17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Detection of Hidden Flaws with GMR-Based Eddy Current Technique

Jeong K. NA

University of Dayton Research Institute
300 College Park, Dayton, Ohio 45469, USA
Tel: 1-937-904-4689, Fax: 1-937-255-9804
E-mail:jeong.na@sbcglobal.net

Abstract

Nondestructive inspections involving multi-layered structures often require a reliable NDI methodology to estimate size and location of a flaw with quantitative information about width and depth. Compared to conventional wire-wound pick-up coil based eddy current NDI methods, Giant Magneto-resistive (GMR) sensor based eddy current methods have shown a much better sensitivity (20–50 times) for a given driving current and frequency. In addition to the higher sensitivity of the GMR sensors, it has been shown that the interpretation of GMR sensor detected signals is much less complicated than the conventional eddy current signals that are normally displayed on an impedance plane. Unlike wire-wound pick up coils, solid-state GMR sensors detect magnetic fields directly, where the magnitudes of magnetic fields are displayed in terms of voltage. Flaw signals detected with GMR sensors (voltage and distance) are similar to flaw signals detected with ultrasonic transducers (voltage and time). In this study, experimental results for various hidden flaws in thick metals and in double-layered aircraft lap joints are presented. The results show that quantitative sizing of flaws can be done fast and reliably.

Keywords: Hidden Flaw, Eddy Current, Giant Magnetoresistive (GMR) Sensors

1. Introduction

1.1 Giant magnetoresistive sensors

Eddy current methods of nondestructive inspection rely on the principles of magnetic induction to interrogate the materials under inspection. The test is based on the premise that, when a drive coil excited by an alternating current brought in close proximity to a material, the terminal impedance of the coil changes because of reduction in inductance of the coil[1]. The change is associated with the fact that the primary field set up by the drive coil induces eddy currents within the electrically conductive specimen. In conformity with Lenz's law, the direction of the induced eddy currents, and consequently the secondary field generated by these currents, is such as to oppose the change in the drive coil. The presence of a discontinuity or inhomogeneity in the test specimen causes a reduction as well as a redistribution of the eddy currents.

Unlike the conventional eddy current methods using a pickup coil to detect the secondary magnetic field generated by eddy currents in test material, in GMR methods the pickup coil is replaced by a circuit composed of Giant Magnetoresistive sensors. Magnetoresistive effects result in a material's electric resistance changing by ~ 1% due to an externally applied magnetic field. Giant Magnetoresistive effects, however, result in a much larger resistance change of 6 to 50%. Typically, the physical dimensions of the GMR die itself are in the range of a few hundreds of microns. They are commercially available in an IC chip format as a Magnetometer measuring magnetic field directly. Figure 1 shows schematic drawings of such a device including magnetic shields over two of the four Wheatstone bridge resistors. When an external magnetic field is applied, the resistances of the unshielded resistors (GMR) decrease while the resistances of the shielded resistors are unchanged. This imbalance results in the bridge output.

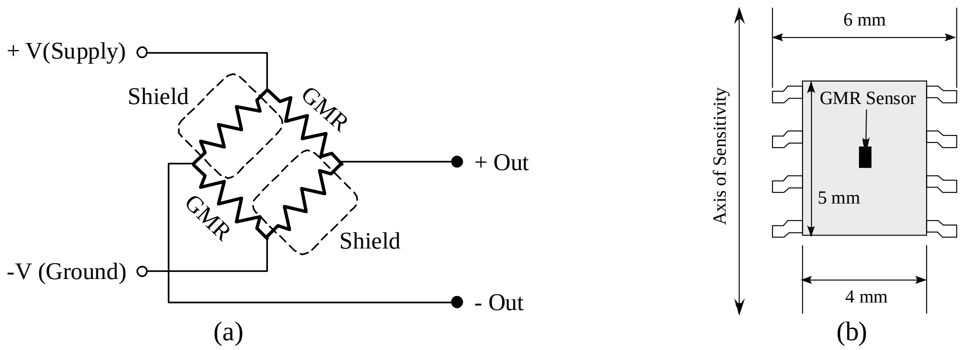
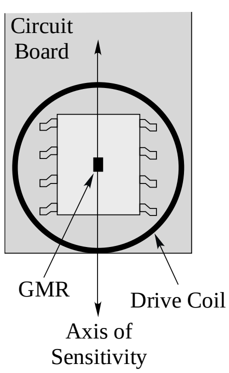


Figure 1. Functional (a) block diagram of GMR Magnetometer sensor, and (b) the integrated package that contains the sensor element.

1.2 GMR based Eddy current probe

Details of the coil and the GMR sensor assembly are shown in Figure 2. The coil is designed to accommodate at least 1 Ampere of continuous current while operating at frequencies between 1 kHz and 200 kHz. As the GMR sensor assembly is swept across the specimen, the output of the GMR sensor appears to be the drive frequency used for the drive coil. However, buried deep inside this large carrier output is a small signal resulting from the varying GMR sensor resistances. This large carrier signal must be removed in order to see the small GMR signal.



Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.

(a) Top view (b) Side view

Figure 2. Schematic drawings of GMR sensor and drive coil mounted on a circuit board.

2. Experimental Setup

The system block diagram for the flaw detection experiment is shown in Figure 3. A sinusoidal signal from the function generator is fed through the power amplifier to drive the coil. The detected signal is routed to the signal conditioning circuit to clean up the detected signal. This signal conditioning step is accomplished by maximizing the clarity of the GMR signal. A lock-in amplifier is used to filter out the carrier frequency leaving only the varying voltage level of the GMR sensor. The GMR “flaw” signal is amplified, buffered and filtered to remove any low frequency background noise[2].

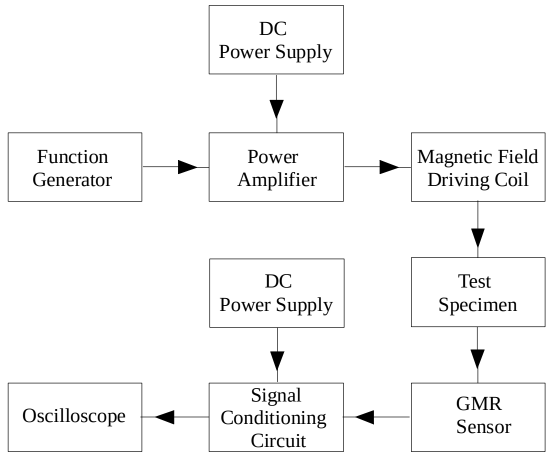


Figure 3. System block diagram of the GMR sensor based eddy current test setup.

3. Experimental Procedures and Results

In relation to an NDI system development program which involves aerospace materials, an aluminum alloy was chosen as the test material. Physical dimensions of the test specimens were selected to fit into a three dimensional scanning jig. For simple and easy fabrication, a V-shaped groove was used as a flaw. Among many different aluminum alloys, aluminum 6061 was selected for the fabricated specimens. Figure 4 shows schematic drawings of the aluminum specimens.

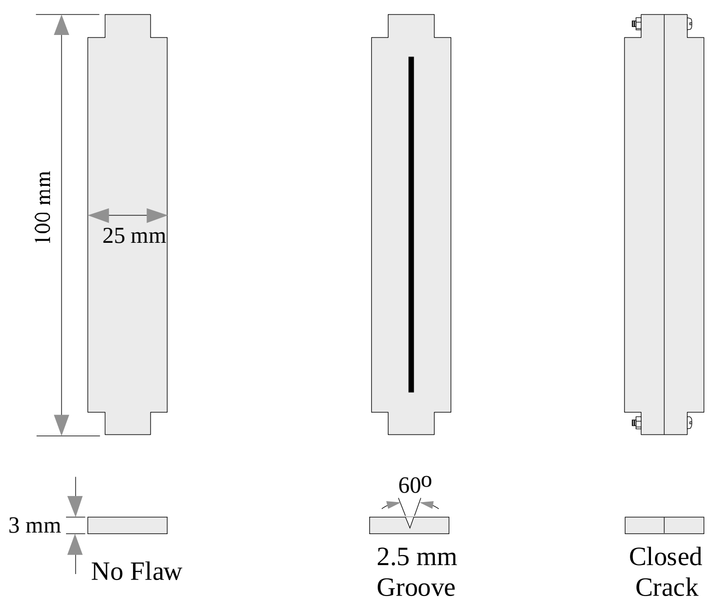
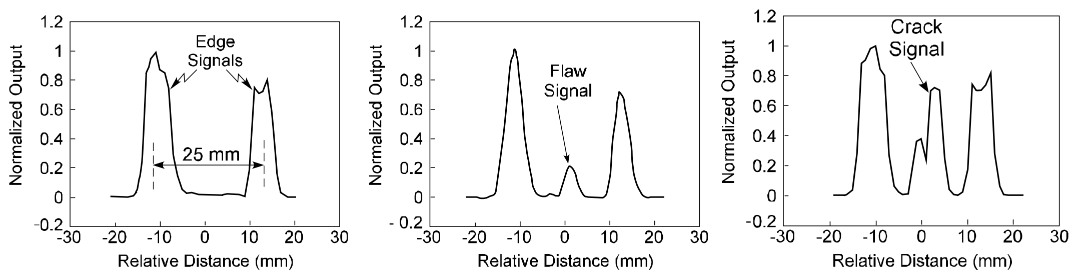


Figure 4. Aluminum 6061 alloy specimens used for Eddy current tests with GMR sensors.

3.1 Results for single plate aluminum specimens

Test specimens were firmly mounted in place above the GMR sensor assembly. This also ensured that the long specimens maintained a position perpendicular to the GMR sensor's path of travel. Two X-Y-Z axis adjustable jigs were used to hold the GMR sensor assembly and the test specimen. This allowed for precise movements up and down to adjust for optimal lift-off distances from the sensor to the specimen. The set up also allowed the GMR sensor to be swept across the bottom of the specimen to scan for flaws while maintaining controlled and consistent lift-off.

The control specimen with no flaw shows two clearly defined edge peaks centered 25 mm apart (the width of the sample) as shown in Figure 5(a). The flat region between the two peaks corresponds to no indication of a flaw presents. For the 0.25 mm grooved specimen, there is a noticeable peak appearing between the two edge peaks as in Figures 5(b). This centered peak increases significantly for the closed crack specimens as shown in Figures 5(c). It should be noted that the output signals for these simulated flaws are in terms of volts and normalized to the maximum peak value for each plot.

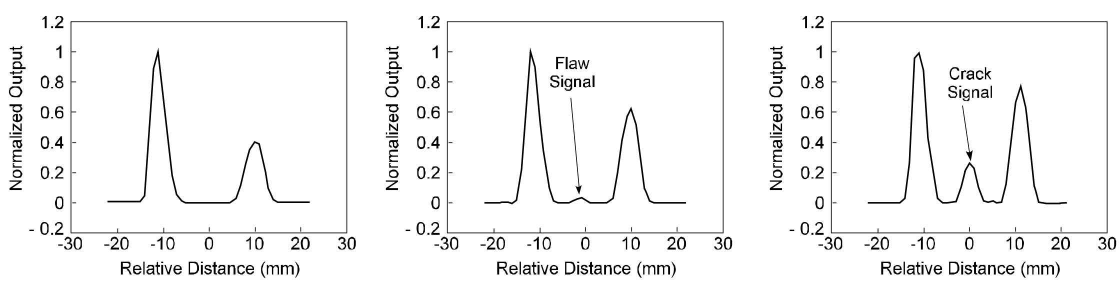


(a) No Flaw (b) 2.5 mm Deep Groove (c) Closed Crack

Figure 5. Test results for the single plate aluminum specimens (f = 5 kHz).

3.2 Results for Stacked Plate Aluminum Specimens

A thin aluminum plate of 1.2 mm in thickness was used to obscure the groove or crack. For deeper penetration, frequency of 1 kHz signal was used for the drive coil. Test results are shown in Figure 6. Like the results in the single plate tests, the control specimen shows two clearly defined edge peaks, Figure 6(a). The area between the two peaks is flat indicating no flaws in the specimen. However, for the 2.5 mm grooved specimen, there is a single peak centered between the two edge peaks as in Figure 6(b). This centered peak clearly indicates the groove. The closed crack specimen produces one distinct peak in the middle as well, Figure 6(c).



(a) No Flaw (b) 2.5 mm Deep Groove (c) Closed Crack

Figure 6. Test results for the stacked aluminum specimens (f = 1 kHz).

3.3 Results for a simulated aircraft lap joint specimen

After the successful detection of a simulated hidden groove and crack, a set of simulated aluminum lap joint test specimen made of Al 2024 alloy were studied (provided by the Boeing Co). A digital photo of an actual lap joint of a Being 737 aircraft fuselage is shown in Figure

7(a) and cross-sectional view of the lap joint section is illustrated in the schematic drawing of Figure 7(b). The goal of this was to use the GMR sensor o detect scribe line cracks on aircraft fuselage, which are often obscured by the sealant and paint.

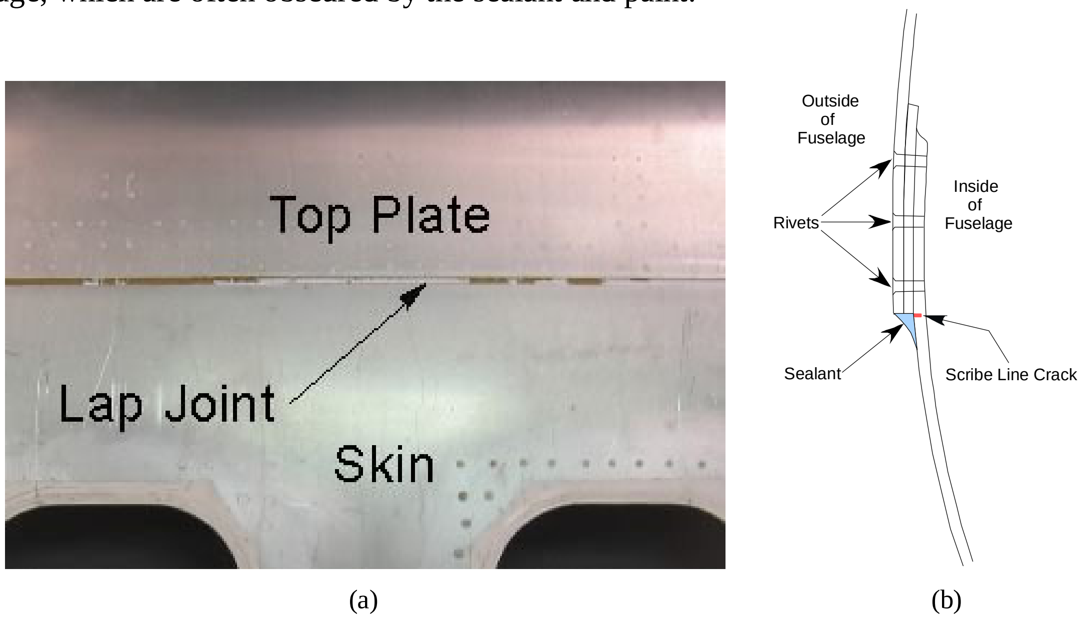


Figure 7. A digital photo of (a) a depainted aircraft lap joint and an illustration for (b) its cross-sectional view.

In order to simulate the scribe line cracks on an aircraft fuselage, EDM notches were made on an aluminum test specimen. Details of the location, length and depth of EDM notches on the test specimen are illustrated in Figure 8. The notches divided into three groups with the same depth. These three groups represent the most probable locations of scribe line cracks on a Boeing 737 aircraft fuselage. The notch location number 0 has no notch and was used as the reference area.

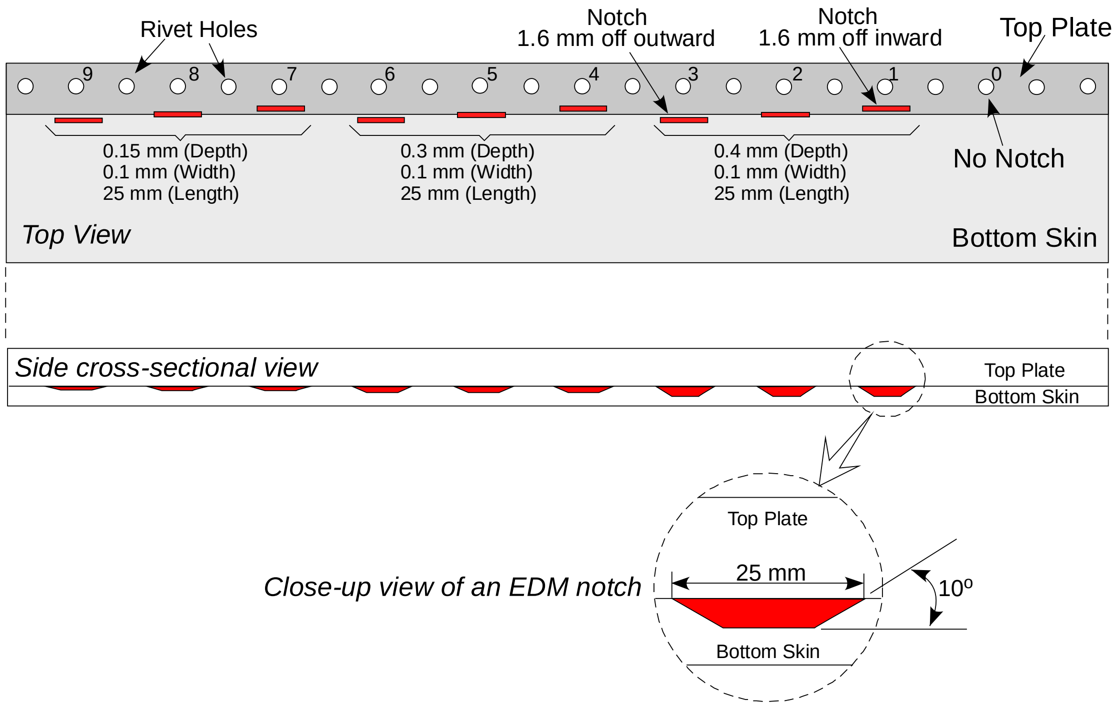


Figure 8. Detailed schematic drawing for the EDM notched test specimens.

The graph in Figure 9 shows the GMR sensor response for different depths of EDM notches at different locations for the most typical 737 fuselage lap joint combination, 1.8 mm top plate and 0.9 mm skin. As one can notice from the graph, EDM notches offset inward from the edge of the top plate give lower crack signals than the edge and outward notches.

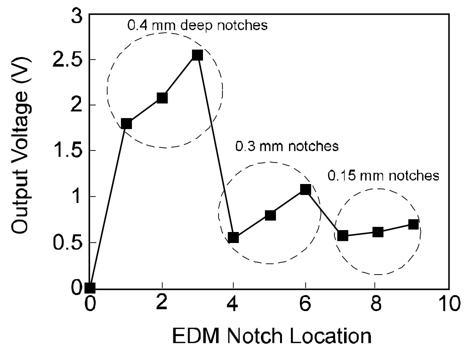


Figure 9. Test result for a typical Boeing 737 aircraft fuselage lap joint combination, 1.8 mm top plate and 0.9 mm skin, with multiple EDM notches (f= 8 kHz).

4. Conclusions

Unlike conventional eddy current pickup coils, a good signal to noise ratio with a high lift-off distance is thought to be the biggest advantage[4]. Both results on a deep groove and a simulated closed crack specimen show a high signal to noise ratio of better 5:1 in terms of DC voltage outputs. For smooth featureless specimens, this approach appears to be very promising, where the high lift-off approach can make the GMR sensor based eddy current inspection method a true noncontact NDE/I technique.

The test results on a set of simulated aircraft fuselage lap joints with a double-layered structure prove that the signals detected with a GMR sensor is easy to interpret for depth and length determinations in terms of DC output voltages. In this case, the signal to noise ratio is better than 10:1 for the 0.4 mm deep notch. Because of its simplicity involving interpretation of crack signals, the system can be designed to be used as a Go/No-Go type of NDI system at aircraft repair facilities for field technicians without being burdened with intensive trainings or time consuming inspection procedures.

Acknowledgements

This research was performed at the Wyle Laboratories, Inc. facility and the funding was provided by the US Air Force and the Boeing Company.

References

[1] Hagemaier, D. J., Fundamentals of Eddy Current Testing, The American Society for Nondestructive Testing, Inc., Columbus, Ohio, 1990, p 40.

[2] Smith, S. T. and Dogaru, T., “Giant Magnetoresistance-Based Eddy Current Sensor”, IEEE Transactions on Magnetics 37-5, 2001, pp. 3831-3838.

[3] Wincheski, B. and Namkung, M., “Deep Flaw Detection with Giant Magnetoresistive (GMR) based self-nulling probe”, in Review of Progress in Quantitative Nondestuctive Evaluation, edited by D.O. Thompson and D. E. Chimenti, American Institute of Physics CP509, 2000, pp. 465-472.