Finite Element Modelling of Pulsed Eddy Current Applied to Ferrous and Titanium Fasteners in F/a-18 Airplane Wing Structure

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Abstract

Introduction: Stress corrosion cracks develop between fasteners on the inner metallic wing spars located below a thick nonconducting composite wing skin of the F/A-18 Hornet aircraft (Figure 1). These defects cannot be detected by conventional eddy current testing, which requires removal of both skin and fasteners. Disassembly of the structure increases the downtime of the aircraft, maintenance cost, and the risk of collateral damage to the wing. Inspection with the pulsed eddy current (PEC) technique is a potential alternative to wing disassembly and is being developed to investigate deep defects in multilayered structures without the removal of fasteners or outer layers [1-5]. A PEC probe is usually designed considering a specific sample/defect geometry and assuming a single type of fastener. However, F/A-18 Hornets have both titanium (Ti) and ferrous fasteners with very different electromagnetic properties and therefore very different responses. Thus, a single probe may not be suitable for the two different fasteners and the development of an optimal probe requires information about the influence of the fastener material on flux penetration into the structure.

Use of COMSOL Multiphysics: Finite element (FE) modeling using COMSOL Multiphysics® has been successfully employed to aid in design and optimization of PEC probes and explore applications of PEC to detect deep flaws in multilayered structures [6, 7]. The present work uses 3D models to explore the difference in behavior of ferrous and Ti fasteners by comparing the penetration of the excitation field as a function of time and the corresponding generation of eddy currents in the neighboring conducting structure. It also investigates the variations in PEC signal caused by an off-centered probe, which is a common occurrence under inspection conditions.

Results: Figure 2 shows the mid-section of a solved FE model of a PEC probe consisting of a driving coil centered around two pickup coils in a 180 degree configuration and a sample with a crack originating from the fastener surface. A comparison of flux density distribution through the sample in the presence of ferrous and Ti fasteners reveals much deeper penetration of flux density into the ferrous fastener than in the Ti fastener, thus causing the generation of much stronger eddy currents in the aluminum structure at greater depths especially in the crack region. Consequently, the differential pickup signal for the case of the ferrous fastener is stronger than for the Ti fastener (Figure 3). The effect of an off-centered probe on the pickup signal (Figure 4) reveals a 7-fold increase in the peak amplitude when the probe is shifted along the spar for a

ferrous fastener compared to only a 2-fold increase for Ti. When the probe shifts transverse to the spar, however, the change in signal amplitude is insignificant in either case.

Conclusion: The presence of a Ti fastener can considerably weaken the PEC signal from deep defects compared to a ferrous fastener, which necessitates recalibration of the PEC probe. However, the signal is more sensitive to the centering of the probe above a ferrous fastener than Ti one. Thus the probe must be carefully centered for inspection of ferrous fastener holes.

Reference

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Figures used in the abstract

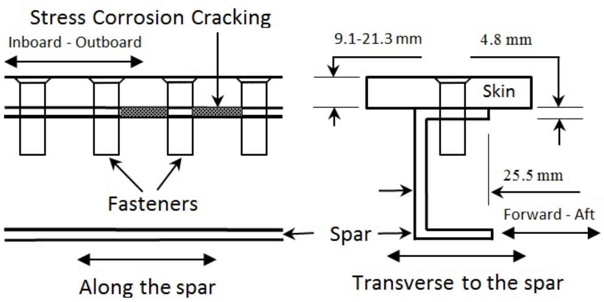

Figure 1: Typical inner wing spar lower cap fastener cross-section and side view.

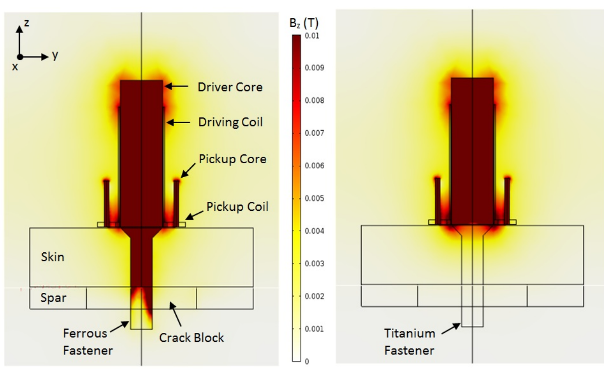

Figure 2: Magnetic flux density (B_z) distribution through ferrous versus titanium fastener at t = 0.5 ms.

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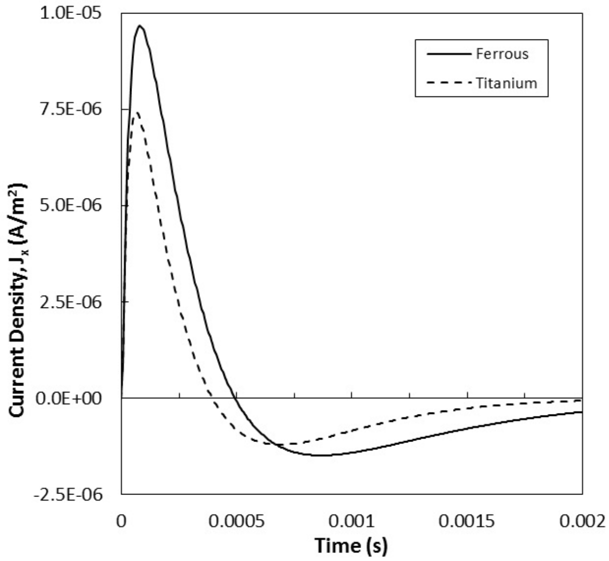

Figure 3: Differential pickup signals from perfectly centered probe for ferrous and Ti fasteners.

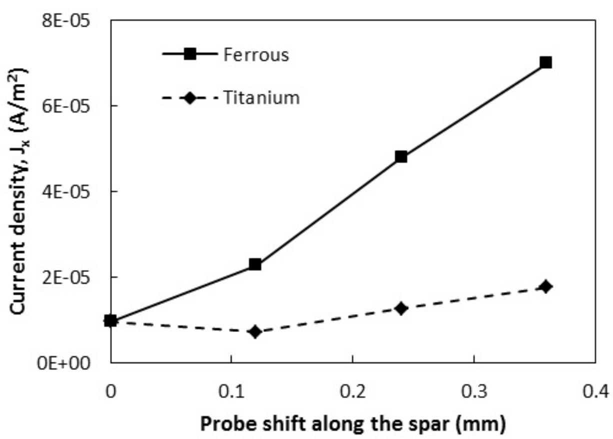

Figure 4: Variation of peak amplitude of differential pickup signal with probe shift along the spar. The signals are normalized with respect to 'no shift' case.