction in strength can be measured and related to the coating thickness. So these green in color is the coating thickness, this is the conductive base metals. So this will weaken the signal.

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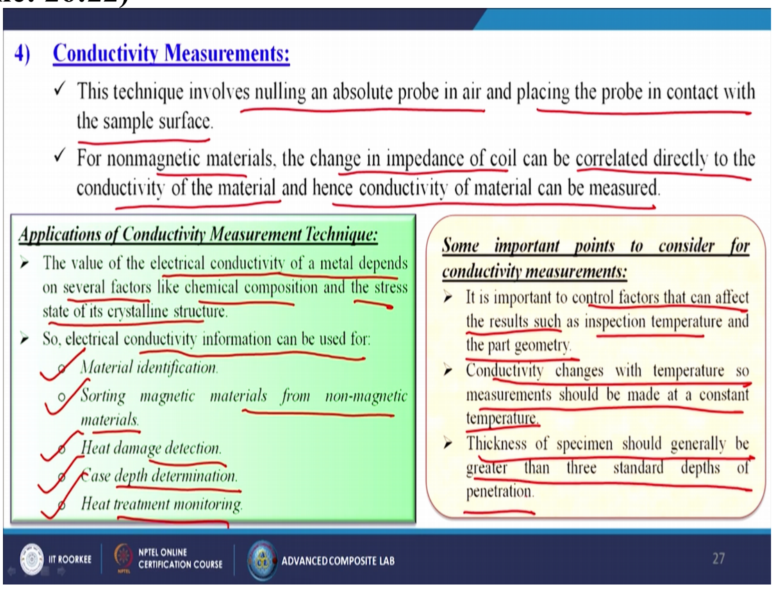

Next Conductivity Measurements, these techniques involves nulling an absolute probe in air and placing the probe in contact with the sample surface. For non-magnetic materials, the change in impedance of coil can be correlated directly to the conductivity of the material and hence conductivity of material can be measured, applications of conductivity measurement techniques.

The value of the electrical conductivity of a metal depends on several factors like chemical compositions and the stress state of its crystalline structure. So electrical conductivity information can be used for material identification, sorting magnetic materials from non-magnetic materials, heat damage detection, case depth determination, and the last one is called the heat treatment monitoring.

Some important points to consider for conductivity measurements: It is important to control factors that can affect the results such as inspection temperatures and the pared geometry. Conductivity changes with temperature so measurement should be made at a constant temperature. Thickness of specimens should generally be greater than the three standard depths of the penetrations.

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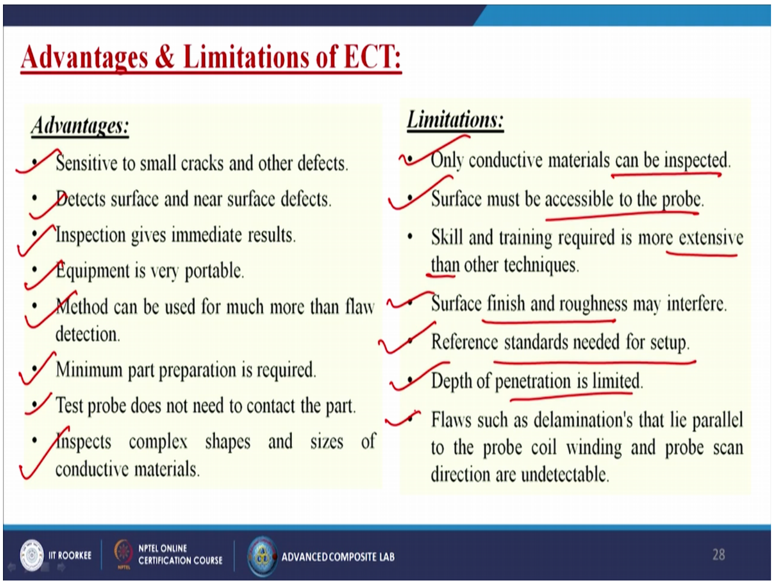

Now what are the advantages and limitations? Advantages are sensitive to small cracks and other defects. Detects surface and near surface defects. Can be easily measured, inspection gives immediate results. Equipment is very portable. Handy method can be used for, much more than flaw detection. A minimum part preparation is required. Test probe does not need to contact the part inspects complex shapes and sizes of conductive materials.

What are the limitations? Only conductive materials can be inspected. Surface must be accessible to the probe. Skill and training required is more extensive than other techniques. Surface finish and roughness may interfere. Reference standards needed for set-up. Depth of penetration is limited. Flaws such as delamination that lie parallel to the probe coil winding and probe scan directions are undetectable.

So that means there are certain advantages and there are certain limitations, so in this particular case what happen, the material should be conductive, and if there is any coating or paints are present on top of the materials so that will create some kind of problem for measuring by measuring these techniques.

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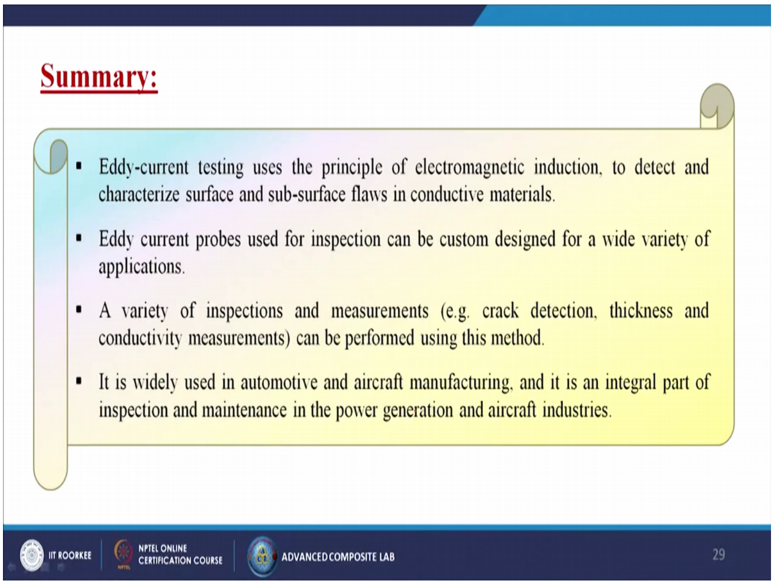

Now we have come to the last slide of this particular lecture. So as a summary, we can say, that eddy current testing, use the principle of electromagnetic induction which has been developed by Faraday to detect and characterize surface and subsurface flaws, in the conductive material. Eddy current probes used for inspections can be custom designed for a wide variety of application. It is totally depends upon your shape and size you can customize your own probe.

A variety of inspections and measurements like crack detection, thickness, and conductivity measurements can be performed using this method. It is widely used in automotive and aircraft manufacturing not only that it is widely used into the petrochemical industry and it is an integral part of inspections and maintenance in the power generations and the aircraft industries too. Thank you.