

Enhanced Detection of Deep Corrosion Using Transient Eddy Currents

Jesse Skramstad
NDT Solutions, Inc. (NDTS)
2192 Goose Lake Road
New Richmond, WI 54017
Tel: 715-248-7522, Cell: 612-554-2105, Fax: 715-248-7519
jesse.skramstad@ndts.net

Robert A Smith
Future Systems Technology Division
QinetiQ Ltd
Farnborough, GU14 0LX, UK
Tel: +44 1252 395655. Fax: + 44 1252 393053.
E-mail: RASmith@QinetiQ.com

David Edgar
Future Systems Technology Division
QinetiQ Ltd
Farnborough, GU14 0LX, UK
Tel: +44 1252 395655. Fax: + 44 1252 393053.
E-mail: DEdgar@QinetiQ.com

Abstract

Recent developments in the use of transient eddy-current methods have demonstrated its advanced ability to detect and characterise corrosion and cracks within complex structures, using a single acquisition scan. In addition, the use of Hall sensors to measure the magnetic field directly provides deeper penetration into metals than is achieved using a conventional coil sensor. However, the rapid increase in effective field size with depth in the structure means that there is always a trade-off between defect sensitivity and susceptibility to the presence of nearby edges, fasteners and other sub-structure. The ability to characterise the defect in terms of metal loss, size and depth can also suffer when defect sensitivity is increased.

This paper reports an investigation to determine how the sensitivity could be increased for metal-loss defects deeper than 16 mm (0.625") in the case when the proximity of structural changes is not an issue. The essential requirement is to increase the contrast between good and defective structure by either reducing noise levels or increasing the strength of the field reflected from the defect. An increase in the reflected field can be achieved by either increasing the incident field strength, or changing its spatial characteristics. Results have shown that defect sensitivity can be increased using these methods to enable a considerable improvement in detectability of metal loss deep in thick aluminum structure.

1. Introduction

Transient eddy-current non-destructive testing is arousing increasing interest for the detection of cracks and corrosion in aging metallic aircraft structures. A major attraction is that a single scan over a large area of structure contains sufficient information for both detection and

characterization of defects, regardless of structural variations. Such a scan can be performed with minimal operator training due to the simple data acquisition procedures. A further benefit is the ability to use advanced analysis methods, supported by analytical models, to determine location, depth, size and severity of defects. The transient eddy-current method requires no parameter changes at acquisition time to allow for changes in thickness or conductivity and the analysis methods enable the removal of lift-off, edge effects, and other structural changes.

Previous publications have addressed the principles of transient (or pulsed) eddy-currents [1-5], the development of the analysis techniques [6-8], and careful determination of the capabilities and limitations of the method [9,10].

In the transient eddy-current method, an electric field pulse is generated at the surface of a structure and as this propagates down into the structure, over the course of a few milliseconds, eddy currents are generated as a response. The magnetic field measured at the surface will be modified by any changes in the propagation path of the pulse, such as caused by defects, conductivity changes, edges or interfaces. The eddy-current pulse contains a broad frequency spectrum, which is of great benefit during analysis of the signals because it includes the equivalent of numerous single-frequency scans using a conventional eddy-current system. However, as the transient response is a slowly-varying function, it is possible to characterise it adequately with a 'compact transient' containing just twelve or so 'timeslice' measurements of field.

The TRECSCAN[®] system, developed by the authors, has been described in full on other occasions [8-10] and comprises a probe, instrument and computer, with the TRECSCAN software library linked to a scanning application such as ANDSCAN[®] or MAUS[™]. Positional information is acquired using one of many different types of scanner controlled by these scanning applications. The probe contains a coil to generate the eddy-current pulse and a Hall sensor to measure the perpendicular component of the magnetic field at the surface of the structure, in the centre of the coil.

2. Deep corrosion detection

The major technical objective of this project was to design and produce a probe for the TRECSCAN[®] system in order to achieve improved flaw detection to a depth of 15 mm. The improved flaw detection capability was to be verified by NDT Solutions in conjunction with QinetiQ, and demonstrated using USAF Hidden Corrosion Experiment specimens and other appropriate defect specimens.

2.1 Signal-to-noise issues

Fundamental to the detectability of defects is the signal-to-noise ratio, in this case in terms of the contrast obtained on an image between the good and defective regions. If noise levels are considerably lower than the contrast obtained then the defect can be detected provided sufficient dynamic range is available. Decreasing the noise levels or increasing the signal levels will enable the detection of smaller defects. In TRECSCAN there are several possible ways of decreasing the noise, but first the sources of the noise needed to be identified. Signal levels could be increased by increasing the eddy-current density at the defect through improved probe design, or using a larger probe. However, larger probes make the detection system more susceptible to nearby edges and structural variations and larger signal levels could result in saturation of the detection system.

2.2 Noise.

Noise investigations showed that the noise on the later-timeslice images was only a few 16-bit digitisation levels. This means that a higher resolution for averaged timeslice data is required. The TRECSCAN software and file format were modified to use 24 bits for timeslice data. The 24-bit data is slightly less noisy although the real improvement will be when probes with a lower signal strength are used as the digitisation resolution will have been the limiting factor for defect detectability. Other sources of noise have been investigated, including phasing with the mains supply frequency. However, none of these have so far shown a significant effect.

2.3 Probe design.

As mentioned above, improved probe designs can increase the current density at the defect, although an increase in probe size can also mean that nearby edges and structure have a larger effect.

A Very Large Ferrite (VLF) probe has been constructed in an attempt to investigate the improvement in defect detectability obtainable by increasing the probe size and consequently the current density deep in the structure. Initial scans suggested that the VLF can detect smaller amounts of metal loss than the FMF probe which was previously one of the best. However, the spatial resolution of the VLF probe is not as good as the FMF and it would be harder to distinguish defects near to edges or other structural variations. Also, very small defects produce images nearer to the field size than the defect size. This is to be expected with such a large probe and, for defect sizing estimates, it may be possible to correct for this effect using -6 dB sizing and Interrogation Width methods [11].

3. Probe geometry issues

A modelling exercise [11] was extended to the new probe, the aim of which was to take the spatial frequency spectra of a range of probes and propagate them down into a structure, mapping how the magnitude, size and shape change with depth. Through this exercise a greater understanding was achieved of the reasons for one probe having a particular sensitivity or lateral resolution.

Conventional skin depth (Standard Depth of Penetration) δ is only defined at a zero spatial frequency ($k = 0$) and hence is only valid for large probes. A more realistic, spatial frequency-dependent depth of penetration δ_k can be defined as the depth at which the amplitude has decayed to $1/e$ of its original value, and is defined in equation (1).

$$\delta_k = \frac{1}{\text{Re}[\sqrt{k^2 + j\omega\mu\sigma}]} \quad (1)$$

where k is the spatial angular frequency, ω is the temporal angular frequency, μ is the permeability, and σ is the conductivity. Hence it can be seen that for high temporal frequencies, k is less significant, but for low temporal frequencies, k dominates the depth dependence. Figure 1 illustrates how this skin depth varies as a function of temporal and spatial frequency in 40 %IACS aluminum. The horizontal asymptote of each curve, for large fields, represents the Standard Depth of Penetration, which is dependent on temporal frequency. The diagonal asymptote (top-right to bottom-left) is the region of total dependence on spatial frequency. The deep defects that are the focus of this study require lower spatial-frequency content and lower temporal frequencies (see Figure 1). It will be preferable to have components in the field at 100

Hz and below, and to start with a field at least 20 mm in radius. In this region of the graph in Figure 1 the depth of penetration is dominated by spatial frequency effects.

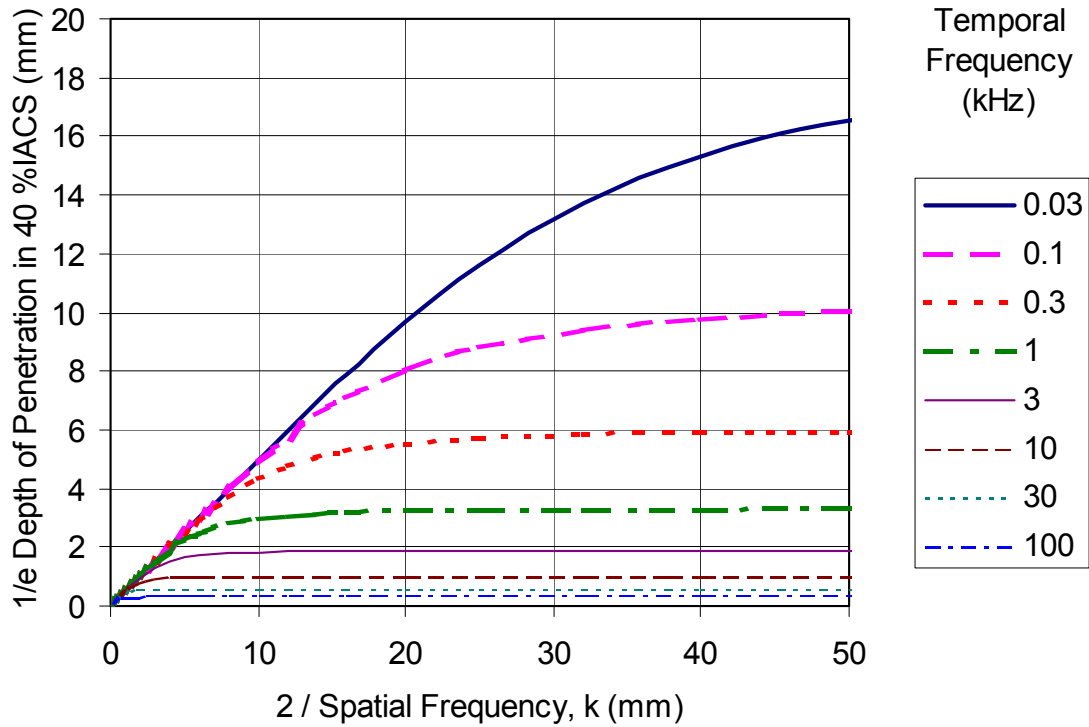


Figure 1: Graph showing how the effective radius of the field (2 / spatial frequency) [11] at the surface affects the depth of penetration into the structure.

The new VLF probe that was constructed for this project has been characterised [12] and its spatial frequency spectrum is shown in Figure 2 in comparison with the other probes that have been produced.

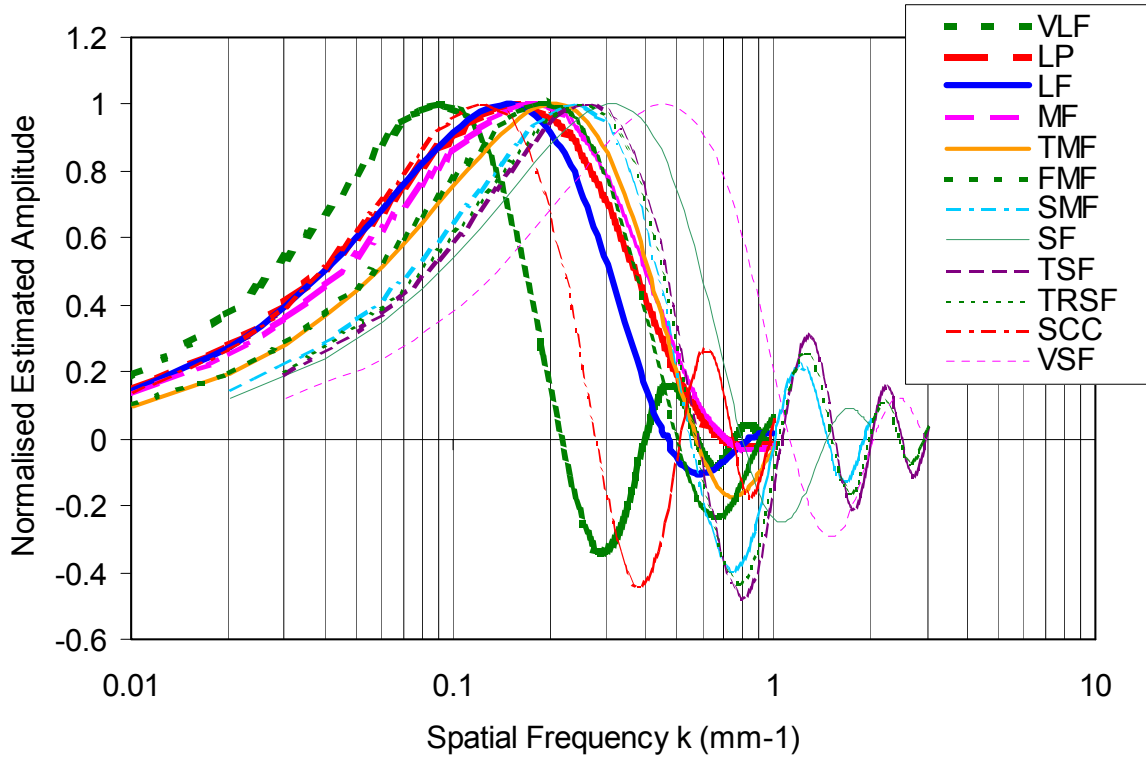


Figure 2: Graph showing the distribution of spatial frequencies in the field for each of the probes including the new VSF and VLF. Each curve is normalized to the peak amplitude for that probe.

The probe that was used for the previous hidden corrosion round-robin was the FMF probe and it can be seen that the new VLF has a lower peak spatial frequency, giving a broader field distribution in the structure

A useful parameter to define at this stage is an *equivalent diameter* at a given depth. This is the diameter of a single-turn coil that would have the same peak in its spatial-frequency spectrum, the field of which could therefore be regarded as representative of ('equivalent' to) the field distribution found at that depth. The peak of the spatial-frequency spectrum of a single-turn coil occurs at $4 / \text{diameter}$ [11]. Hence:

$$\text{Equivalent Diameter} = 4 / \text{Peak Spatial Frequency} \quad (2)$$

A plot of such a parameter as a function of depth in Figure 3 gives an indication of how the field distribution spreads out with depth for various probes at one temporal frequency – 300 Hz.

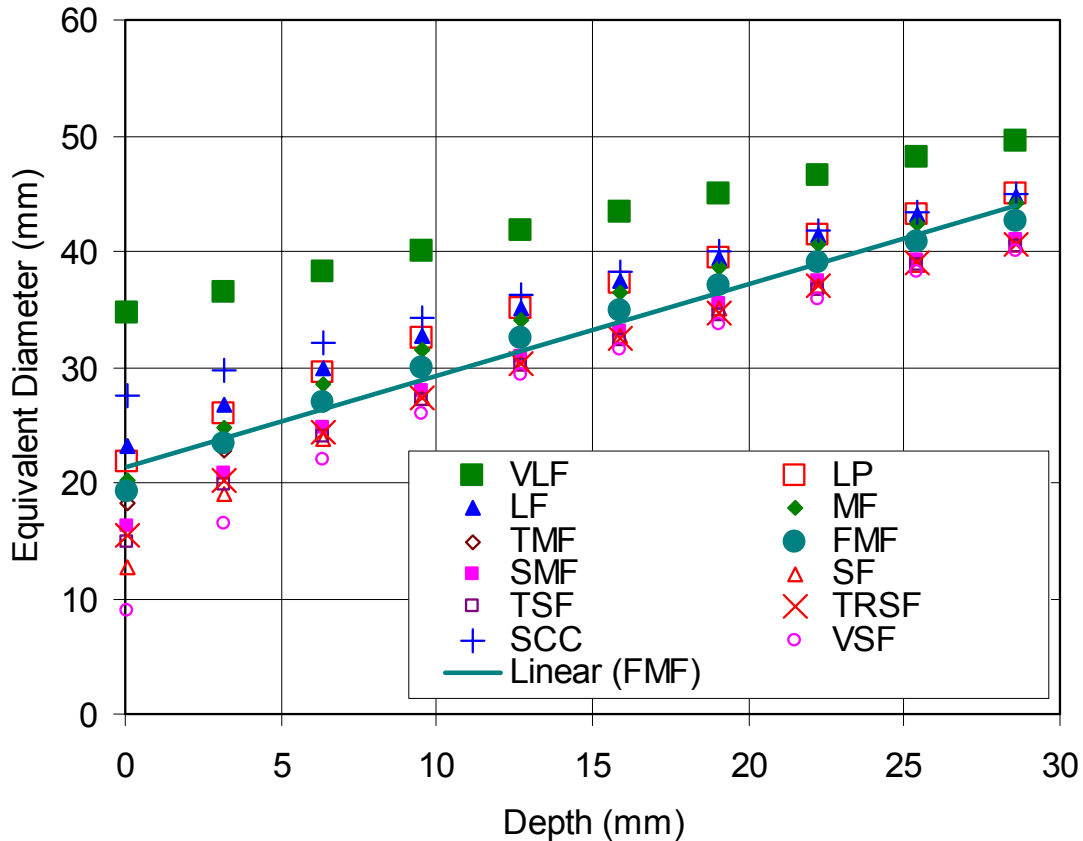


Figure 3: Depth dependence of field size for different probes at a temporal frequency of 100 Hz. A linear regression line has been drawn through the FMF probe data as this probe was used for the original hidden corrosion scans.

4. Results

The following scans were obtained on hidden-corrosion reference specimens comprising three layers. Layers one and three were 3.2 mm (0.125") thick and the middle layer was 12.7 mm (0.500") thick. In the original round-robin exercise, TRECSCAN could not find any of the second-interface defects (at 15.9 mm / 0.625" depth) using any of the probes available at that time – see Figure 4. Initial scans with the VLF probe have now found the most severe deep corrosion site and also the medium amount of metal loss, but not the least severe defect. It may be possible to improve on this and see all three defects (see Figure 5).

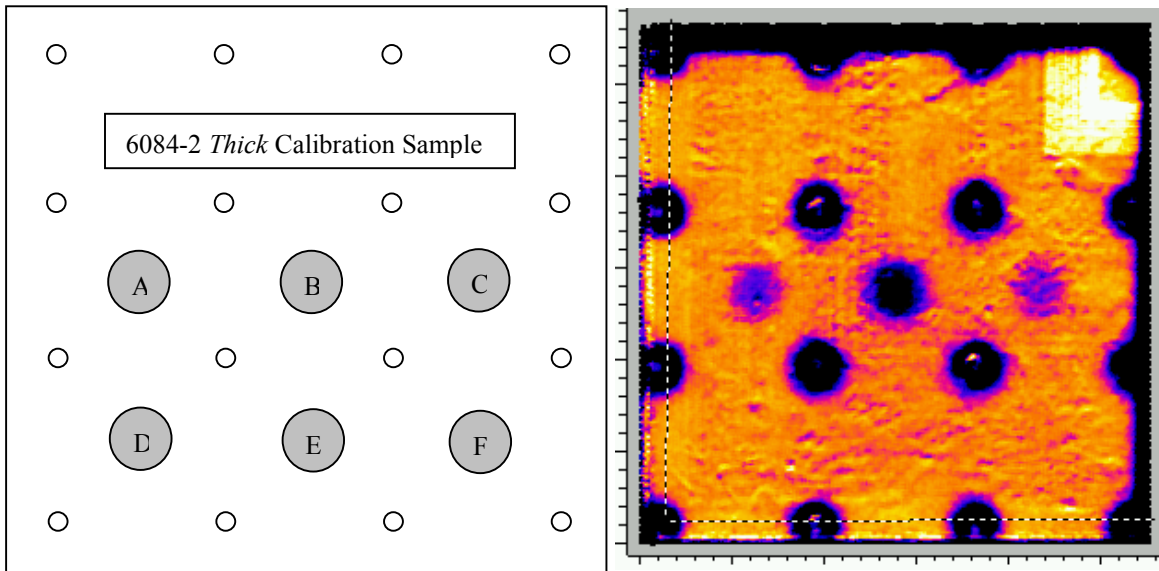


Figure 4: Diagram (left) and 16-bit FMF probe scan of the hidden-corrosion reference specimen showing first-interface (3.2 mm / 0.125" deep) A, B and C, (metal loss: 0.5, 1.0 and 0.5 mm respectively) and second-interface (15.9 mm / 0.625" deep) defects D, E and F (metal loss: 0.625, 1.9 and 3.17 mm respectively). Note that only the shallow defects can be detected despite this being a timeslice 10 scan which should correspond to the depth of the deep defects.

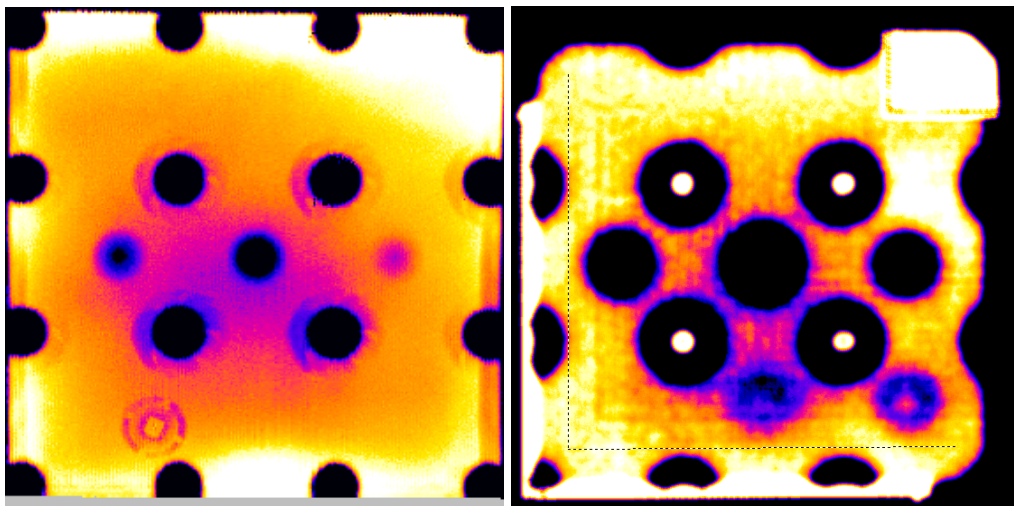


Figure 5: Scan of specimen 6084-2 using the new VLF probe with 24-bit resolution transient data. Timeslice 2 (left) and Timeslice 11 (right). The latter is shown with edge subtraction at the left and bottom edges simultaneously and 2 of the 3 deep defects can be seen clearly.

5. Conclusions

This paper describes a project aimed at improving the detection of 16 mm deep metal loss defects such as corrosion. The issues preventing detection with current transient eddy-current probes and acquisition systems have been addressed. TRECSCAN software was modified and

a new probe developed and these improvements have succeeded in producing a system capable of deep defect detection, finding all of the 16 mm deep defects with 1.9 mm metal loss or more.

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