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Review Article

Inspection of aircraft parts by eddy current method

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ABSTRACT

Aviation technologies are developing due to the need for advancements at military field and the increase in commercial air transportation. The development of aviation technology also forces the development of Non-Destructive Testing (NDT) Standards. The accuracy of these inspections, their fast results and their applicability on many materials is one of the important issues to be studied. Eddy current testing, which has a significant advantage in terms of test speed and accuracy, is one of the main methods used in the non-destructive testing of aircraft parts. The test is used not only in metal and metal alloy materials, but also in composite materials with high conductivity such as carbon fiber to detect failures. Also, improvements at the eddy current test system and probes play a major role in the failure assessment of aircraft parts. In this article, comprehensive technical information about the eddy current testing method is given and the case studies are presented.

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1. Introduction

Although aviation technology is developing day by day, it also brings many problems. At the beginning of these problems are the failures that can occur in the aircraft. Failures can occur in various parts of the aircraft and some test techniques are applied to detect them. Non-destructive testing methods are used to obtain information about the dimensions and depths of these failures that may occur on the aircraft part, without leaving any damage to the part. There are 6 types of non-destructive testing methods commonly used in aviation [1]. These;

- Visual Inspection
- Ultrasonic Testing
- Liquid Penentrant Test
- Radiographic Test
- Magnetic Particle Test
- Eddy Currents Test

In this study, comprehensive technical information about the eddy current testing method is given and the case studies are examined.

2. Eddy Current Testing (Eddy Current)

Eddy current testing method is a method used to detect surface and near-surface defects of the material. The working principle of the eddy currents test is based on the induction of circular eddy currents on the material by a magnetic field obtained through the coil of an alternating current. If there is an irregularity on the surface where these eddy currents are located, the currents arising from the electrical resistance gap between the test sample and the defective area will follow a different path [2]. This path is defined with the test coil as in Figure 1.

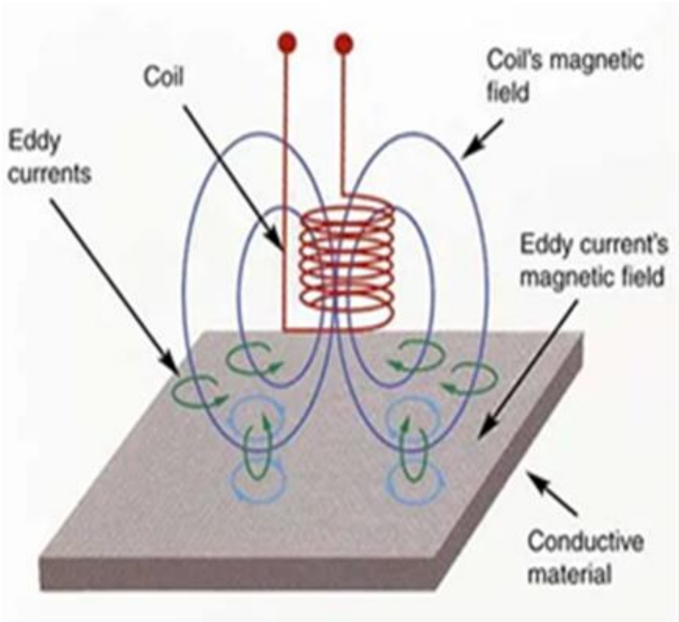

Fig. 1. Working principle of eddy current test [3]

The material to be used for the test can be all metals and alloys with electrical conductivity properties. With the eddy current test method, the failure, the paint and coating thickness on the material surface can be measured. This method cannot be applied to electrically insulating materials, in addition, special conditions and environment are

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required for testing ferromagnetic materials. The penetration depth is limited. Compared to other inspection methods, it depends on the technical knowledge and experience of the person performing the test. The surface of the material to be tested greatly affects the test results. Special reference blocks are required for the experiment. Calibration (measurement) of the device with reference blocks should be ensured before each experiment. High accuracy results can be achieved by performing it before each experiment [4].

2.1 Low velocity impact test

- It is used to detect gaps in welding seams.
- Used to detect surface and near-surface cracks.
- Used to measure defects in metal alloy composite parts.
- It is used to measure the thickness of the non-conductive coating (paint) on the conductive material.
- It is used to measure the electrical conductivity of metal alloys.
- It is used to detect unwanted metal parts in non-magnetic materials.
- It is used to classify metals according to their chemical forms [1].

2.1.1. Advantages of eddy current testing

- It gives fast results.
- Test equipment is portable.
- Experiment can be performed on the working system.
- It is sensitive to minor damage.
- Contact of the probes on the test piece is not necessary.
- The test does not cause damage to the material; it can be tested again.
- It can also be used in complex systems.
- Devices are battery powered or charged, so they can be carried [5].

2.1.2. Disadvantages of eddy current testing

- Special environment is required for testing ferromagnetic metals.
- The measuring depth is limited.
- It can be applied to conductive materials only.
- It is more comprehensive than other methods and training is required.
- The test specimen must be cleaned as it is extremely sensitive to surface imperfections [5].

2.2. Material properties affecting eddy current

2.2.1. Electrical conductivity

Objects that pass electrical energy and heat energy are called conductors. The greater the number of electrons moving in the material, the greater the electrical conductivity. The higher the conductivity of the material, the higher the eddy currents will be. Each material has its own conductivity property [6].

2.2.2. Magnetic permeability

Magnetic permeability is the property of a material to be magnetized. It is found by the ratio of the magnetic induction to the magnetic intensity [7].

2.2.3. Geometry

2.2.3.1. Material thickness

Eddy currents cannot reach depths in very thick materials, but they can reach the surface and near the surface. Therefore, they have a finite depth of penetration. The standard depth of penetration is expressed as the depth value at which the eddy current density at the surface of the material drops to 37% of the initial value [6].

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2.2.3.2. Lift-off Effect

While performing eddy currents inspection, the farther the coil-tipped probe moves away from the test surface, the less intense the coil field will show itself on the material. This change will overshadow the accuracy in graphs. This is known as the gap effect [7].

2.2.3.3. Edge and tip effect

Eddy currents probe does not give accurate results on the edge and tip of the sample while traveling on the surface and appears as a discontinuity in the graph. This discontinuity can be perceived as a failure. This is called the edge and edge effect [7].

2.2.3.4. Fill factor

It is the distance between the examined test sample and the probe. The fill factor is the spacing effect value for peripheral probes and internal probes [8].

2.2.3.5 Discontinuities

A factor that affects the flow of eddy currents, informing that there is a defect on the test piece. Discontinuities; foreign materials on the material (slag layer formed as a result of welding), visible or invisible porosity and cracks that occur due to fatigue of the material. Eddy currents extend the path by passing around the discontinuities so as not to disturb the magnetic field. Thus, it causes a change in the field, giving information about the failure size [7].

2.2.3.6. Depth of penetration

Eddy currents do not spread equally all over the sample. The current density is higher at the surface and near the surface [7].

2.3. Factors affecting test condition

2.3.1. Test frequency

Frequency is the number of vibrations per unit time applied to produce the magnetic field in eddy currents. The frequency of the alternating current in the test probe and the rate of change of the magnetic field are the same. The intensity of the eddy currents formed in the material increases in proportion to the frequency of the magnetic flux. When the other variables are constant, the depth of penetration in the material decreases as the magnitude of the frequency increases. The frequency of the test is an important factor for the eddy current inspection [7].

2.3.2. Magnetic contact

Magnetic contact is defined as the relationship of the variable magnetic field created by the test material and the test probe. The magnetic field strength of the coil decreases with distance from the part. Magnetic contact is related to the size and shape of the test coil and the thickness of the surface coating (paint etc.) on the test material [7].

2.3.3. Current of the test coil

When the other variables are constant, as the current of the test coil is increased the magnetic field strength applied to the test sample also increases. At high currents, the test coil may be damaged [9].

2.3.4. Temperature

Temperature is an effective factor on both magnetic and conductivity properties of the material. As the temperature increases, the intensity of the eddy currents on the surface of the sample weakens [8].

3. Case Studies

Tests were carried out on conductive aircraft parts using the eddy current inspection method [2-16]. Screws are used as fasteners at aircrafts. Baygut and Durmuş compared the eddy current inspection method data with the microstructure results of the small cracks at the screws produced by using the cold forging method in their study. The head and thread sections of the screws were examined by the eddy current test method. Various cracks were observed in some samples [2].

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Chady et al. have conducted a recent study on the NDT of damaged materials for the aircraft industry. Their finding is based on the use of the Structural Similarity (SSIM4) image quality metric modified by the defect identification method. The developed method has been extensively tested for various locations, sizes and configurations of defects in the studied structure. In this way, they were able not only to detect the presence of cracks, but also to obtain information about their size [10].

Hu et al., investigated the rotor eddy current loss of 30 kW/60000 rpm high speed permanent magnet motor for aerospace applications in their study. The results show that the smaller the stator slot opening, the smaller the eddy current loss, but the greater the stator core loss [11].

Aquilina et al. investigated a technique for detecting second layer cracks in aircraft structure without removing them for bilayer structures held together by universal head aluminum rivets. Probes and samples were prepared to examine cracks from holes fastened with 1/8 and 3/16 rivets. When the data was analyzed, 100% detection of all notches was achieved with a 5% false call rate [12].

Le et al. developed a machine learning system that includes an electromagnetic test system to finely detect inconspicuous corrosion in riveted areas on airplanes. Various machine system methods have been specified for the detection of different sizes and corrosion zones. The training strategy of machine learning models on a small number of data was also examined, and as a result, they observed that the proposed approach could effectively detect 89.48% of latent corrosion between 2.8 and 195.4 mm^3 [13].

Based on the difficulty in detecting invisible damage to aircraft cage structures (aluminum alloy), Zhang et al. improved the far-field eddy current probe in two aspects, magnetic field enhancement and near-field signal suppression using the finite element method. Experimental results are consistent with simulation results [14].

Wang et al. designed a planar remote-field detection test probe to examine the invisible capillary defects around the holes of aircraft riveted components by eddy current test method and created a three-dimensional simulation model for the detection of capillary cracks in aircraft riveted components. When the inclination angle of the excitation coil is 10° and the coil pitch is 0 mm, the optimized focused remote-field eddy current probe can effectively detect the defect of 10mm × 0.2mm × 1mm length × width × depth under 9mm buried depth. can detect. It was concluded that when the depth of the defect is 6mm-9mm, the focused remote-field eddy current probe has better detection ability than the non-focused remote-field eddy current probe [15].

Ai et al. carried out and examined the eddy current test on carbon fiber material, which is widely applied to aircraft and has high conductivity. Experimental results show that the system can effectively detect defects of woven carbon fiber parts [16].

At the same time, innovative and prospective studies on the system and probes of the eddy current testing were also examined [5, 17-19].

Çelikadam aimed to develop a completely digital eddy current testing system, unlike other crack and hole inspection devices. The analog signal obtained from the test probe was converted to digital without any signal processing, except for RF band filtering and analog signal gain operations. An algorithm that can work in real time has been created by testing the digital signal received after analog-to-digital conversion. By running the algorithm on a dual-core Digital Signal Processor (DSP) in real time, the production errors in the pipes could be determined in real time. In addition, the fact that these developed methods are all based on digital signal processing also allowed the system to be open to development with only software changes in the future [17].

Taşkın, is used the eddy current test to detect the damages that may occur on metals and metal alloys, has been examined and modelled starting from the sensor/coil theory Maxwell equations. The coil design was carried out with the necessary calculations, and the reactions of the test coil were observed and examined. As a result, it has been seen that the coil inductance changes in case of an error on the material, and depending on this change, it can

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be examined depending on the type of error detected. Looking at the test graphics, it was seen that the defects affect the eddy currents created on the conductor wire by the coil and accordingly the coil magnetic field [5].

Hernandez et al. used pulsed eddy current thermography (PECT) for defect characterization, performed inspection on painted corroded aluminum parts which have defects ranging 0.4 mm to 5 mm to see thermal transient limited responses. The results show that larger defects outshine smaller defects due to saturation at thermal response and an alternative approach is needed to detect defects less than 1 mm in diameter [18].

In the study of Fan et al., the crack tracking system of the eddy current sensor was analyzed and the fatigue crack tracking experiment was performed. It has been found that the cracks' length and position can be evaluated according to the characteristic points of the sensitivity change curve. The error of the crack monitoring eddy current sensor is less than 0.1 mm [19].

4. Conclusion

As a result of the studies, it is observed that the eddy current test, which is one of the non-destructive testing methods, is a very effective method for detecting visible or invisible defects on aircraft parts. It is preferred in aircraft materials due to its many advantages such as being cost-effective, portable and fast results.

Experiments have been carried out on many metal and metal alloy systems in airplanes, especially in riveted areas where defects are most common, and even on carbon fiber structures with high conductivity and it gives important results to detect defects.

Improvements have been performed to the eddy current test system and probes, making it sustainable for future use. These developments will play a major role in the failure assessment of aircraft parts in the future.

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