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Finite Element Modeling of Transient Eddy Currents in Multilayer Aluminum Structures

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Outline

- Background
- Experimental Work
- Finite Element Modeling
- Results
- Conclusion

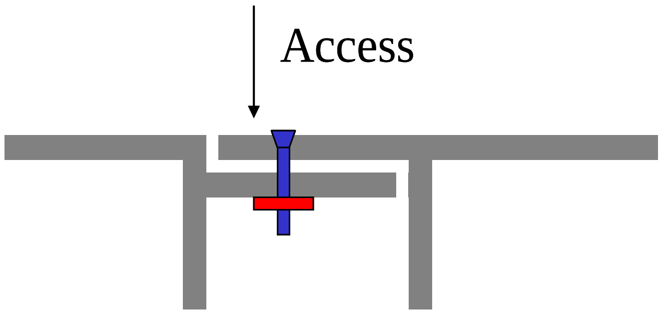
Background

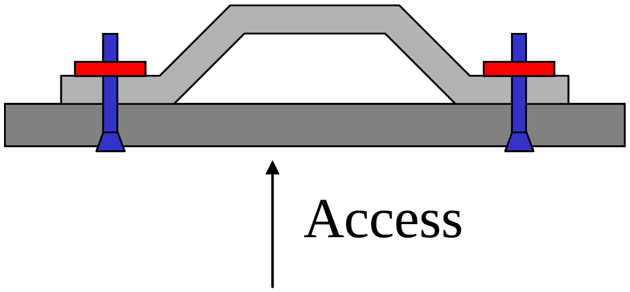
- Transient (or pulsed) eddy current inspection employs a pulsed excitation to induce a transient response from electromagnetic field interactions within a conducting structure.
- Useful for detection of defects in thick multilayered non-ferromagnetic structures at greater depths with higher resolution than conventional EC technique.
- Fatigue induced crack growth at ferrous fasteners is a common mode of failure in aircraft wing structures. Locations of cracks in the second layer are not normally inspectable by conventional techniques (EC or UT).

  - Typical crack depth ~ 0.10" or less

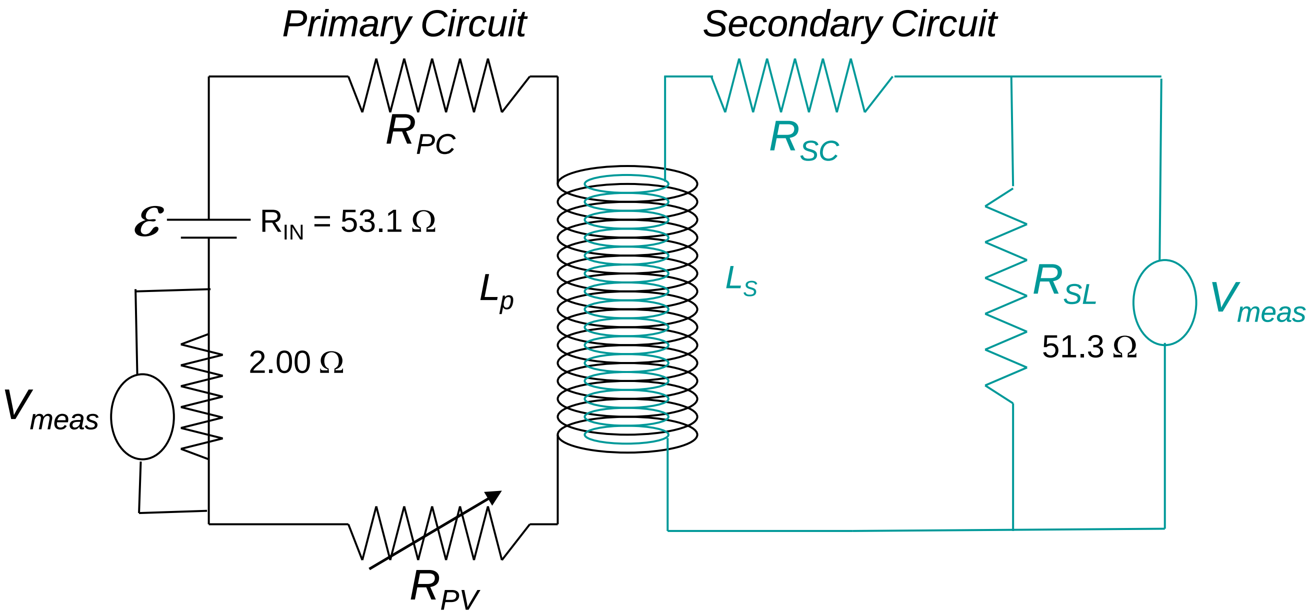
  - Thickness of wing structure ~ 0.25"

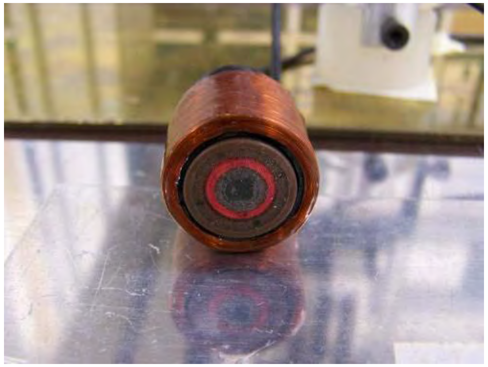
  - Geometry may be locally varying with only one side access, under installed fasteners.





Circuit Diagram

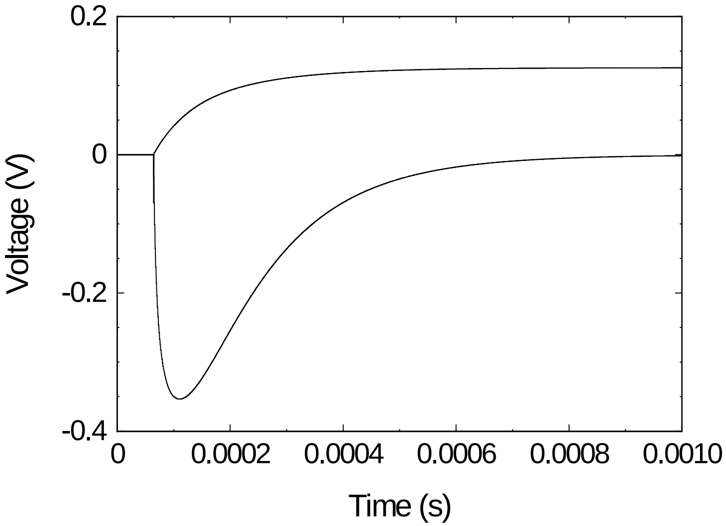




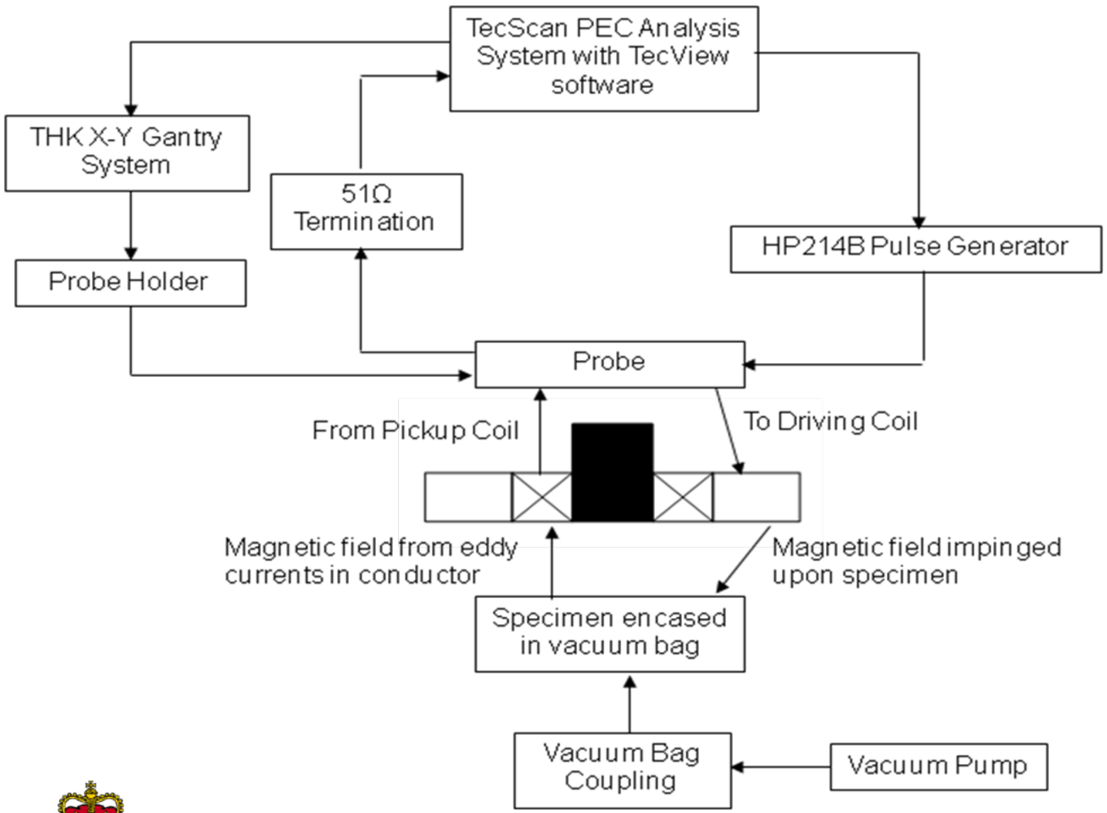
Driver Signal

$$I = \frac{\varepsilon}{R}\left(1 - e^{-t/\tau_c}\right) \qquad \tau_C = \frac{L}{R}$$

Pickup signal depends on the interaction between the two coils as well as between the coils and the sample.

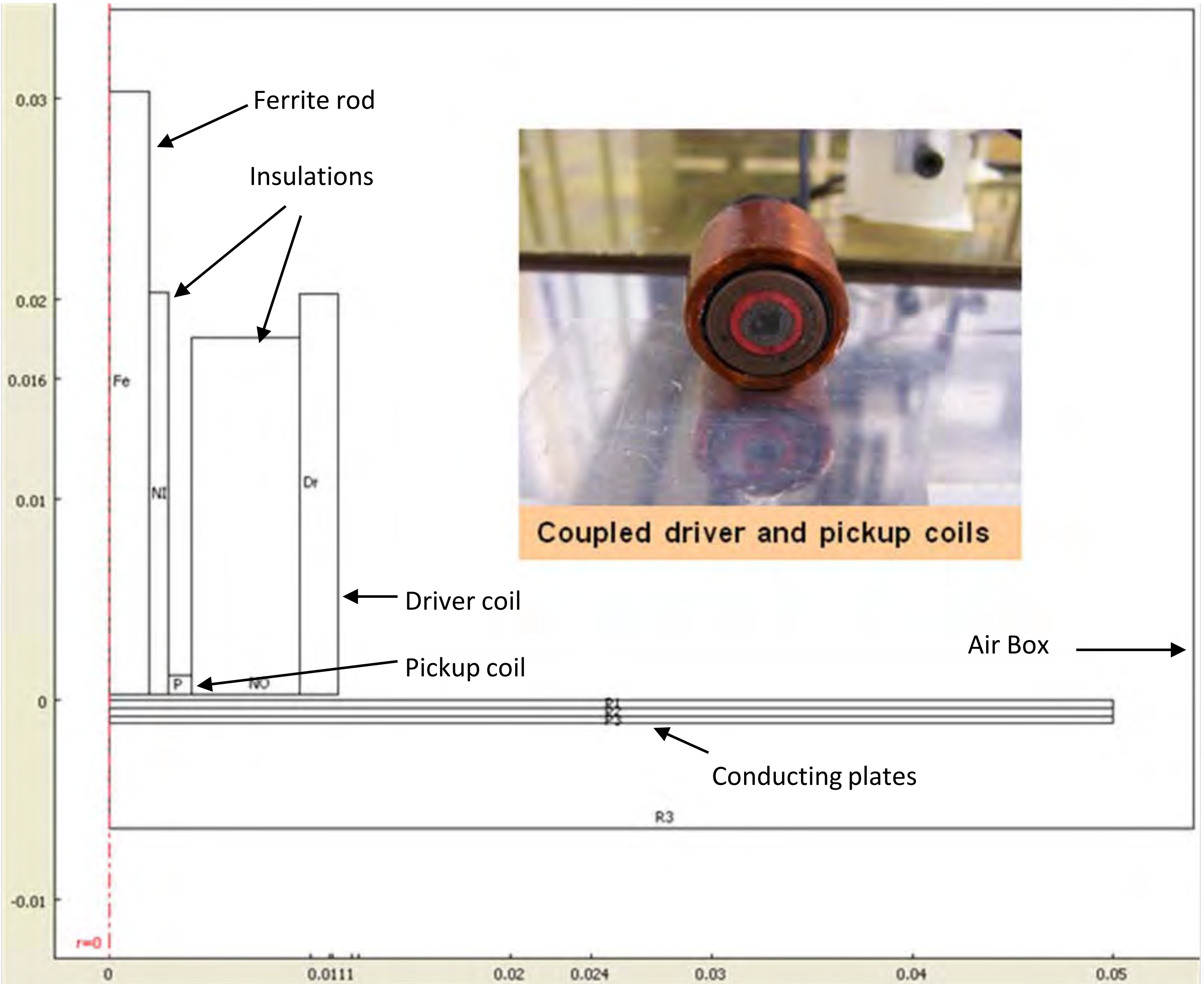


Experimental Set-Up



	Driver	Pickup Coil
Length, mm	20.0	1.0
Inner diameter, mm	18.9	5.9
Outer diameter, mm	20.9-23.9	8.2
Number of turns	400-1600	300
AWG	34	44
Resistance, Ω	26.0-122	64.0
Length of ferrite core, mm	20.0-30.0	
Diameter of ferrite core, mm	4.0	
Permeability of ferrite	1500-3100	
Conductivity of ferrite, S/m	0.5	
Conductivity of aluminum, S/m	2.46×10^7	

FE Modeling – 2D Model of Conducting Plates



COMSOL 3.4 Multiphysics

Smoothed Heaviside function

flc2hs(x, scale)

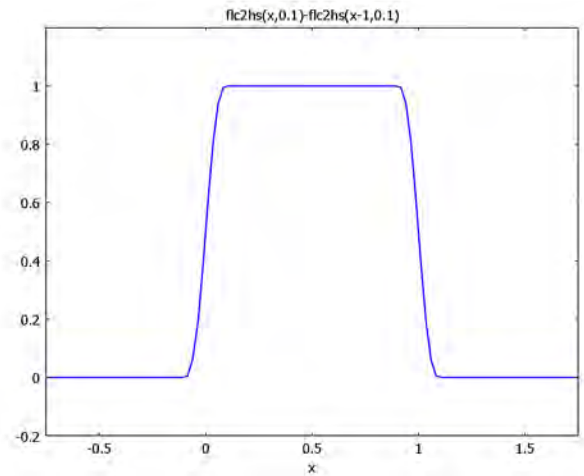
- a step function that smoothes within the interval

–scale <x < scale

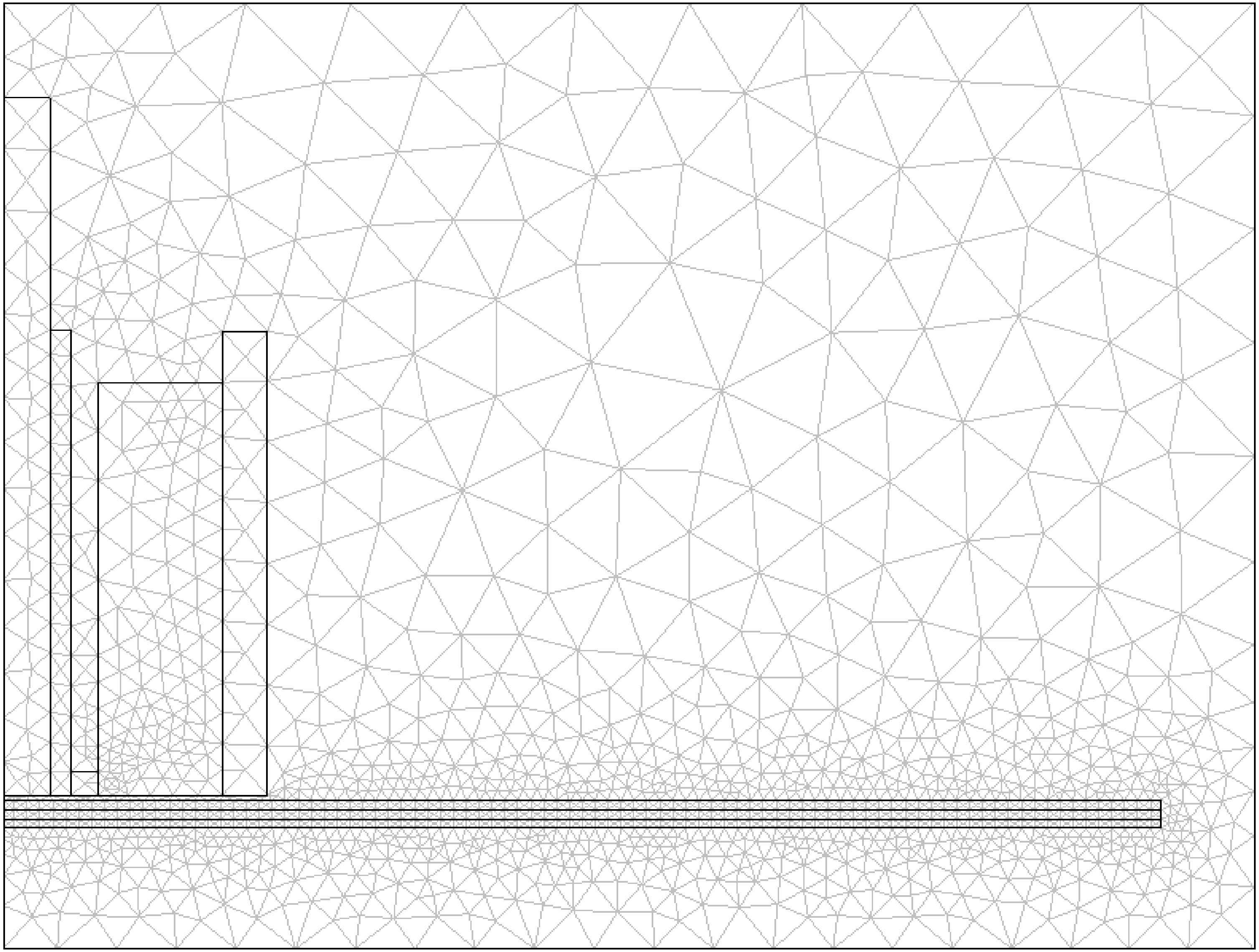
scale: 5×10^{-7} s

Time range: 0 to 1.00×10^{-3} s

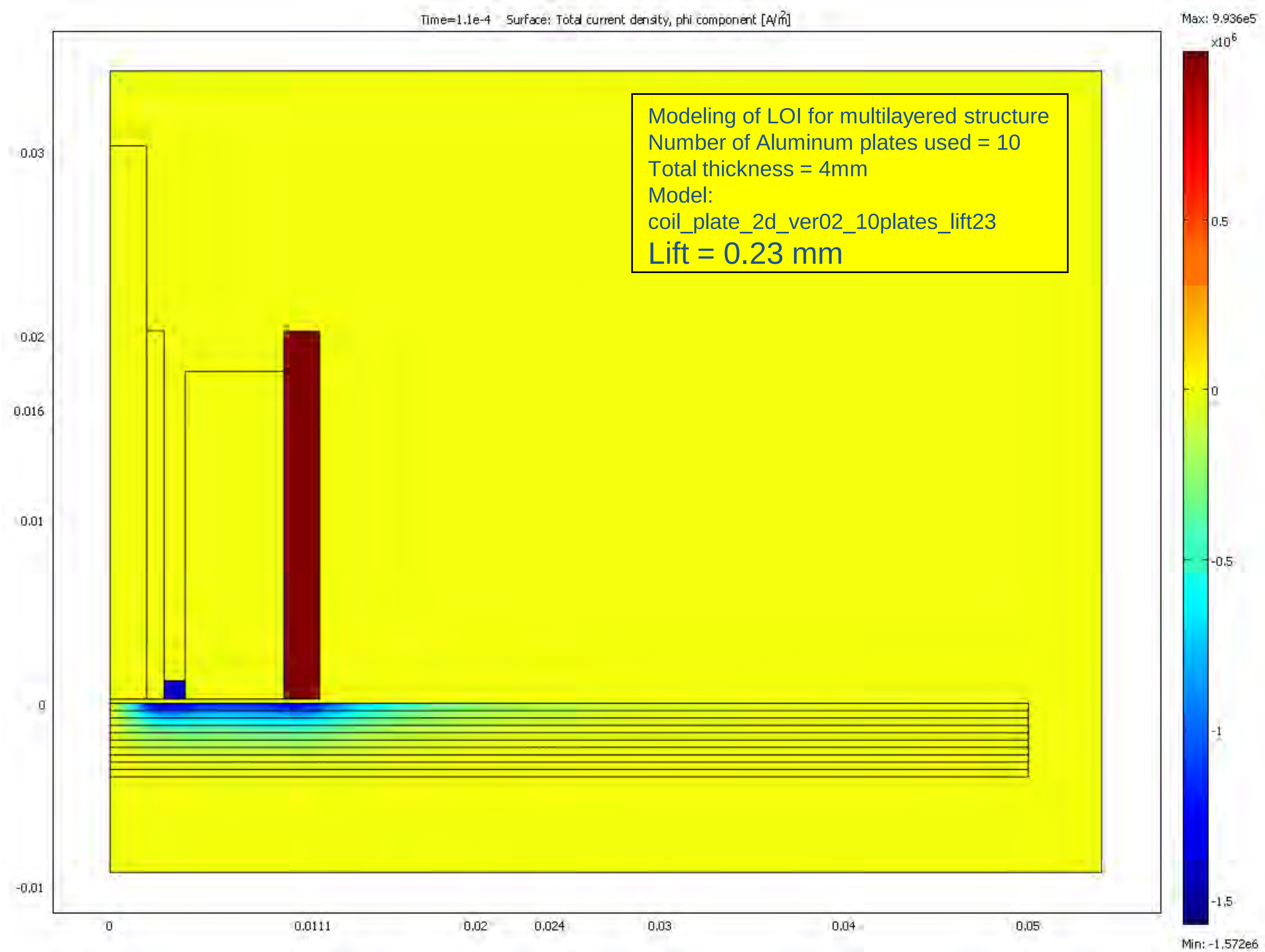
Step size: 2×10^{-7} s



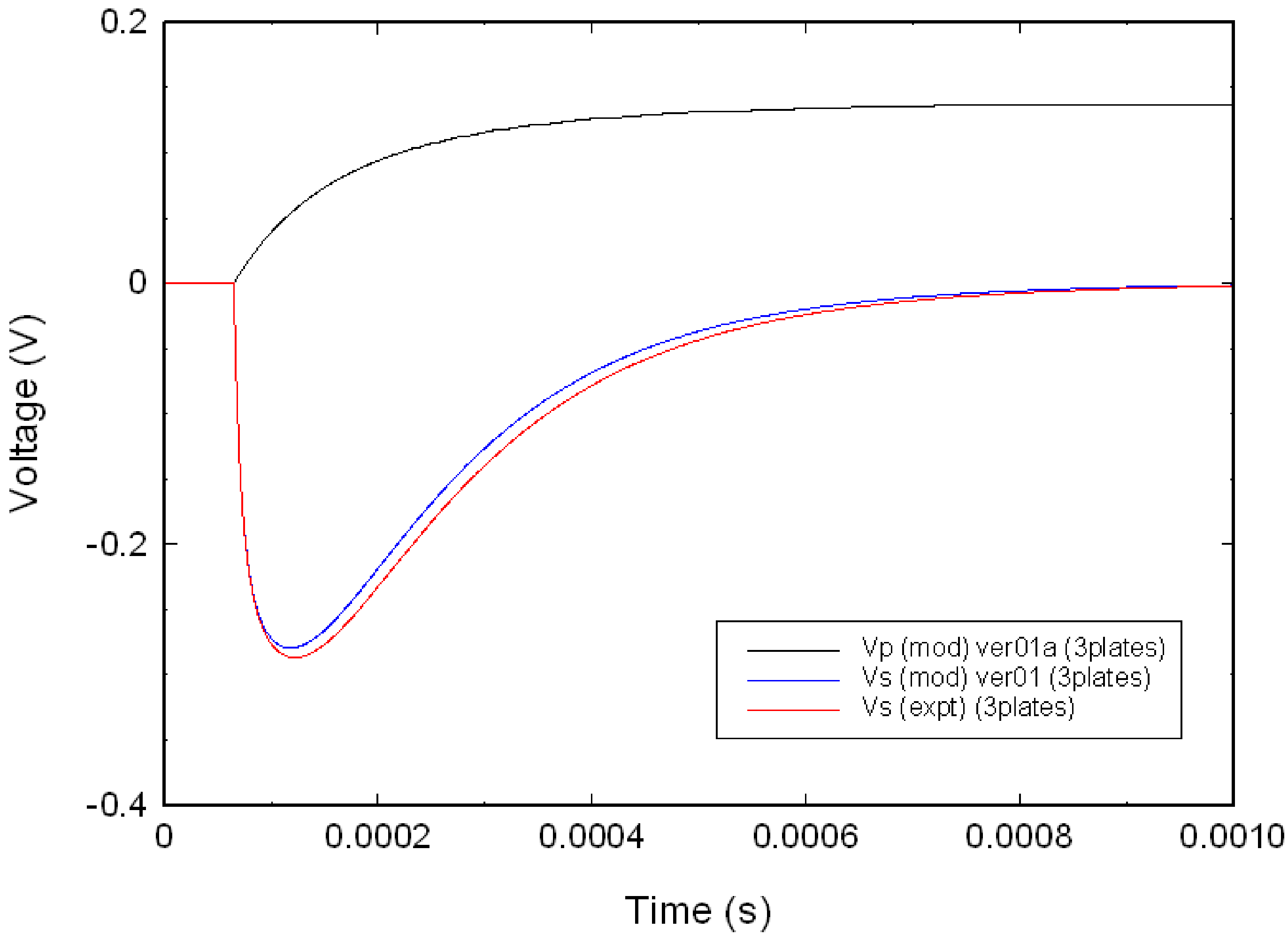
2D Finite Element Mesh



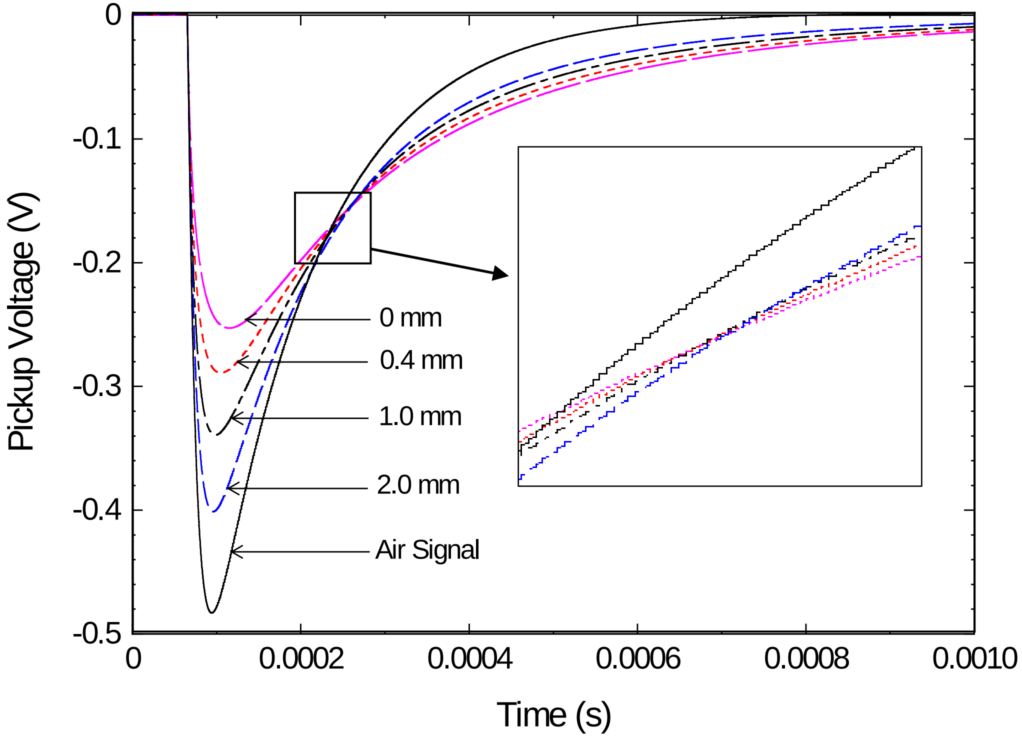
Total Surface Current Density



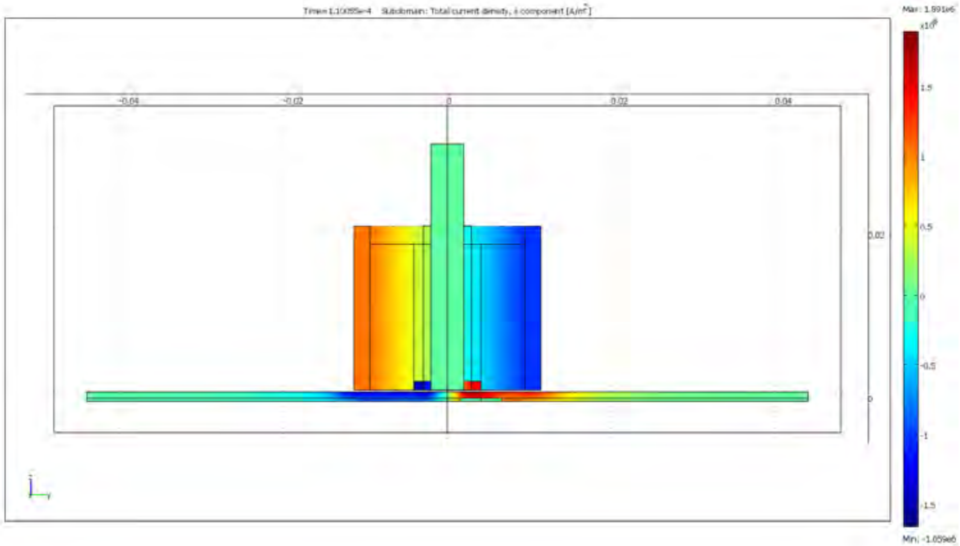
Driver and Pickup Voltages (Experiment vs. Model)

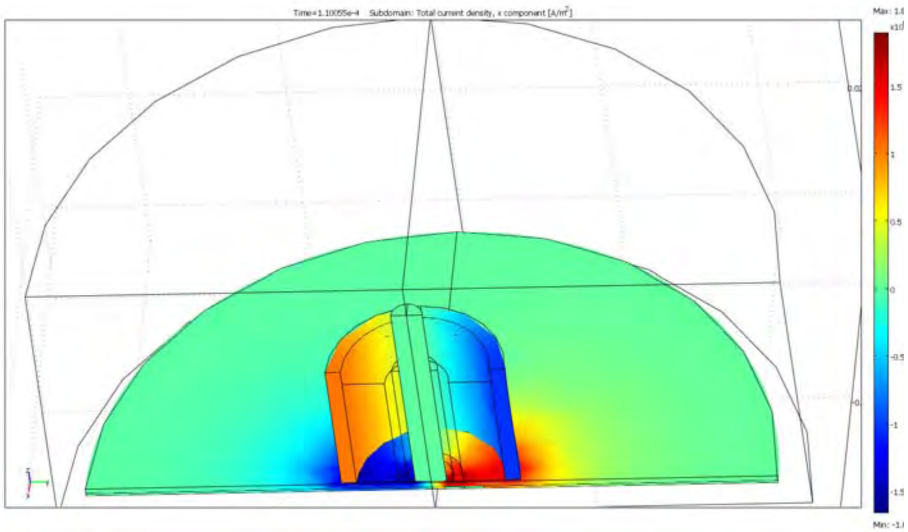


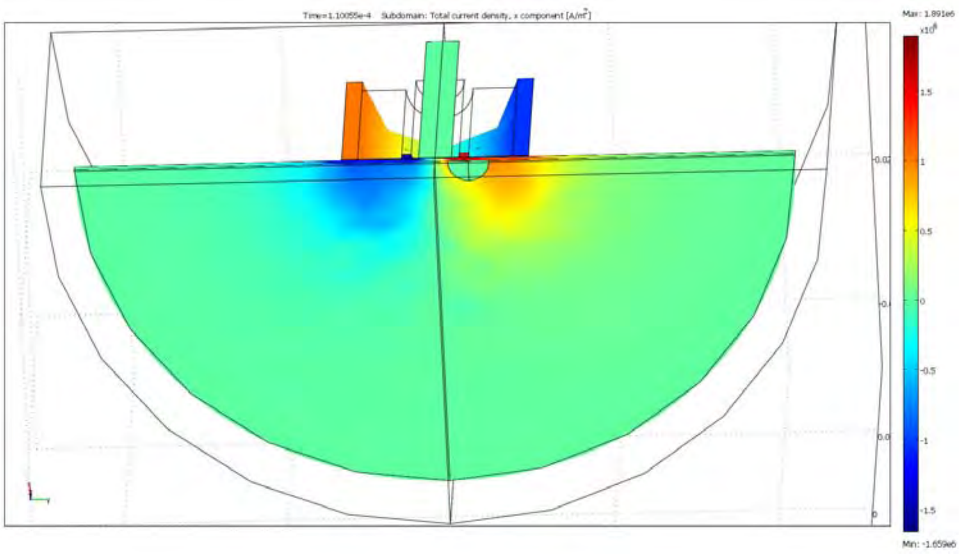
Model Verification of LOI Point for Flat Plates



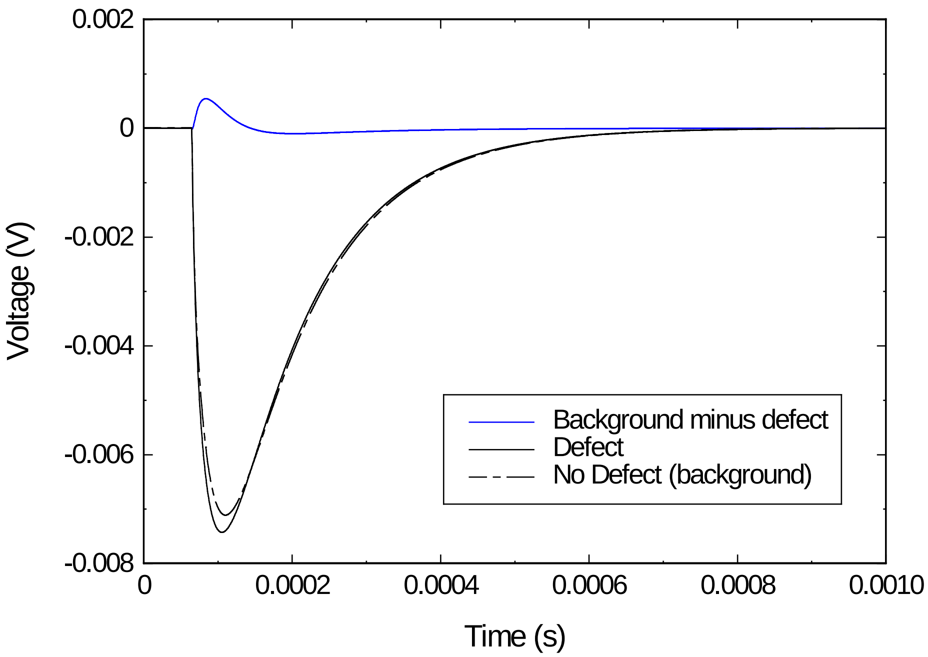
3D Model with Hole: Surface Current Density

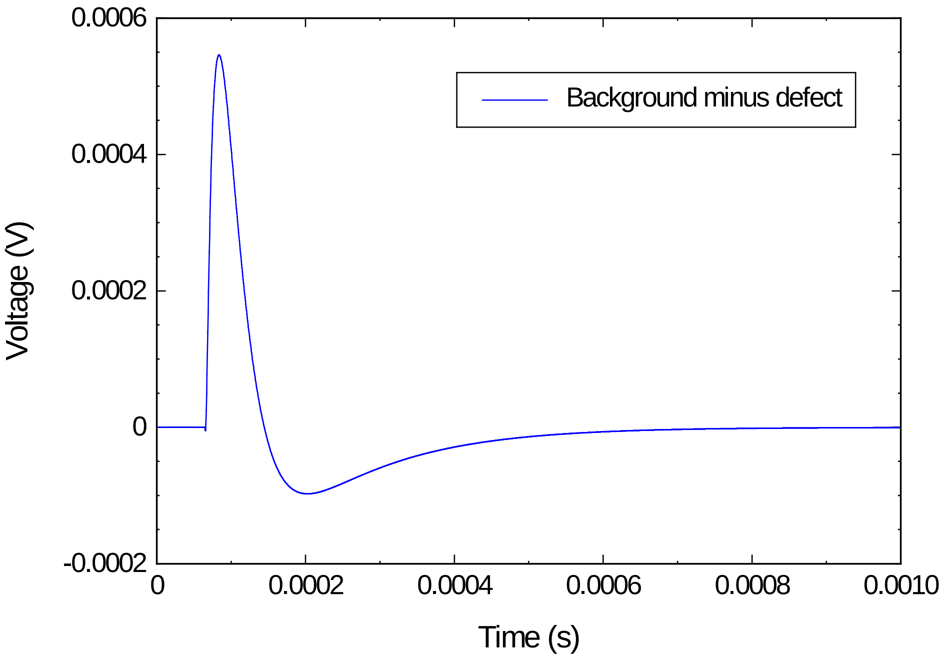




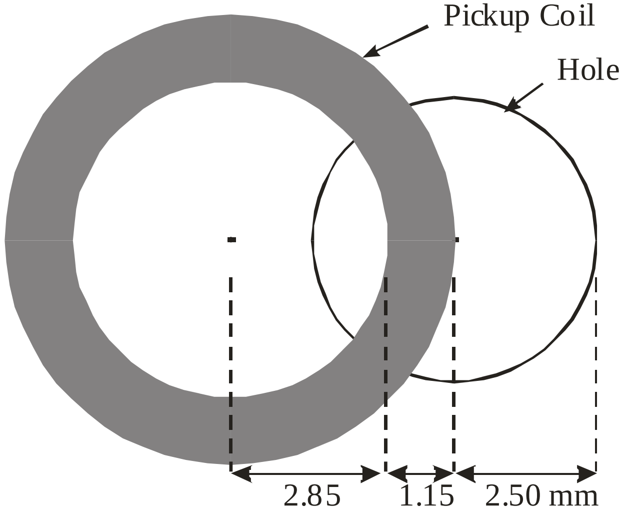


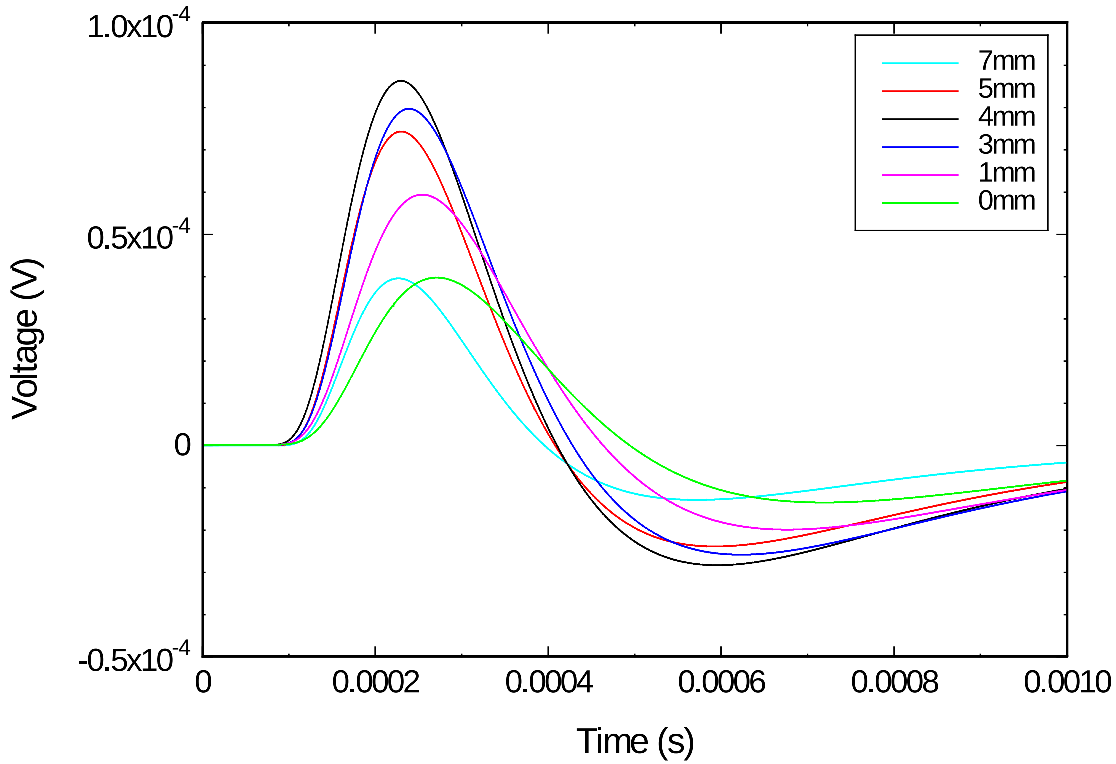
Defect and Reference Signals for 1 Plate



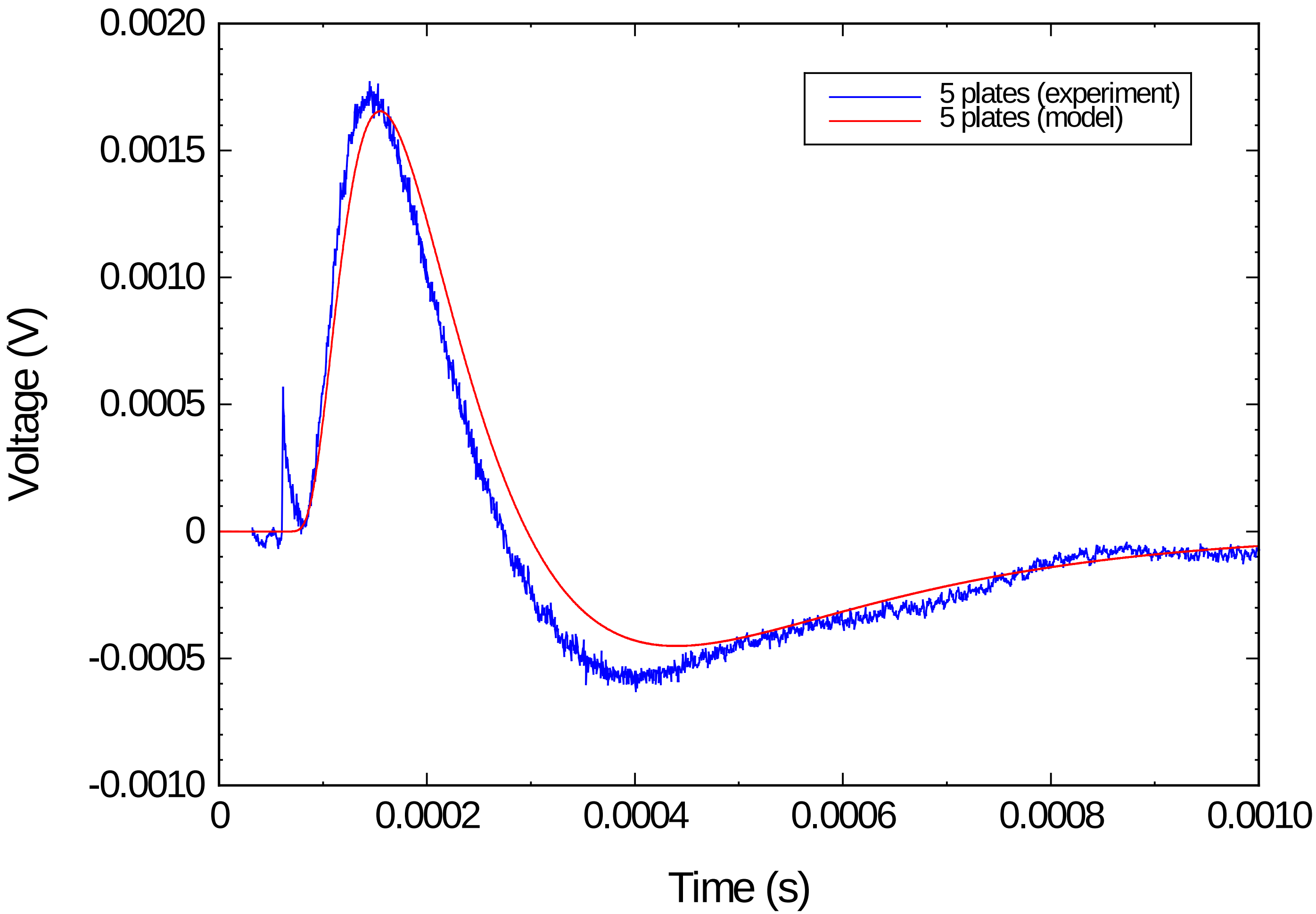


Subtracted Defect Signal vs. Probe Position



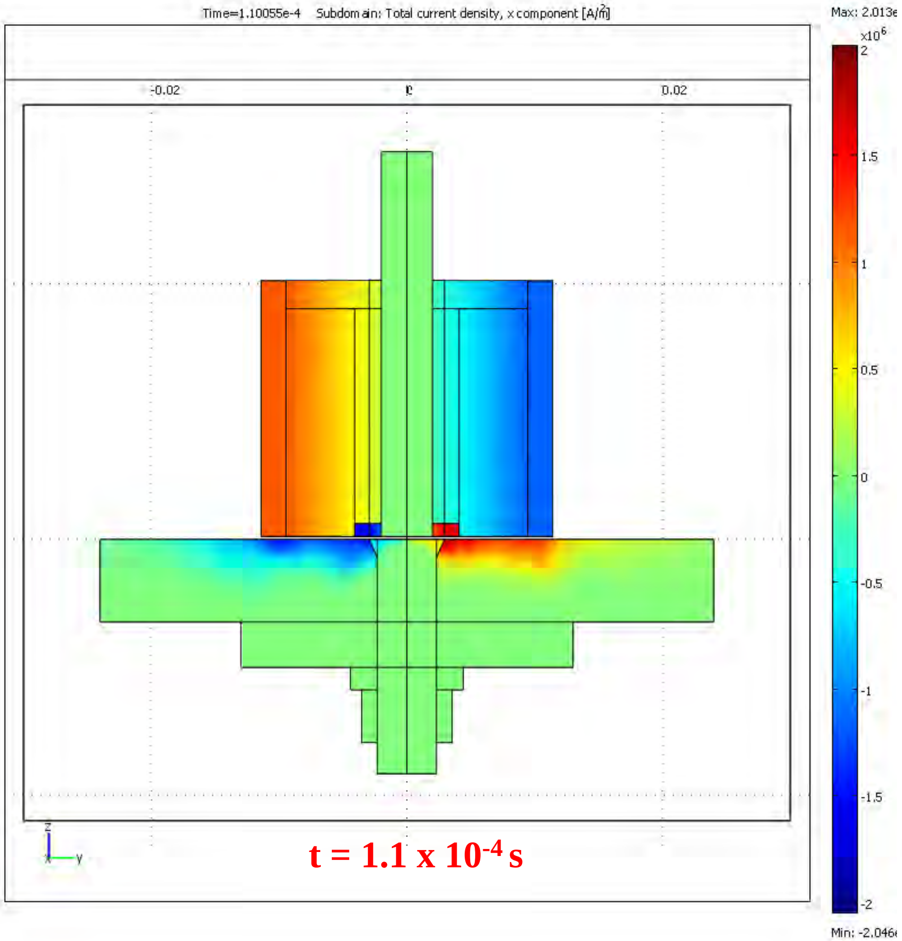


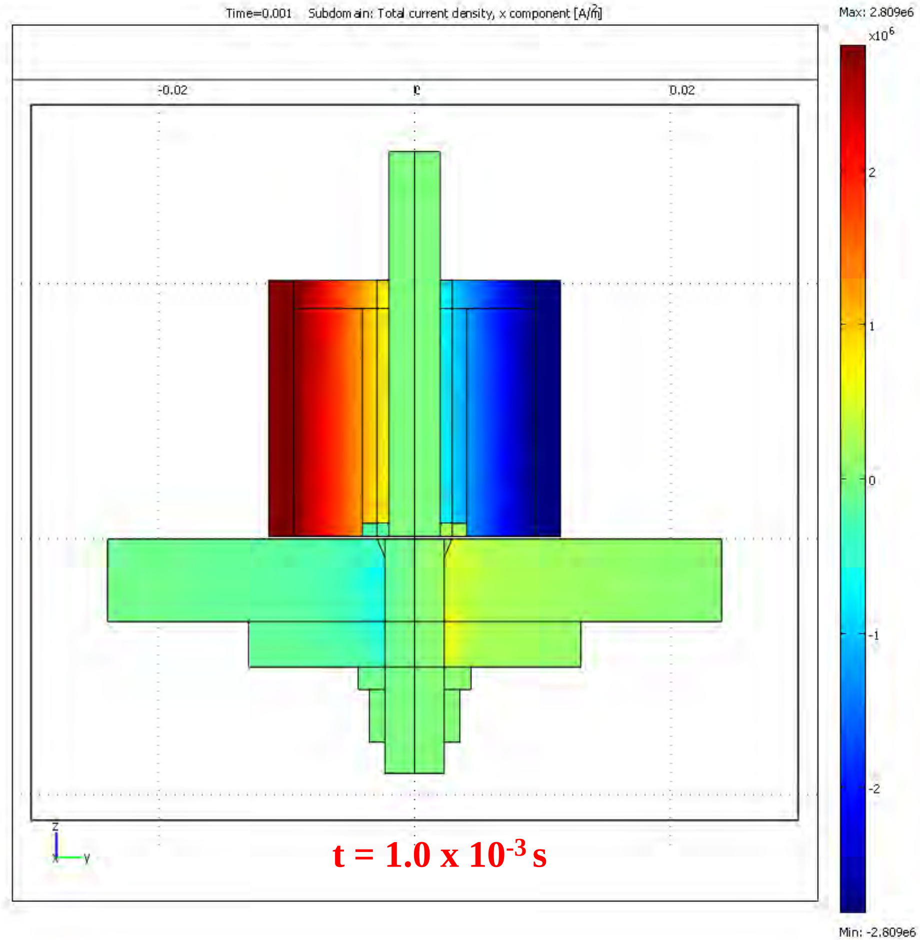
Modeled vs. Experimental Signal (5 Plates)



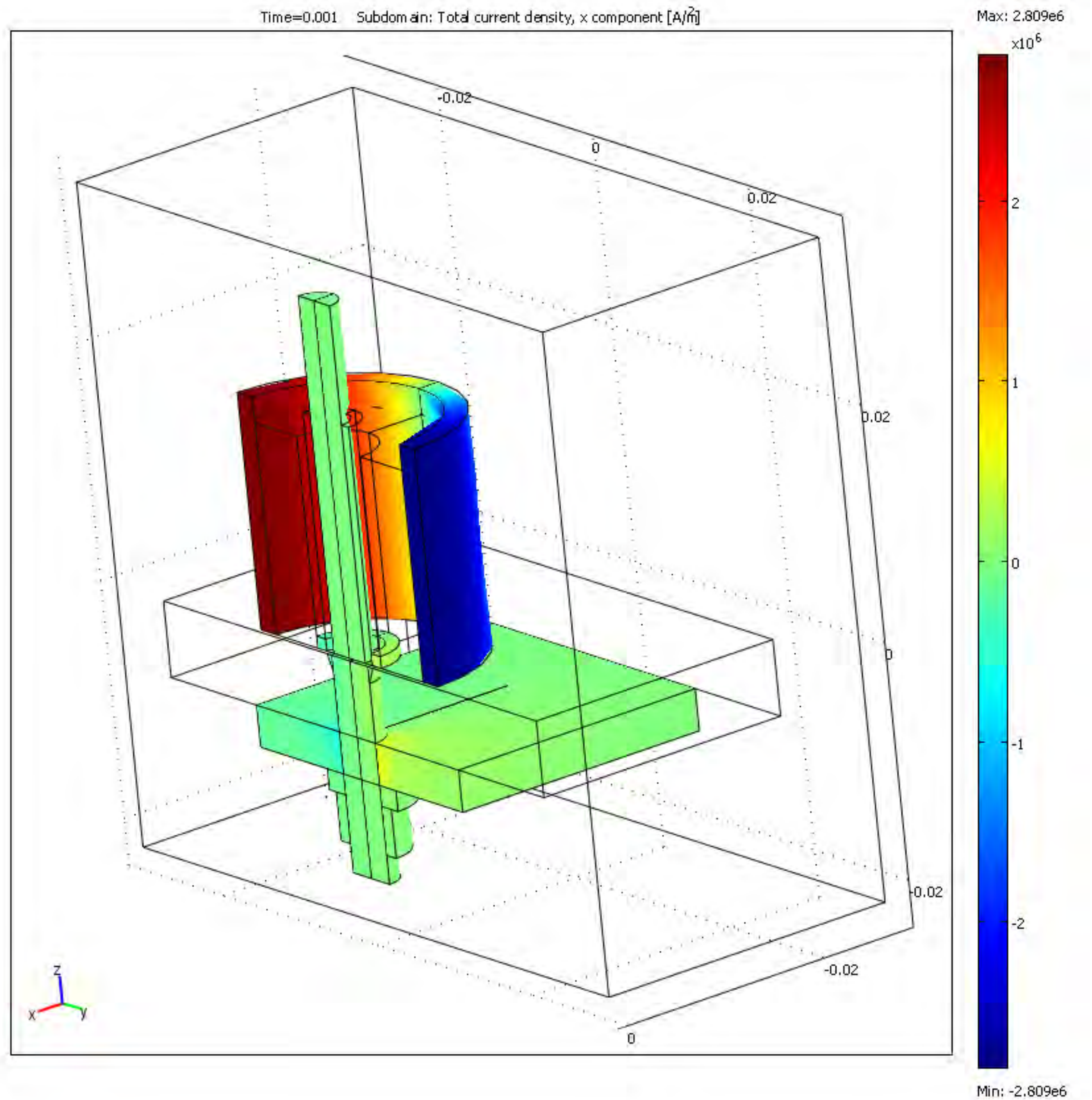
3D Half Model with Fastener and Crack

Current Density, J_x



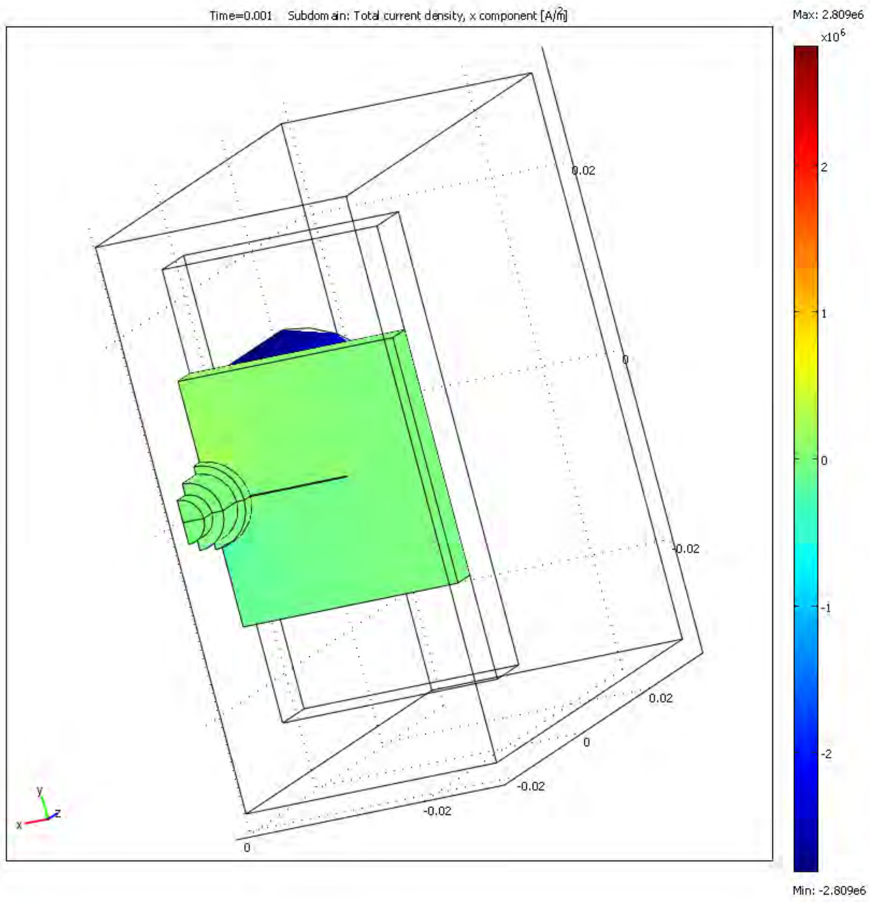


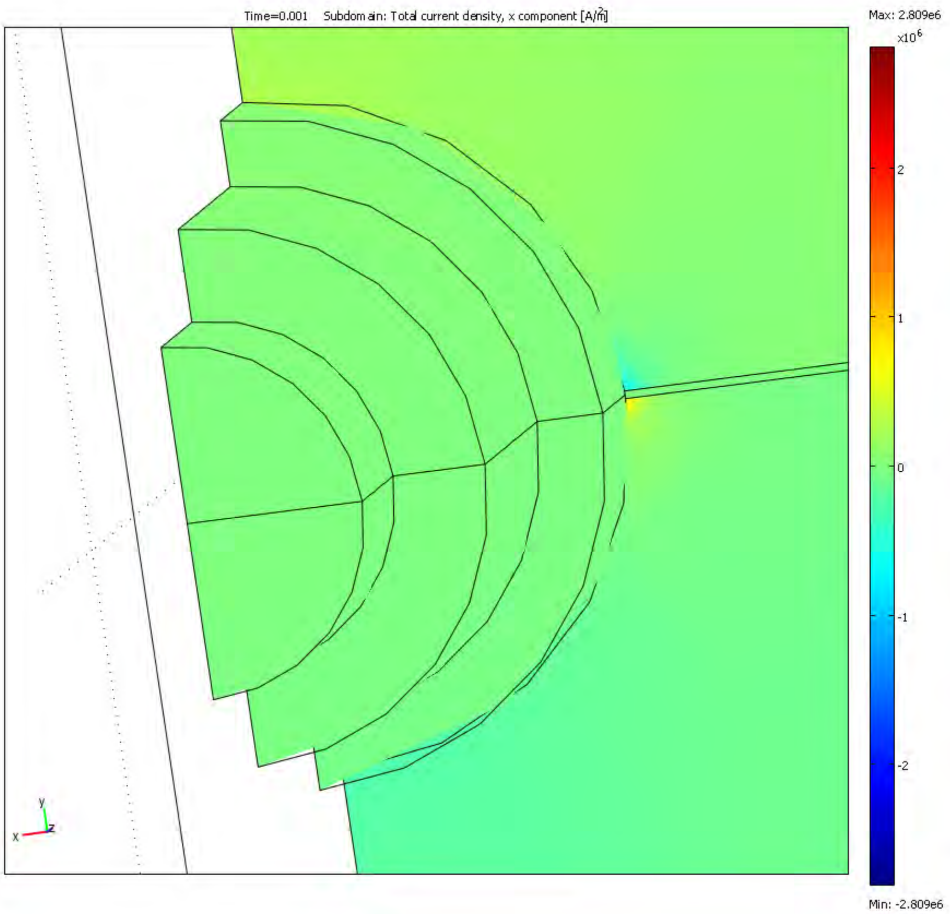
$\mu_{ferrite} = 2300$, $\mu_{fastener} = 66$



Time=0.001 Subdomain: Total current density, x component [A/m²]
Max: 2.809e6
x10⁶
2
1
0
-1
-2
Min: -2.809e6
-0.02
0
0.02
0.02
0
-0.02
-0.02
0
z
x
y

Underside Views of Crack Near Fastener





Summary

- COMSOL Multiphysics software has proved very successful for modeling the pulsed eddy current response in conducting plates in the presence of defects. Modeling in the presence of ferrous fastener has also produced important information.
- The models have been validated against experimental data.
- The interaction of pulser, drive coil and transient response of pick-up coil in air and in the presence of conducting material is successfully modeled.
- FE Modeling helped in investigating the effect of changing probe parameters on the probe characteristics. It also provided useful information on the diffusion of current density with time in conducting plates.
- FE modeling can potentially help in theoretical understanding of transient eddy current phenomenon, designing of new probes, and dealing with a variety of complex physical situations.

Thank You !

Questions ?