NDE with SQUIDs

Sheet Inducers and Depth-Selective, Oriented Current Imaging

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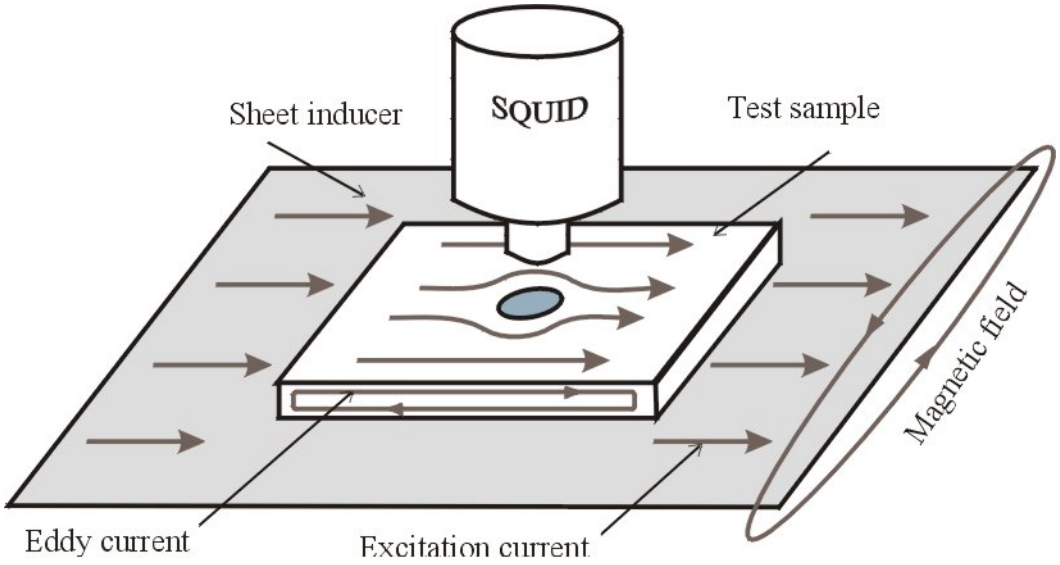
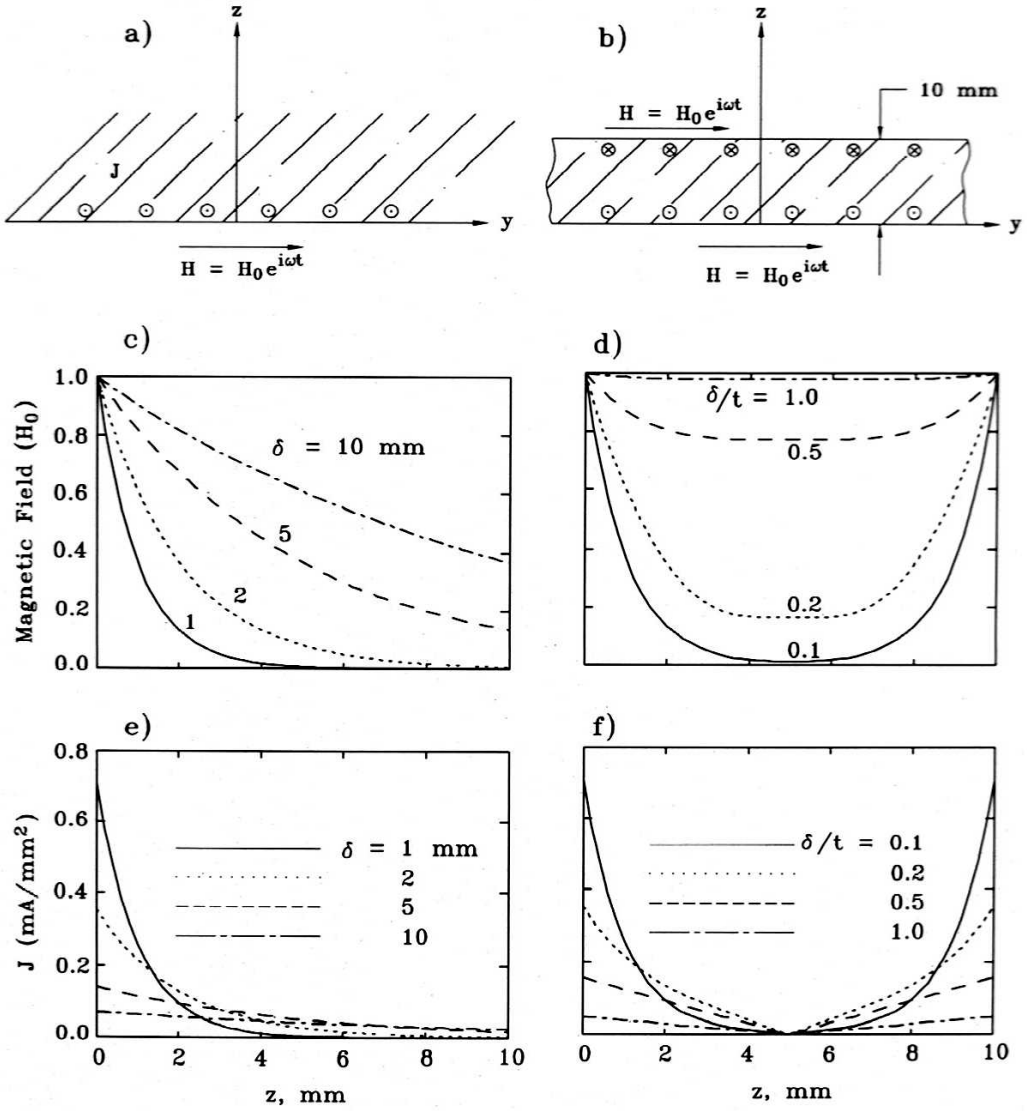
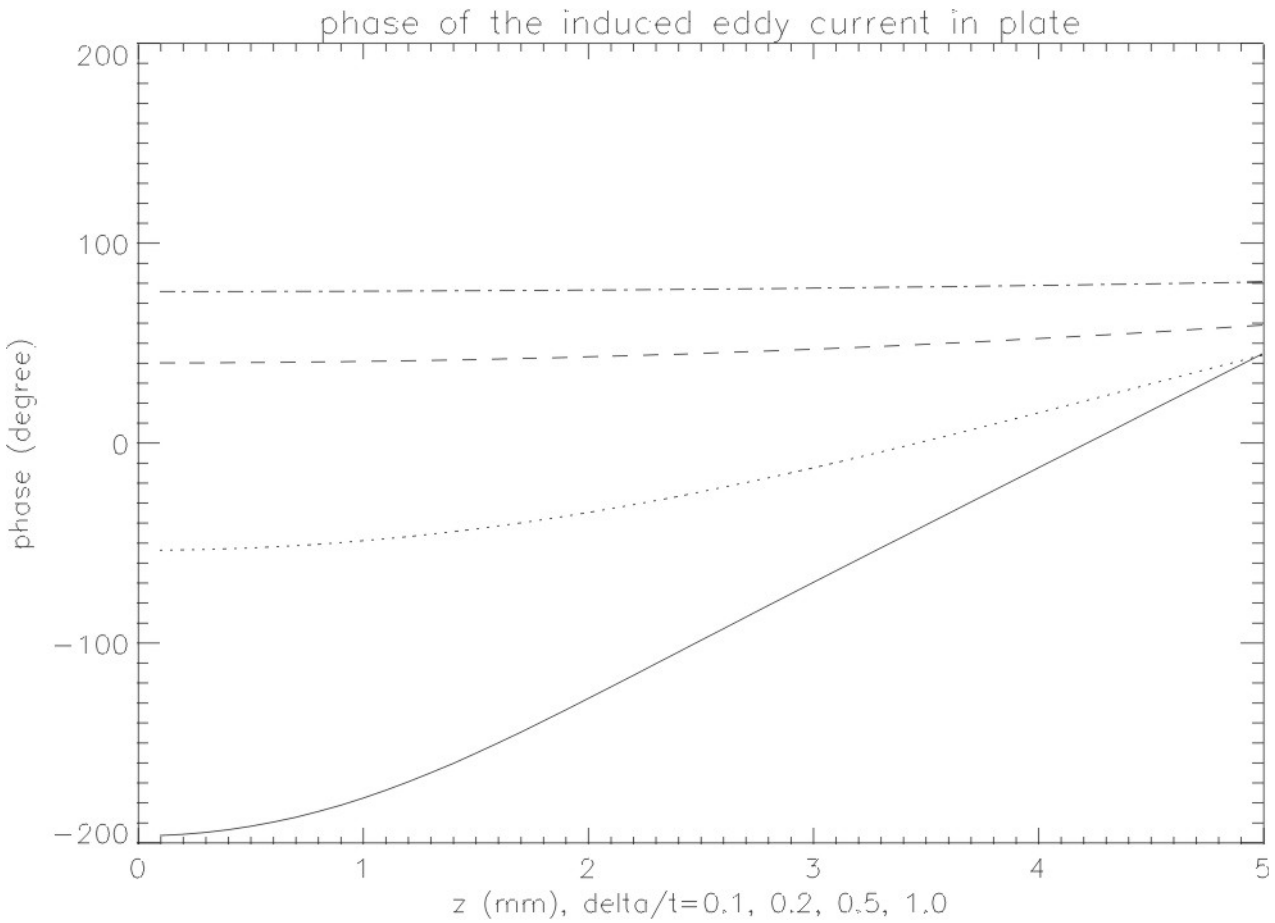
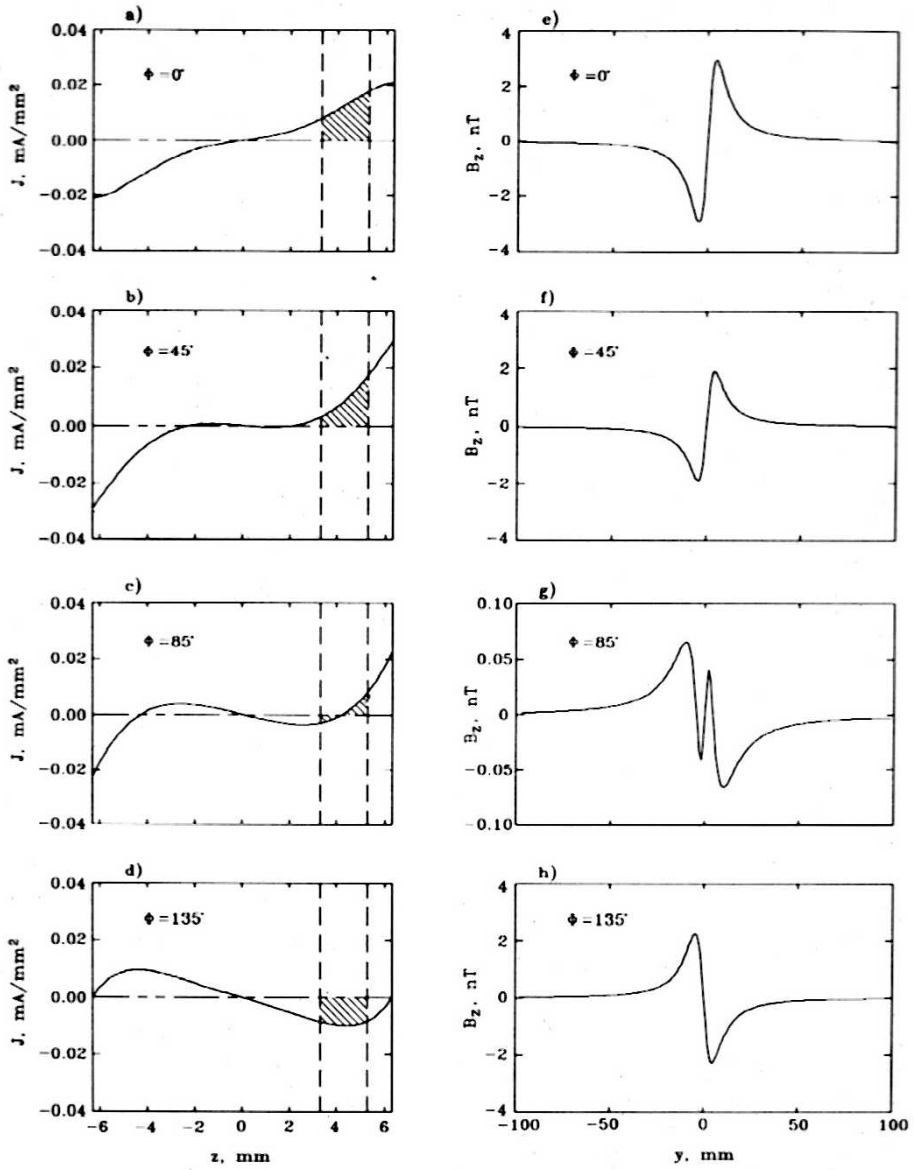

Sheet inducer
SQUID
Test sample
Magnetic field
Eddy current
Excitation current


a)
z
J
y
H = H0 e^iωt
b)
z
H = H0 e^iωt
10 mm
y
H = H0 e^iωt
c)
Magnetic Field (H0)
1.0
0.8
0.6
0.4
0.2
0.0
δ = 10 mm
5
2
1
d)
δ/t = 1.0
0.5
0.2
0.1
e)
J (mA/mm²)
0.8
0.6
0.4
0.2
0.0
δ = 1 mm
2
5
10
0
2
4
6
8
10
z, mm
f)
δ/t = 0.1
0.2
0.5
1.0
0
2
4
6
8
10
z, mm


phase of the induced eddy current in plate
200
100
0
−100
−200
phase (degree)
0
1
2
3
4
5
z (mm), delta/t=0.1, 0.2, 0.5, 1.0

Calculated current distribution

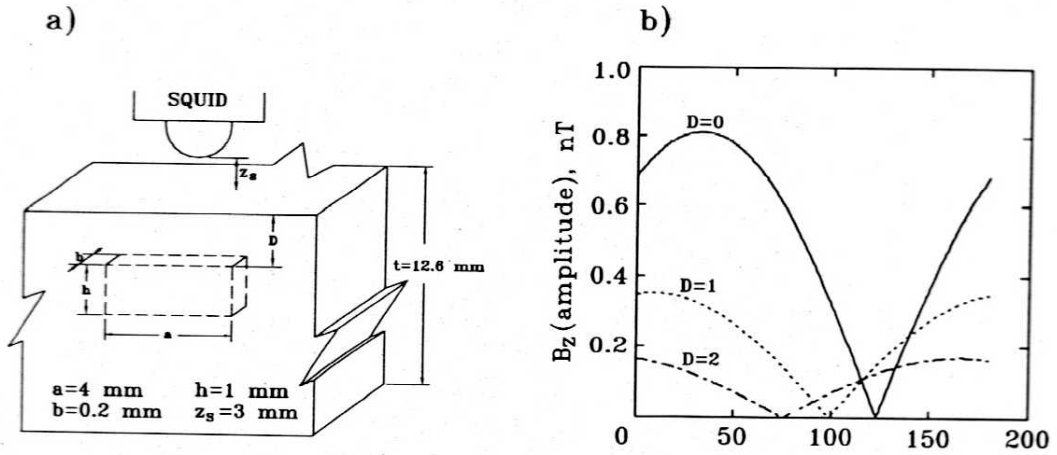
Calculated magnetic signal



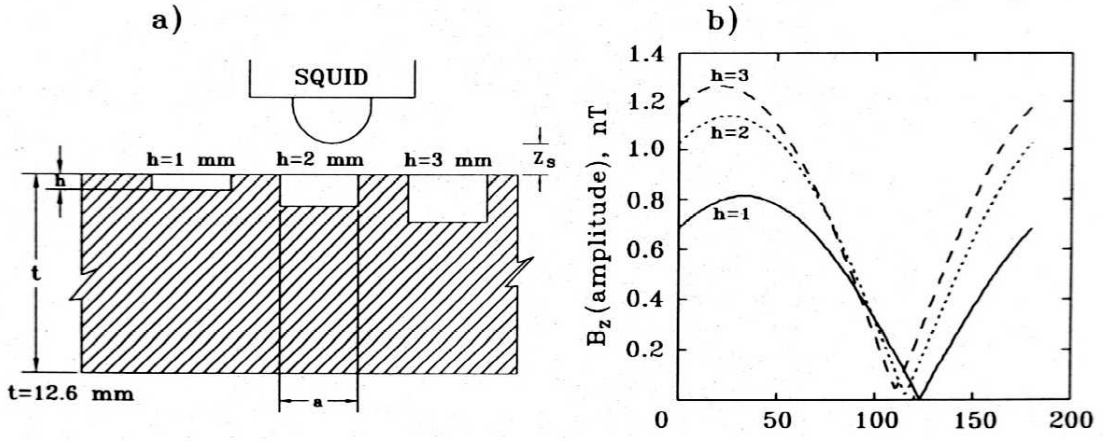
$\delta = 2.4\text{mm}, t = 12.6\text{mm}$ Void: $\phi 8 \times 3\text{mm}$ at 1mm below the surface

Phase Analysis

- Squared maximum value of the signal vs depth of flaw

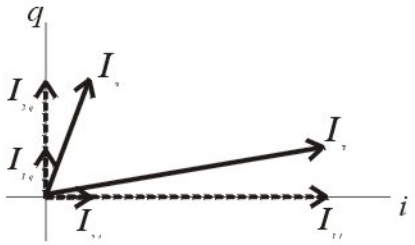


- Squared maximum value of the signal vs size of flaw

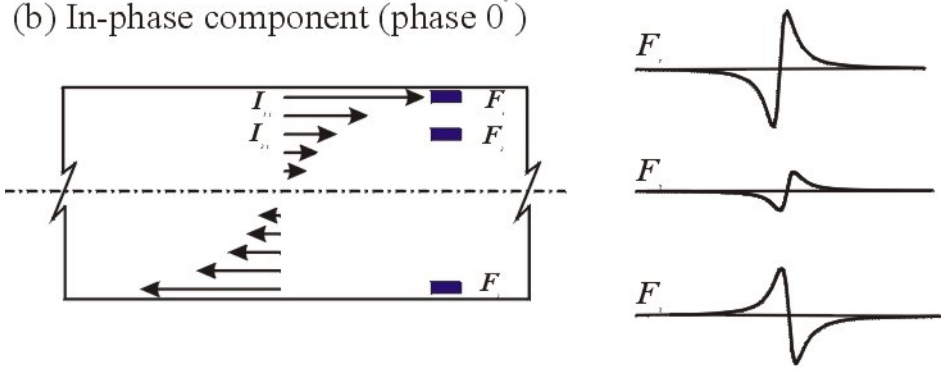


DEPTH - SELECTIVE TECHNIQUE

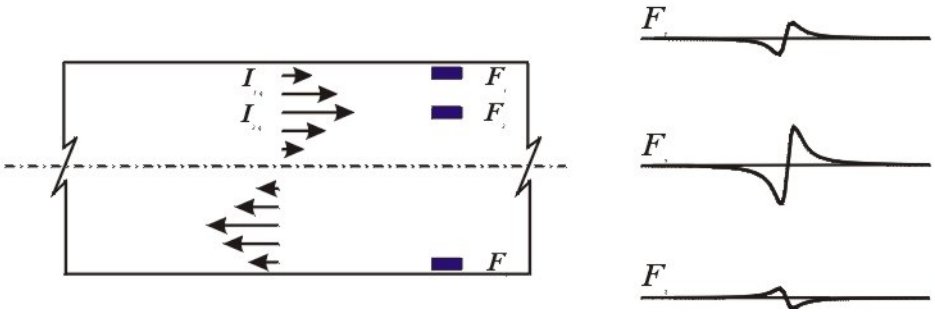
(a) Current vector

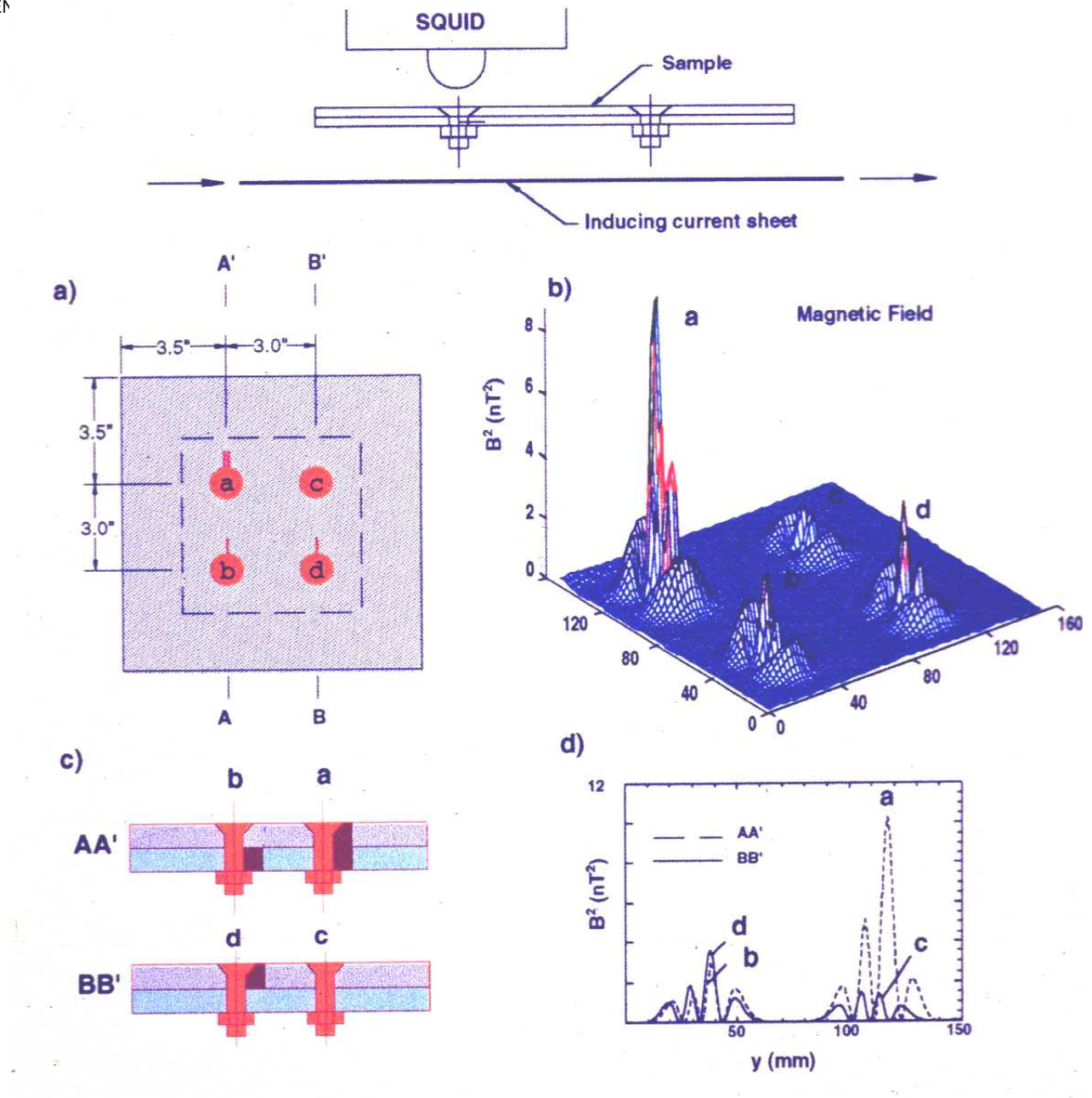


(b) In-phase component (phase 0°)



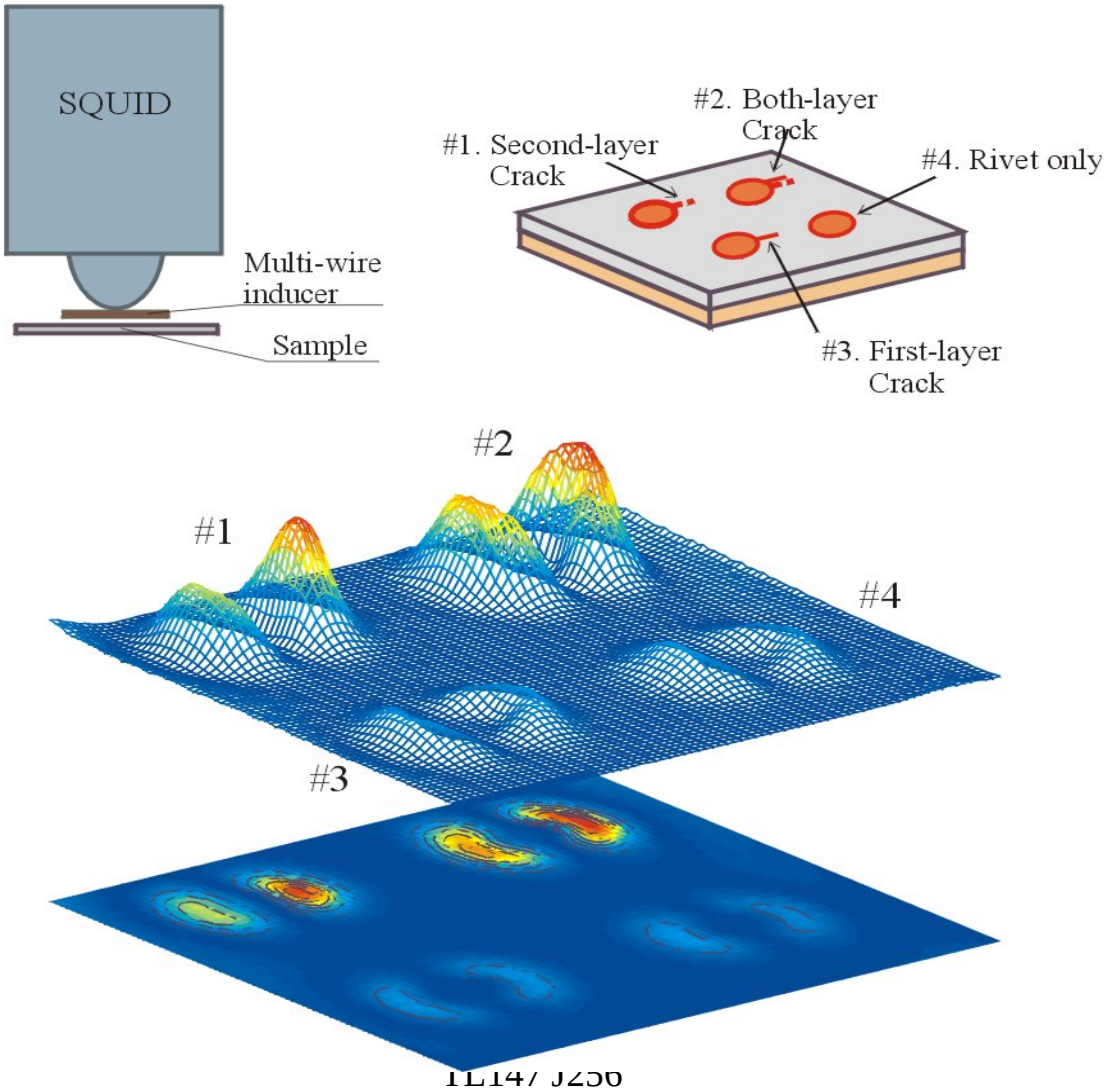
(c) Quadrature component (phase 90°)

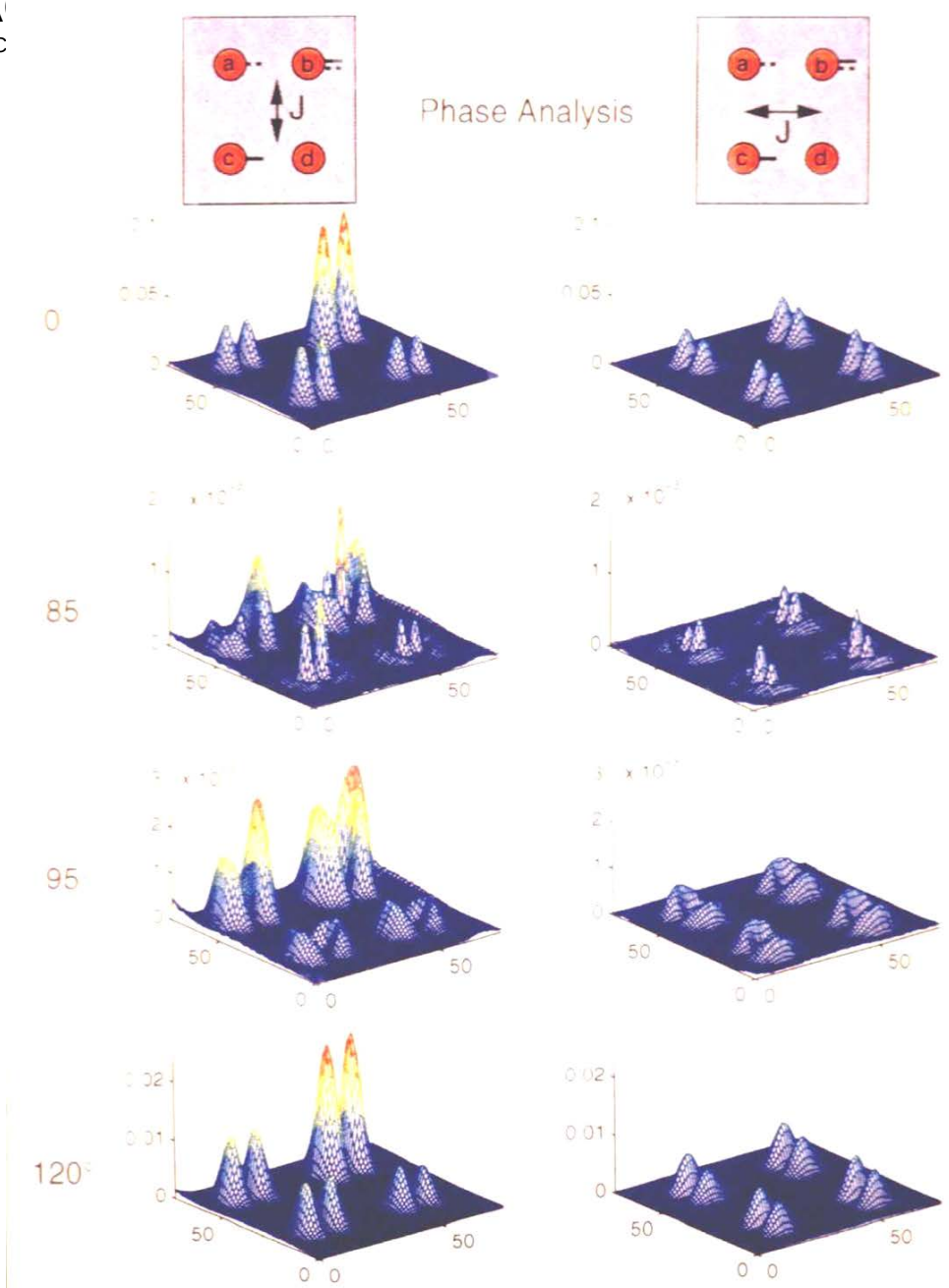



SQUID
Sample
Inducing current sheet
a)
A'
B'
3.5"
3.0"
3.5"
3.0"
a
c
b
d
A
B
b)
Magnetic Field
a
d
B^2 (nT^2)
8
6
4
2
0
120
80
40
0
0
40
80
120
160
c)
b
a
AA'
d
c
BB'
d)
12
a
AA'
BB'
d
b
c
B^2 (nT^2)
50
100
150
y (mm)

MAGNETIC IMAGE OF CRACKS ADJACENT TO RIVETS

(Using Depth-Selective Technique)

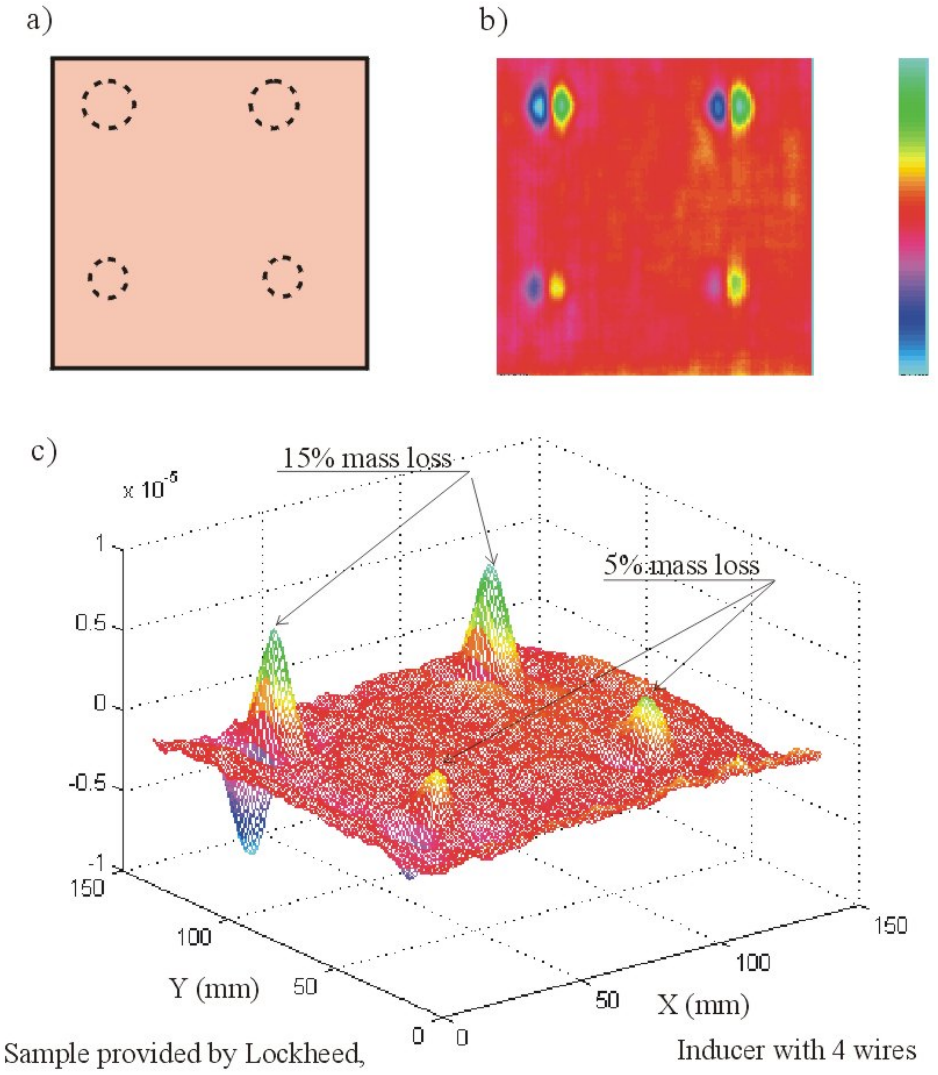



Phase Analysis
a
b
c
d
J
J
0
85
95
120
50
50
0
0

SAMPLE WITH HIDDEN CORROSION (7075-T6)

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

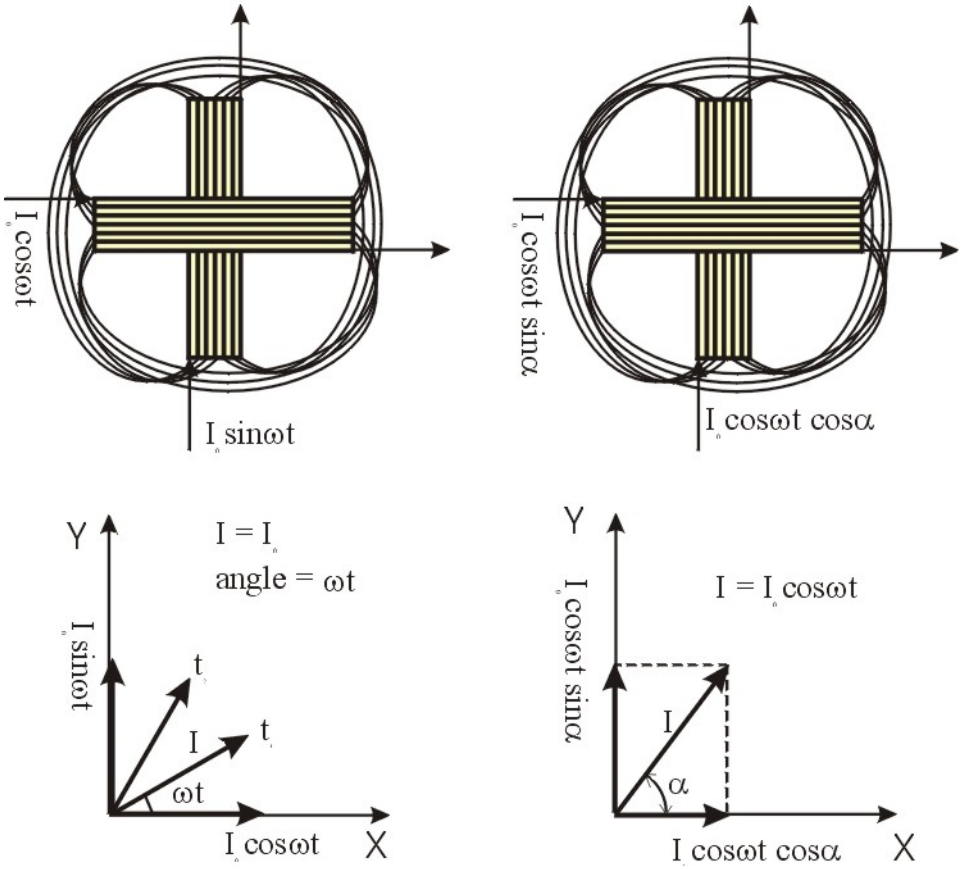
f = 210 Hz, Phase = 130°



Sample provided by Lockheed,

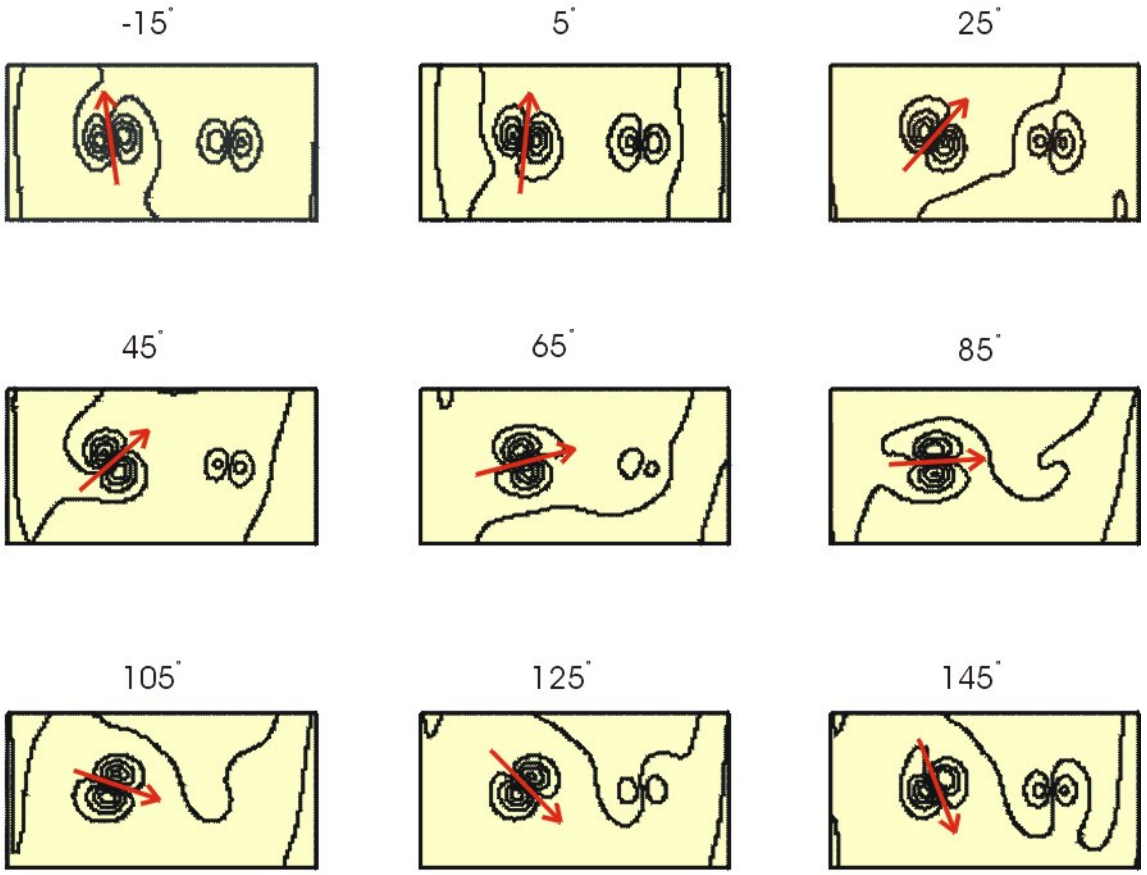
Inducer with 4 wires

ORTHOGNAL SHEET INDUCER

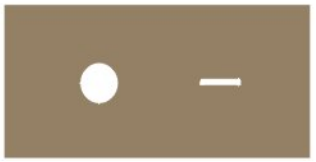


ROTATING CURRENT

Orthogonal inducer with 90° phase shift.

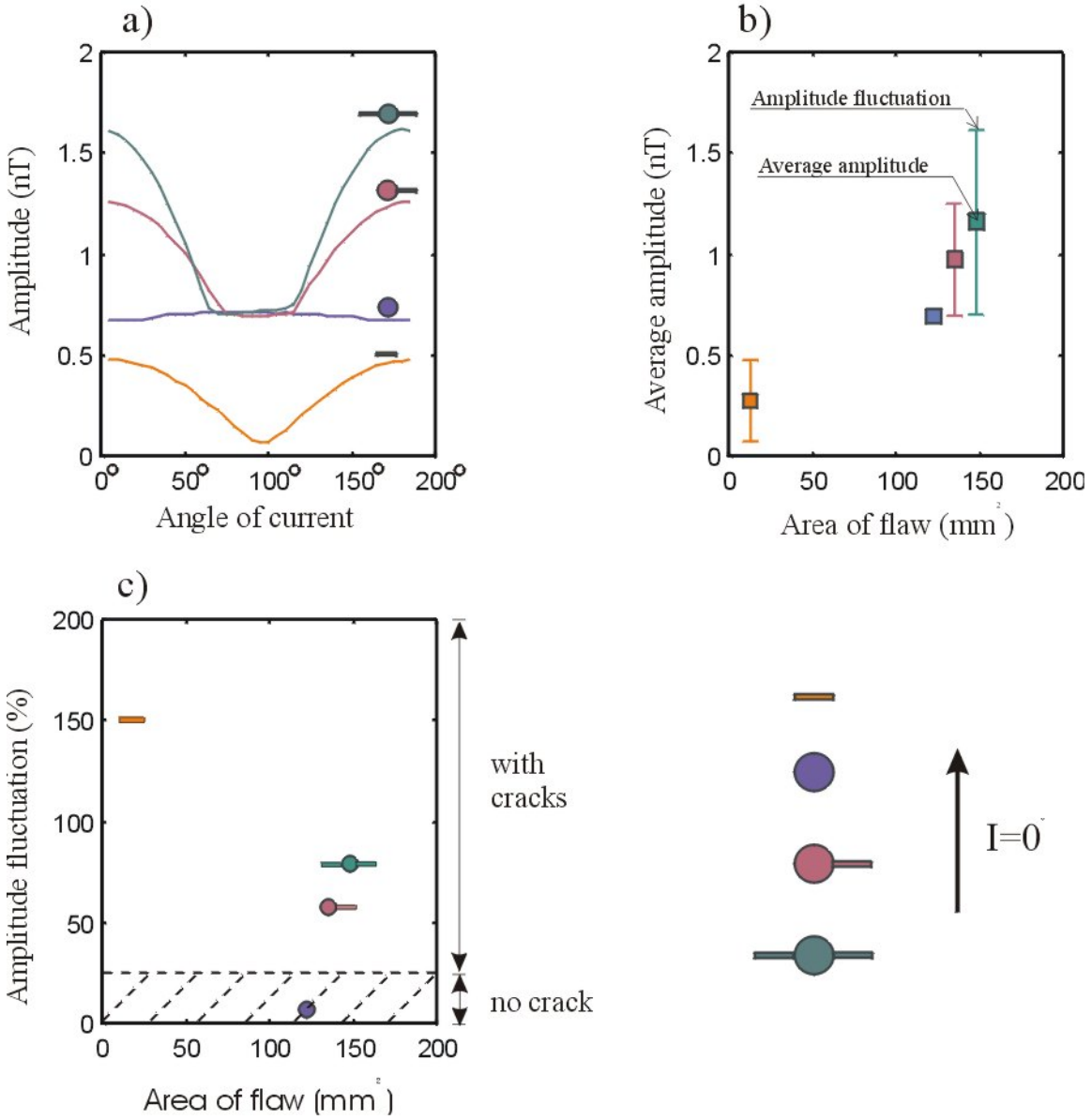


SAMPLE: 2mm thick aluminum plate.



SELF-REFERENCE

SELF REFERENCE FOR CRACKS ADJACENT TO HOLE

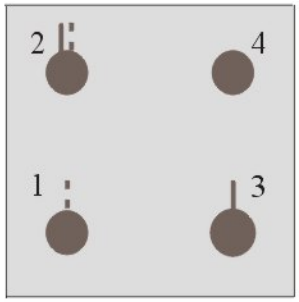


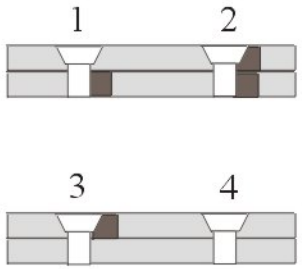
SELF-REFERENCING

and

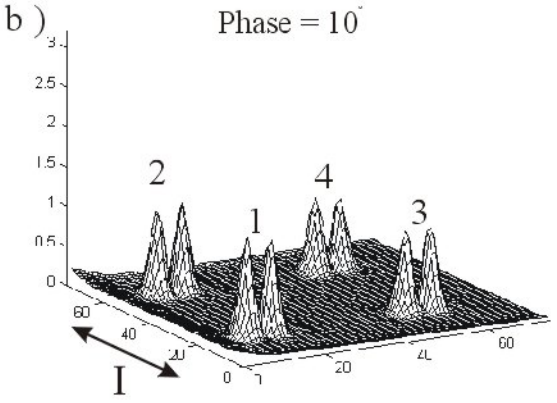
PHASE SELECTION

a)

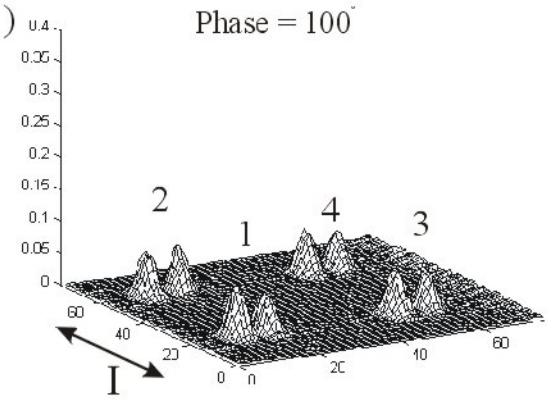

2
4
1
3


1
2
3
4

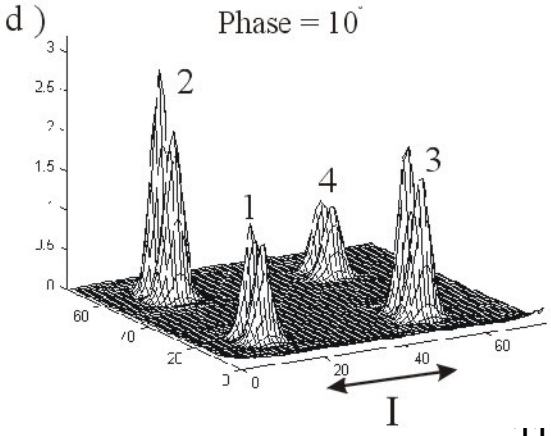
b)


Phase = 10°
2
1
4
3
I

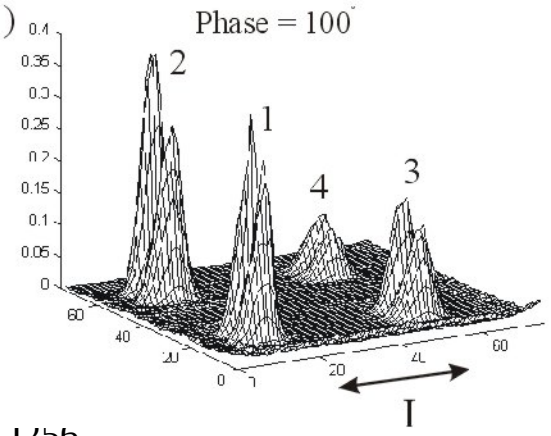
c)


Phase = 100°
2
1
4
3
I

d)

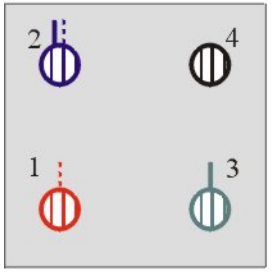

Phase = 10°
2
1
4
3
I

e)

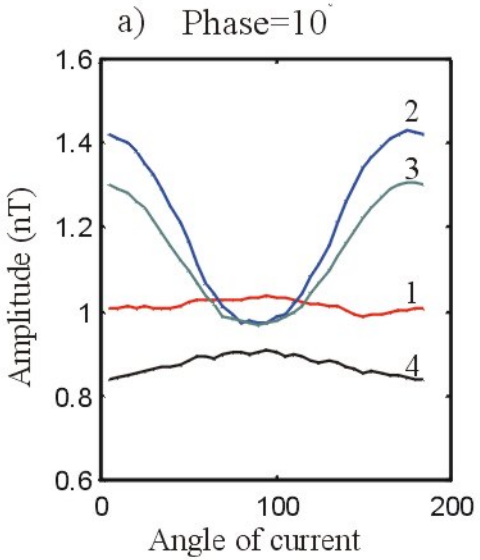

Phase = 100°
2
1
4
3
I

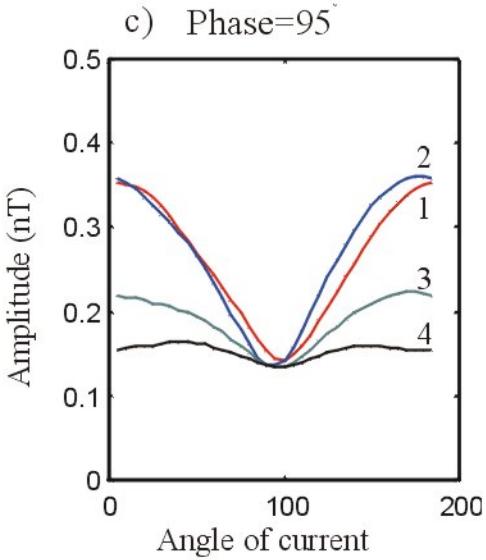
SELF REFERENCE WITH PHASE ANALYSIS

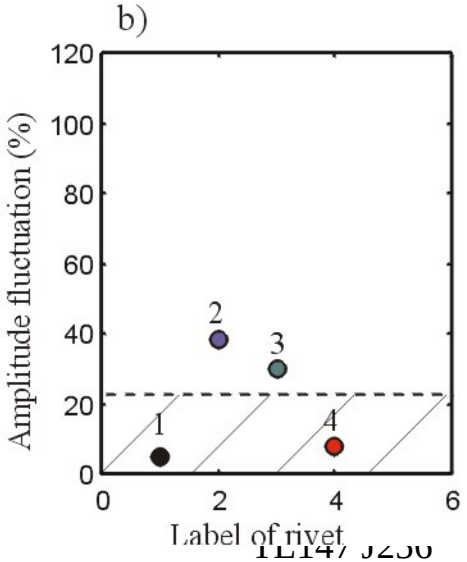
Oorthognal sheet inducer with in- phase currents

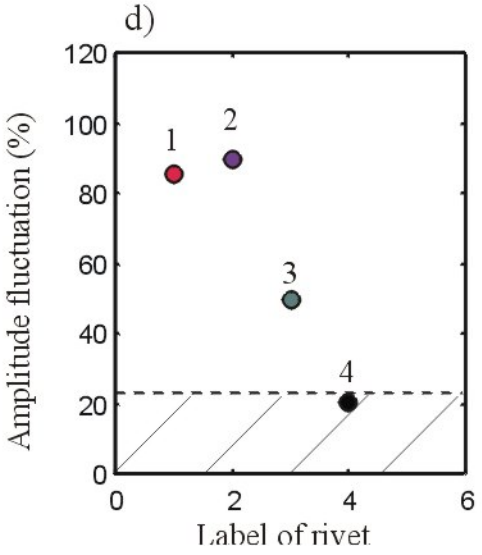


Ttwo layers Al plate with four rivets.

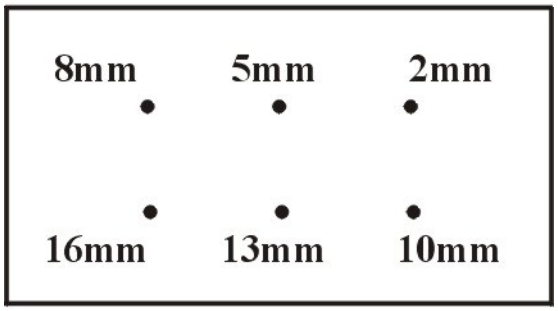


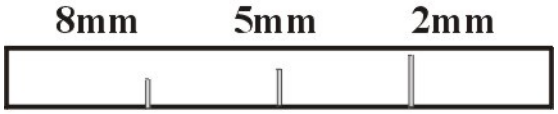






SAMPLE #1 Al 7075-T6
#2 Al A356



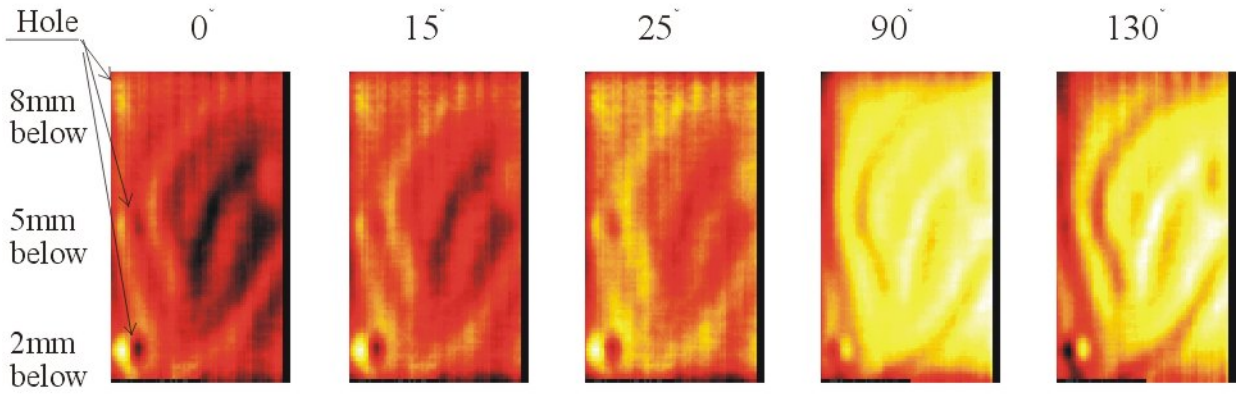


All holes are 1.2 mm diameter.
Samples are provided by Alcoa

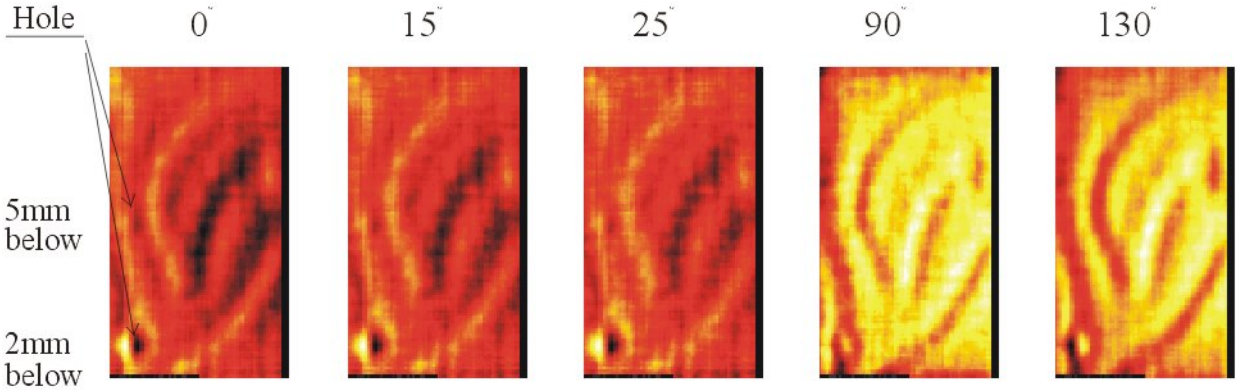
SAMPLE #1 (7075-T6-1)

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

f=170Hz



f=340Hz

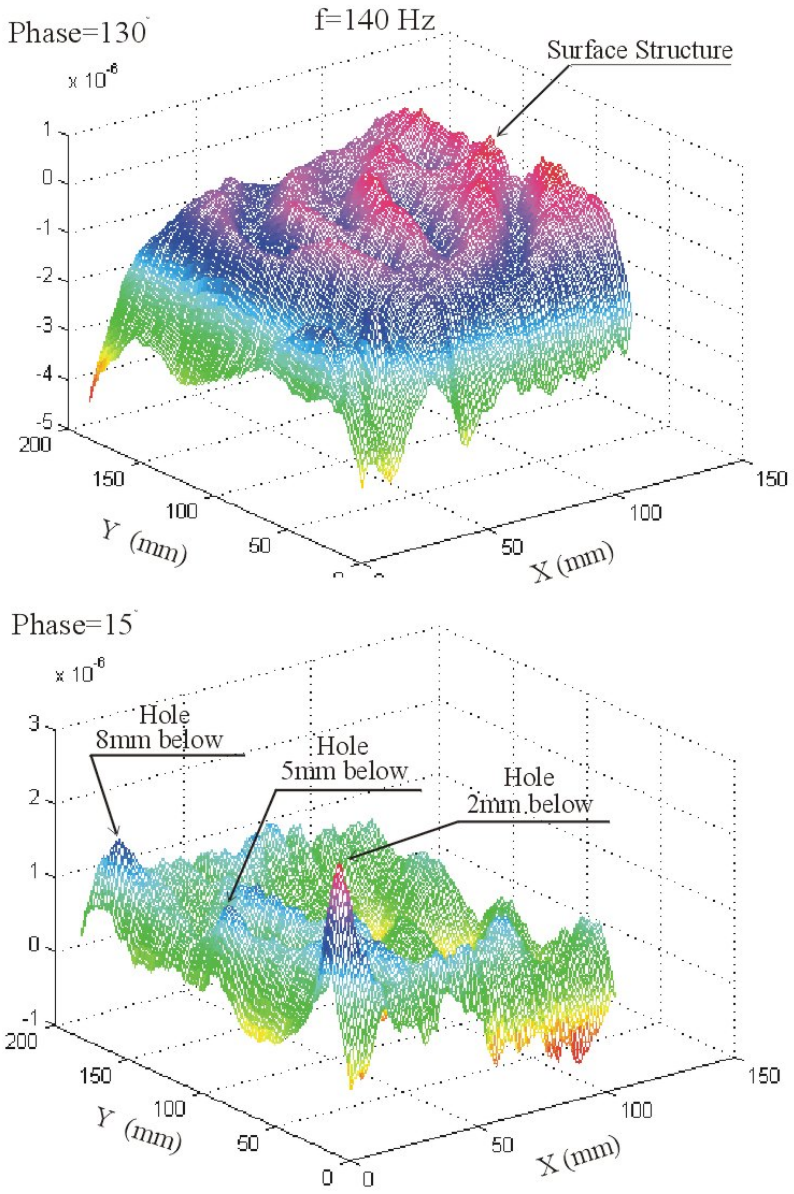


Sample provided by Alcoa

Inducer with 4 wires

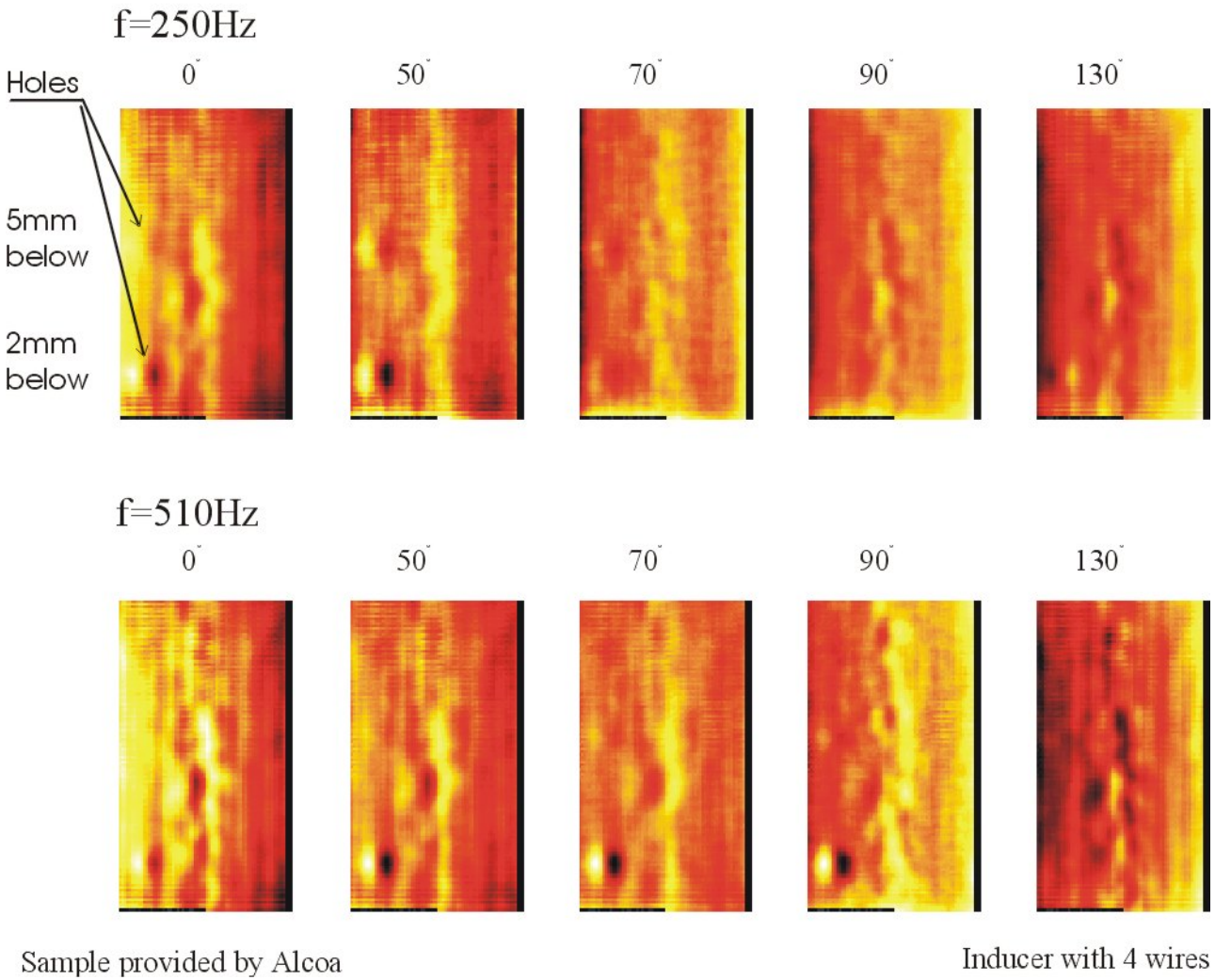
SAMPLE #1 (7075-T6-1)

(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)



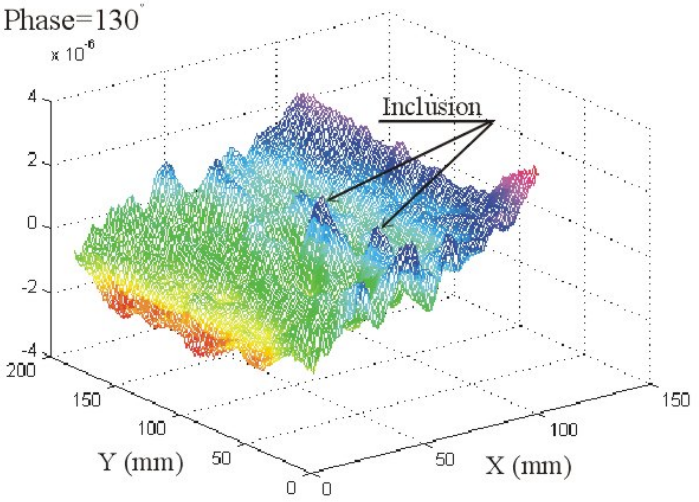
Sample provided by Alcoa

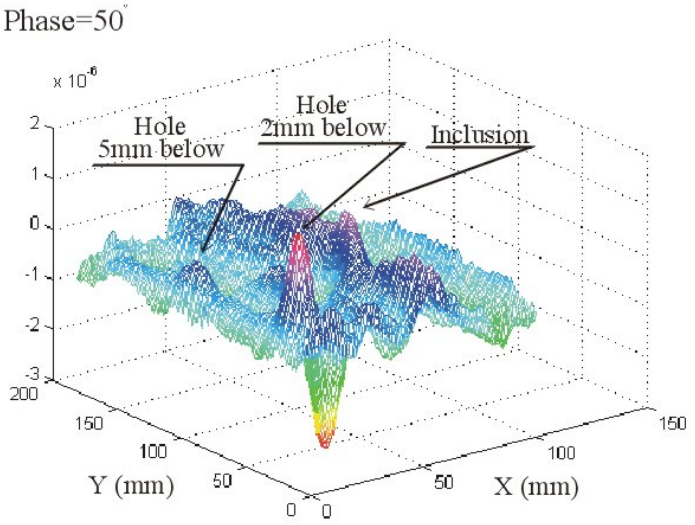
Inducer with 4 wires

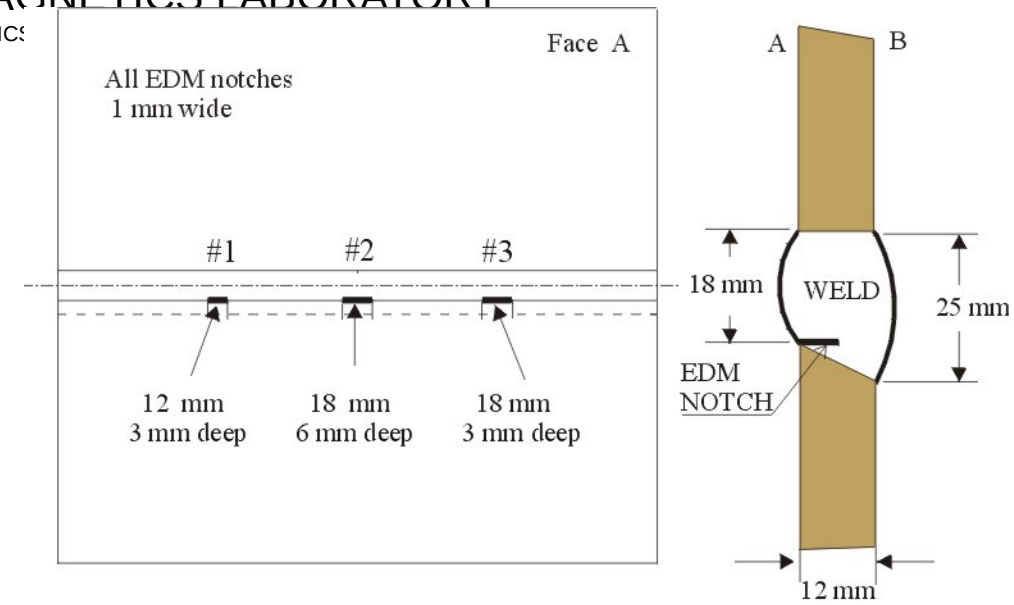
SAMPLE #2 (A356-2)

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

f=250Hz

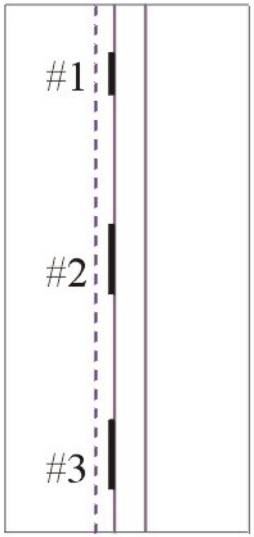




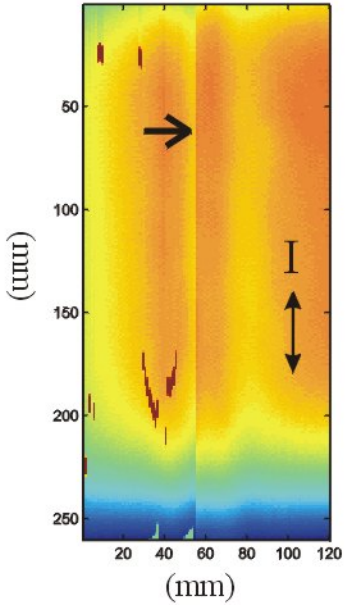

Face A
All EDM notches
1 mm wide
#1
#2
#3
12 mm
3 mm deep
18 mm
6 mm deep
18 mm
3 mm deep
A
B
18 mm
WELD
25 mm
EDM
NOTCH
12 mm


#1
#2
#3

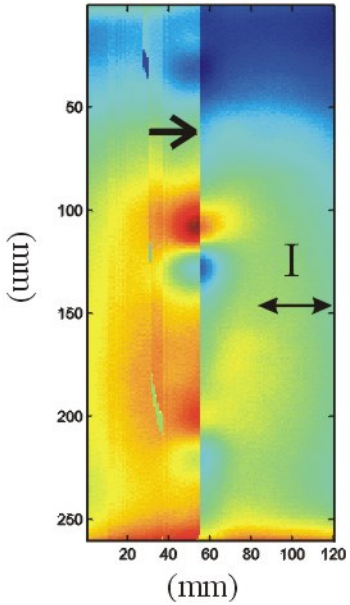
a) Face A

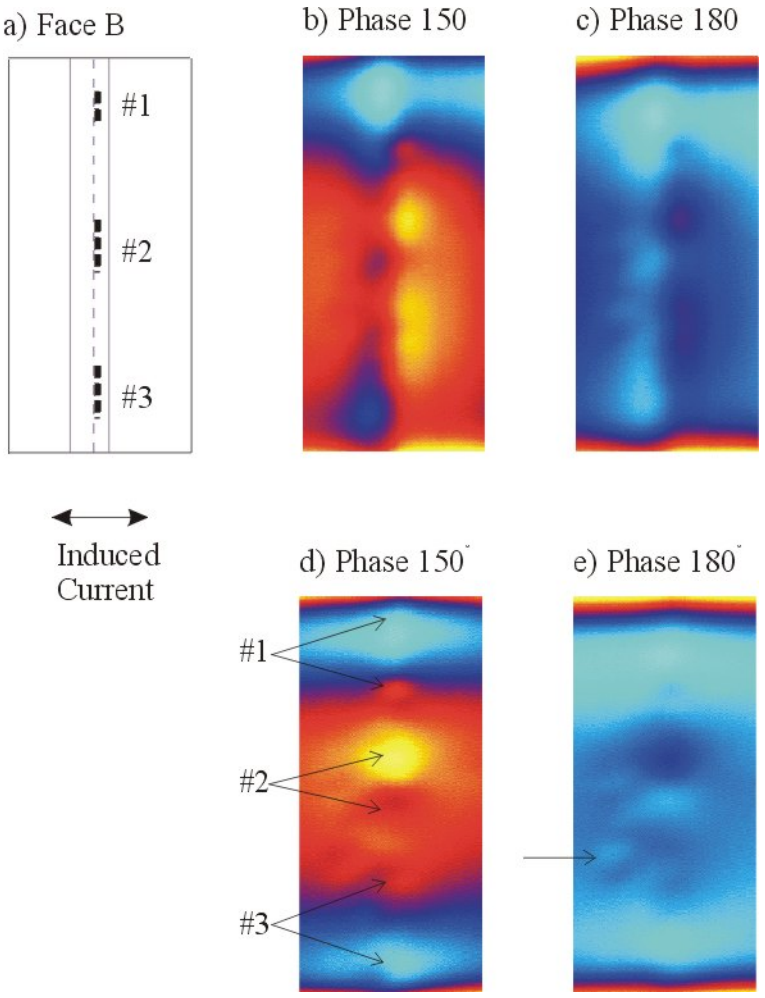


b) Longitudinal current

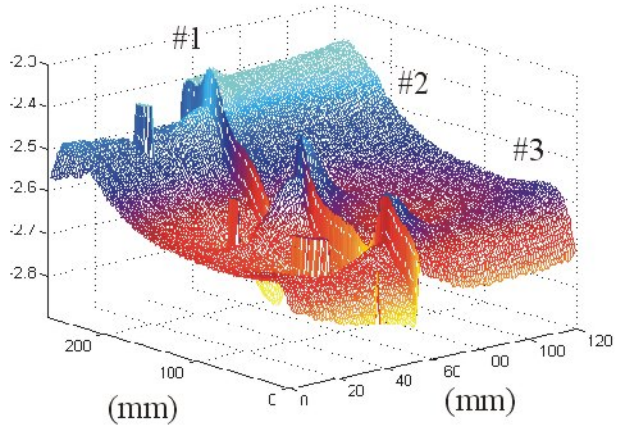


c) Transverse current

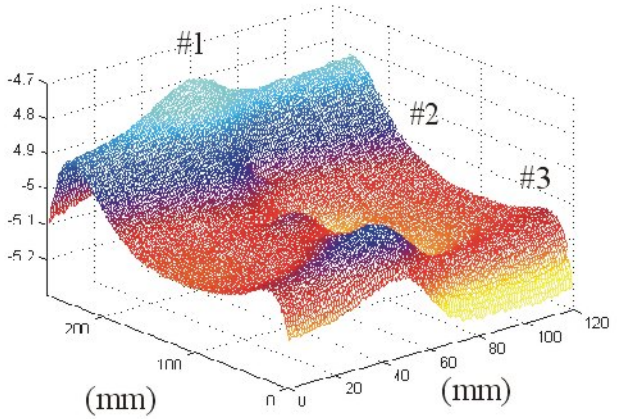



a) Face B
#1
#2
#3
Induced
Current
b) Phase 150
c) Phase 180
d) Phase 150˚
e) Phase 180˚
#1
#2
#3

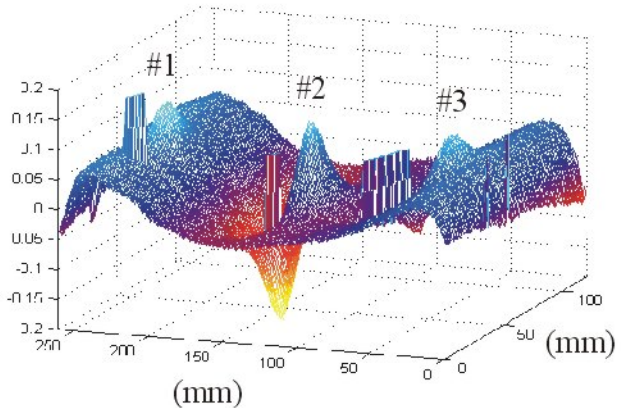
a) Face A with open notches



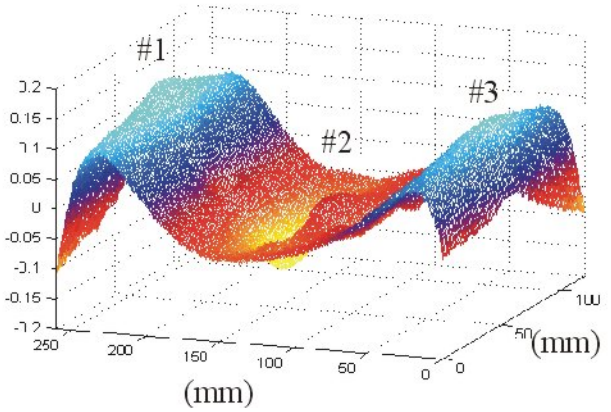
b) Face B without open notches



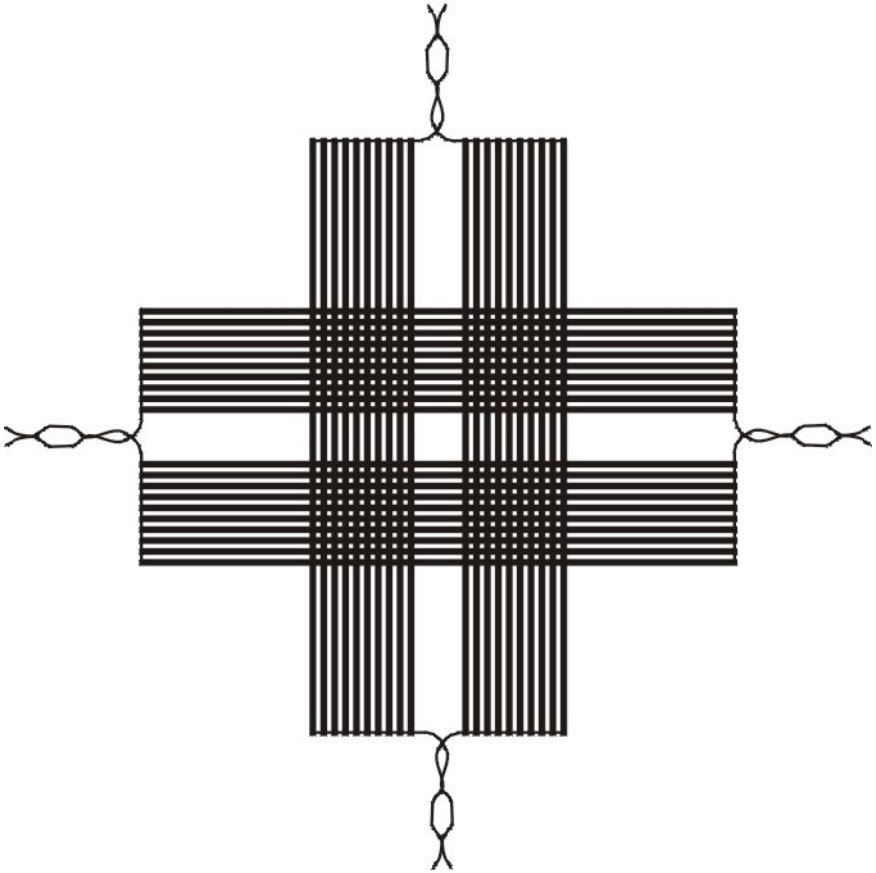
c) Face A with open notches
after removing the shift in (a)



d) Face B without open notches
after removing the shift in (b)

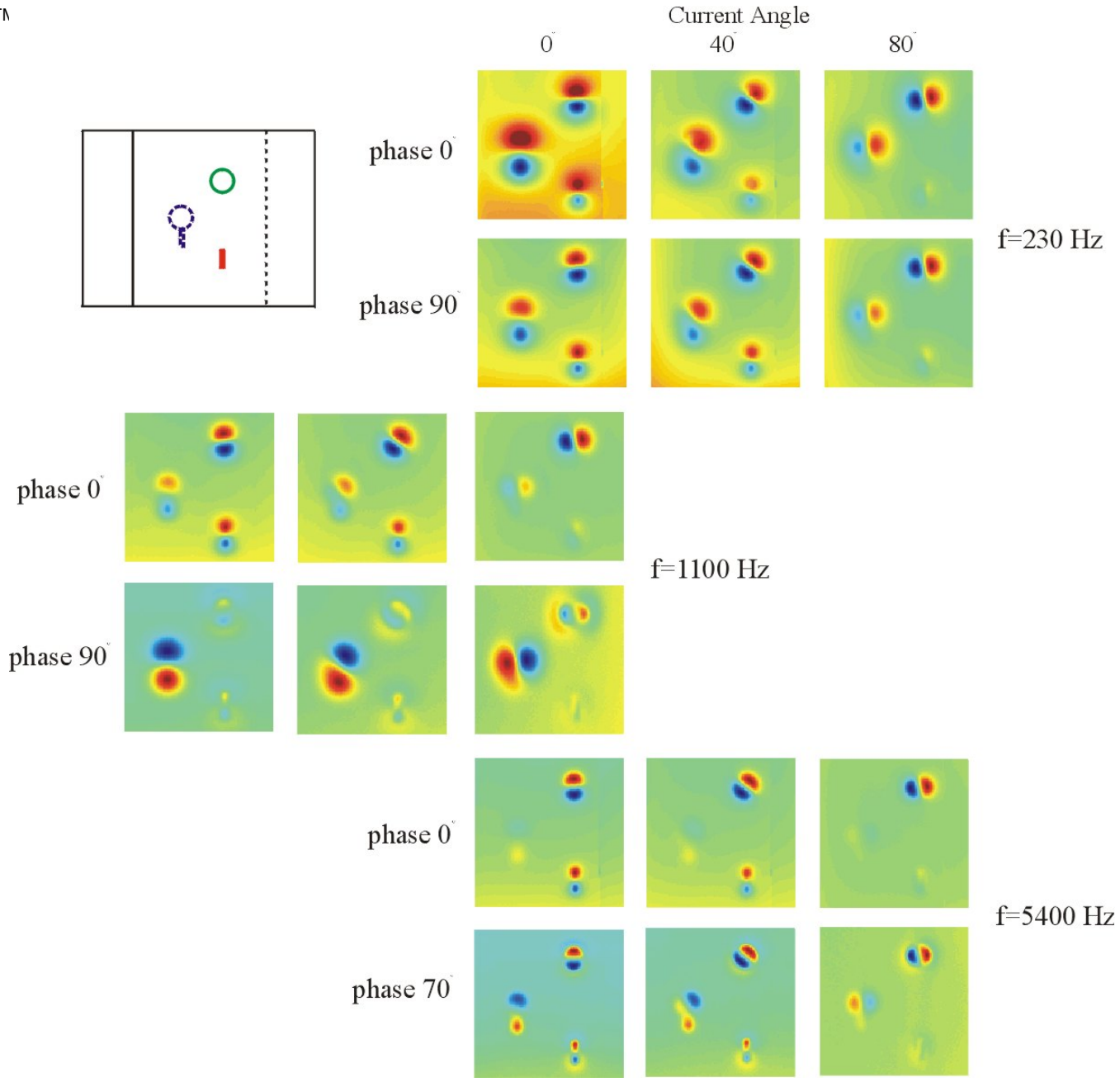


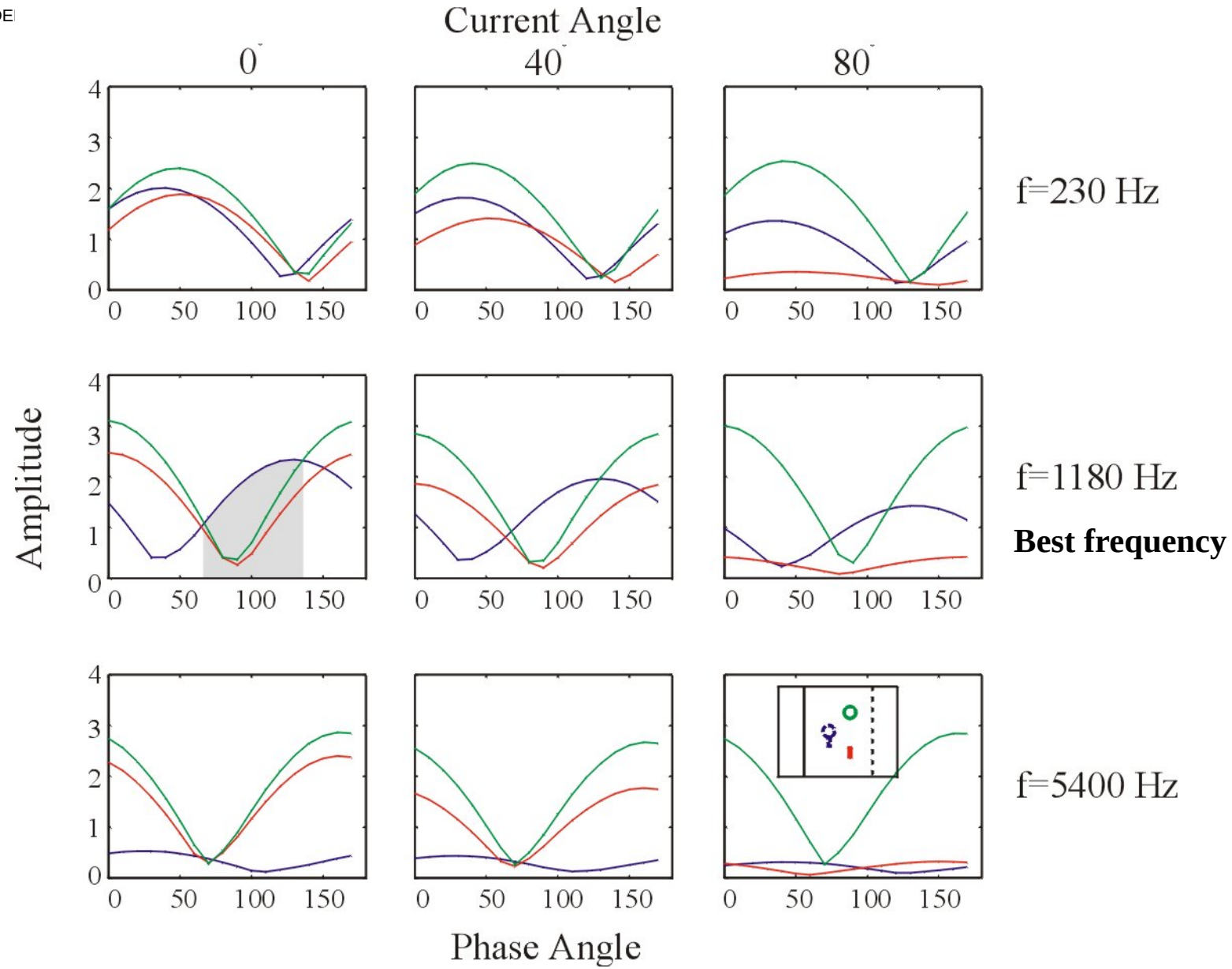
PC Orthogonal Sheet Inducer

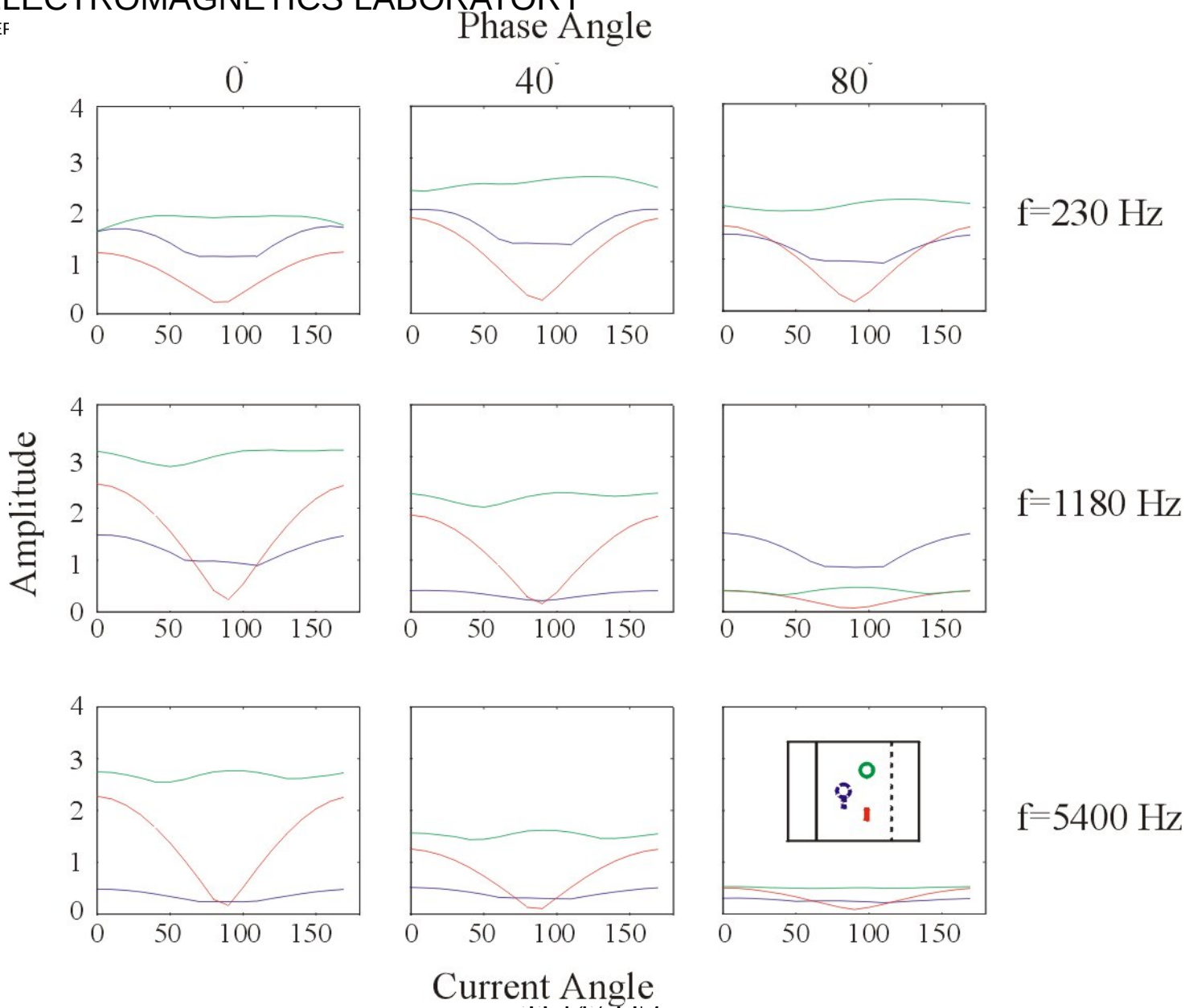


FREQUENCY OPTIMIZATION

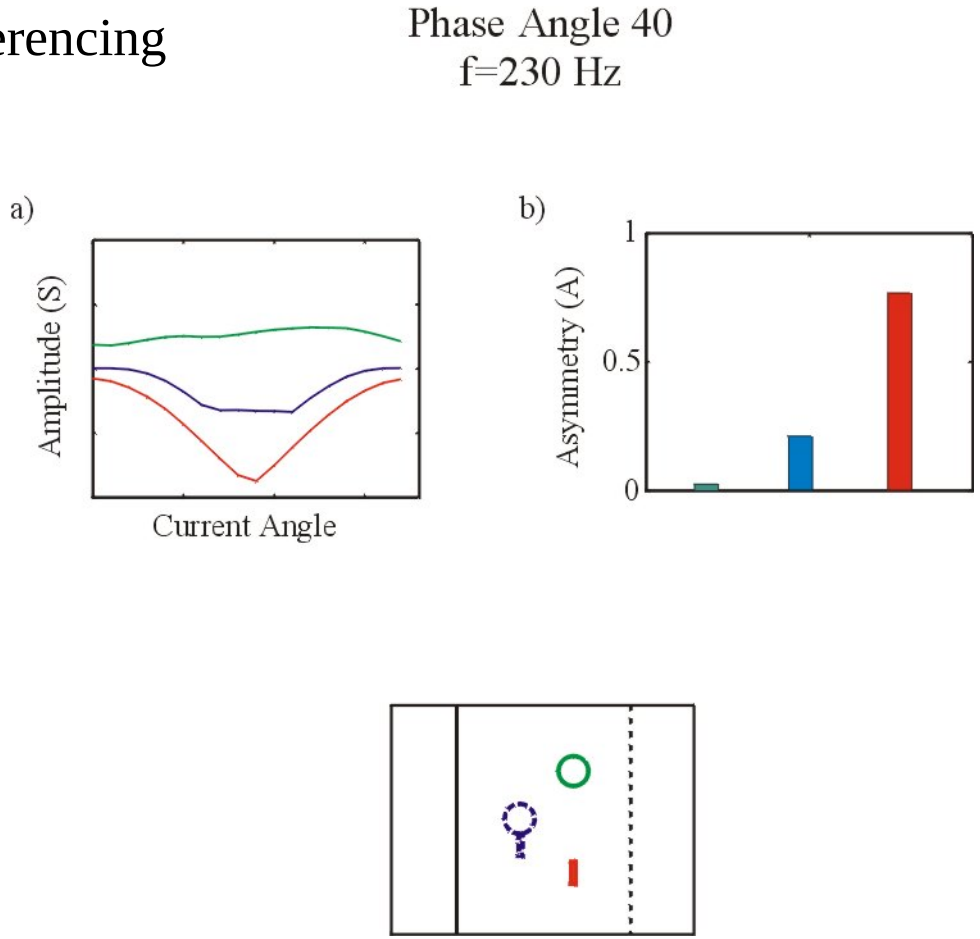
for phase-selection


Current Angle
0°
40°
80°
phase 0°
phase 90°
f=230 Hz
phase 0°
phase 90°
f=1100 Hz
phase 0°
phase 70°
f=5400 Hz

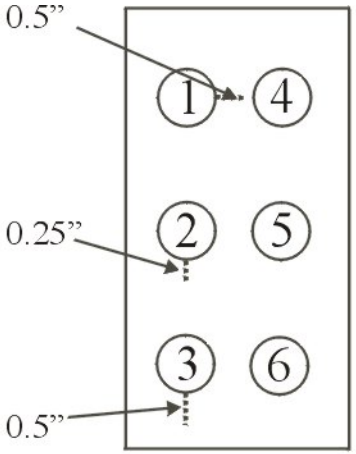

Current Angle
0
40
80
Amplitude
Phase Angle
f=230 Hz
f=1180 Hz
Best frequency
f=5400 Hz


Phase Angle
0°
40°
80°
f=230 Hz
f=1180 Hz
f=5400 Hz
Amplitude
Current Angle
0
1
2
3
4
0
50
100
150

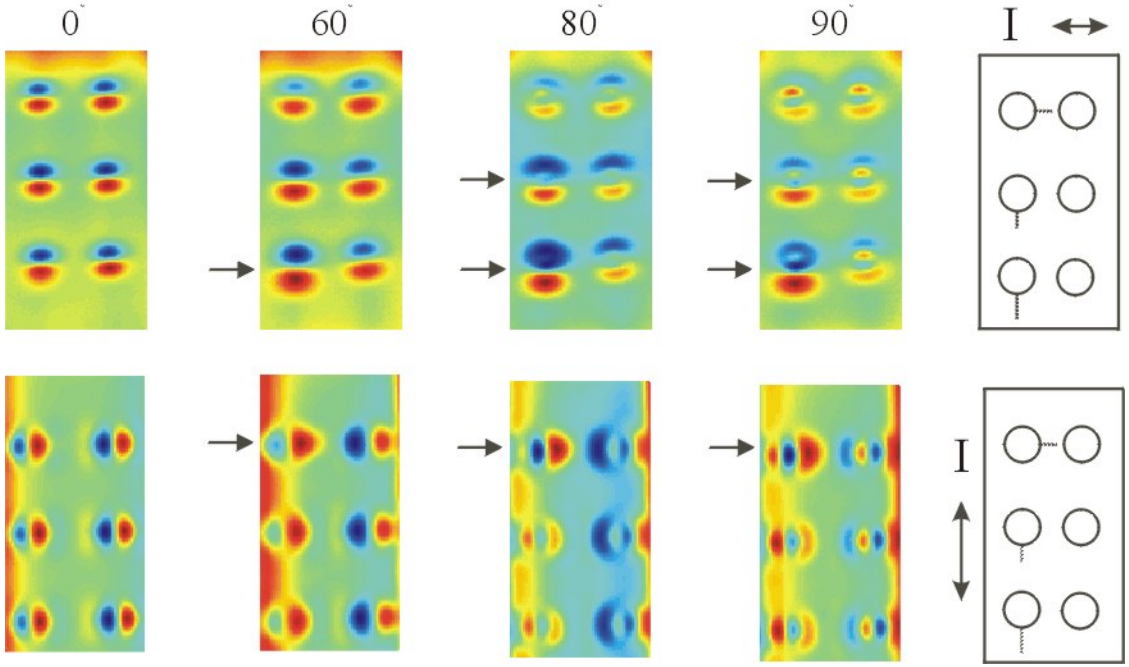
Self-referencing



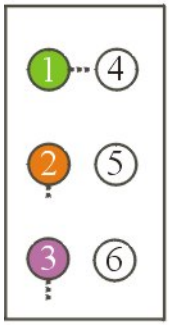
Second Layer slots



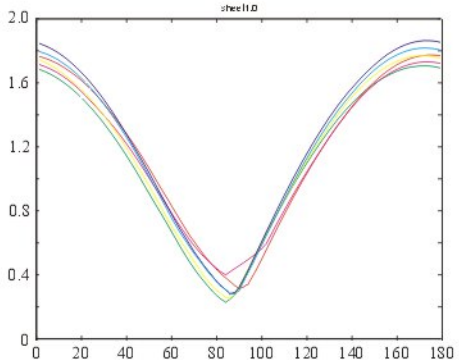
Phase



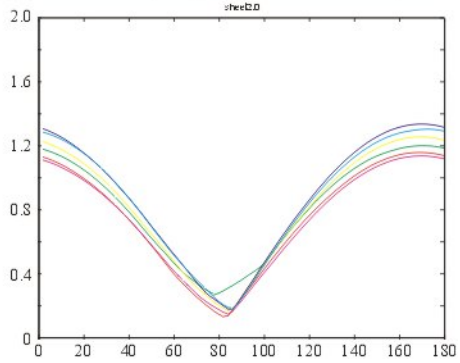
Phase Analysis



(a) 1010 Hz (transverse current)

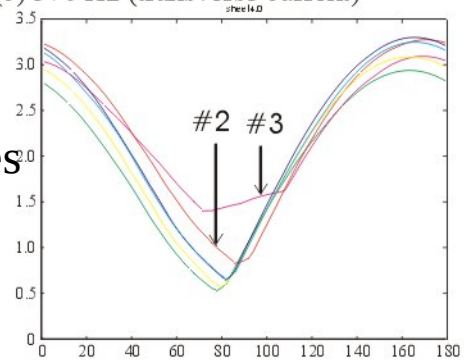


(b) 1010 Hz (longitudinal current)

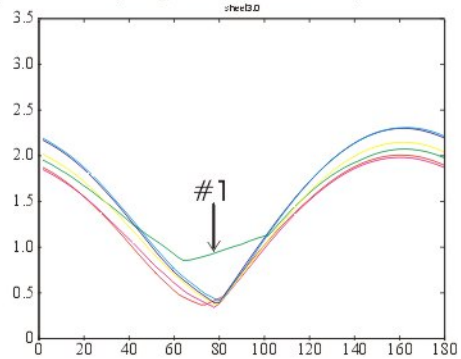


Better frequencies
570 Hz - 1 kHz

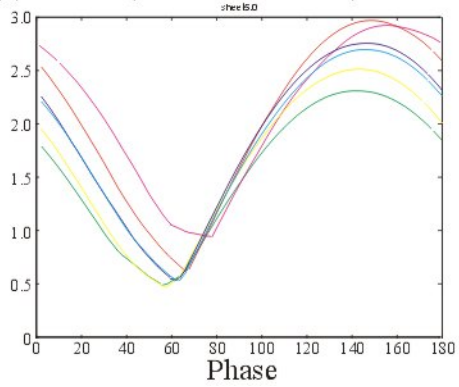
(c) 570 Hz (transverse current)



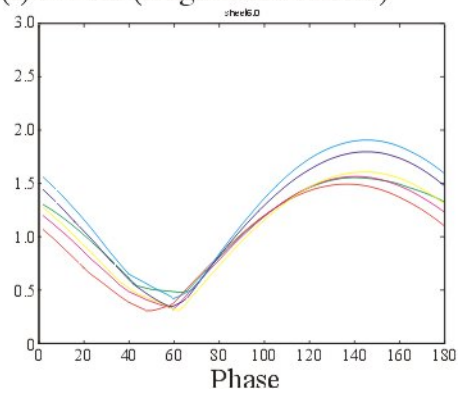
(d) 570 Hz (longitudinal current)



(e) 370 Hz (transverse current)

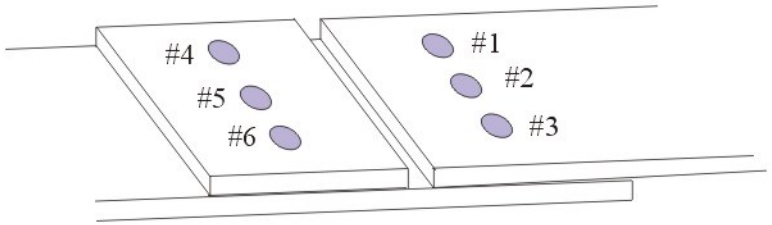


(f) 370 Hz (longitudinal current)

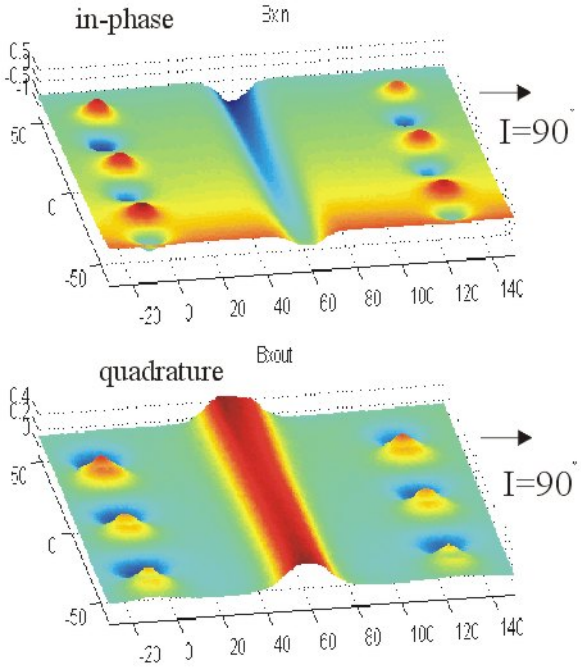


FATIGUE CRACKS SAMPLE

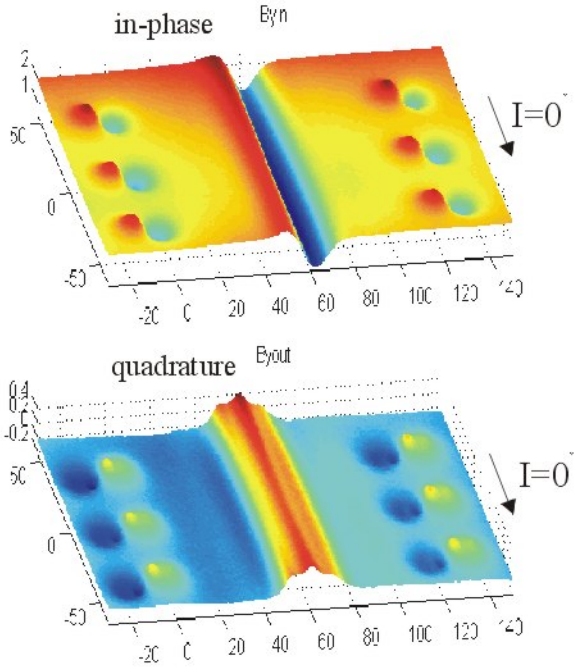
a)



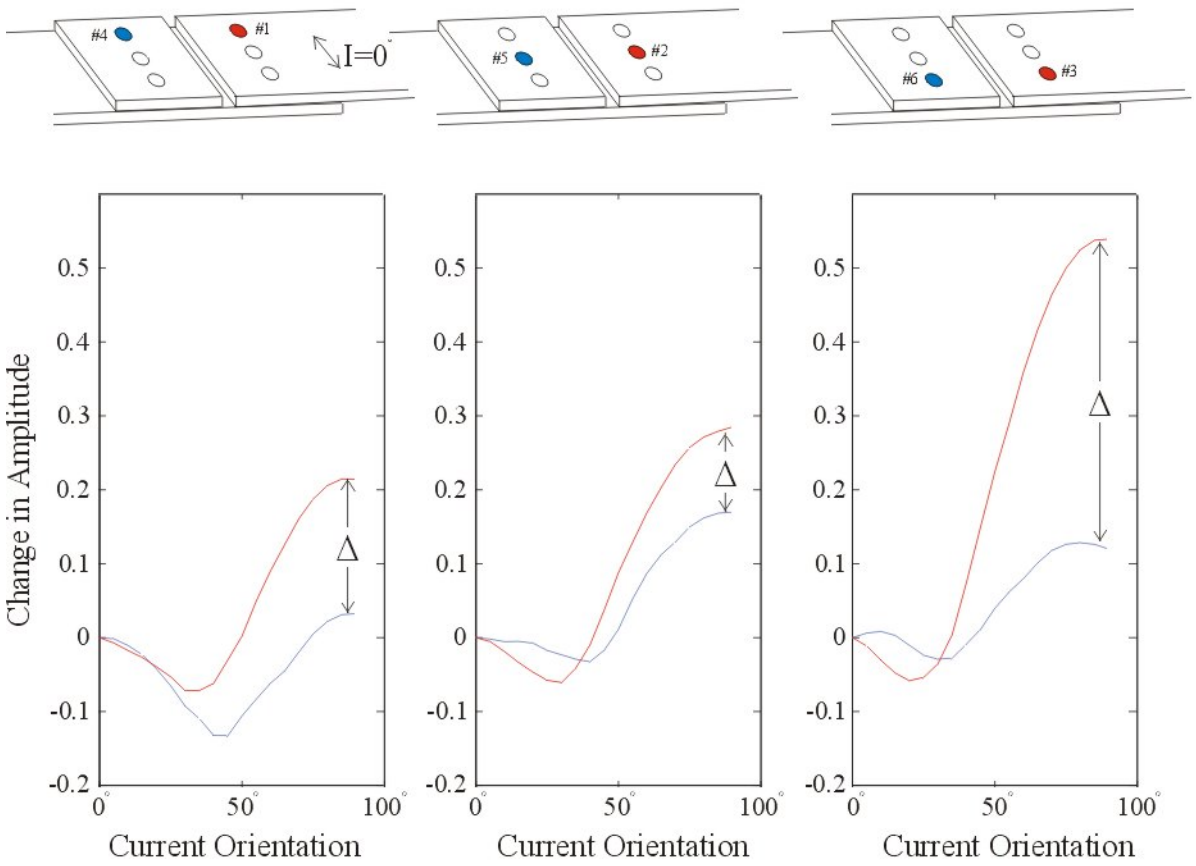
b) Longitudinal current



c) Transverse current



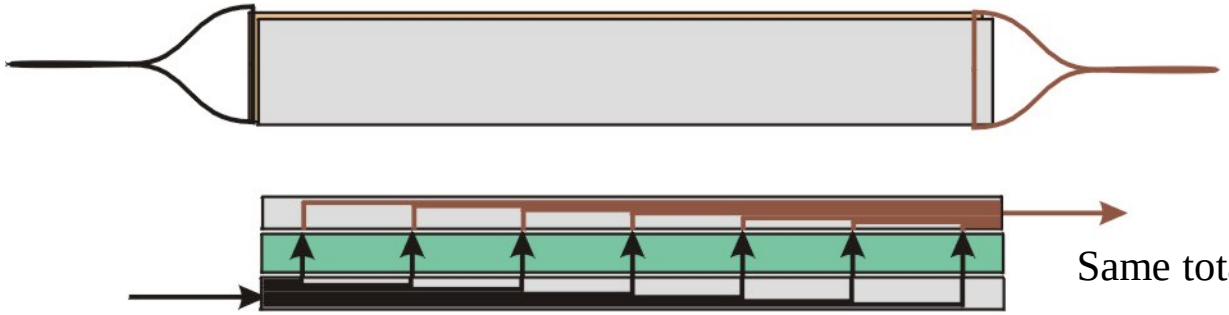
DETECTION FOR FATIGUE CRACKS BENEATH RIVETS



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

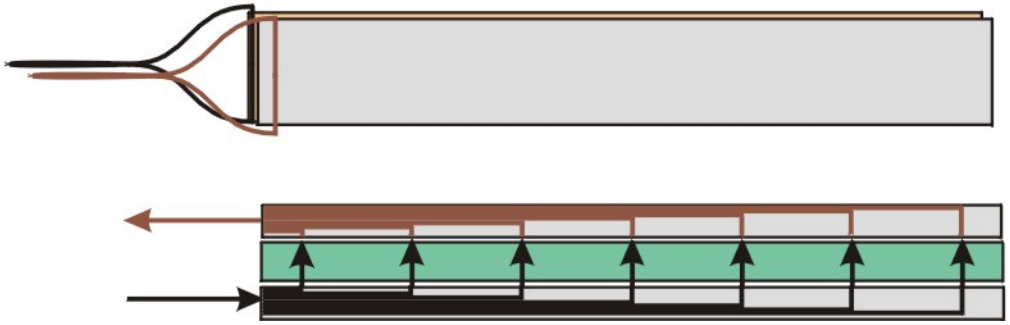
ALUMINUM CAPACITOR

a) Different end leads connection



Same total currents

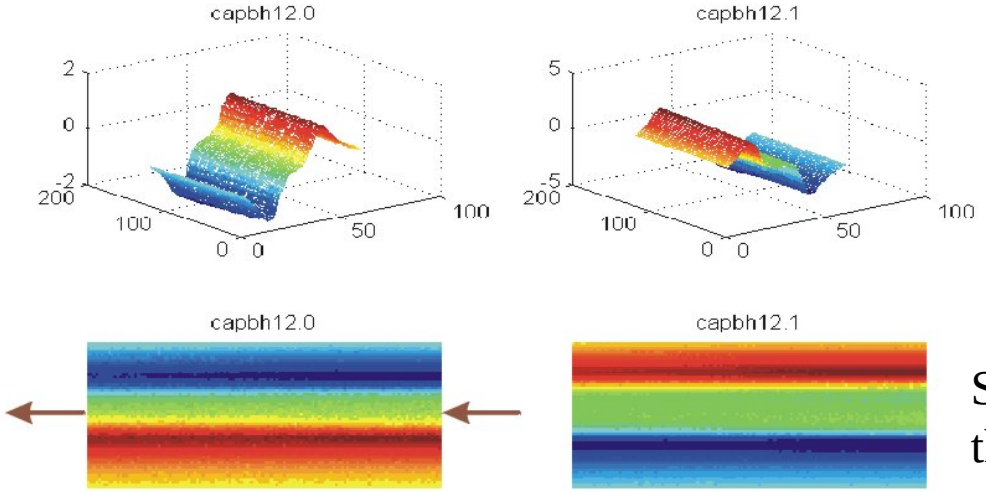
b) Same end leads connection



Larger currents near leads

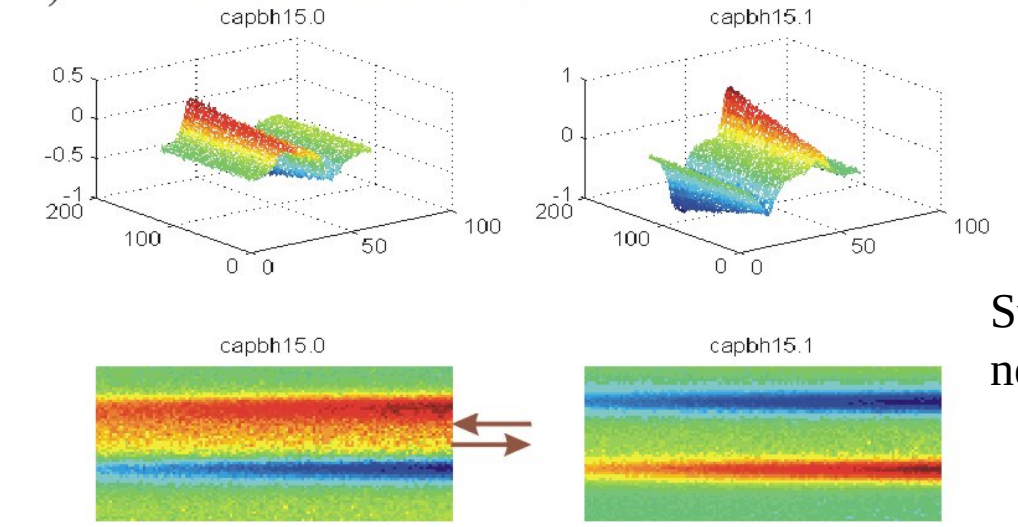
FIELD MAP FOR ALUMINUM CAPACITOR
(G-10 layer has a hole, 2kHz)

a) Different end leads connection



Same fields through length

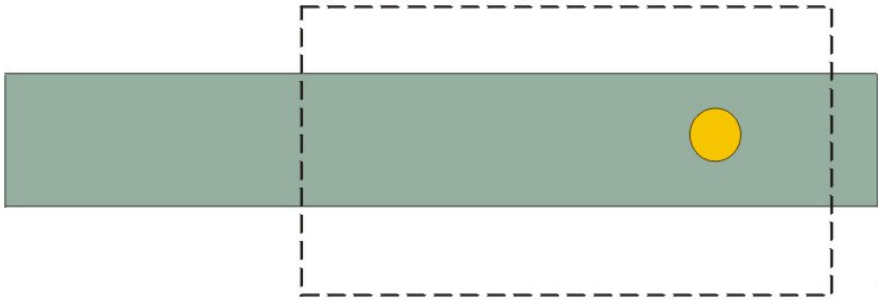
b) Same end leads connection



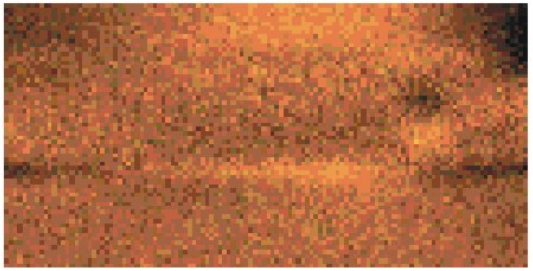
Strong fields near leads

ALUMINUM CAPACITOR WITH A COPPER DISK

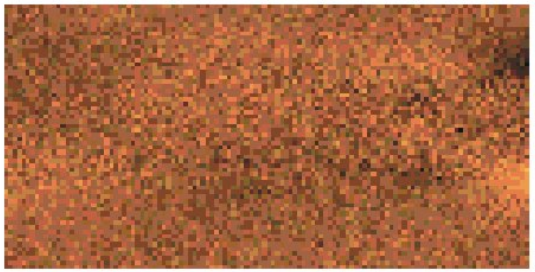
(a) G-10 layer has a copper disk



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



(c) Image of a 3/8 inch diameter copper dick



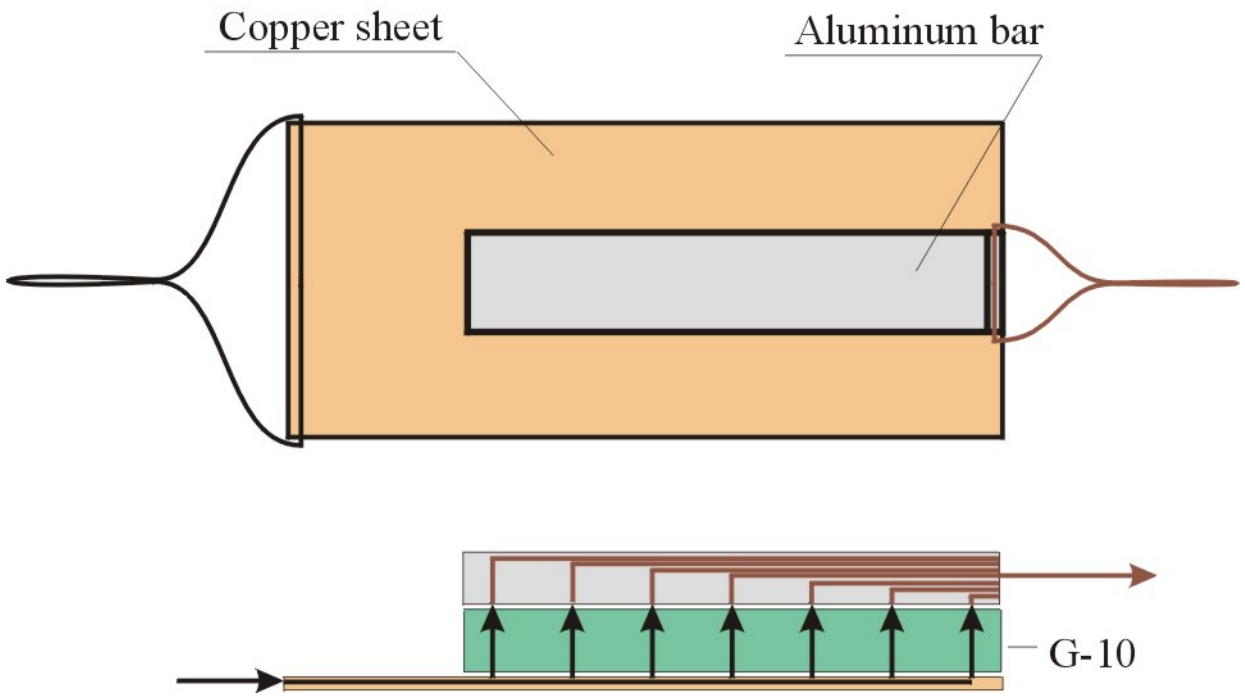
Displacement currents are collected by leads through aluminum.

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

How to increase the feasibility of displacement current distribution??

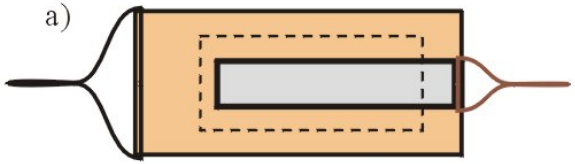
----Reduce cancellation between two electrodes

COPPER - ALUMINUM CAPACITOR

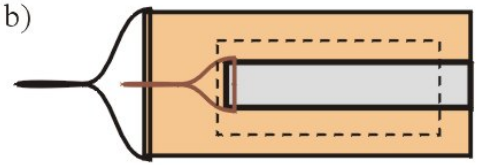


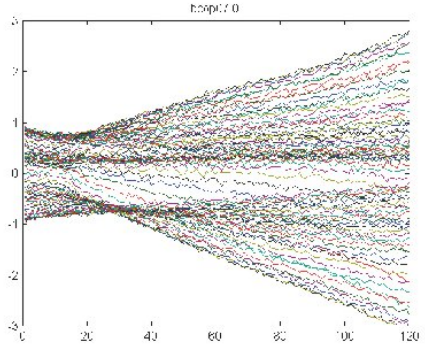
MAGNETIC FIELD OF CAPACITOR

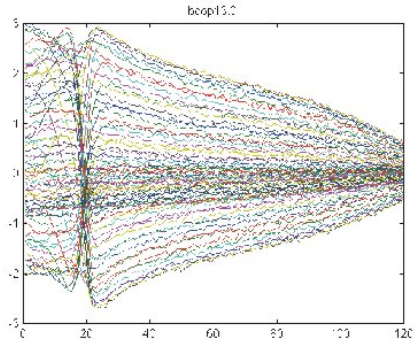
a)



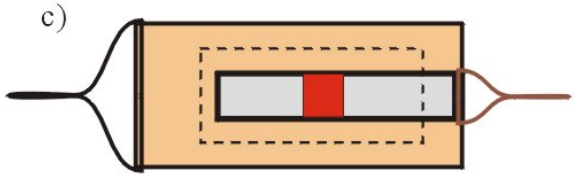
b)



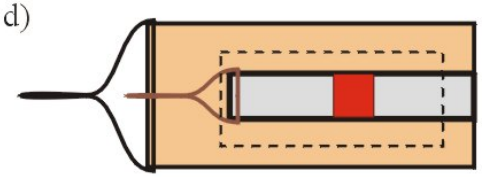


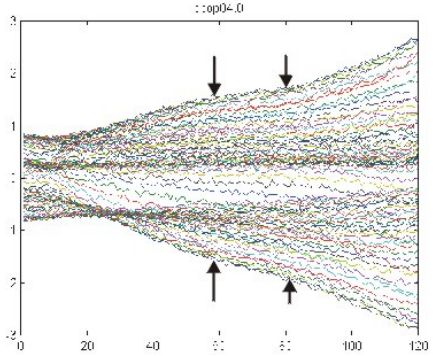


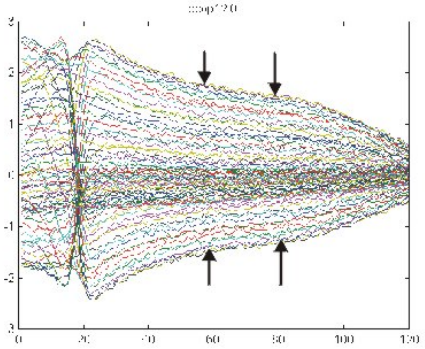
c)



d)





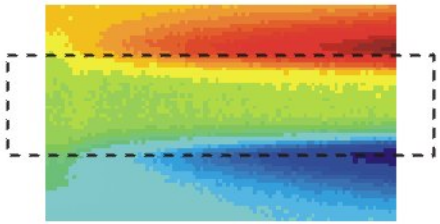


COPPER - ALUMINUM CAPACITOR
(Imaging processing)

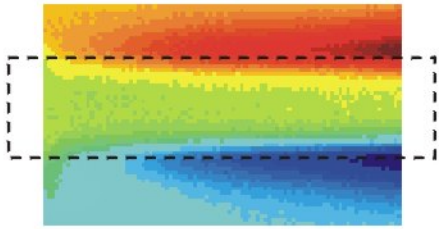
Unflawed G-10

Flawed G-10

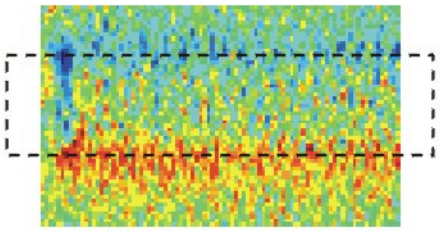
a) Raw data



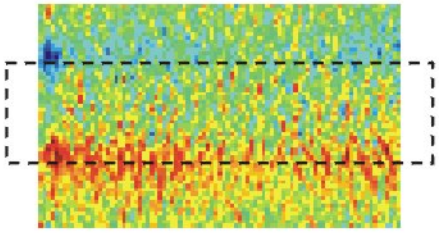
b)Raw data



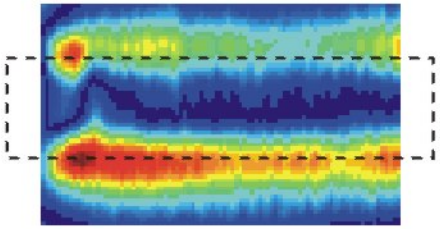
c) Derivative filtering



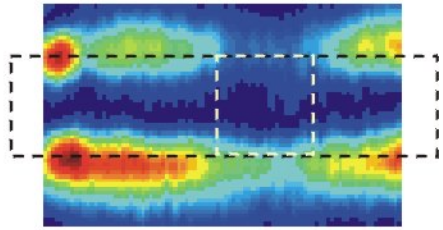
d) Derivative filtering



e) Low pass filtering

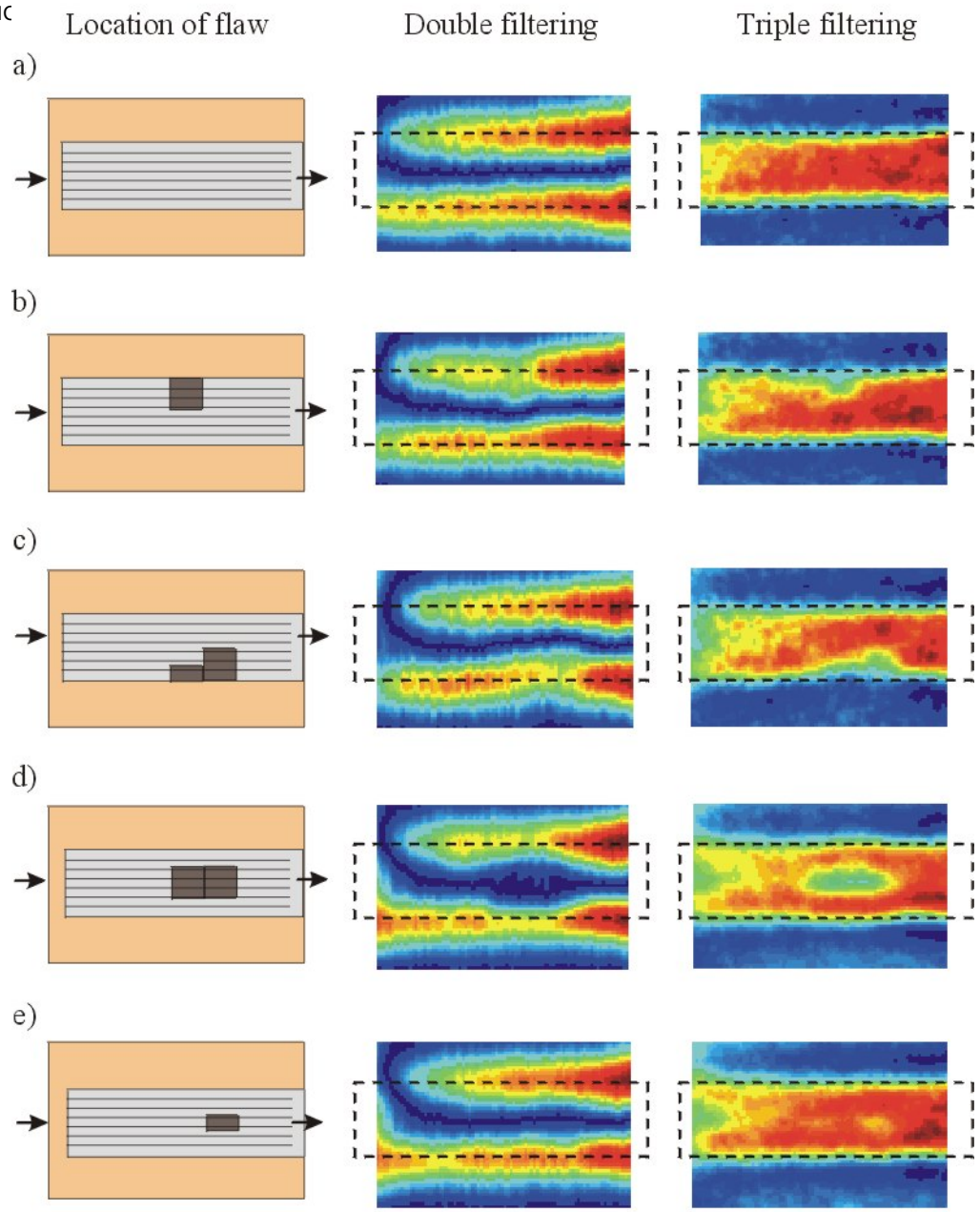


f) Low pass filtering



INCREASE EDGES !!!

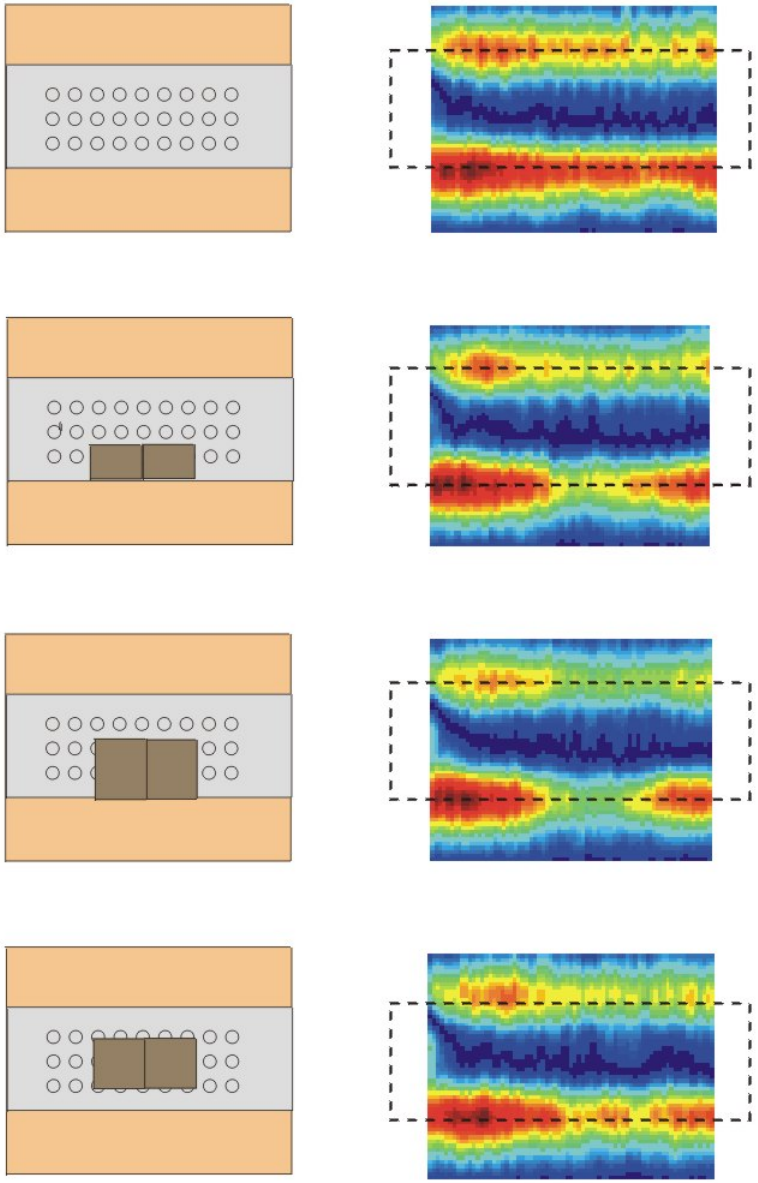
COPPER - SLOTTED ALUMINUM CAPACITOR



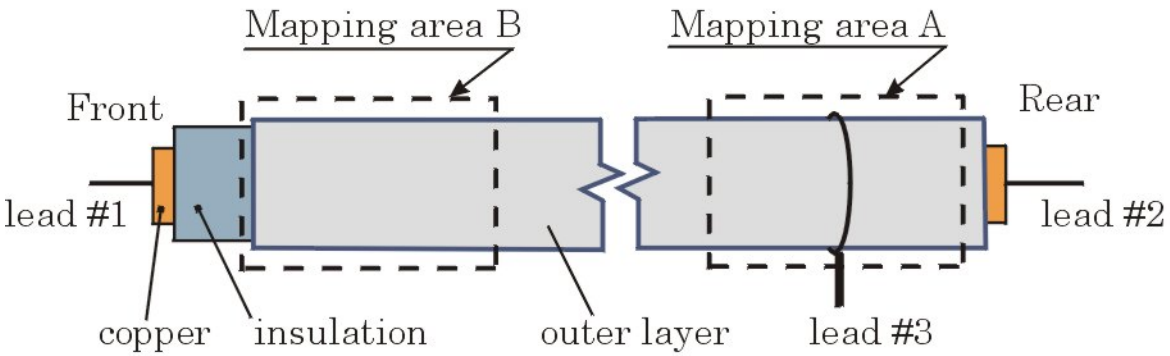
COPPER - MULT HOLE ALUMINUM CAPACITOR

Location of the flaw

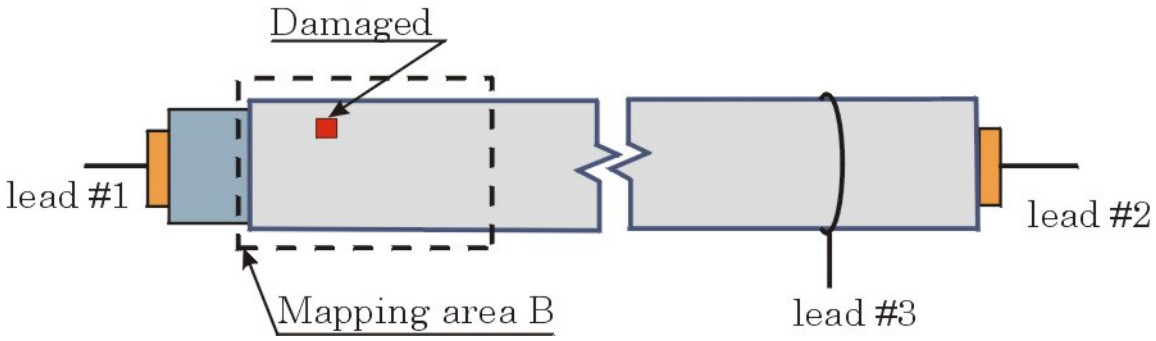
Double filtering

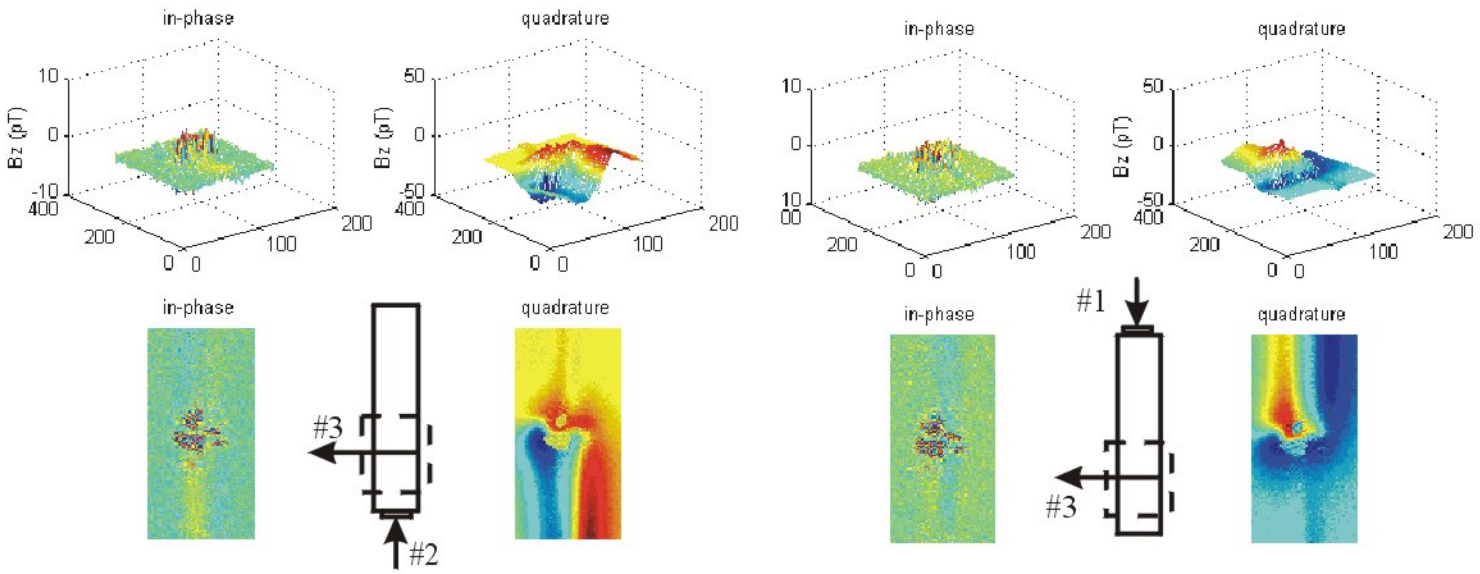


UNFLAWED BAR

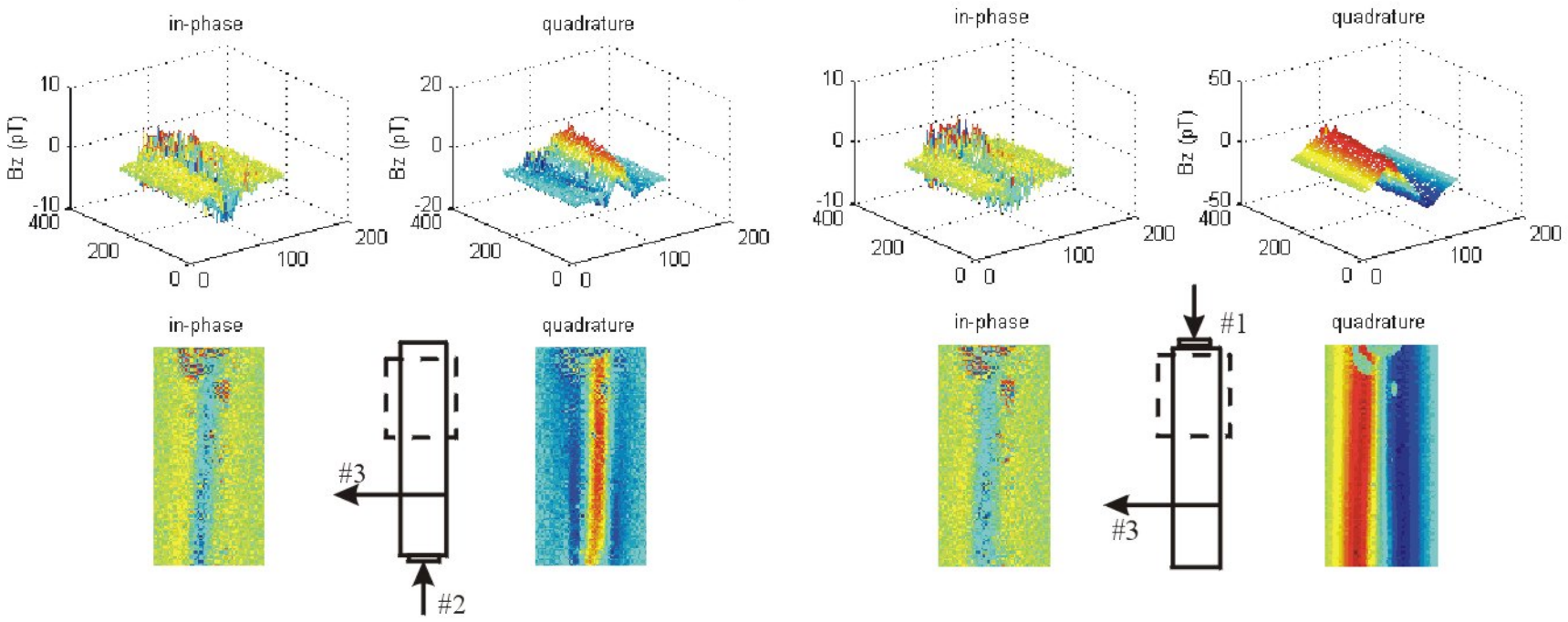


FLAWED BAR

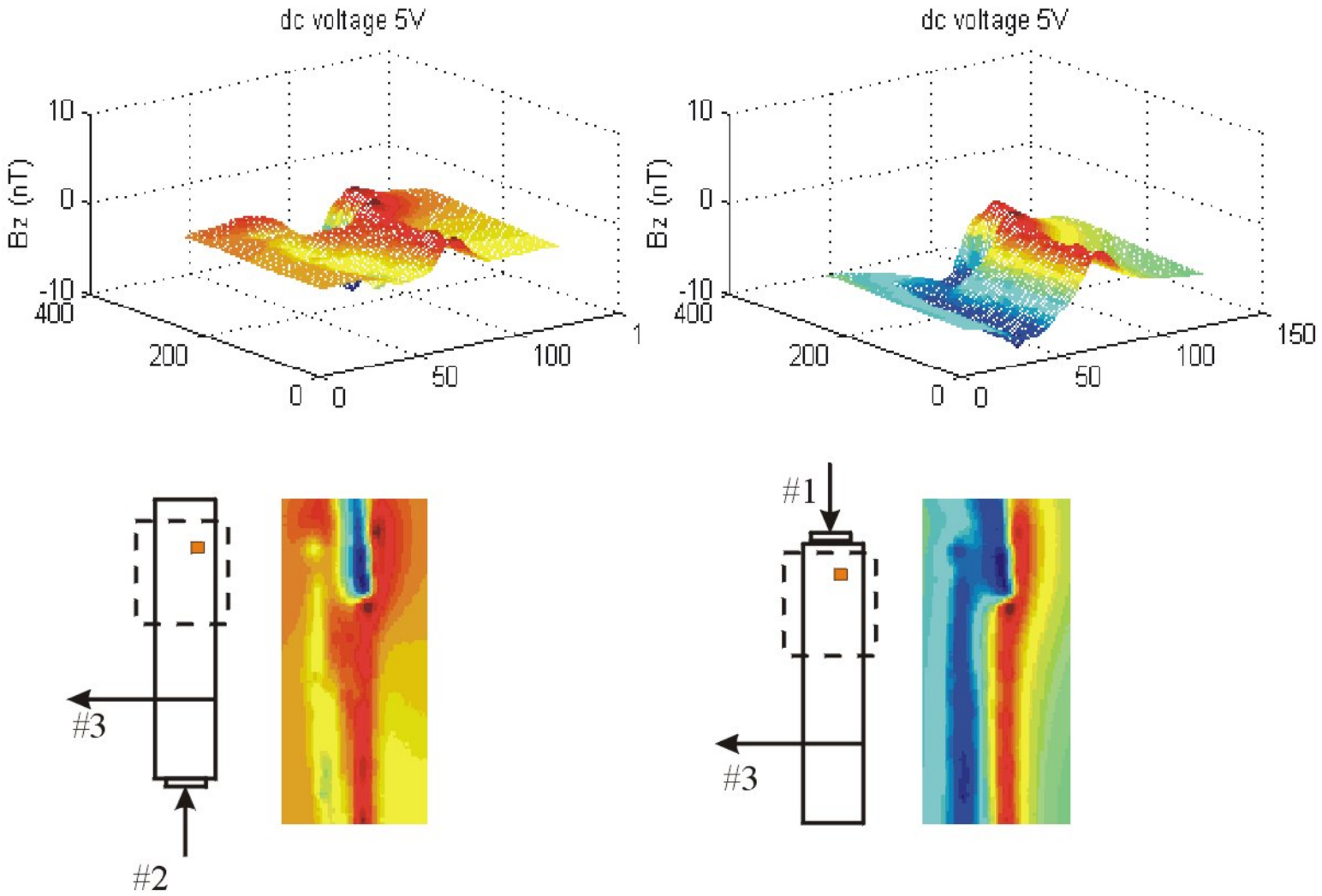




Unflawed bar
10V 200 Hz voltage



Unflawed bar
10V 200 Hz voltage



Flawed bar with breakage
5V dc voltage