Role of Physics-Based Models in Cracks Versus Notch Response Determination

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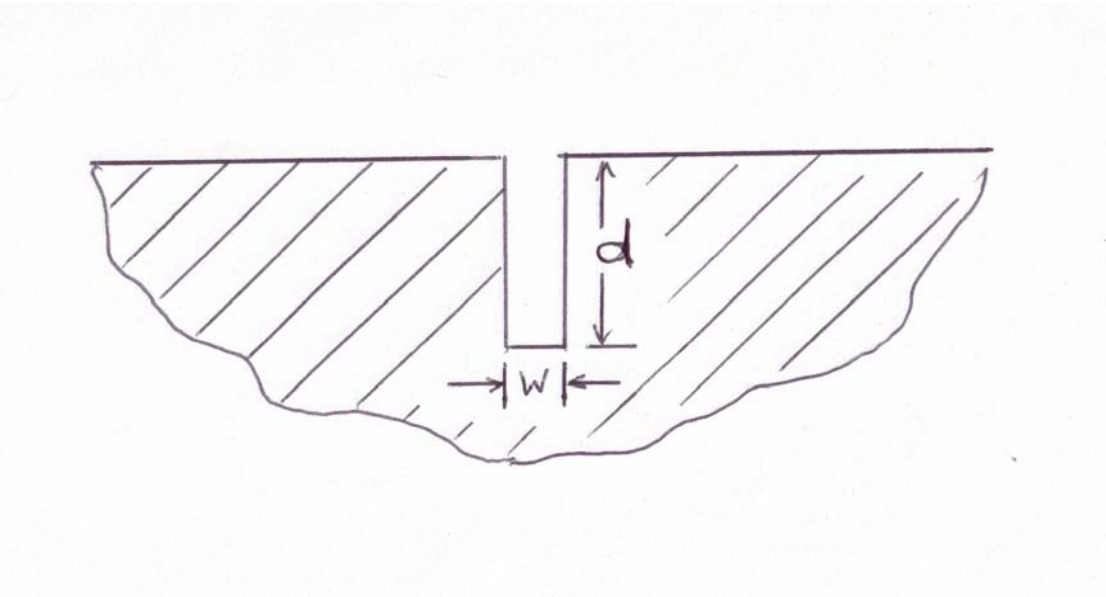
Outline

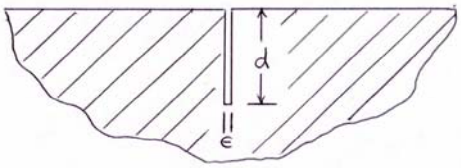
- Different Types of Cracks
- Their Effects on NDE Measurements
- Possible Model-Assisted Approach to Account for Crack Versus Notch Effects

Notch

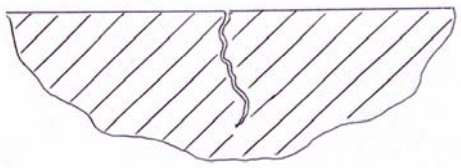


Cracks

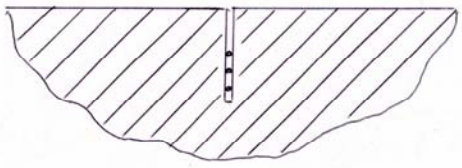
Ideal Mathematical Crack



Morphology Effects



Electrical/Mechanical Contact Effects



Material Mechanisms

- Growth along grain boundaries
- Non-uniform residual stresses

- Oxides and other debris
- Contacting asperities
- Sheared faces

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Ultrasonics

Response as Compared to Notch Response

Measurement	Ideal Crack	Morphology Effects	Mechanical Contact Effects
Specular Reflection	Equivalent	Reduced Due to Interference	Reduced Due to Transmission
Tip Diffraction	Different; Often Less	Different; Often Less	Different; Often less
Through Transmission	Equivalent	Equivalent	Increased

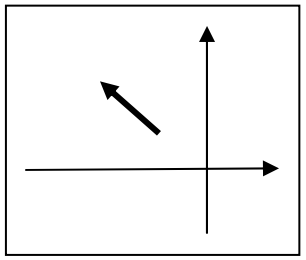
Eddy Currents

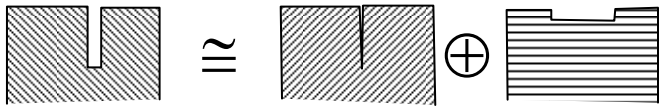
General Comments

- Electrical contacts (bridging) will always have an effect if currents, following along crack faces, are “short circuited”
- Morphology effects are less significant than for UT
- Open cracks have greater “inductance” than ideal mathematical crack because of stored energy in magnetic fields
- The difference increases with frequency
- In the impedance plane, this is similar to, and hard to differentiate from, lift-off effect

Notch vs. Crack: EC Model

- Notch-Crack difference appears
  - Strongly in impedance amplitude
  - Weakly in vertical components (when lift-off is horizontal)
- Reason
  - The volume effects behave similarly to the lift-off effect
    - More volume energy = higher reactance
    - Less material = lower resistance





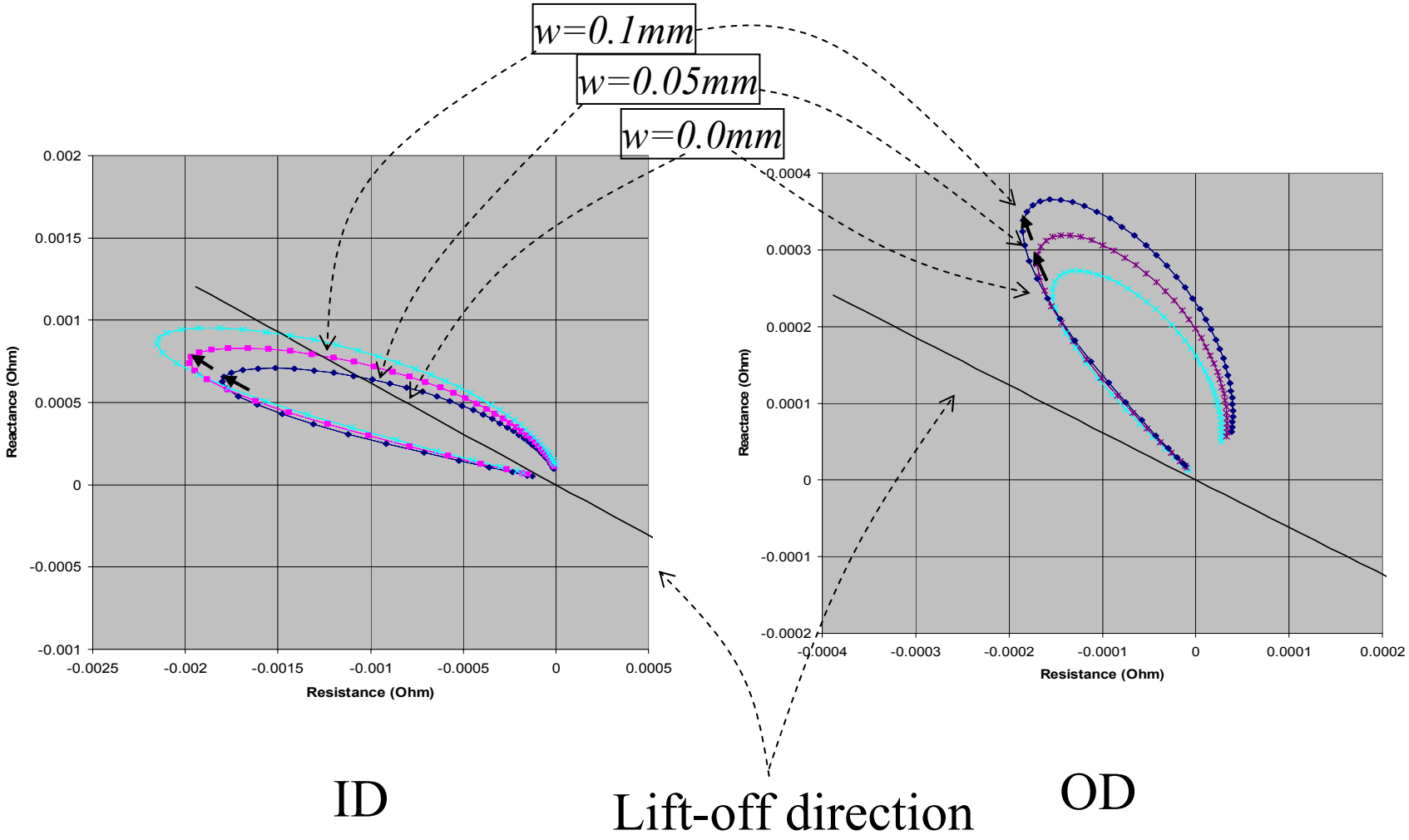
Example Calculation

Model Parameters

- Notch *l*ength×*d*epth×*w*idth
  - *l*=1mm, *d*=0.5mm
  - *w*=0.0, 0.05, 0.1mm
- Solenoid coil
  - *ID*=1.07mm, *OD*=2.62mm
  - *L*=2.79mm
  - Lift off=0.73mm
  - *F*=100kHz
- Part = a plate
  - Inconel 600 (1.02×10^6 S/m)
  - 1.27mm thick

- In two configurations
  - "ID" (same side)
  - "OD" (opposite side)
- Results
  - ~20% increase in amplitude with 10% opening (i.e. *w*/*l*=0.1)
  - Increase in the lift-off direction
  - Vertical components are insensitive to notch openings.

Calculated Opening Effects



Eddy Currents

Measurement	**Ideal crack response as compared to notch response**
Absolute coil ■ Lift-off rotated to horizontal ■ "Response" taken as vertical response	**Difference often small** ■ Ideal crack can have greater or less response
Differential coil ■ "Response" taken as magnitude of impedance change	Significant Difference $\left\|\Delta Z_{NOTCH}\right\| > \left\|\Delta Z_{CRACK}\right\|$

Internal Defects

- Similar issues exist for internal defect
- X-ray techniques as well as ultrasonic and eddy current techniques must be considered

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Suggested Strategy

- Use physics-based models to correct notch data for difference between ideal cracks and notches
- Create database of deviations of responses real cracks from expectations for ideal cracks
  - Include salient materials variables specifying growth factors controlling morphology
    - HCF vs LCF
    - Closure
    - Etc.
- Long term goal
  - Develop “knock down factors” that can be confidentially used in new studies

Questions

- Is there quantitative data for non-bridged cracks in slots or bolt holes in engines or faster holes in lap joints, that could be used to validate theories?
- How would we determine depths independently?