Detection of cracks in Multi-Layer Aircraft Structures with Fasteners Using Remote Field Eddy Current Method

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INTRODUCTION

- Significant improvement must be made to existing ECT to meet the demand for deeply hidden flaw detection.
- Recent development of RFEC Technique shows promise in this area.
- WPAFB provided crack specimens for improvement of RFECT.
- Live demonstration will be given to show the progress.
Remote Field Eddy Current Technique

Indirect energy coupling path

Excitation coil

Direct energy coupling path

Pick-up coil

Indirect energy coupling path
Remote Field Eddy Current Technique

**Phenomenon:**
- Signals received by pick-up coil is closely related to the wall condition: thickness, conductivity, and permeability.

**Underlying Physics:**
- Direct energy coupling is restricted by EC in the wall.
- Pick-up coil signal, $\Phi_{RF}$, is dominated by the energy diffusing along the indirect coupling path that traverses the wall twice.
- Phase of $\Phi_{RF}$ has a linear relation with the wall thickness.
RFECT virus ECT

**ECT**

- **Z** is proportional to total flux
  
  \[
  Z = R + j\omega L 
  \]
  
  \[
  L = N\Phi / I 
  \]
  
  \( \Phi \) - **Total flux**

- A flaw causes very limited Change in \( \Phi \), so does in \( Z \).

- The change in \( \Phi \) caused by a deeply hidden flaw may be less than 0.01\% - 0.001\%. It is very difficult to separate the change from a normal signal.
RFECT virus ECT

RFECT

- E is proportional to a portion of flux, $\Phi_{RF}$, that has passed the tested object twice.
- A flaw causes significant change in $\Phi_{RF}$, so does in E.
- The change in phase of $\Phi_{RF}$ caused by a flaw has a linear relation with the wall thickness.
RFECT virus ECT

ECT
- Lift-off alters $Z$ quite a lot.
- Signal level is high, but the variation due to a flaw is low, or flaw-signal/normal-signal ratio is low.
- Low-frequency may increase change of $\Phi$ and $L$, but the signal may not increase due to lower induction at lower frequencies:
  $$Z = R + j\omega L$$
- MR or GMR is a better solution.
RFECT virus ECT

RFECT

- **Lift-off** alters signal magnitude, but does not alter much signal phase.
- **Signal level** is low, but **flaw-signal/ normal-signal** ratio is high.
- **Low-frequencies** are always used in RFECT.
- **MR or GMR** can be used in RFECT too.
Specimens

- CNDE Corrosion Specimens:
  - 12”x12”x0.063” 2024-T3

Corrosion Thinning

Specimen

Thicker AL sheet

RFEC Probe
Specimens

- Lockheed Georgia Crack Specimens B4-1

A 0.031” long crack on the bottom surface of the second layer

10 fasteners in ¼” holes 0.73” apart
Demo 1: Detecting Hidden Material Discontinuity

- **Demo 1-1**
  - 0.33"

- **Demo 1-2**
  - 0.33"
  - 0.047” Gap
  - 0.047”

- **Demo 1-3**
  - 0.33"
  - 0.182"
  - 0.047” Gap
  - 0.047”
Demo 1: Detecting Hidden Material Discontinuity

DEM0 #1 - Detecting Material Discontinuity Far Below Surface

- 0.33 inches below
- 0.51 inches below

Reference - Clear sheet
Demo 1: Detecting Hidden Material Discontinuity
Demo 2: Detecting 0.006” Hidden Corrosion Thinning

DEM0 #2-1 - Detecting 10% Corrosion Thinning on Specimen #5

- Imaginary Component
  - frequency = 500 Hz
  - phase rotation = 340 degrees

- Real Component

0.063”

10% thinning
Demo 2: Detecting 0.006” Hidden Corrosion Thinning

DEMO #2 - Detecting 4% Corrosion Thinning on Specimen #5

- frequency = 500 Hz
- phase rotation = 274 degrees

0.09”
4% thinning
Demo 2: Detecting 0.006” Hidden Corrosion Thinning

DEMO #2-3 - Detecting 2.45% Corrosion Thinning on Specimen #5

- Frequency = 500 Hz
- Phase rotation = 225 degrees

- Imaginary Component
- Real Component

0.182”

2.45% thinning
Demo 2: Detecting 0.006” Hidden Corrosion Thinning
Demo 3: Detecting 0.002” Hidden Corrosion Thinning

Figure 7. DEMO #3-1 - Thickness = 0.063”, Corrosion Depth = 0.002”, Relative Depth = 3.17%
Demo 3: Detecting 0.002” Hidden Corrosion Thinning

Figure 8. DEMO #3-2 - Detecting 1.32% Corrosion Thinning on Specimen #1

- Frequency = 500 Hz
- Phase rotation = -260 degrees

Graph showing:
- Imaginary Component
- Real Component

- Sample Points range from 20 to 160
- 0.09” thickness indicated
- 1.32% thinning
Demo 3: Detecting 0.002” Hidden Corrosion Thinning

Figure 9. DEMO #3-3 - Thickness = 0.245”, Corrosion Depth = 0.002”, Relative Depth = 0.82%
Demo 3: Detecting 0.002” Hidden Corrosion Thinning

DEM0 #3 - Comparing Complex Signals From Different Depths and Thinning

- 0.153” thick, 4.31% thinning
- 0.245” thick, 0.82% thinning
Demo 4: Detecting 0.031” Hidden Fastener Hole Crack

DEMO #4 - Detecting Cracks on Lockheed Specimen #B4-1: Raw Data

Excit. Coil-Center - Rivet Cent. Distance = +15 mm
Excitation coil on the left of the rivet
Demo 4: Detecting 0.031” Hidden Fastener Hole Crack
Demo 4: Detecting 0.031” Hidden Fastener Hole Crack

DEM0 #4 - Detecting Cracks on Lockheed Specimen #B4-1: Zoom-In Complex Plane

Excit. Coil Center - Rivet Cent Distance = 15 mm
Excitation coil on the left of the rivet

Solid - #8, cracked hole, Dotted - others
Demo 4: Detecting 0.031” Hidden Fastener Hole Crack

2-D Phase Indication of Abnormal Rivet Holes on Specimen B4-1

- Frequency = 250 Hz
- Excitation Coil on the Right
- Threshold = 1.5 Degrees
- Dotted vertical lines indicate the center locations of each fastener
The RFEC system is capable of detecting:

1. Materials break that is about half a inch below the surface of inspection.
2. Corrosion that is about 1/4" below the surface with accuracy around 1% or 2%.
3. A 0.031" long crack that is 0.446" below the surface on a fastener hole.
PARAMETER STUDY

FREQUENCY SELECTION

- The higher the frequency is used the shallower the penetration is expected.
- However, the higher induced voltage is received from the same amount of flux and the sharper edge indication is seen in the signals.
- Therefore, there is an optimal frequency range for each application.
PARAMETER STUDY

*Minimize influence from a steel fastener*

Signals from #4 & #6

Signals from #4 & #6
PARAMETER STUDY

Example:

Lockheed Specimen B2-26 at F=3.0kHz: a crack on counter-sunk surface
PARAMETER STUDY

- **Excitation - Pickup Coil Distance (EPD)**
  A smaller EPD allows higher sensitivity to shallower cracks and a greater EPD is used for detecting a deeper crack

- **Excitation Coil - Fastener Distance (EFD)**
  The deeper the crack is located, the greater the EFD is used, but keep the pickup coil slightly away from the fastener edge
CONCLUSIONS

- A novel RFEC system has been introduced and demonstrated.
- The new technique shows great superiority over the conventional ECT in the detection of deeply hidden corrosion and cracks.
- A brief description of the selection of RFEC probe parameters have also been introduced.
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