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Comparison Study of Non-Destructive Testing Techniques: A Review

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***Abstract*— Non-destructive Testing has drawn attention of different researchers due its economical and operational effectiveness.it has been considered that by using Non-Destructive testing we could save lot of economical damages. There are lot of Non-destructive testing and this paper presents the advancement of various Non-Destructive Testing (NDT) techniques. These techniques include Eddy Current, Ultrasonic, Magnetic Particle, and Dye Penetration method. These testing techniques were chosen as these are widely used in the manufacturing industry, aerospace industry, pipe inspection, and many more. Non-destructive testing is essentially a service and is not a direct producer of goods. Also, it is generally easier to determine the ratio of output/input of a factory or organization producing goods than it is to determine the contribution made by the individual. This paper reviews different research papers in the field of Non-Destructive Testing and based on these techniques background of working operation is discussed. The main aim of this paper is to compare the various testing techniques based on their advantages, limitations of using different techniques and at last, the conclusion is made that the ultrasonic testing technique is widely used for the detection of defects in the component.**

***Keywords*— Nondestructive testing, Ultrasonic testing, Magnetic Particle, Eddy current testing, Dye penetrant**

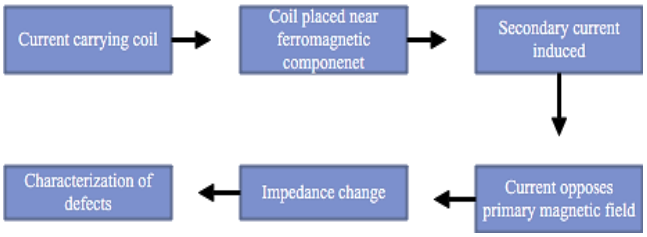
I. INTRODUCTION

Nondestructive testing (NDT) techniques have a great impact on the modernization of industries. Despite being other options NDT proves to be well suited for the rapid growth of industries in every sector whether its aviation, automotive, etc. The defect detection, quality inspection, and evaluation of parts plays a crucial role in industrial production [1]. Non Destructive Testing is a technical technique used for detection, evaluation, and to predict the location of the defects without affecting the parts or a component [2]. On the other side, there are destructive methods also which are used to measure the physical properties of a component that includes ultimate tensile strength, compression strength, fatigue strength, ductility, and many more [2]. But, the biggest disadvantage of using destructive testing is it will destroy the part that is to be inspected.

Thus, NDT comes into the picture and plays a significant role in industrial development [3]. The NDT techniques that are widely used includes Radiographic, Ultrasonic, Magnetic particle, Eddy Current, Penetration Testing [4]. The purpose of this paper is to give a glimpse of different non-destructive methods, discuss the pros and cons of various non-destructive methods, and comparison is made discussing how one technique is different from another [5].

1.1 Different Type of Non-Destructive Testing Technique: On the basis of testing environment and condition, different types of Non-Destructive testing have been used which are given below:

- Visual Testing
- Eddy Current Testing
- Magnetic Particle Testing
- Liquid Penetrating Testing
- Radiography testing
- Ultrasonic Testing



Eddy Current Testing- Eddy current is a nondestructive testing technique which works on the principle of electromagnetic induction [6]. This technique is mainly used to detect flaws, depth of defect in the conducting materials

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[4,6]. This method works on the faraday's law according to which a current-carrying coil induces a magnetic field around itself [11]. In this method when a current-carrying conductor is placed near the electrically conducting material results in the formation of eddy current in the material as shown in fig 1 [13].

Systematic Process of Ultrasonic process

In eddy current testing the formation of eddy loops is affected by the defects in the material thus affecting the electrical properties such as inductance, reactance, resistance of the materials and this change in the electrical properties help us to analyze the phase and amplitude of the frequency waves thus resulting in the determination of defects in the components. Sandeep Kumar Dwivedi et.al explained the effect of skin effect which states that change in the depth of cracks results in a significant decrease in the amount of density formed by eddy current. Thus eddy current method has a limitation of not being significant in determining deep cracks [6]. Damhuji Rifai et.al proves that in a conductive material eddy current testing is best suited for measuring the depth of a defect in a component [19].

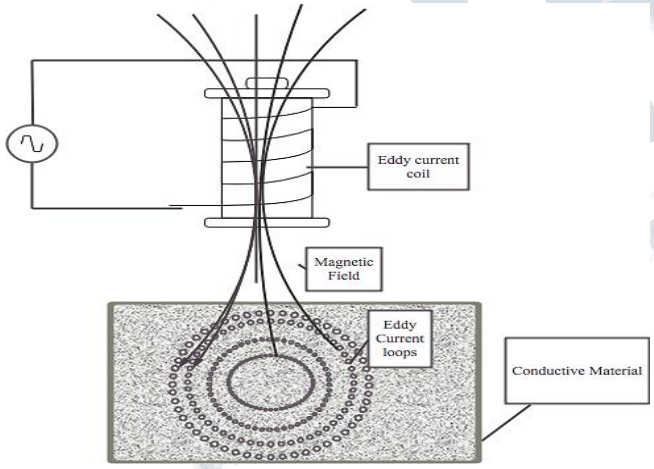

Figure 1: Eddy current testing [17]

1.3 Ultrasonic Testing- Ultrasonic Testing or SONAR Testing method is one that works on the principle of sound energy. It is a Non Destructive testing technique that is used to detect defects in a component. The basic working principle of ultrasonic testing relies on the transmitting and receiving pulses. The Ultrasonic testing method consists of a transmitter that transmits sound waves generated by a pulsar at a very high frequency higher than the human hearing capacity [2][14]. The sound energy transmitted from the pulsar is passed through the piezoelectric crystal which converts the mechanical energy into the sound energy [12] and gets propagated into the material to be inspected once the wave propagates it gets reflected into the receiver from interruption such as cracks, flaws in between the surface not only this ultrasonic testing is also used for analysis of depth, location and exact size of the defect [6].

The sound waves which are reflected are analyzed graphically by using online software or by using an oscilloscope as shown in fig 2 [6,7]. The time required for the sound waves to get transmitted reflected is calibrated in distance to find out the exact location of the defect. The distance of the defect is calculated using time, velocity and distance relationship given by Ayad **Ahmed Ebrahim et.al [8].**

$$D=(T*C)/2 \qquad (I)$$

D= Distance of defect
C= Velocity of sound
T= Time taken by sound wave to get transmitted and reflected from the defect

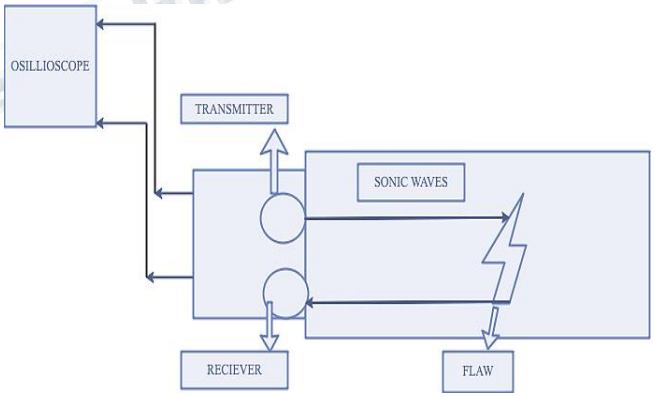

Figure 2: Ultrasonic Testing [14]

1.6 Magnetic Particle Testing- This NDT technique relies on the use of the magnetic field (flux flow) to detect the defects in a component. In this, the component to be inspected is magnetized using many ways such as magnetizing using threading bars, electromagnets, coil, horseshoe magnets, and many more [15]. But, the commonly used method is magnetizing using electromagnets. In this technique, the component to be inspected should be ferromagnetic. Working on magnetic

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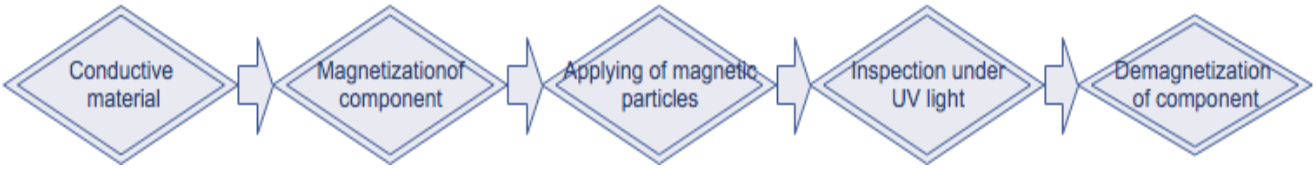
particle testing proceeds by placing a component in between two electromagnets and the component is being magnetized by inducing current through it as shown in fig 3.



Systematic process of Magnetic particle testing

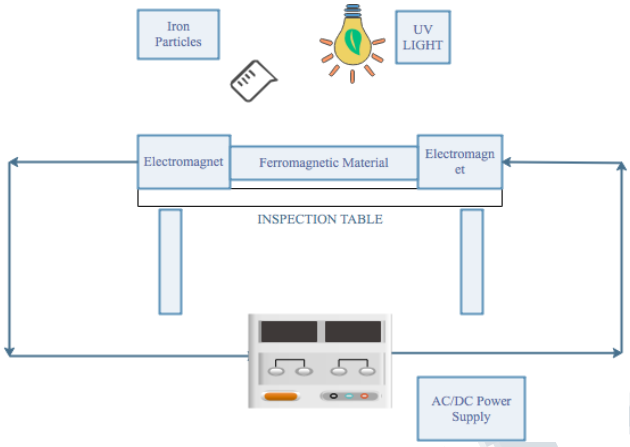


Figure 3: Magnetic Particle Testing [16]

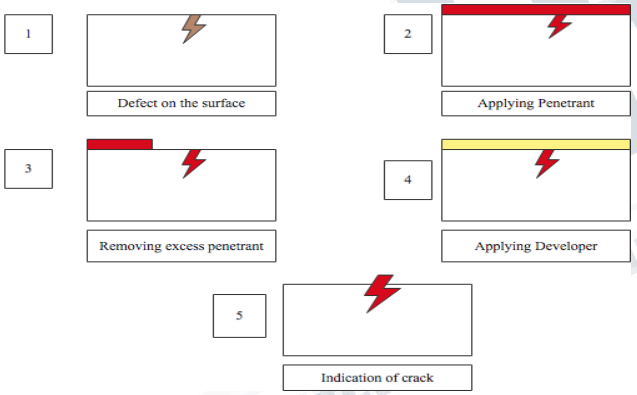


Figure 3: Magnetic Particle Testing [16]

In magnetic particle testing once the component is magnetized the ferromagnetic suspension particles are poured on the surface so that if there is any crack on the surface of the component, magnetic flux lines get broken and reverse the polarity of the magnetic poles. Thus resulting in the formation of south and north poles around the crack and the suspended particles will get attracted to the cracks of the component to form a cluster of particles over the surface. These particles can be seen clearly under the UV light thus resulting in the clear visibility of cracks [2].

According to S.K. Babu et.al magnetic particle is best suited for surface inspection of welds due to simple operation and portable [18].

1.8 Dye Penetration Test- This method is widely used as a non-destructive testing technique and it mainly depends on the ability of a liquid to penetrate the cavities on the surface using the principle of capillary action. Capillary action is the process of up and down of liquid in narrow cavities [10]. Dye penetration testing is applicable for both ferrous and nonferrous materials [6].

The process of penetration testing starts with the cleaning of the surface to be inspected. Once the cleaning of the component is done. Penetrant is applied to the component employing brushing, spraying, or dipping. After the applying of the penetrant, the component is placed for a dwell time of 30 minutes [15]. And the excess penetrant is removed. It is very important to apply the developer once the excess penetrant is removed. As the developer helps inspect

the cracks, flaws on the material very clearly by drawing penetrant out of crack. Inspection of crack is performed under the UV or visible light for better crack recognition as shown in fig 4 [6,9].

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II. COMPARISON BETWEEN DIFFERENT NON-DESTRUCTIVE TECHNIQUES

Non Destructive Testing Methods	Advantages	Application	Limitation
Eddy Current Testing	•This can detect surface and beneath surface defects. •Fast and highly sensitive for minute cracks and discontinuities. Instrument required is light weight and easy for portable.	Defect detection in conductive material	•Defect parallel to surface cannot be detected. •Less depth of penetration •Skill requirement is more as compared to other techniques. •Rough surface cannot be easily inspected.
Ultrasonic Testing	• Best suited for detecting the location of flaw •Detection of internal and external defects is possible in ultrasound conducting material. •Defects with much larger depth can be easily inspected. • Much deeper defects can be detected using UT probe. •High precision of cracks, flaw inspection. •Vitally used technique for inspection of minute flaws in material. •Less hazardous to observer as compared to MPT.	Crack, flaws identification in sound conducting material	•Irregular, rough surface defects cannot be easily inspected using ultrasonic testing. •Coarse grained components cannot be easily inspected due to low wave propagation. •Expensive instruments •Skilled operator is required
Magnetic Particle Testing	• Useful in inspection of surface and close to surface defects in ferromagnetic material. •Immediate inspection of defects •Simple as compared to other testing techniques.	Inspection of macrostructure defects in ferromagnetic material	•Not applicable to work on thick sheets. •Cannot detect the defects clearly.
Dye Penetration Testing	•Useful in detection of surface pores. •Cheaper •Effective inspection of surface discontinuities and can work well in complex geometries. •Provide clear visibility to unseen defects.	Small surface interruptions	•Only surface defects can be inspected. •Surface finish is affected while inspecting the component. •Many processes are involved during inspection.

III. INVESTIGATION THROUGH NDT

Different authors have been investigated to identified different types of defects**.** Some investigation has been discussed is given below:

Xiaochen Mao et.al[1]- investigated one of the latest methods such as digital image-based 3-D image technology which includes CT tomography, image detection technology for determining the different parameters of the components. **Prajapati Vraj et.al[2]**- describes the various Destructive testing techniques that include the Bend Test, Tensile Test, and various nondestructive techniques that include Dye Penetration, Ultrasonic testing, Magnetic Particle testing used for the detection of welding defects. **S.G.N Swamy[3]**- explained the role of NDT in increasing the standard of industries in traditional India. It provides the knowledge about how NDT comes into the picture in India.

C.S Angani et.al[4]- explained the pulsed eddy current method for the detection of defects, flaws in pipes. In this paper a differential pulsed eddy current type probe with hall

sensor been used for measurement of defects. Also, they find the effect of eddy current on the depth of defects. **Paul. Kab et.al[5]**- investigated various NDT methods for welding. These methods include ultrasonic, eddy current, and radiography. From this study, Paul et.al has explained the techniques of NDT and compared these techniques based on there advantages and limitations, geometry, welding process, type of defect, and their position. **Sandeep Kumar Dwivedi et.al[6]**-describes the advancement and research in the field of NDT for defect recognition. This paper describes the capabilities of various NDT methods such as Ultrasonic, Thermography, Magnetic Particle, Radiography, Shearography, Acoustic, Visual Testing techniques, and also reviewed the findings of other researchers in the field of NDT.**AR Sahebi et.al[7]**-describes the 3- Dimensional Ultrasonic nondestructive technique determining the welding defects with accuracy. And also concluded that the 3-D Ultrasonic Method is much accurate than the radiographic method. **Ayad. Ahmed Ebrahim et.al[8]**-investigated the distance measurement in the car for providing safe parking and avoiding accidents using the ultrasonic sensor. This paper discussed the equation for measuring the distance of the object and also proves the effect of temperature of air on the velocity of ultrasonic waves. **C.Chris Roshan et.al[9]**-describes the latest research in the field of liquid penetration testing and ultrasonic testing. This paper concluded the comparison between liquid penetration and ultrasonic testing. **Suhaila Yacob et.al[10]**-explained the liquid penetration testing in weld material and discussed the procedure for testing a material using liquid penetration and also analyses the experimental result and proves that the liquid penetration is suitable for a particular range of harness value of the component to be inspected.

Javier Garcia-Martin et.al[13]-explained the concept of eddy current testing. In this paper, Javier Garcia-Martin discussed the principle of eddy current inspection, the effect of eddy current on the ferromagnetic and no ferromagnetic materials. This paper also discussed the effect of eddy current in determining the stress, hardness of the material.

Ahmad Hosseini and Dr. R. Ashokan[14]-discussed the damage identification of polymer composites using ultrasonic nondestructive testing techniques. In this paper experimental study was conducted on the fiber polymers. Fiber polymers were damaged using the drop weight impact test. The cracks, defects occurred in the material are identified using ultrasonic testing and the results were compared on the effect of damage occurred following the impact load. **F.I. Al-Naemi et.al[16]**-describes the effect of magnetic flux leakage in the inspection of a metallic plate. In this paper, the results obtained from the 2D and 3D models were compared using the Finite element modeling tool. The results obtained predicted that the uniform lines are produced near the middle of the scanner and more variation is there in signal at the ends of the scanner. **Ho Young. Mun and Chang-Rob Kim[17]**-explained the effect of characteristics of magnetic field lines with the change in impedance in eddy current testing. In this paper, different results were analyzed using different testing probes in the modeling software and the results proved that the impedance probe is better than T/T, T/R probe in defect detection. **S.K. Babu et.al[18]**-reviewed the various works done by researchers in the field of nondestructive testing techniques for inspection of weld joints. In this paper, the results obtained by testing samples using magnetic particle and eddy current testing were compared, and then the conclusion is drawn that eddy current testing is more suitable and reliable in defect detection.**Damhuji Rifai et.al[19]**-explained the eddy current testing technique for surface defect detection. In this paper, they experimented with the effect of eddy current probes on the surface defects at different frequencies. In this paper experiment was conducted on the virtual artificial defect block made on the designing software. Various machining processes and defects were performed on the surface at various depths and the results were concluded showing the graphical comparison of defects by weld probes at different diameters by using different frequencies.

IV. SUMMARY OF LITERATURE REVIEW

Authors Name & Year	Techniques Used	Findings
Xiaochen Mao, Yibo Zhao, Tianlei Xiao(2018)	Ultrasonic Imaging	Various non-destructive imaging technologies can be used for crack detection, size identification using ultrasonic 3D image. Laser type non-destructive imaging system is well suited for detection of component with high time discrimination rate as compared to ultrasonic, ray and microwave imaging techniques.

Prajapati Vraj, Jaiswal Ayush, Patil Hardik, M.A. Vohra(2020)	Dye Penetration, Magnetic Particle, Ultrasonic, Bend test, Tensile test	Non-destructive techniques are suited for defect detection in inner and outer surfaces. Destructive testing is used to find strength, hardness of weld metals.
S.G.N Swamy(1976)	Advancement of Various NDT techniques	In earlier times NDT plays a significant role for industrial growth in India. In this paper S.G.N Swamy discussed about how first NDT instruments set up in India and how test centres were established in India in earlier times.
C.S. Angani, D.G park, C.G. Kim, P.Leela, M.Kishore, Y.M Cheong(2011)	Pulsed Eddy current	Pulsed eddy current testing technique is suited for detection of defects in insulated SS pipes. The results were analysed using energy and spectral power density of detected pulse using signal processing technique.
Paul Kah, Belinga Mvola, Jukka Martikaina, Raimo Suoranta(2014)	Eddy current, Ultrasonic, Radiography	Radiographic testing can be used for macroscopic flaws detection. Eddy current testing has limited depth of current penetration thus can detect only cracks whereas ultrasonic testing can detect defects with larger depth.
Sandeep Kumar Dwivedi, Manish Vishwakarma, Prof. Akhilesh Soni(2017)	Visual inspection, Radiography, Eddy current, Magnetic particle, Dye penetration, Acoustic emission	Non-destructive techniques are used for defect characterization in composite and construction material. One particular method is not suitable for defect characterization as each and every method has their own limitations. Therefore inspection of material using two or more techniques would give better results.
AR Sahebi, S.Hosseinzadeh, V. Salimasdi(2016)	Three Dimensional Ultrasonic	Ultrasonic method has higher speed and accuracy as compared to other non-destructive testing methods such as radiographic testing technique.
Ayad Ahmed Ebrahim, Ruzairi Abdul Rahim, Anita Ahmad, Khairul Hamimah Abas(2016)	Ultrasonic Sensor	Ultrasonic sensor in cars can measure the distance very precisely and accurately. There is a linear graphical representation between the actual distance and measured distance. Thus, ultrasonic sensors can be used for higher range measurements and are affected by atmospheric weather conditions.
C. Chris Roshan, Raghul C, Hari Vasanth Ram, Suraj K.P. , John Solomon(2019)	Liquid Penetration, Ultrasonic	The author compares the non-destructive testing technique and concluded that liquid penetration is effective way in crack detection whereas ultrasonic testing reduces the man made errors, requires less time and is more accurate.
Suhaila Yacob, Rafidah Ali, Nurul Huda Ariffin, Arzina Arshad, Shaiful Anuar Ismail, Fairul Anwar Abu Bakar, Mustaffa Ibrahim(2014)	Liquid penetration	The dwell time for liquid penetration testing performed on the weld joints of different sample is less than 10 minutes and the welded joints having surface roughness obtains lower development time in penetration testing.
Javier Garcia-Martin, Jaime Gomez-Gil, Ernesto Vazquez-Sanchez(2011)	Eddy Current	Eddy current testing is well suited and widely used technique for satisfying high quality standards in industry. Eddy current testing is not affected by environmental factors such as dust, humidity etc. Eddy current testing can be applied in identification of macrostructures, inspection of bars and profile at higher temperature. Eddy current testing can also proves helpful in detection of residual stresses in components.

Ahmad hosseini and Dr.R.Ashokan(2020)	Ultrasonic CT scan	In this study inspection of composite polymers were performed using ultrasonic testing CT scan for identification, measurement and evaluation of flaws. The impact energy of the composites is measured with different loads using drop weight impact testing machine and the effect of load on the damage is analysed.
F.I. Al-Naemi, J.P. Hall, A.J. Moses(2006)	Magnetic flux leakage	Non-destructive inspection of test sample of steel plate obtained from 2D and 3D models were compared and the results proved that there is better flux distribution in 3D model as compared to 2D model. In 3D model uniform results were formed when the sensor is at middle position as compared to sensor placed closer to edges.
Ho Young Mun and Chang-Eob Kim(2014)	Eddy current	In this study of eddy current testing comparison is drawn between different eddy current probes using FEM with respect to the impedance change. The analysis of results proved that impedance probe is better as compared to other T/R, T/T probes.
S.K. Babu, W.T. Chan, Alan Chan(2017)	Magnetic particle, Eddy current	Defect detection in steel welds by magnetic particle and eddy current is performed on various samples findings proved that magnetic particle testing gives higher productivity of 22% more as compared to eddy current testing and moreover productivity of magnetic particle is more for defect detection in steel welds.
Damhuji Rifai, Ahmed N.Abdalla, Noraznafulisma Khamsah, Mohd Aizat and Muhd Fadzli(2016)	Eddy current	Eddy current testing is commonly used in various industries including oil & gas, aircraft, nuclear and coating industries. The experimental results were compared on artificial defect block at on different samples at different depths with different probe diameter at different frequencies.

V. CONCLUSION

In this present study based on the literature review and survey carried out by researchers in the field of nondestructive testing. Conclusion is drawn by comparing the pros and cons of various testing techniques and it is found that among various nondestructive testing techniques ultrasonic testing is best suited for defect identification, detection, spotting of cracks and discontinuities in a component.

- Ultrasonic testing is widely used for inspecting complex parts.
- Deeper defects can be easily identified as compared to eddy current testing technique.
- Ultrasonic testing is an effective way in determining the position of internal flaws.
- Liquid penetration testing can easily detect the on surface defects but cannot detect the defects beneath the surface.
- Sensitivity of ultrasonic testing is high thus it can detect minute flaws very easily.
- Ultrasonic testing reduces human errors and provide accurate and precise component.
- Ultrasonic testing is less hazardous as compared to other testing techniques.

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