DIFFICULTIES AND OPPORTUNITIES IN EDDY CURRENT BASED MECHANICAL TESTING OF METALS A REVIEW

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ABSTRACT

The field of NDT is a very broad, interdisciplinary that plays a vital role in inspecting so that structural component and systems perform their function in a reliable fashion. This paper presents the reviews of difficulties and opportunities in eddy current based mechanical testing of metals, different works done in the area of eddy current based mechanical testing and tries to find out latest developments and trends available in industries and other fields in order to minimize damages, minimize the total equipment cost and maximize the safety of structures, machines, materials etc, this paper also emphasis upon possibilities of further probable developments in the field of eddy current testing.

Review of literature is divided in following three categories in the order of increasing precision of eddy current based testing

1. *Works related to presence of defect*
2. *Works related to size of defect*
3. *Works related to location of defect.*

Keywords:-Eddy Current Testing, Destructive Testing, Non Destructive Testing, Inspection

I.INTRODUCTION

Testing is, most generally, an organized examination or formal evaluation exercise. In engineering activities testing involves the measurement, tests, sampling and gauges applied to certain characteristics in regard to an activity or object. The results are usually compared to specified requirements and standards for determining whether the item or activity is in line with these targets, often with a Standard Testing Procedure in place to ensure consistent checking.

Testing is of two types i.e destructive testing and non destructive testing

II.DESTRUCTIVE TESTING

In destructive testing, tests are carried out to the specimen's failure, in order to understand a specimen's structural performance or material behaviour under different loads. These tests are generally much easier to carry out, yield more information, and are easier to interpret than non-destructive testing.

III.NON-DESTRUCTIVE TESTING (NDT)

It is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research.[1]

of the popular and important non-destructive testing are listed below along with their requirements, equipment

Technique cost, inspection cost and remarks.[2 Some]

Technique	Access requirements	Equipment cost	Inspection cost	Remarks
Radiography	Must be able to reach both sides.	Very High	High	Very versatile; Little skill required; Repays consideration at design stage.
Magnetic particle	Requires a clean and reasonably smooth surface	Medium	Medium	Only useful on magnetic materials such as steel; Little skill required; Only detects surface breaking or near surface cracks.
Liquid Penetrant	Requires flaw to be accessible to the penetrant.	Low	Low	For all materials; Some skill required; Only detects surface breaking defects; Rather messy.
Ultrasonic	One or both sides (or ends) must be accessible.	High	Medium	Requires point-by-point search hence extensive work needed on large structures; Skilled personnel required.
Eddy current	Testing surface must be smooth and clean	Medium	Low	For electrically conductive materials only; For surface breaking flaws; Variations in

				thickness of coatings, or comparison of materials; For other than simple comparison considerable skill is usually required.

The main advantage of non-destructive testing is that it can be used where application of destructive testing is very complicated or where it cannot be used. For small lot sizes non- destructive testing is more preferred than that of destructive testing.

For all NDT inspection methods it is very common to only inspect a percentage of test material. This percentage is called a sample. Sampling statistics are used to estimate characteristics about the entire population or the entire test material. The entire test material is rarely inspected because the cost is too high and takes too long. When testing an item that has been used, or in-situ, the inspection is called a Fitness-For- Service inspection. There are also standards for determining the choice of sample for inspection.[3]

To satisfy a Fitness-For-Service inspection, a 100% inspection is almost never required. For Eddy Current testing, it is common to inspect an item with two probes. The purpose of using two probes is to look for different flaw types and for ease of analysis. In nuclear power plant steam generators, bobbin probes are used for a large sample of the tubing, while an array probe is used for a much smaller sample. This is mainly due to the complexity in analyzing the collected data.[3]

There are some areas where 100% inspection is necessary because due to safety reasons one cannot take any risks and, therefore, absolutely defect free parts are needed, examples of such areas includes critical parts in nuclear reactors, aerospace industry.

The current study is all about Eddy current testing which falls under non destructive testing.

IV.EDDY CURRENT TESTING

The method is based on the detection of the magnetic field due to the eddy currents induced on the specimen. The presence of a defect modifies the eddy current pattern and hence gives rise to a field perturbation closely related to the position and shape of the defects.[4]

Eddy current testing is one of the most extensively used non-destructive techniques for inspecting electrically conductive materials at very high speeds that does not require any contact between the test piece and the sensor.

Eddy current testing falls under non destructive testing. It is widely used to detect surface flaws,to measure thickness of thin sheets of conductive materials, measure thin coatings and in some applications to measure case depth, etc.

V.PRINCIPLE OF EDDY CURRENT TESTING

Eddy-current testing uses electromagnetic induction to detect flaws in conductive materials. In this method eddy currents are produced in the test-piece by bringing it in proximity of alternating current carrying coil. The changing magnetic field of the coil is modified by the eddy currents' magnetic fields. This modification, which depends on the condition of the nearby part of the coil, is then shown as a meter reading or cathode ray tube presentation. That meter reading or cathode ray tube presentation gives an idea about any discontinuities, cracks, impurities in the materials, flatness etc.[5]

VI.OPPORTUNITIES AND ADVANTAGES

non-destructive testing has got very good opportunity in the industry-

Low cost of inspection of eddy current testing

High speed testing

100% inspection is possible due to low cost and high speed

Talking about opportunities one can say that due to lot of following aspects Eddy current Testing setup can be customized as per need i.e. shape and size of testing setup can be varied as per the work-piece to be tested.

Eddy current non-destructive testing is widely used because of its number of advantages.

Eddy current techniques are non-contact, which means minimum surface preparation, and they are even able to penetrate through non-conductive coatings. Other advantages include high sensitivity, relatively low development and running costs, and high operation speed. Eddy current testing is highly customized in nature and it can be easily automated it is also used as comparators and GO, NO-GO gauges.[6]

VII.DIFFICULTIES AND LIMITATIONS

Some of difficulties which arises in eddy current non-destructive testing are; design of suitable probes, change in the ideal workpiece which is taken as reference. On the other hand, the disadvantages include limitation to electrically conductive materials, and sensitivity to lift-off, i. e. the space distance between the coil and the test specimen, required response interpretation skills etc.

VIII.REVIEW OF LITERATURE

Works related Purpose of this review is to study the different works in the area of eddy current based mechanical measurement and explore possibilities of further developments. This work considers the source of identification of further developments as the gap between existing uses and the need.

1. to presence of defect

2. Works related to size of defect

Works related to location In this review we will categorise the different works which are carried out in following fields-

3. of defect.

IX.WORKS RELATED TO PRESENCE OF DEFECT

In a standard eddy current testing a circular coil carrying current is placed in proximity to the test workpiece. The alternating current in the coil leads to change in magnetic field which interacts with test specimen and produces eddy currents or Foucault currents. Phase and magnitude variations of these eddy currents can be monitored using a 'receiver' coil (secondary coil), or by measuring changes to the current flowing in the primary 'excitation' coil. These variations of the test object in the electrical conductivity or magnetic permeability, or the presence of any flaws, will cause a change in eddy currents and a corresponding change in the phase and amplitude of the measured currents. [7]

As for detection of flaws or defects only thing required is change in eddy currents and a corresponding change in the phase and amplitude of the measured currents. All papers discussed in this review are capable of telling presence of defect in the workpiece.

X.WORKS RELATED TO SIZE OF DEFECT

μ is permeability of workpiece material.

Standard depth of penetration is defined as the depth at which eddy current intensity drops down to 37% of eddy current intensity at the surface.

There is an inverse relationship between penetration of eddy currents and sensitivity. Lower the frequency, the higher the penetration. Unfortunately, this also means a lower sensitivity to flaws. A compromise must be established so that sufficient penetration is achieved without sacrificing too much sensitivity.

B. Sasi et al. (2009)[11] they presented an eddy current test procedure developed for reliable detection of simulated fatigue cracks and corrosion products in rivets of air-intake structures Papers listed in this review, which are mainly concern with size(i.e length, depth or width) of the defects, are following-

Daniel Lamtenzan et al. (2000)[8] studied and summarized research pertaining to the application of the eddy current method as a means of crack detection in structural steel members of highway bridges. Eddy currents were induced when an energized coil was placed near the surface of a conductive material. Discontinuities like cracks disturb the trajectories of the eddy current and thus affect the magnitude and phase of the current which is induced. These changes can be detected by the probe or sensors.

In this paper author did not claim the exact locations of the defects, only presence of defects and probable locations were worked out.

Deqiang Zhou et al. (2008) [9] introduced the state-of-the-art of pulsed eddy current NDT systems and their practice for surface defect measurement. Using pulsed eddy current inspection on the cracks with the dimensional parameters varying in three following cases were reported which were:

(1) Different depths;

(2) Different widths;

(3) Variable depth and width but with fixed crack volume.

It was found that quantitative surface defects can be estimated by substantial relations between the defect depth, width and the peak amplitudes. It was shown that the differential output peak value was more sensitive to the depth of surface defects than the variation of width in static measurement. In their investigation authors only considered defects having same volumes, it was the limitation of their study.

Joseph M. Buckley (2008) [10]studied about history, principles and factors effecting eddy current testing. In their study he found that eddy current testing is basically dependent upon material conductivity of both workpiece and coil materials, Permeability, Frequency, Geometry of coil, Proximity / Lift-off.

Depth of Penetration was also worked in this study and it was given by

$$X = 50\sqrt{\frac{\rho}{f.\mu}}$$

Where **X** is depth of penetration

ρ is resistivity of the workpiece material i.e. inverse of conductivity,

fis frequency of alternating current,

. That procedure was capable of reliably detecting approximately 0.25 mm deep defects in 4 mm dia rivets and 0.75 mm deep defects in 5 mm dia rivets. Moreover, it was not influenced by thickness of the multi-layers.

Authors studied that cracks having depth less than .25 mm depth cannot be detected in their study, which may cause problems in case of air-intake structures.

G. Zenzinger et al. (2010) [12] this study combined the well established inspection techniques eddy current testing and thermography. The advantage of this method was to use the high performance of eddy current testing without the known problem of the edge effect, specially for components of complex geometry.

The principle of this technique and an algorithm was to increase the sensitivity for small defects

For using this technique one should have the thorough knowledge of eddy current testing and thermography, i.e it leads to high cost inspection.

L. Dziczkowski(2008)[13] worked to determine optimal frequency of the electromagnetic field that raises eddy currents during the search for surface defects in non-ferromagnetic materials or conductivity measurements by means of eddy currents methods. The frequency choice took into consideration were sensitivity of measuring device, elimination of undesirable phenomena that affects result of the exploration and depth of the eddy currents penetration.

Depending on specific requirements, recommendations enabling proper choice of the electromagnetic field frequency were formulated.

A modified definition given of the actual penetration depth of eddy currents proposed in the paper differs from the classical approach based on the 1/e level.

Javier Garcia Martin et al. (2011) [14]gives an overview of the fundamentals and main variables of eddy current testing. It also describes the state-of-the-art sensors and modern techniques such as multi-frequency and pulsed systems. Recent advances in complex models towards solving crack-sensor interaction, developments in instrumentation due to advances in electronic devices, and the evolution of data processing suggest that eddy current testing systems will be increasingly used in the future.

Yunze He et al.(2010) [15] in the field of eddy current testing Pulsed eddy current (PEC) testing is a new emerging and effective technique. The main aim of this study was to identify surface defects and sub-surface defects using features-based rectangular pulsed eddy current sensor or sensors' matrix. In different directions of sensor scanning, peak waves of pick-up coil were studied. Above setup proposed by the authors becomes complicated and difficult to use as it is having a matrix of sensors and collective data obtained by each sensor of the matrix is to be studied to get result.

XI.WORKS RELATED TO LOCATION OF DEFECT

field probe including a giant magneto resistor sensor. The algorithm is based on a conformal transformation and is able to preview the shape of the electrical current lines when a metallic plate with a superficial straight crack is subject to a sinusoidal excitation field with constant amplitude and orientation in a bounded zone around the sensor element. Author said that by studying the shape of electrical current line defects were found Following are the papers which had studied about defect location also along with the presence of defects and size of defects.

Gui Yun Tian et al (2005)[16] gave an approach using normalisation and two reference signals to reduce the lift-off problem with pulsed eddy current techniques was proposed. The technique can also be applied for measurement of metal thickness beneath non-conductive coatings, microstructure, strain/stress measurement, where the output is sensitive to the lift-off effect.

Notwithstanding that of the idea, microstructure and strain/ stress measurement can also be done by this method; it is not described that how it was studied or measured exactly.

Antje Zosch et al. (2006)[17] studied that eddy current method could be tested for detection and classification of defects in laser welded seams. Influence of disturbance effects was investigated. Before analysis, data have been processed for consideration of changes in material properties. It can be shown that different seam defects lead to different characteristic indication ranges in the impedance plane. By investigation of samples with known defects a basis of valuation has been created. The application of this basis allowed an experimental validation of industrial samples. The study showed that by the help of eddy current technique detection and classification of defects in laser welded seams are possible. The results were in good agreement with reference methods such as radiography and metallography.

Authors used this eddy current testing method as a comparator in their presented work as they compared their samples with the known defected work piece. A complete evaluation and correct separation of irregularities may not possible in all cases because the characteristic areas in the impedance plane overlap.

Ahmed Haddad et al. (2010) [18] examine the applicability of eddy current techniques in-process for monitoring of powder density particle size and the time necessary to structure variation. Monitoring system based in eddy current developed to measure metal powder density was expanded for monitoring metal powder diameter in metal compounds. According to author location of variation in density was reported as the result.

Anthony Simm (2012) [2] In this work, 3D FEM numerical simulations were used to predict the response of an eddy current probe being scanned over the area of a defect and understand the underlying change in magnetic field due to the presence of the defect.

Experimental investigations were performed to study the feasibility of the proposed magnetic field measurement techniques for defect detection. This experimental work investigated the inspection of both surface and subsurface defects, the use of rectangular (directional) probes and the measurement of complex magnetic field values, as the response in these cases has been found to have a greater correlation with the shape of the defect being studied. As well as the detection of defects, both frequency spectrum and transient information from pulsed eddy current responses were used to reconstruct the profile (depth and width) of a slot shaped defect.

The work concludes that the use of magnetic field measurements provides useful information for defect detection and quantification. This has applications in both industrial and research areas, including visualisation of defects from magnetic field measurements, which can be applied to the monitoring of safety critical components.

Bo Hu et al (2012) [19] propose an eddy current non-destructive testing method for thin-plate aluminium alloys. A high-precision magnetic sensor was used to measure slight changes in the strength of magnetic field. The relative permeability of aluminium alloys was proven to be greater than that of aluminium through the magnetization of aluminium alloy materials. The aim of the study was to analyze the effect of magnetic field on defects, their locations and to determine the test mechanism based on the differences in relative permeability.

RimondHamia et al. (2013) [20] in this paper they studied that the detection sensitivity of eddy current NDT depends on the interaction between the crack length direction and the EC flowing in the materials. This paper presented a new excitation method for generating a pseudo-rotating a.c magnetic field and, consequently, pseudo-rotating eddy currents. This method significantly improved the detection of deep cracks of any orientation. The detected signal due to the crack was measured by an improved giant magneto-resistance magnetometer. The magnetic flux density signature of the crack was studied using a 3D finite element model.

A. Lopes Ribeiro et al.(2012) [21] show that a simple algorithm used to model the eddy current inspection of an aluminium plate can be used to preview the acquired voltage signals. Thus, the algorithm is suitable to work as a forward problem solver to determine the expected measurement signal obtained with a uniform excitation.

XII.CONCLUSION

Nowadays, non-destructive techniques are more frequently used to test products due to the increase prevalence of quality controls. While destructive techniques verify only some samples that are destroyed and can give some invalid results in other industrial processes, we find non-destructive techniques more interesting than destructive ones since all production can be tested without permanent alterations i.e. 100% inspection is possible in case of non-destructive testing.

This paper reviews the state-of-the-art methods and past work carried out in the area of eddy current testing which is one of the most widely used non-destructive forms of testing. Eddy current testing permits crack detection and measurements that are beyond the scope of many other techniques.

In this paper we present literature which gives the possibility to determine surface and sub-surface defects or discontinuities on metallic parts, optimum excitation frequencies, metal thickness, conductivity of metal, depth of penetration etc. by using principle of eddy current testing.

Although eddy current testing has been developed for several decades, research into developing new sensitive probes, optimized techniques and instrumentation is currently being conducted by manufacturers and research groups around the world in order to satisfy the increasingly higher quality standards required. These days, scientists are trying to develop new coil probes and research the use of other magnetometers such as superconducting quantum interference devices (SQUIDs), Hall-effect and magneto resistive sensors that also provide very interesting responses.

In conclusion, as researchers based on eddy current testing, we have found that eddy current techniques can provide the industry reliable quality control systems. Although there are excellent improvements due to the effort of the many scientists during the last several years, we believe that more research in eddy current techniques, in terms of sensors, equipment and signal processing, will lead to even more applications of these techniques.

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