46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-1234

FEM MODELING AND SENSITIVITY STUDY FOR LOW FREQUENCY MULTILAYER DONUT PROBE INSPECTIONS

Nicholas Van Zandt
Southwest Ohio Council for Higher Education
Dayton, OH

Matthew Cherry
AFRL
Dayton, OH

John Aldrin
Computational Tools
Gurnee, IL

ABSTRACT

In this work, a finite element model was developed to simulate donut probe inspections in multilayer stackups fastened with bolts. The model was developed to include the effect of adjacent fasteners, bolt angle/properties, and the geometry of the substructure. Experiments were run using samples developed as part of a previous reliability assessment of low frequency electromagnetic techniques. The model was found to be in good agreement with the experiments, and was transitioned to the HPC for large parametric studies. The model development, verification and validation, and the results from the parametric studies accomplished to date are given here.

Keywords: eddy current, low frequency, multilayer, donut

NOMENCLATURE

LFEC	low frequency eddy current
POD	probability of detection
MR	magnetoresistance
GMR	giant magnetoresistance
PEC	pulse eddy current

1. INTRODUCTION

Low frequency ring probe (or donut probe) inspections are commonly used to find subsurface damage in multilayer stackups fastened by bolts. The typical inspection scenario is shown in Fig. 1. A coil with an OD larger than the bolt head is situated as close to concentric with the head as possible. The low frequencies at which the coil is excited (<500 Hz) allow the fields to penetrate deeply into the stackup, giving sensitivity to damage in layers beneath the first layer. This is an excellent alternative inspection to perform when ultrasound is not feasible due to poor coupling conditions. However, the POD study performed in [1] showed that the "rule of thumb" capability of these inspections is typically on the order of the amount of material through which this inspection is performed (i.e. the distance from the surface to the damage).

Multiple different technologies have been explored to improve the inspection capability of low frequency eddy current inspections around fasteners. For instance, in [2], MR arrays were used to detect the magnetic fields excited by the coils. This sensor had directionally dependent properties based on the sheet current excitation used. In [3], a GMR array was used in conjunction with two sheet current sources excited 90º out of phase with one another. This was shown to be effective in reducing the directionality of the sensor, improving the sensitivity to cracks of different orientations. Other approaches have looked at improving the capability of typical donut probes by including magnetic field sensors and/or using transient excitations sources (i.e. PEC).

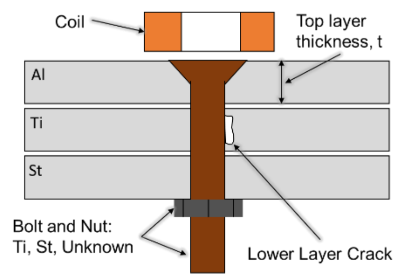

FIGURE 1: IMAGE DEPICTING TYPICAL DONUT PROBE INSPECTION.

These works have focused on probe design and made significant strides in improving the sensitivity of LFEC sensors. However, for effective implementation, a reliability study is needed that incorporates relevant sources of variability from real aircraft structures. Unfortunately, incorporating every source of variability in this inspection is cost prohibitive. In this work, a model was developed to predict the most relevant sources of variability for the purposes of a POD study. The model (Fig. 2) was made in COMSOL Multiphysics and is parameterized to include the geometry of the surrounding bolts and structure, the properties of the bolt under inspection, as well as the geometry of the bolt and flaw under inspection. The model calibration procedure is consistent with that of the actual inspection. This model was validated using experimental data collected from

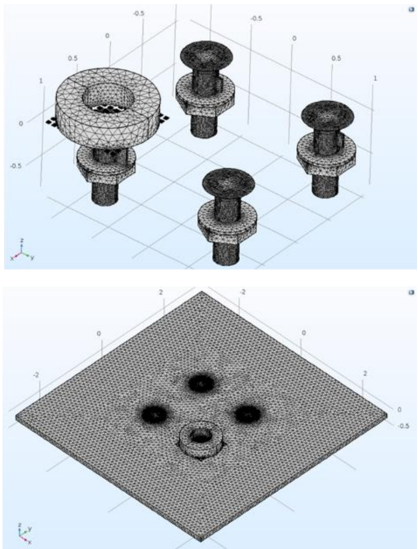

FIGURE 2: GEOMETRY AND MESH OF THE MODEL WITHOUT THE PLATE (TOP) AND WITH THE PLATE (BOTTOM). THE BOLTS AND NUTS ARE SHOWN IN THE TOP IMAGE.

samples from a previous POD study [1]. The design of the model was driven donut probe inspections currently used in structures, but the modeling and simulation framework is adaptable to other sensors. The results of the model verification and validation will be shown in this presentation. Additionally, magnetic field sensors were simulated below the coil to understand the fields measured by the sensors and the effect of varying bolt conditions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge John McClure and John Brausch of AFRL for their valuable contribution to this work.

REFERENCES

[1] Motes, Doyle, John C. Aldrin, Mark Keiser, Gary Steffes, and David S. Forsyth. "GMR sensing array technique validation study for the inspection of multi-layer metallic structures." In *AIP Conference Proceedings*, vol. 1511, no. 1, pp. 1562-1569. AIP, 2013.

[2] Palmer, D. D. and Wood, N. L., “Magnetoresistive (MR) Sensor Technologies for MAUS Aircraft Inspections”, May 2009, AFRL-RX-WP-TR-2009-4312.

[3] Yang, Guang, Gerges Dib, Lalita Udpa, Antonello Tamburrino, and Satish S. Udpa. "Rotating field EC-GMR sensor for crack detection at fastener site in layered structures." *IEEE Sensors Journal* 15, no. 1 (2015): 463-470.