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Application of the Eddy Current Testing

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ABSTRACT: ***Eddy current testing is a non-destructive testing method that is often used in many sectors to identify flaws, evaluate the qualities of the material, and assess the durability of conductive materials. To find abnormalities or changes in the electrical conductivity, magnetic permeability, and thickness of the test material, it uses the electromagnetic induction concept. Eddy current testing involves passing an alternating current through a coil or probe to produce a magnetic field. In the test material, this magnetic field causes eddy currents, which produce their magnetic field. Impedance variations in the coil or probe are caused by the interaction of the two magnetic fields and may be measured and evaluated.***

KEYWORDS: ***Coil Probe, Current Testing, Eddy Currents, Magnetic Field, Testing Method.***

INTRODUCTION

A popular non-destructive testing (NDT) method for checking for faults or defects in conductive materials is eddy current testing. It is particularly useful for finding surface cracks, corrosion, and other discontinuities in metal components and is based on electromagnetic induction principles. Eddy currents, a type of electrical current, are introduced into the material being examined as part of this technique. A probe or coil that creates a changing magnetic field is used to do this. Eddy currents are created inside the conductive material as a result of the magnetic field's interaction with it, producing a secondary magnetic field. These eddy currents change in flow in the presence of any abnormalities or faults in the material, which may be identified and examined to locate and define the flaws Depending on the exact application, the probe is generally moved over the material's surface or the substance is passed through the probe. The impedance or phase of the eddy currents is measured while the probe scans the material. Then, using specialized tools or equipment, these changes are translated into electrical impulses and examined. Inspectors can ascertain the presence, position, magnitude, and other details of the observed defects by deciphering the signals [1] [2].

As an NDT technique, eddy current testing has various advantages. Both production facilities and field inspections can benefit from its quick assessment of huge regions and prompt findings. Being a non-contact method, it may be used on materials with intricate geometries or challenging-to-reach surfaces. Eddy's current testing does not necessitate the use of hazardous chemicals and does not endanger the substance being tested. Numerous sectors, including aerospace, automotive, power generation, manufacturing, and others, find substantial use for this testing method. It is often used to check pipelines, heat exchangers, turbines, aircraft parts, and other conductive components that need regular upkeep and quality control. To ensure safety and dependability in a variety of sectors, eddy current testing is a flexible and effective approach for the nondestructive examination of conductive materials. It offers important insights into the integrity and quality of components. Eddy current testing is a non-destructive testing method that is often used in many sectors to identify flaws, evaluate the qualities of the material, and assess the durability of conductive materials. To find abnormalities or changes in the electrical conductivity, magnetic permeability, and thickness of the test material, it uses the electromagnetic induction concept [3].

Eddy current testing involves passing an alternating current through a coil or probe to produce a magnetic field. In the test material, this magnetic field causes eddy currents, which produce their magnetic field. Impedance variations in the coil or probe are caused by the interaction of the two magnetic fields and may be measured and evaluated. Eddy's current signal analysis yields insightful data about the substance under test. Defects including fractures, voids, corrosion, and discontinuities can be found by looking for differences in the impedance, amplitude, phase, or frequency of the produced currents. The method may be used on a variety of conductive materials, including metals and alloys, and is sensitive to surface and near-surface flaws. Eddy's current testing has several benefits, including its non-contact nature, quick examination speed, and ability to find flaws without needing to prepare the surface thoroughly. In fields including aerospace, automotive, power generation, and manufacturing, it is frequently utilized for quality control, maintenance inspections, and safety evaluations [4]. An effective non-destructive testing technique called eddy current testing makes use of

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electromagnetic induction to evaluate the reliability and caliber of conductive materials. It offers useful information for identifying flaws and assessing material conditions by examining differences in electrical characteristics brought on by eddy currents. Eddy current testing is a non-destructive testing technique that is often used in numerous industries to spot faults, analyze the material's properties, and gauge the robustness of conductive materials. It makes use of the electromagnetic induction principle to detect deviations or changes in the electrical conductivity, magnetic permeability, and thickness of the test material. To create a magnetic field for eddy current testing, an alternating current is sent through a coil or probe. This magnetic field induces eddy currents in the test material, which create their magnetic field. The interaction of the two magnetic fields results in impedance fluctuations in the coil or probe, which may be measured and assessed [5].

DISCUSSION

Eddy Current Analysis

Eddy's current testing's numerous uses, scope, and restrictions have been discussed. The eddy current testing sensitivity is depending on several different variables, including the kind of specimen, its geometry, shape, surface condition, conductivity, and composition; the nature, location, and size of defects; probe characteristics like frequency, impedance, and diameter; the type of equipment; the caliber and precision of known-defect specimens used for calibration; and the operator's training, expertise, and experience. Since eddy currents are mostly a surface phenomenon and exhibit skin effects, the restricted depth of eddy current penetration into the test specimen is an essential factor. The formula 5 = l/(Tcfuo|-ia) yields the standard depth of penetration, with all numbers having the same meanings as stated. This demonstrates how the skin depth varies with conductivity, permeability, and frequency but is little for most metals (about 0.2 mm or 0.008 in. for copper at 100 kHz. As a result, there are two significant implications for the design of eddy current probesthe transducers are more beneficial for surface testing, and lower frequencies may be required for subsurface testing in addition to unique techniques for increasing skin depth such magnetic saturation [6].

Eddy's current testing is essentially a means of comparison. With the use of standard test specimens with known standards for composition, dimensions, conductivity, permeability, etc., and faults of exactly defined dimensions, the system is calibrated, and its sensitivity is established. These faults typically take the form of perfectly cut holes with specific diameters, electro-discharge machined (EDM) notches, manufactured and natural fractures, and accurately machined thicknesses. Given the wide range of inspection issues that Eddy's current testing may address, it becomes sensitive to assume that there will also be a wide range of standard test specimens for calibration and sensitivity setting. There are standards for seamless and welded pipes made of steel, titanium, copper, and aluminum as well as their alloys, as well as for tubing for heat exchangers and nuclear reactors, heat-treated parts, bolt holes, coated substrates, and thickness, conductivity, resistivity, and hardness. displays an illustration of a discontinuity standard with through-hole and electro-machined notches for cladding tubing [7].

In virtually all of these situations, the sensitivity is achieved by calibrating the apparatus, in particular the probe frequency, so that the known faults in common test blocks or test tubes produce a uniform and predictable pattern on the oscilloscope screen. Sensitivity is obtained, for instance, in the case of the tubing by setting the frequency to produce eddy current penetration equal to one cladding wall thickness or less. Phase control adjustments are accomplished during standard calibration between the strip chart recorders and the CRT screen's OD, ID, or through-wall response. The through-hole with a diameter of 0.23 mm indicates the best sensitivity. it was already discussed how various eddy current equipment screens looked for sensitivity calibration. It is possible to quantify signal amplitudes and phase angle changes brought on by faults with great accuracy, analyze them, and connect the results to the flaw characteristics. Additionally, the signals are easily digitized for display or recording. The eddy current density (A/cm2) produced within the tube wall and the change in eddy current phase angle between the interior diameter and the outer diameter of the tube are important considerations in choosing the best fracture test settings [8].

It is not adequate to presume that the requisite eddy current magnitudes and phase conditions will be ideal for the detection of both inside surface and outside surface cracks in non-magnetic tubes if the stimulating AC magnetizing field penetrates through the tube wall. To produce a recognizable signal in the encircling coil tests of tubes for cracks, the cracks or other discontinuities must disrupt or distort the eddy current flow routes and affect the magnetic response field of the eddy currents. The ratio of the

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eddy current density at the inner surface to that at the outer surface of the tube corresponds to the test sensitivity for detecting an inside surface discontinuity to that of an outside surface discontinuity. With the aid of surrounding coils, bar sorting, and testing is carried out. The voltage created in the secondary coil is analyzed using the ideas of characteristic or limit frequency and effective permeability. Additionally, the similarity law may be used, which states that if the frequency ratio f/fg is the same for each test item, then the effective permeability, as well as the geometrical distributions of the magnetic field strength and eddy current densities, are the same for two separate test objects. The crack depths can either be quantitatively determined using equations and charts especially created by Institute Dr. Forster or can be computed from the calibrated instrument indications when using the comparison coil method, where there are two coils and one of them contains a crack-free bar with a known fill factor while the other coil is empty. The following steps are included in the latter procedure:

1. Check the signal deflection height of the instrument. When the instrument's sensitivity control is set to N = 1% per centimeter and f/fg = 15, for instance, a break of unknown depth may be indicated by a signal deflection amplitude of A = 2.5 cm.
2. To calculate the ratio Q, multiply the signal deflection A by the sensitivity setting N. According to this example, Q = N x A = 1% per centimeter x 2.5% of the absolute value = 2.5%.
3. Find the point where the ordinate for (Q = 2.5%) and the crack depth curve for f/fg = 15 intersect using the curves. On the abscissa scale, note the fracture depth that corresponds. To achieve the larger voltage magnitudes from cracks in ferromagnetic bars at a certain frequency ratio, the crack voltages described above for non-magnetic bars must be multiplied by the relative magnetic permeability of the ferromagnetic material. For ferromagnetic test bars, low-frequency ratios offer the optimum crack depth sensitivity.
4. The relative permeability of steels and other highly ferromagnetic materials may be decreased to values close to one via magnetic saturation techniques, though. Once this is completed, ferromagnetic bars can be tested for cracks using the same methods described for nonmagnetic bars, with good approximation to real test results.

Eddy current tests are widely used in non-contact thickness, electrical conductivity, and magnetic permeability studies of flat metallic sheets, foils, and surface coatings. These tests provide quick thickness measuring, alloy separation, wall thinning detection due to corrosion or wear, heat treatment operation management, and evaluation of metallic material damage. It is frequently possible to create test coils or probes with tiny dimensions for simple manual positioning and access to various portions of parts made of sheet materials. The detection of discontinuities in sheet materials is only possible when the discontinuity has a component that is parallel to the eddy current flow channels. Because the generated eddy current flow is frequently parallel to the sheet surface through which excitation is delivered, laminations and separations between parallel layers in sheet materials cannot generally be recognized with sufficient accuracy by eddy current testing. Utilizing circular test coils, items that are spherical and cylindrical may be examined. In ferromagnetic pipes, the wall thickness, wall thinning, etc. may also be measured. Pits and fissures in these pipelines can also be found by putting a single, reasonably straightforward probe through them.

Radiographic Examination

The kind of specimen, its geometry, form, thickness, and physical density, as well as the radiographic testing method used, all have an impact on the sensitivity of fault detection. The type of film used and the film processing conditions; the viewing conditions of the film; and the operator's eyesight, qualifications, skill, and experience. The location and orientation of defects concerning the direction of the beam of radiation; exposure conditions such as radiation energy, scattering, source-to-film distance, object-to-film distance, source size, filters if used, intensifying screens, etc. Image quality indicators (IQI), of which there are several varieties, are used to measure sensitivity. The wide variety of IQIs, which contain many wires of various but known sizes spaced 5 mm apart in a plastic housing, are the most often used. In theory, the wires are made of the same substance as the test subject. Before making the exposure and processing the film, these IQIs are put on the test specimen's surface that is facing the source. The smallest wire diameter that can be seen on the radiograph is reported.

The formula S = (diameter of the thinnest visible wire x 100)/(total test specimen thickness) is used to determine the sensitivity. The sensitivity, S, is expressed as a percentage, such as 1%, 2%, 4%, etc.

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The lower the figure, the more sensitive the method is for detecting flaws.

The 'step and hole' form of IQI is the other kind. It consists of a piece of metal with a hole bored through each step, each step having a specified thickness. The step's thickness is the same as the hole's diameter. Provides some common step thickness and hole diameter values. These dimensions have a tolerance of 5%. Each ASME and ASTM has its own IQI. It is made up of a plate with a consistent thickness, three drilled holes, and letters for identification. The hole diameters are T, 2T, and 4T if the penetrometer thickness is T. There are three broad quality levels mentioned: 2-IT, 2-2T, and 2-4T. The first of these numbers relates to the thickness of the penetrometer represented as a percentage of specimen thickness, and the second to the diameter of the penetrometer hole visible on the radiograph expressed as a multiple of the thickness of the penetrometer. The sensitivity for quality levels 2-IT, 2-2T, and 2-4T is 1.4%, 2%, and 2.8%, respectively. The special quality levels 1-1T, 1-2T, and 4-2T equate to 0.7, 1.0, and 4% sensitivity, respectively.

The final radiograph is carefully interpreted to assess the kind, extent, and location of abnormalities. When interpreting, it is important to use illuminators with the correct intensities and good illumination. It is important to confirm that the radiograph's density is within the permitted range. Next, by examining the radiograph, it is possible to determine the radiograph's identity and the sensitivity of the IQI. The radiograph's holes and thinnest wires or steps are observed. Achieving recommended sensitivity values is necessary. Giving explanations for all of the density changes shown on the radiograph is the last stage in the interpreting process. These might be caused by flaws on the outside and the surface, flaws within, or flaws in the artifacts. The majority of the flaws' characteristics may be detected, and 210 can be identified from their images in a radiograph. However, it should be taken into account that shadows of various shapes will result from flaws of various shapes. It should be kept in mind that a radiograph only depicts a three-dimensional lesion in two dimensions. For instance, a spherical gas hole will seem like a circular patch.

If a crack with true length, breadth, and depth is found, it will appear as a line. Depending on how they are oriented concerning the beam direction, pipes, and other cylindrical flaws will appear in the radiograph in a variety of forms. The shadow will be deformed if the beam direction is not perpendicular or if the plane of the defect is not parallel to the plane of the film. Because of this distortion, a specific flaw may occasionally create a shadow that may be mistaken for another kind of imperfection. A little fissure might be diluted completely without leaving any trace of the picture. Although one may not be aware of the orientation of the flaws before obtaining a radiograph, attempts are often taken to position the film as parallel to the specimen and as perpendicular to the radiation direction as feasible. To ascertain the type of flaws, pictures from radiographs may be compared with a set of standard reference radiographs that depict how they typically appear. The following is a description of a few common casting and welding defects:

1. **Gas Inclusions:** Gas can form during welding for a variety of reasons, including the parent metal's quality, the electrodes used, improper arc current management, etc. The gas may become ensnared and assume other guises.
2. **Gas Pore:** It's a tiny gas bubble that has become trapped inside the molten metal. Its diameter is typically under 1.6 mm (1/16 inch). Porosity refers to a collection of gas pores. Radiographs of gas pores show them as a collection of black patches close to one another.
3. **Blowing Hole:** Except for its somewhat bigger size, it is comparable to a gas pore. It also has a black shadow with rounded contours in its radiography appearance.
4. **Wormhole or Pipe:** Some gas inclusions have an extended shape called pipes or wormholes. Typically, they are almost perpendicular to the weld surface. They may be the result of using wet powdered flux or poor welding current management. Another common type of pipe has the look of a tree branch. The use of wet welding electrodes can lead to these. Depending on their position concerning the beam direction, they cast circular or elongated shadows on the radiograph.
5. **Inclusions of Slag:** When the metal is placed, some slag may become trapped during its solidification, especially if the metal doesn't stay molten long enough to let the slag ascend to the top. In multiphases welding, inadequate cleaning in between weld passes might leave some of the slag coatings in situ, waiting to be covered by the next pass. A distinctive feature of slag inclusions is the slag line, which can be intermittent or continuous. Such slag lines frequently show a clear absence of fusion to the base metal. These provide dark radiographic signals. These black pictures typically have an erratic form. The picture density is frequently changing, sometimes even becoming close to the sound metal. Compared to a gas cavity of

the same size, the slag pictures' contrast is reduced. Large, isolated inclusions are seen as a black shadow with a distorted form. Small inclusion clusters are seen as a collection of hazy, black dots. Along the weld, line inclusions are visible as a black shadow with wavy borders. It occasionally appears in fairly parallel lines around both margins of a run of welding. The uneven deposits on subsequent passes that leave holes between passes cause another discontinuity of different origin but a similar radiographic appearance. Welds produced in the above position, for instance, may experience this lack of fill.

6. **Inclusions of Tungsten:** The inert atmosphere welding techniques are characterized by the presence of tungsten inclusions. Some tungsten particles are trapped in the deposited metal if the tungsten electrode supporting the electric arc comes into touch with the weld metal. These could resemble tiny splinters or possibly be fragments of tungsten wire. In the radiograph, the tungsten inclusions show as extremely faint marks.
7. **A lack of Root Encroachment:** A root aperture is often left during butt welding at the bottom of the groove during one-side welding or in the middle of the weld during two-side welding. It is challenging to accomplish full penetration and fusion at the weld's root if the gap between the two plates is small. The weld has a gap in it still. Such discontinuities may result from improper weld groove preparation or poor beveling. It can be seen on a radiograph as a continuous or sporadic dark line near the weld seems center. It may have two straight edges or one straight and one wavy edge.

Insufficient Fusion

This is because there was no union in the weld between the parent metal and the metal being joined, the metal being joined, or the metal being joined. a lack of the following forms of fusion is possible:

a. **Insufficient Side Fusion:** This results from a side weld outside the root when there is an insufficient fusion between the parent and weld metals. It shows as a black, straight line with low intensity and well-defined borders on the radiograph.

b. **Insufficient Root Fusion:** This results from a lack of union between the parent metal's neighboring face at the root. It appears as a black, straight line with low intensity and well-defined borders in the radiograph.

c. **A Lack of Integration Between Runs:** In a multi-run weld, this results from a lack of union between neighboring runs of weld metal. It shows as a thin line with well-defined edges in the radiograph.

d. **Crumbs:** A discontinuity known as a crack may be described as one that is created either by the metal rupturing while it is still pliable or by breaking when it is cold. In using a radiograph When the segments are generally parallel but slightly offset and potentially overlapping, the former is exposed as a thin black line that wanders in direction and is tapering at the ends, frequently discontinuous. The typical appearance of a cold crack is a very tiny line that is straighter, continuous, and devoid of bifurcations.

e. **Reduced:** The exposed top edges of the beveled weld preparation tend to melt and flow into the deposited metal in the weld groove during the final or cover pass. The result is a groove along the weld reinforcement that may be intermittent or continuous and have more or less sharp edges. Undercut appears as a dark line on radiographs, ranging in width and length, with often diffused edges at the weld's sides. The depth of the undercut is indicated by the picture density.

A Concavity at the Weld's Base

With no cover pass on the root side, pipe welding is especially prone to producing a concave surface at the weld's root. Gravity forces the molten metal to sink away from the inaccessible upper surface of the weld during overhead welding, leading to this situation. If slag is caught between the molten metal and the backing strip during down-hand welding with the backing strip, it may also happen at the root of the weld groove. This is demonstrated by a broad black line with unsharp edges at the center of the weld picture as opposed to edges where there has been no penetration.

a. **A Different Electrode:** An inexperienced welder may select the incorrect position for commencing the new electrode at spots when the electrodes are changed while fabricating the cover pass. Slag inclusions can occasionally be seen when electrodes were replaced. The radiograph displays an image in the shape of a crescent that corresponds to the electrode switching location.

b. **Abnormal Penetration:** Molten metal can occasionally flow through the groove at the bottom of a weld, creating an excessive reinforcement on the backside of the weld. In general, this lacks a continuous form and has distinctive dangling drips of extra metal. A line of reduced image density will be visible in the weld's center if there has been excessive penetration.

c. **Electrode Splatter (k):** Using the wrong electrodes or creating a lengthy arc might result in molten metal spattering all over the weld area. Close to the weld seam, these drips adhere to the metal's surface. Several bright circular dots may be seen on the radiograph, and they all correlate to localized areas of increasing thickness.

d. **Grinding Marks (I):** The resulting thickness varies above and below the base metal when weld reinforcements are not ground out smoothly. The parent metal or the welded region may appear as prolonged bright or dark patches with diffused borders in the radiograph [9] [10].

CONCLUSION

Eddy's current testing is an effective nondestructive testing method for finding surface and near-surface flaws in conductive materials. Eddy currents are generated in the material being tested using electromagnetic induction, and changes in these currents brought on by flaws or variations in the material's characteristics are then measured. The benefits of eddy current testing include its ability to find flaws without coming into touch with the material, sensitivity to minute cracks, and appropriateness for evaluating a variety of materials, including metals and alloys. In comparison to other testing methods, it is also a quick and reasonably priced methodology.

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