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Buried Corrosion Detection in Multi-layer Airframe Structures Using Pulsed Eddy Current

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Abstract:

Substantial enhancements in Pulsed Eddy Current instrumentation and array probes provide a unique capability for the detection and imaging of sub-layer corrosion. The use of giant magnetoresistive (GMR) elements in an inductive array provides increased depth of sensitivity over conventional eddy-current sensing coils. This paper provides an overview of newly developed instrumentation, which provides a portable, battery-operated platform for multi-layer corrosion detection in flight line or repair facilities. Demonstrated capability includes rapid inspection and detection of material loss in lap joints with air gaps and complex geometries. Advanced imaging capability and post-processing allows multi-layer analysis, with distinct C-scan images of up to four (4) 1-mm layers.

Keywords: pulsed eddy current (PEC), GMR array, corrosion detection.

1. Introduction

As aircraft fleets around the world age, the structural integrity of these vehicles becomes a concern for both military and commercial aircraft operators. The eddy current technique offers advantages over ultrasonic or thermal techniques for inspection complex multi-layer structures such as riveted lap joints often found in aircraft structures. Defects under the surface can be detected without mechanical or thermal coupling at the surface or between layers.

Unlike conventional eddy current inspections in which the depth of penetration depends on the frequency of the excitation current, Pulsed Eddy Current (PEC) uses a pulse of electric current through a drive coil to induce a multi-frequency mix of eddy currents. Low frequency eddy currents can penetrate a conductive structure more deeply, providing a basis for buried corrosion detection.

The Pulsed Eddy Current (PEC) technique has been demonstrated as a unique capability for the detection of sub-layer corrosion and extraction of depth related information of such defects. Although demonstrated in a research context, this capability has not been made available in a portable instrument for application to aircraft structures or other industries where corrosion detection outside of a laboratory environment is necessary. This paper reviews the science of PEC technology, with specific focus on advances in commercially available portable instruments and comparison of results to traditional eddy current arrays.

2. Pulsed Eddy Current Method

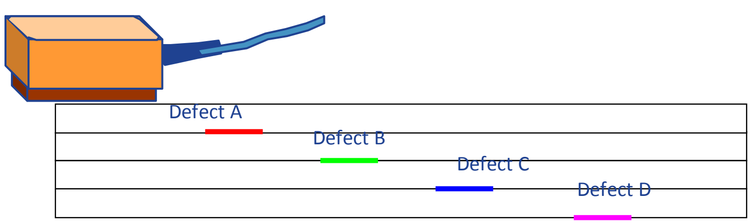
The pulsed eddy current technique was developed to improve the efficiency of eddy current testing with harmonic excitation (Libby, 1971; Moulder et all., 1995; Waidelich, 1970). For this technique a square pulse of electrical current is sent through a drive coil in order to induce eddy currents into the test material. A giant magnetoresistor sensor is then used to detect the secondary magnetic fields. These transient eddy current are then digitized and processed as described in previously published works (need reference here). This pulsed excitation is equivalent to superimposing a range of frequencies simultaneously in one spatial location, which can improve the efficiency of eddy current testing because all of the necessary information is collected in a single scan.

3. New Instrumentation and approach

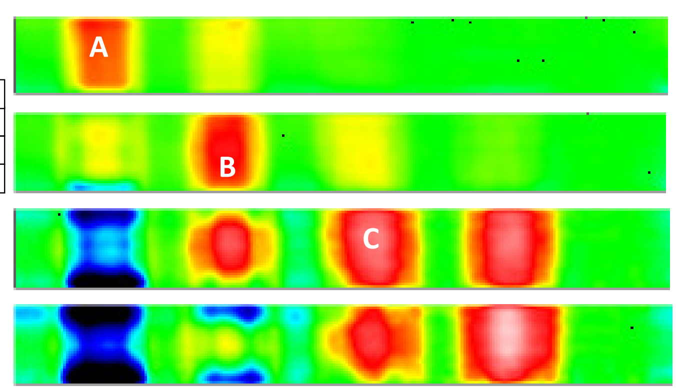
There is now a commercial instrument that offers PEC technology in a compact battery operated instrument. This portable instrument utilizes a Hybrid coil driver with GMR sensors in an array configuration for measuring the magnitude of the second magnetic field. In the case of the Pulsec TM instrument, the pickup array can be operated with 8, 16 or 32 elements. Information is post-processed internally, with the resulting data represented in a unique layer-by-layer image. Different processing time intervals, or time gates are utilized to evaluate the transient response in separate layers. After collecting the data in a single scan, the processing time interval and phase shift parameters can be adjusted to display discontinuities in a particular layer. Other analysis can be employed to generate simultaneous images of several layers. Defects identified in this manner, can be sized and an estimate of the depth of such defects can also be made.

3.1 Multi Layer corrosion detection

A test specimen of five layers of aircraft aluminium with thickness of approximately 1 mm each is shown below. Thirteen (13) mm wide areas where milled out of the bottom of each layer (round bottom holes) to simulate discontinuities in the multi-layer stack-up. Results from a single PulsecTM scan of the specimen, yields the results in figure 1 below.



1a). Sketch of test specimen. Four 1mm plates with milled defects on lower edge (flat bottom hole)



b). Image output from single scan

Figure 1

In figure 1, green is no change in transient signal (material without defects); red to white represent material loss; light and dark blue indicate positive material – or a material loss above the reference layer.

3.2 Comparison to conventional eddy current array

A comparison was conducted internally by GE Inspection Technologies to evaluate the speed and detection a commercially available modular eddy current instrument compared to the Pulsec ™.

The test was performed by stacking 10 sheet of Aluminium 2014 T6 – L157 cut 330mm by 330mm. In one sheet (see below) 6 thru holes were made of different sizes, as shown in figure 2.

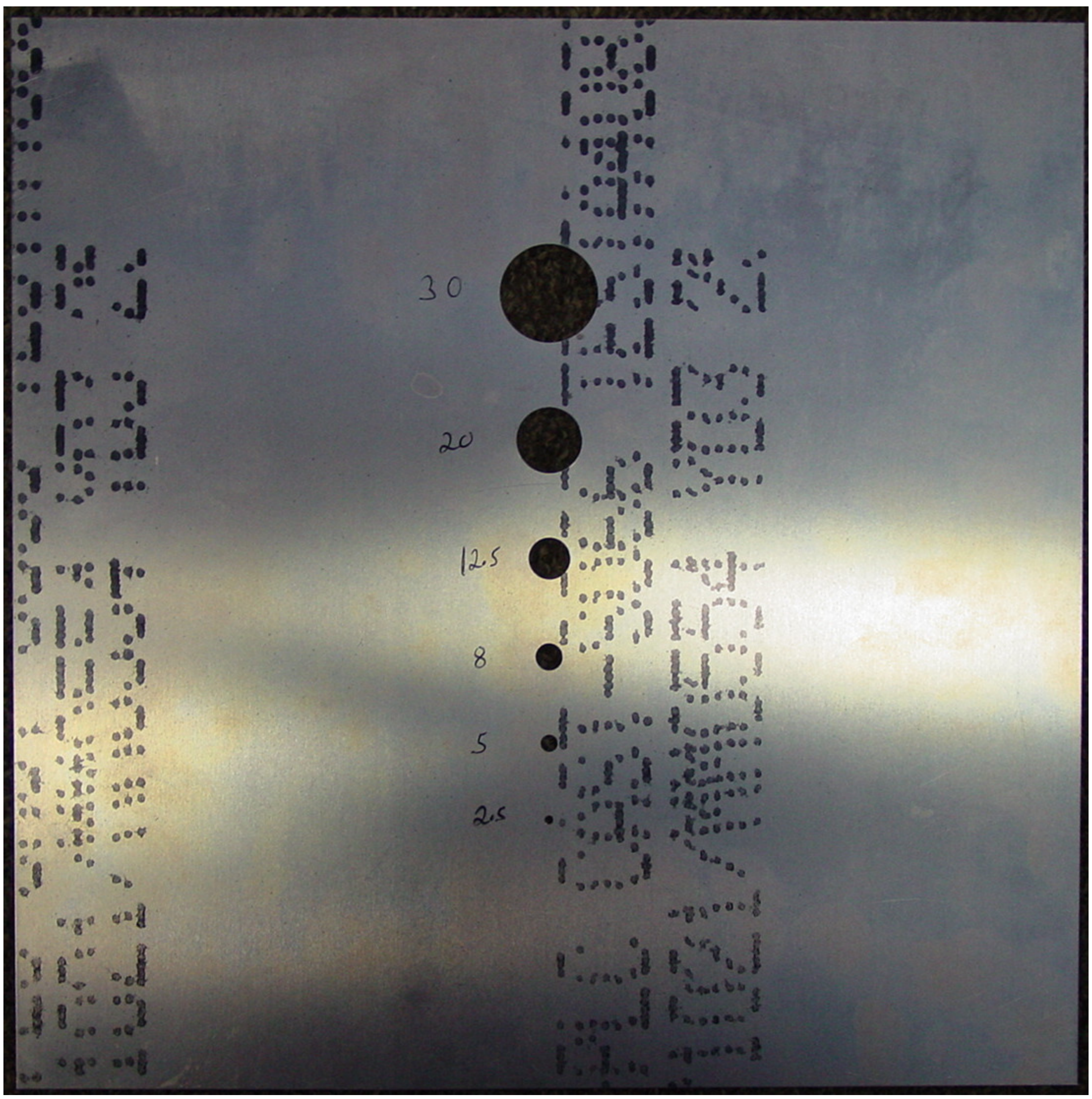


Figure 2

The hole diameters were
2.5 mm
5 mm
8 mm
12.5mm
20mm
30mm

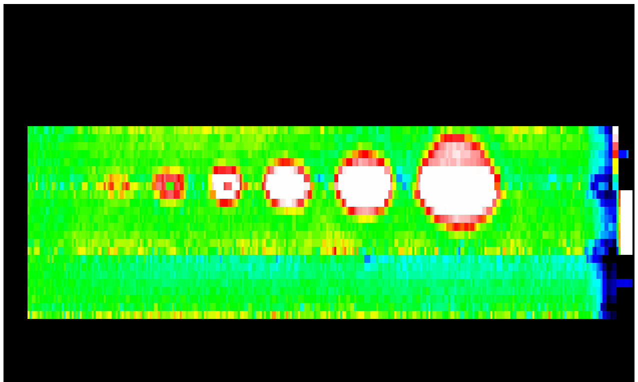
These hole sizes were chosen to follow approximately a square law/area ratio. So as each hole becomes smaller it has roughly a response of half the previous hole. The edges of each hole were chamfered to avoid preferential detection of the sides of the holes versus the loss of material.

For the test all 10 sheets were stacked up to make a 10 mm stack. A test with each technique was performed 10 different times, each time the layer with the holes was moved sequentially lower in the stack. Details of the test set-up are outlined below.

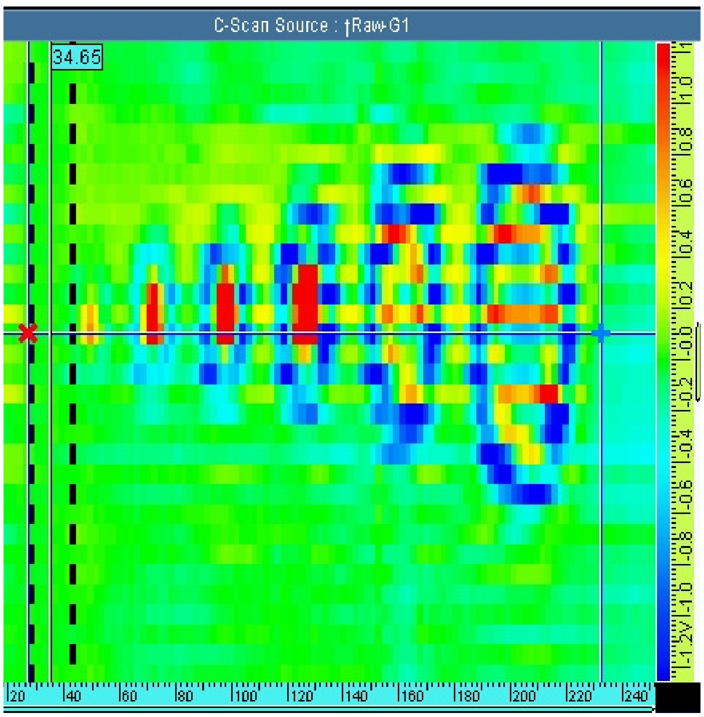
1. The modular eddy current array instrument was normalized on 10 sheets with a 10 mm wide gap in one layer at layer 5 for the 2kHz channel (G2) and layer 10 for the 500Hz channel (G1). Phase was set normal. The x direction scan resolution was set equal to the array pitch in the y direction i.e. square pixels. An encoder was added to the probe to improve the alignment of the data from obtained from the two overlapping rows of array elements. In the images shown, subtraction was used to compensate for balance errors found at the –1 to +1 sensitivity; the phase was then adjusted to obtain the optimum image.

2. The Pulsec was calibrated on the 4 by 2.5 mm specimen and lift off set with a 0.5 mm shim. For the scans the Pulsec was set to the lowest resolution of 3 mm. For the Pulsec ™ images, no subtraction was used. The Gaussian filter was used for deeper images to despeckle the image (where this is used it is noted). The colour scale for the c-scan were attempted to match each other as closely as practical.

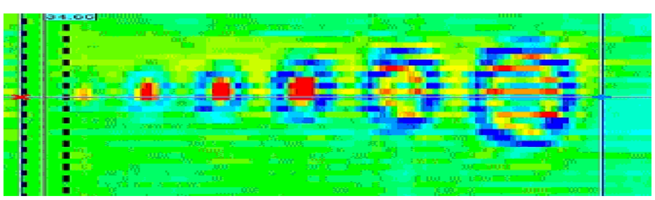
For each layer, the smallest defect that could be discerned was noted, and graphed in figure 4. As an example, the output from the defect specimen at layer 4 (3 mm of good material above the test specimen) is shown for both methods in Figure 3.



3a. Pulsec ™ image for 4th layer defects (1mm material loss plate below 3 1mm layers)



3b. Traditional modular eddy current array output for 4th layer defects (1mm material loss plate below 3 1mm layers)



3c. Traditional modular eddy current array output for 4th layer defects (1mm material loss plate below 3 1mm layers). Image rescaled to 1:1 aspect ratio.

Figure 3

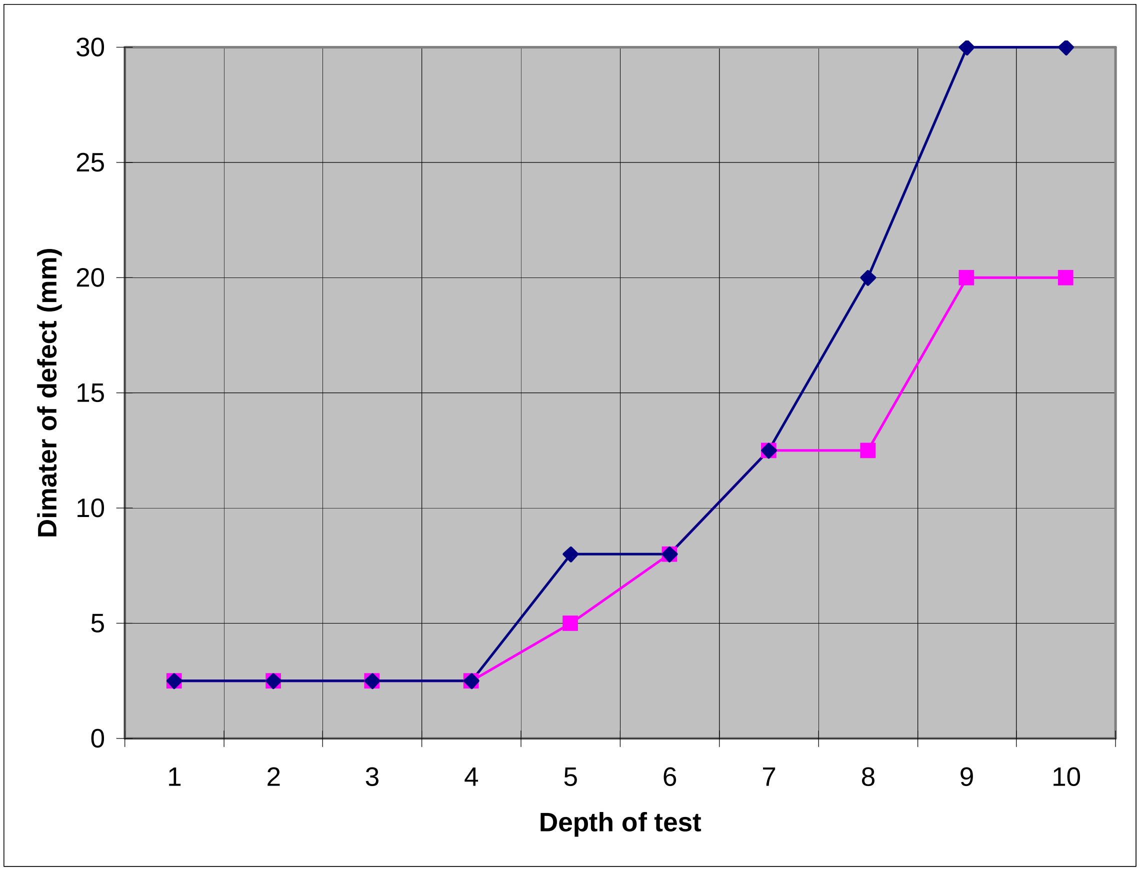


Figure 4. Blue = Traditional modular eddy current; Pink = Pulsec ™ Pulsed eddy current

In this internal analysis, both techniques were able to find small material loss in the first few layers, preliminary data suggests that for thicknesses deeper than 4mm, Pulsec™ may provide increased detection. POD studies should be done to confirm this suggestion.

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