NDE with SQUIDs

Sheet Inducers and Depth-Selective, Oriented Current Imaging

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phase of the induced eddy current in plate

phase (degree)

z (mm), delta/t = 0.1, 0.2, 0.5, 1.0

0 1 2 3 4 5
δ = 2.4mm, t = 12.6mm    Void: φ8 × 3mm at 1mm below the surface
Phase Analysis

- Squared maximum value of the signal vs depth of flaw

a) ![Diagram](image1)

b) ![Graph](image2)

- Squared maximum value of the signal vs size of flaw

a) ![Diagram](image3)

b) ![Graph](image4)
DEPTH - SELECTIVE TECHNIQUE
(a) Current vector

(b) In-phase component (phase 0°)

(c) Quadrature component (phase 90°)
MAGNETIC IMAGE OF CRACKS
ADJACENT TO RIVETS
(Using Depth-Selective Technique)
SAMPLE WITH HIDDEN CORROSION (7075-T6)

(Two 0.125 inch thick aluminum plates with four sites of corrosion in the second layer)

\[ f = 210 \text{ Hz, Phase} = 130^\circ \]

Sample provided by Lockheed, Inducer with 4 wires
ORTHOGONAL SHEET INDUCER

\[ I = I \cos \omega t \]

\[ \text{angle} = \omega t \]

\[ Y \]

\[ X \]

\[ I \sin \omega t \]

\[ I \cos \omega t \cos \alpha \]
ROTATING CURRENT
Orthogonal inducer with 90° phase shift.

-15°  5°  25°

45°  65°  85°

105°  125°  145°

SAMPLE: 2mm thick aluminum plate.
SELF-REFERENCE
SELF REFERENCE FOR CRACKS ADJACENT TO HOLE

(a) Amplitude (nT) vs. Angle of current

(b) Average amplitude (nT) vs. Area of flaw (mm²)

(c) Amplitude fluctuation (%) vs. Area of flaw (mm²)

With cracks: I≠0

No crack: I=0
SELF-REFERENCING

and

PHASE SELECTION
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DEPARTMENT

TL147 J256 18
SELF REFERENCE WITH PHASE ANALYSIS
Oorthogonal sheet inducer with in-phase currents

Two layers Al plate with four rivets.
SAMPLE #1  Al 7075-T6  
#2  Al A356

<table>
<thead>
<tr>
<th>8mm</th>
<th>5mm</th>
<th>2mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10mm</td>
<td></td>
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All holes are 1.2 mm diameter. 
Samples are provided by Alcoa
SAMPLE #1 (7075-T6-1)

(18 mm aluminum plate with 1.2 mm diameter holes below surface)

f=170Hz

<table>
<thead>
<tr>
<th>Hole</th>
<th>0°</th>
<th>15°</th>
<th>25°</th>
<th>90°</th>
<th>130°</th>
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<tbody>
<tr>
<td>8mm below</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5mm below</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2mm below</td>
<td></td>
<td></td>
<td></td>
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</table>

f=340Hz

<table>
<thead>
<tr>
<th>Hole</th>
<th>0°</th>
<th>15°</th>
<th>25°</th>
<th>90°</th>
<th>130°</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mm below</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2mm below</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample provided by Alcoa

Inducer with 4 wires
SAMPLE #1 (7075-T6-1)

(18 mm aluminum plate with 1.2 mm diameter holes below surface)
SAMPLE #2 (A356-2)

(18 mm aluminum plate with 1.2 mm diameter holes below surface)

f=250Hz

Holes

0°   50°   70°   90°   130°

5mm below

2mm below

f=510Hz

0°   50°   70°   90°   130°

Sample provided by Alcoa

Inducer with 4 wires
SAMPLE #2 (A356-2)

(18 mm aluminum plate with 1.2 mm diameter holes below surface)

$f=250\text{Hz}$

Phase = 130°

Phase = 50°
All EDM notches
1 mm wide

#1  #2  #3
12 mm  18 mm  18 mm
3 mm deep  6 mm deep  3 mm deep

WELD
EDM NOTCH

18 mm
12 mm
25 mm
a) Face A  

b) Longitudinal current  

c) Transverse current
a) Face A with open notches

b) Face B without open notches

c) Face A with open notches after removing the shift in (a)

d) Face B without open notches after removing the shift in (b)
PC Orthogonal Sheet Inducer
FREQUENCY OPTIMIZATION

for phase-selection
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Current Angle

0
40
80

f=230 Hz

f=1100 Hz

f=5400 Hz

phase 0

phase 90°

phase 0°

phase 90°

phase 0°

phase 70°
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Best frequency

Current Angle

Amplitude

Phase Angle

TL147 J256

f=230 Hz

f=1180 Hz

Best frequency

f=5400 Hz
Self-referencing

Phase Angle 40
f=230 Hz

a)

b)
Second Layer slots

Phase

0°  

60°  

80°  

90°  

TL147 J256
Phase Analysis

Better frequencies
570 Hz - 1 kHz
FATIGUE CRACKS SAMPLE

a)

b) Longitudinal current
c) Transverse current
DETECTION FOR FATIGUE CRACKS BENEATH RIVETS

Total length of crack: #1 --- 4.41mm, #2 --- 3.53mm, #3 --- 4.66mm
ALUMINUM CAPACITOR

a) Different end leads connection

Same total currents

b) Same end leads connection

Larger currents near leads
FIELD MAP FOR ALUMINUM CAPACITOR
(G-10 layer has a hole, 2kHz)

a) Different end leads connection

Same fields through length

b) Same end leads connection

Strong fields near leads
(a) G-10 layer has a copper disk

(b) Image of a 3/4 inch diameter copper disk

(c) Image of a 3/8 inch diameter copper disk
Displacement currents are collected by leads through aluminum.

Magnetic fields (Bz) is mainly due to the collected currents.

How to increase the feasibility of displacement current distribution??

----Reduce cancellation between two electrodes
COPPER - ALUMINUM CAPACITOR

Copper sheet

Aluminum bar

G-10
COPPER - ALUMINUM CAPACITOR
(Imaging processing)

Unflawed G-10

Flawed G-10

a) Raw data

b) Raw data

c) Derivative filtering

d) Derivative filtering

e) Low pass filtering

f) Low pass filtering
INCREASE EDGES !!!
UNFLAWED BAR

Mapping area B
Front
lead #1
copper
insulation
outer layer
lead #3
Mapping area A
Rear
lead #2

FLAWED BAR

Damaged
lead #1
Mapping area B
lead #3
lead #2
Unflawed bar
10V 200 Hz voltage
Unflawed bar
10V 200 Hz voltage
Flawed bar with breakage
5V dc voltage
TL147 J256