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COMSOL CONFERENCE 2016 BOSTON

Maximizing the Fatigue Crack Response in Surface Eddy Current Inspections of Aircraft Structures

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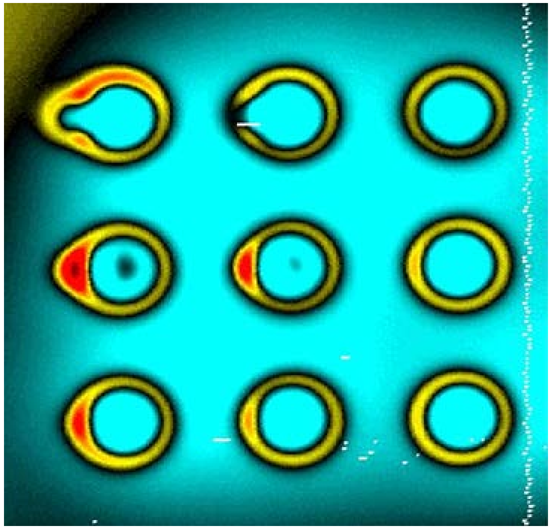
Background

Effects of fatigue cracking in airplanes

Typical crack detection with eddy currents



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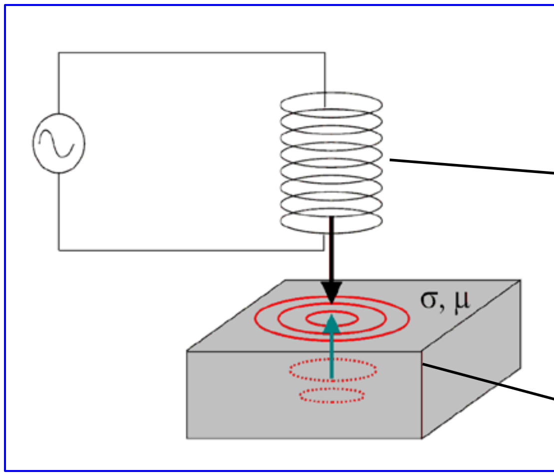
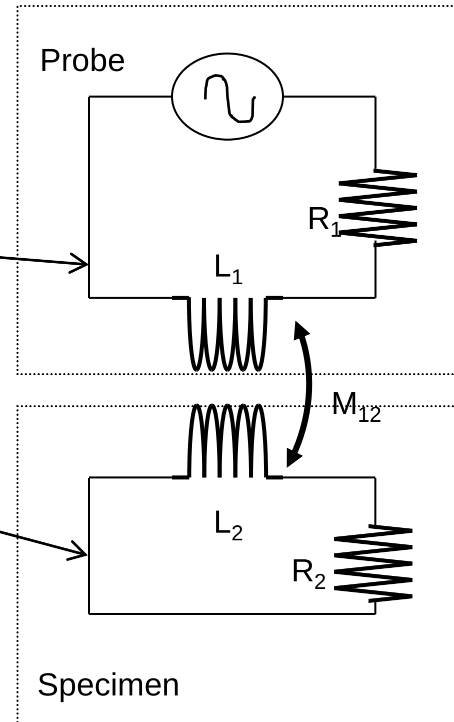
Principles of eddy current testing





Based on Faraday's electromagnetic induction law

$$V = -N \frac{d\Phi}{dt}$$

Skin depth of penetration

$$\delta = 1 \Big/ \sqrt{\pi \cdot \sigma \cdot \mu \cdot f}$$

$$V(t) = R_1\, i_1(t) + L_1 \frac{di_1(t)}{dt} - M_{12} \frac{di_2(t)}{dt}$$

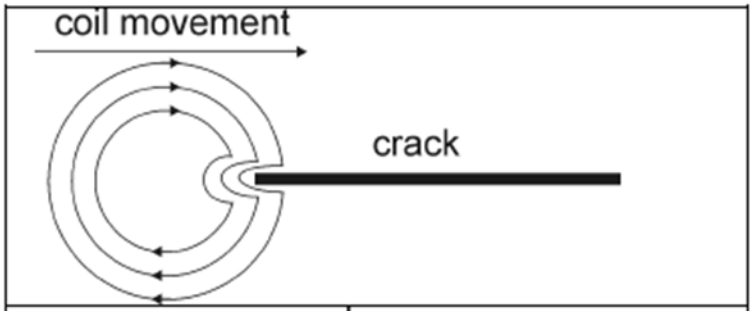
$$0 = R_2\, i_2(t) + L_2 \frac{di_2(t)}{dt} - M_{12} \frac{di_1(t)}{dt}$$

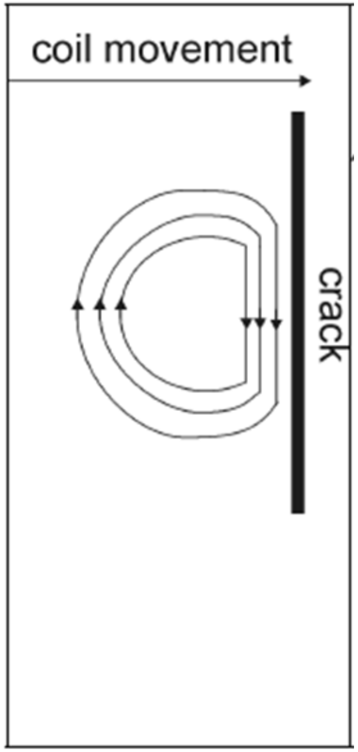
$$M_{12} = L_1 L_2 k^2$$

Interaction of eddy currents with fatigue cracks is complex

- Coil/probe characteristics
- Inspection settings
- Material nonlinearities
- Diffusion-based phenomenon

$$\nabla^2 \boldsymbol{A} - \mu \cdot \sigma \frac{\partial \boldsymbol{A}}{\partial t} = -\mu \boldsymbol{J}$$

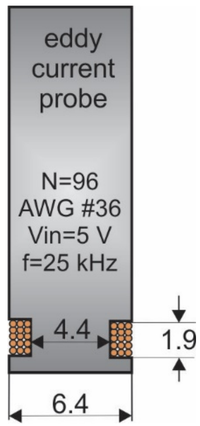




Objectives

- Understand the interaction between the magnetic field and the crack in eddy current inspection
  - Crack length
  - Crack depth
  - Crack orientation
- Identify signal features that could characterize the crack (size, location, orientation, etc)
- Optimize the scanning parameters for maximum response

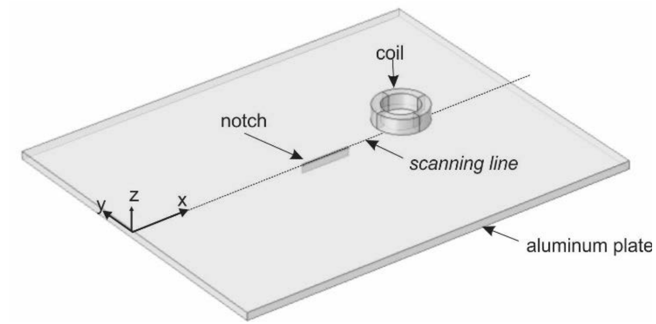
Experimental approach

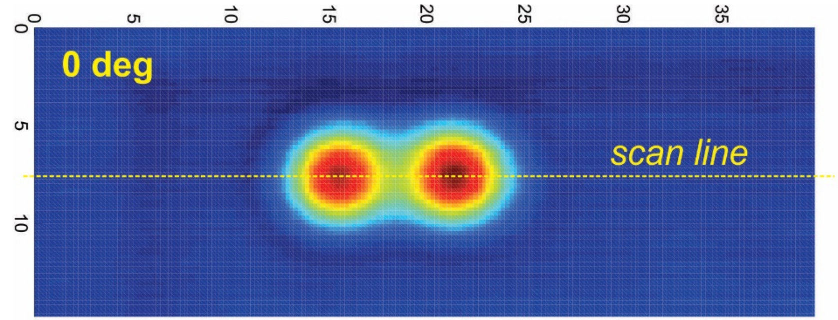


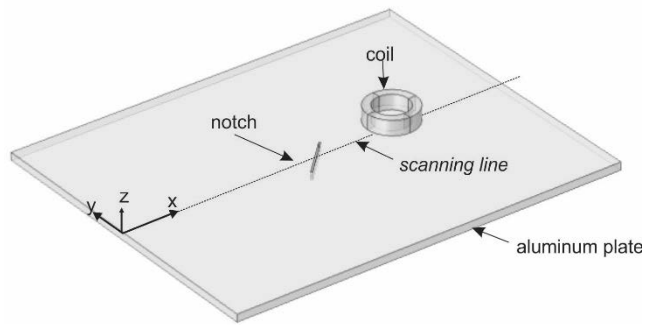
Specimens:

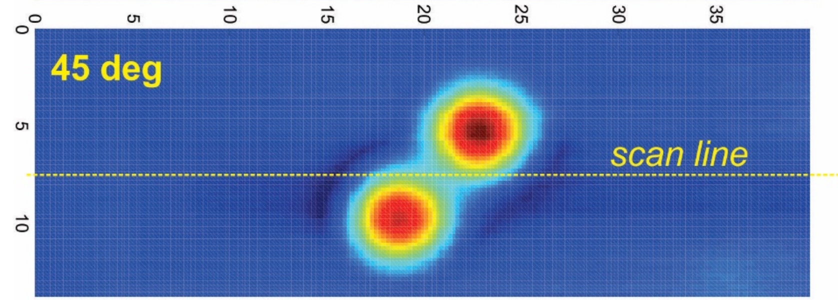
- 2024-T3
- 1.9575 x 10^7 S/m
- 1 mm thick
- 2, 4, 6 mm long EDM notches
- 100% through-wall

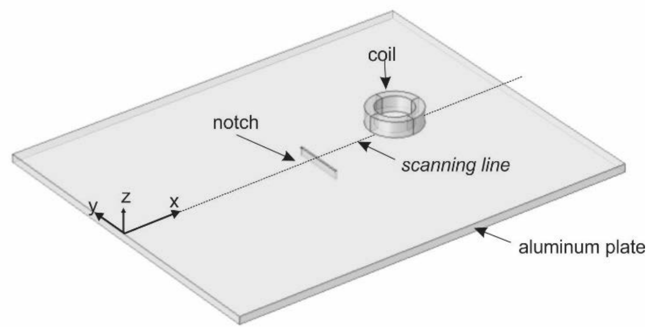
Experimental area scan for a 6 mm notch at different orientations

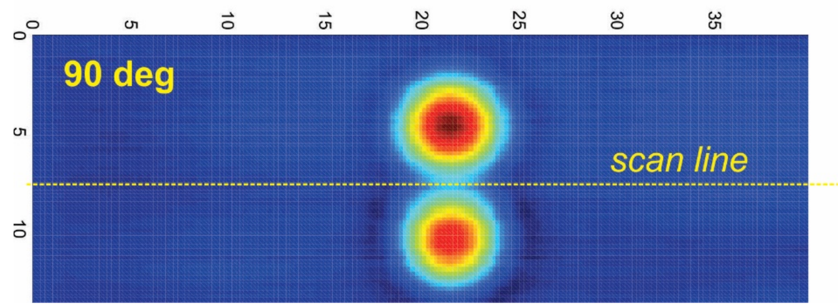




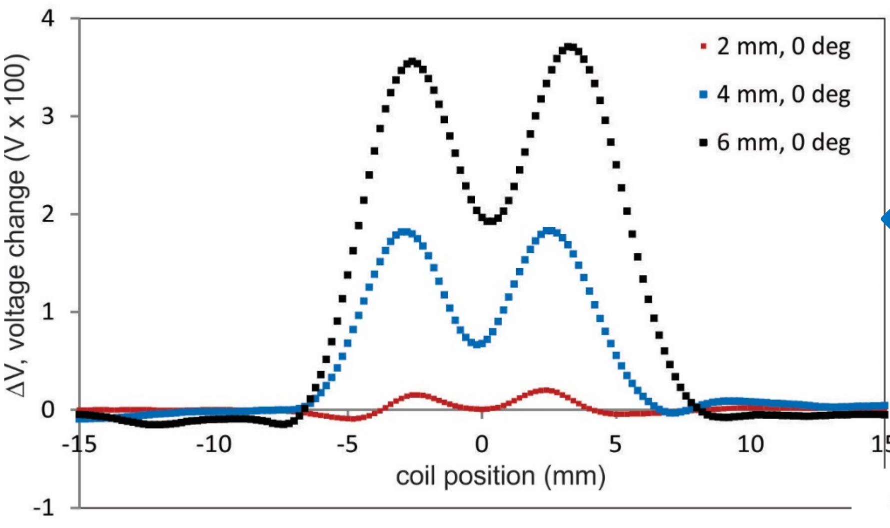






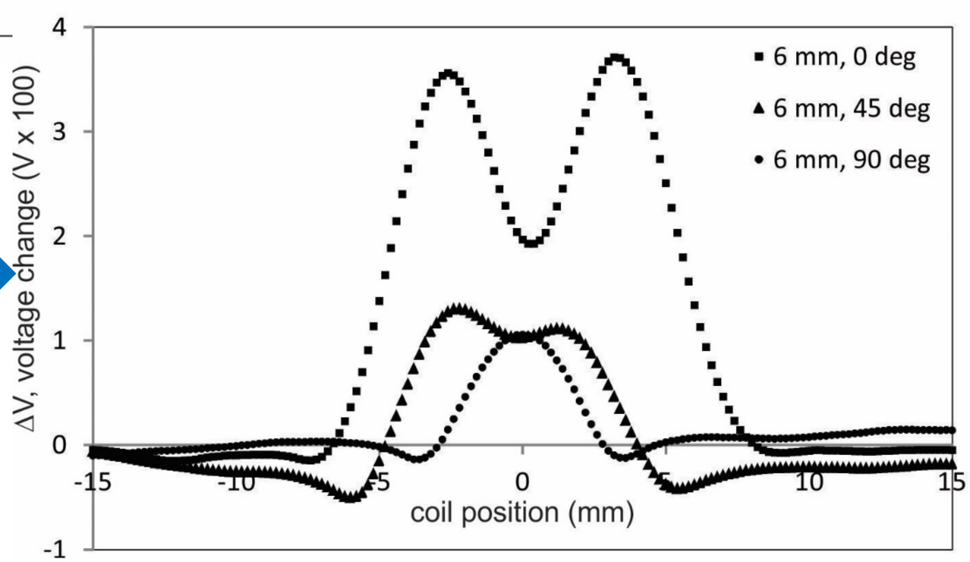


Experimental results – scanning profiles



Line scans along the length of three notches

Line scans along the center line of the 6 mm notch at different orientations



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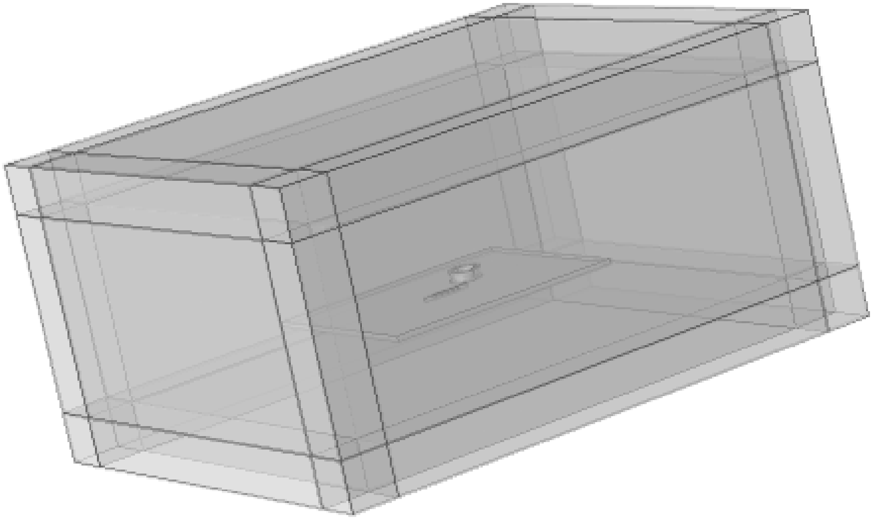
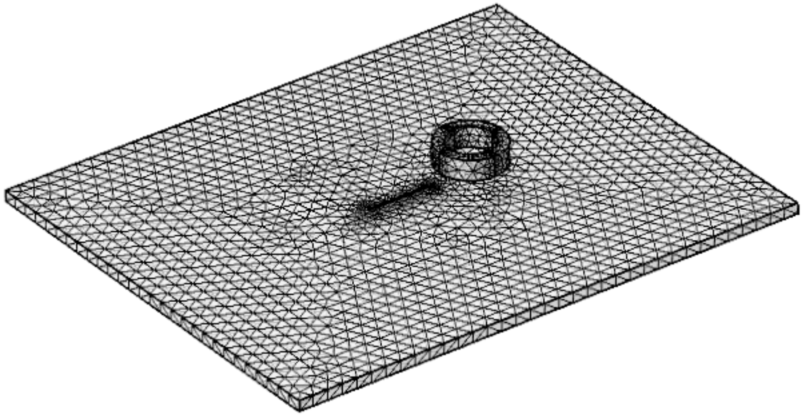
Modelling approach

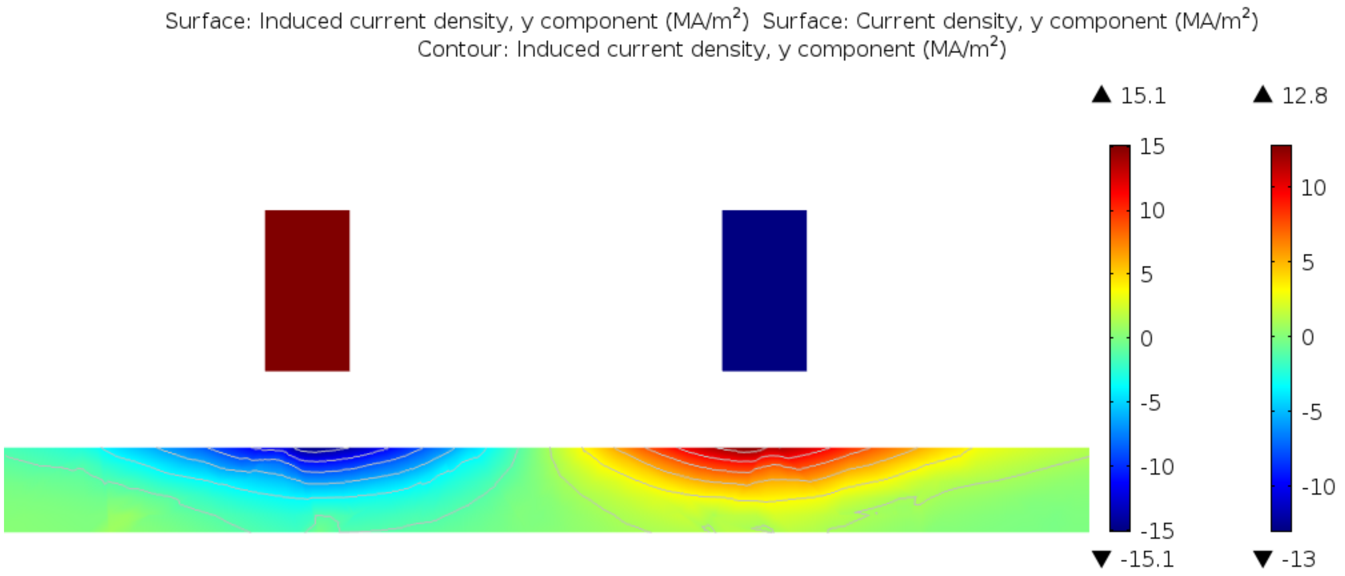




- COMSOL Multiphysics v 4.4
- 3D Geometry
- AC/DC Module
- Frequency Domain study
- Intel Xeon, 64 GB RAM, 3.2 GHz

- Multi-turn coil, Numeric type
- *Finer* Physics-based meshing
- Over 100k domain elements
- Infinite domains defined
- Default solver (MUMPS)

Generation of eddy currents in an Al plate



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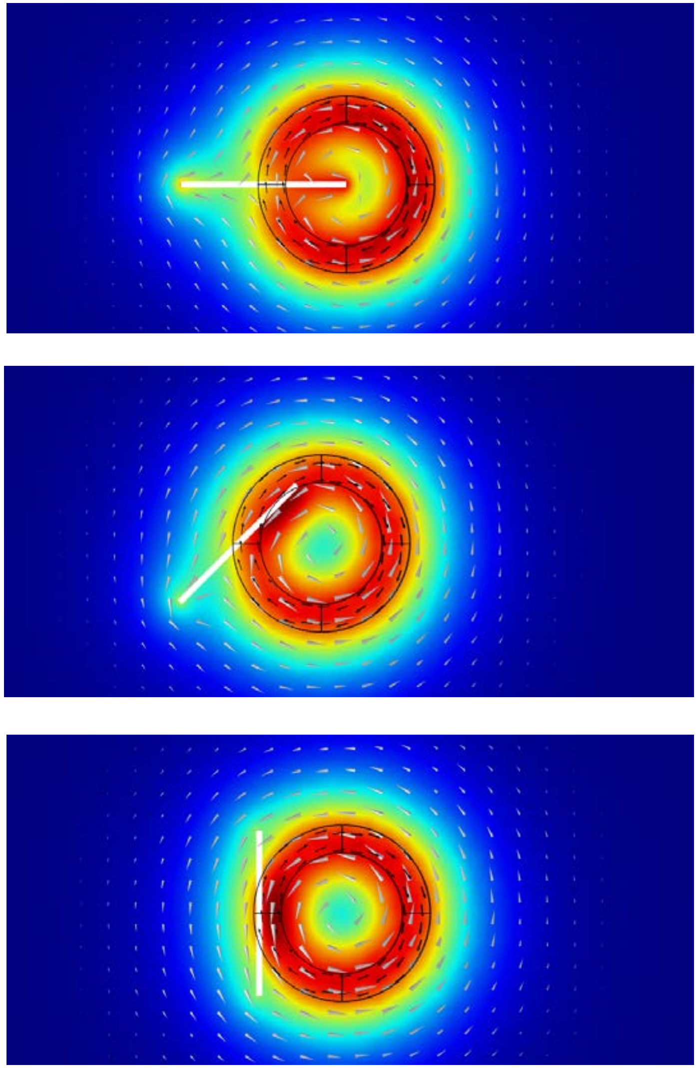
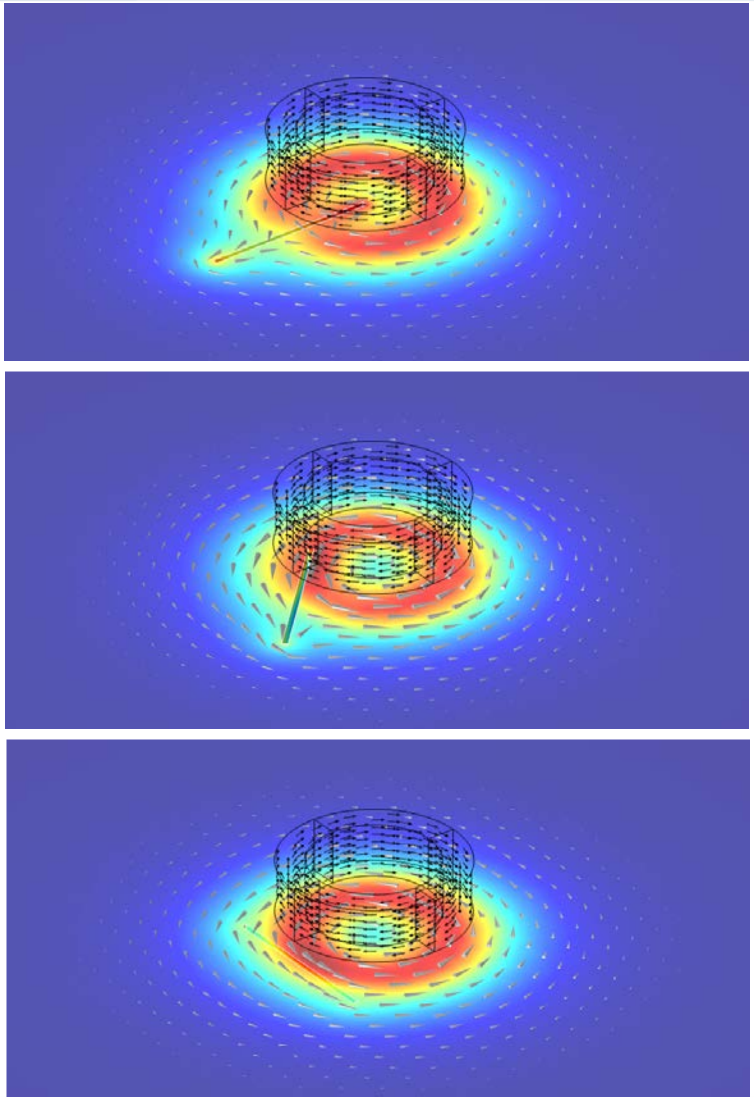
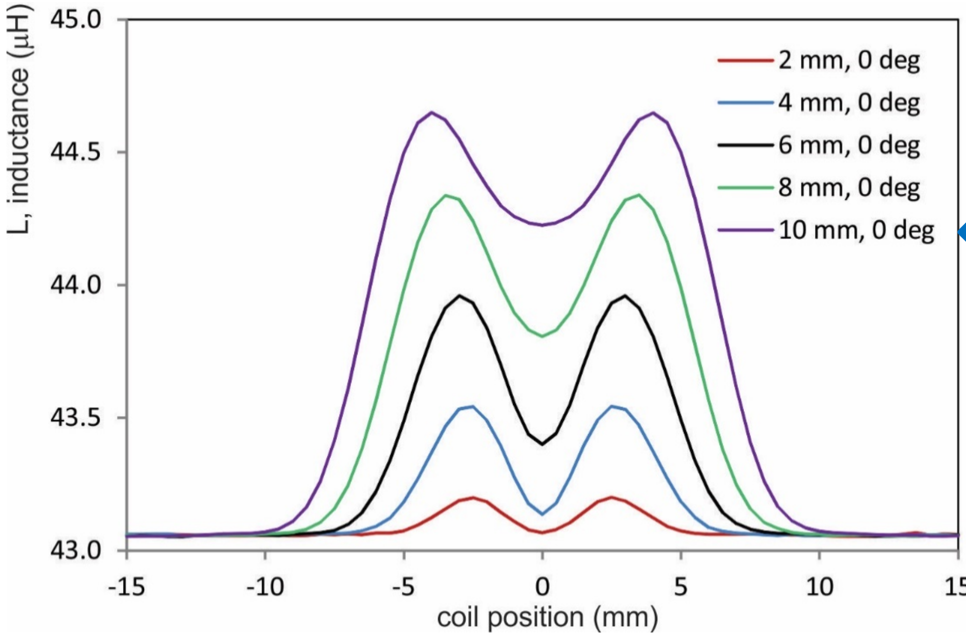
Influence of the crack orientation



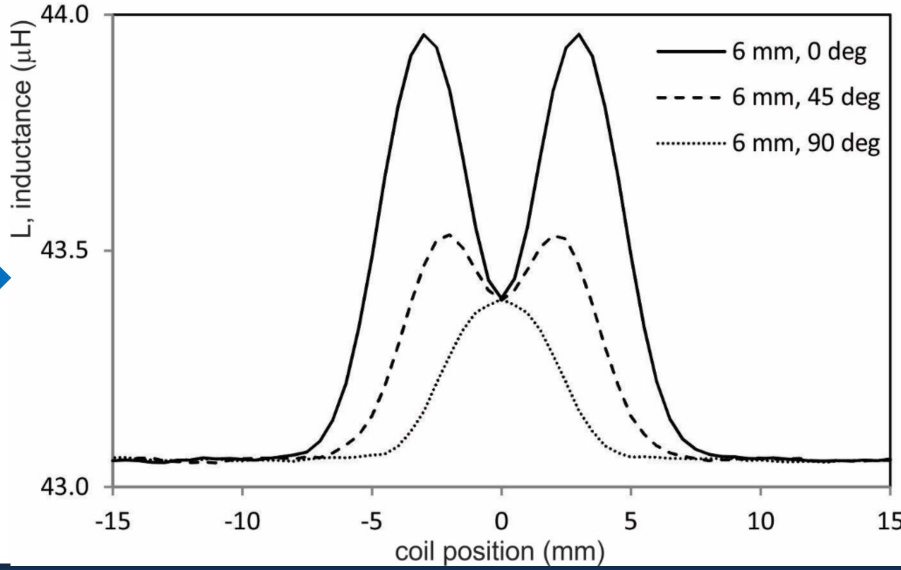


Modeling results – scanning profiles



Simulations of the line scans along the length of three notches

Simulations of the line scans along the center line of the 6 mm notch at different orientations



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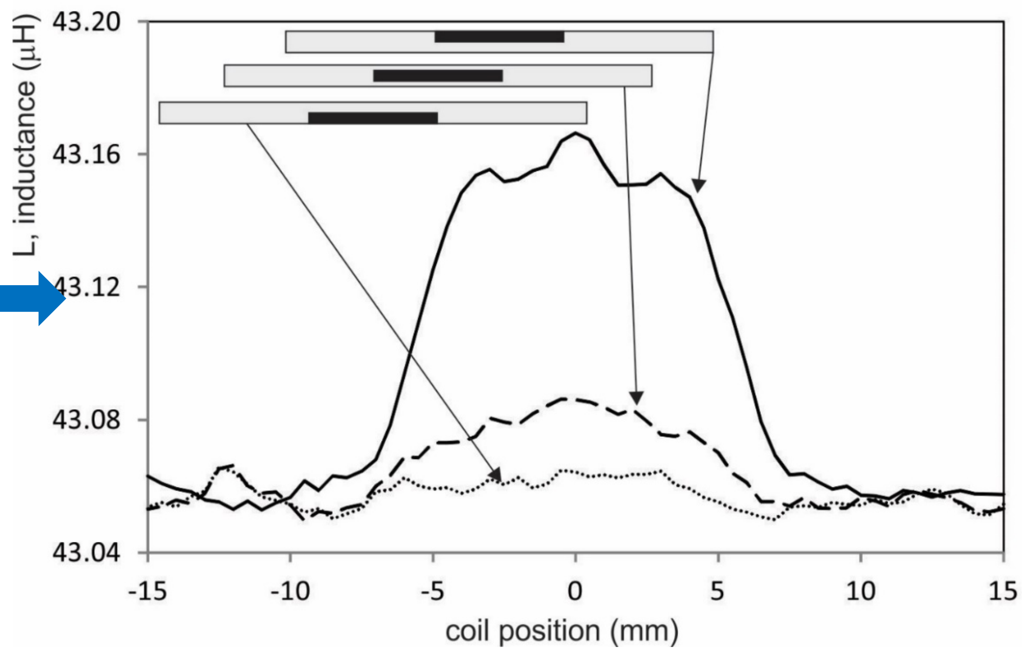
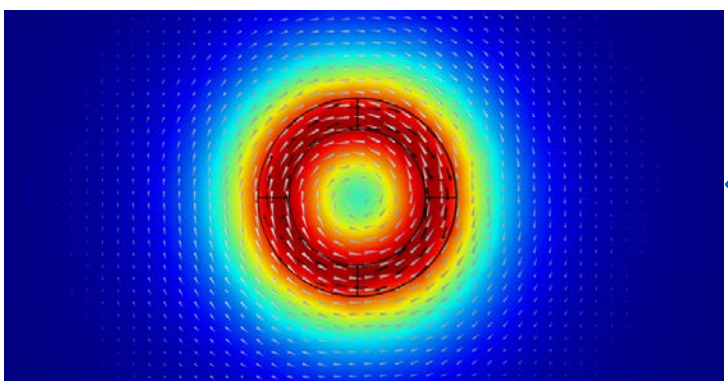
Simulation results to embedded notches

Simulations of the line scans along the center line of the 6 mm notch at different depth locations





Interaction when the notch is embedded

Estimation of crack length

True notch length value (mm)	Peak-to-peak separation	
	Experimental (±0.2 mm)	Numerical (±0.5 mm)
2	4.8	5
4	5.4	5
6	5.8	6
8	-	7
10	-	8

Conclusions

- The maximum eddy current response is detected at the crack tip, but only when the scanning direction is aligned with the crack length,
- The line scan profile can be used to size the crack length, but only when this has dimensions comparable to the coil diameter,
- Interpretation for sizing of the hidden cracks cannot be done on signal amplitude alone.