# Three-Point Calibration
# --- Possible roles played by models

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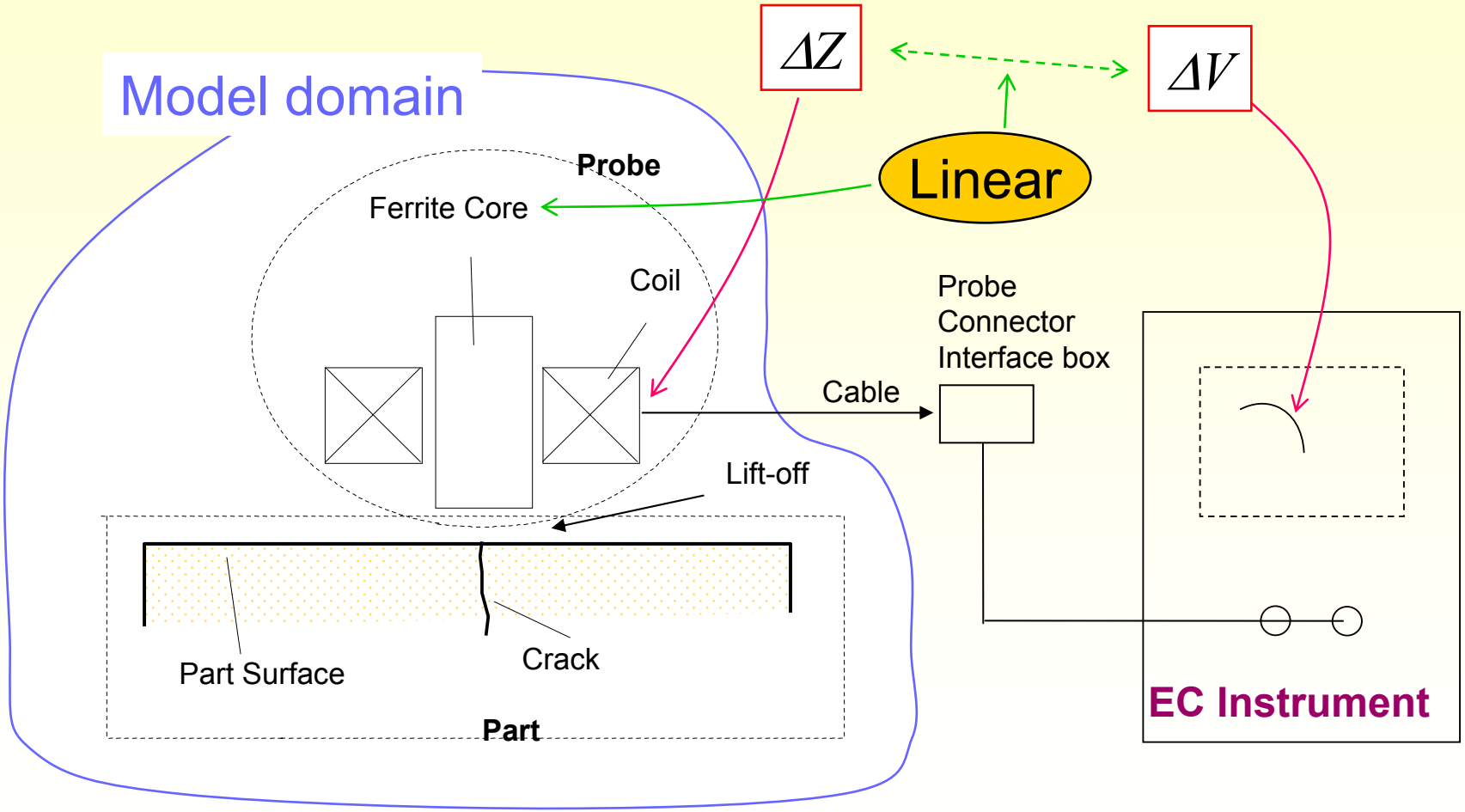
# Outline

- Demonstrated role of models
  - To select calibration notch sizes appropriately
  - Have shown that CNDE EC model provides help.
    - B.P.C. Rao and NN, Review of QNDE, Golden, CO
    - B.P.C. Rao, N. Nakagawa, and L. Brasche, WCNDT, Montreal

- Brief Comment on Possible Advanced Role
  - To ensure the “<a> vs. a” relation consistent/repeatable
    - W. Rummel, Review of QNDE, Golden, CO
  - Model scope/capability may require extension

# CNDE EC Models -- Scope



# Notch size selection via model prediction

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# Model Study of 3pt Cal. -- Motivation

- SAE ARP* Committee-K is preparing a standard document
  - EDDY CURRENT "PENCIL" PROBE SURFACE CRACK DETECTION IN AEROSPACE STRUCTURES (doc)

*Society of Automotive Engineering (SAE), Aerospace Recommended Practice (ARP)*

- RECOMMENDED PRACTICE covers ranges of
  - Materials (σ, 1% to 62% IACS)
  - Instruments (CRT, Meter, Time-base etc.)
  - Probes (Absolute, Differential)
  - Excitation frequencies (3500/σ to 18500/σ kHz)
  - Test situations (Manufacturing, Service, Painted etc.)
- Calibration notches

| | |
|---|---|
| 0.2mm – 0.5mm – 1mm D, 25mm L | ☺ |
| 0.37mm – 0.75 mm – 1.5 mm, 2-to-1 | ☹ |

# Objective/Approach

- Objective
  - To provide SAE Committee-K with data to assist in the three-point calibration standard development

- Approach
  - Simulation by numerical model (inexpensive)
  - Predict probe signals from 3 calibration notches, for a ranges of materials, probes, and frequencies
  - Experimental validation (few selected cases)
  - Analyze specific questions

# Specs vs. Model Study Matrix

**SAE RECOMMENDED PRACTICE**
**parameter ranges**

- **Model Study Matrix (540 data sets)**
  - 2 Probes (Absolute/differential)
  - 18 Materials (6-groups, 3-categtories)
  - 5 Frequencies ($f_\delta = f_{0.15}, f_{0.2}, f_{0.25}, f_{0.3}, f_{0.35}$)
  - 3 Notches (0.2,0.5, 1.0 mm deep)
  - 1 Lift-off

- **Materials** **Category (%IACS)**

| | | | |
|---|---|---|---|
| – Group – 1 | 1.0 | 1.2 | 1.5 |
| – Group – 2 | 2.4 | 2.7 | 3.1 |
| – Group – 3 | 5.0 | 6.0 | 7.0 |
| – Group – 4 | 12 | 13 | 15 |
| – Group – 5 | 30 | 33 | 36 |
| – Group – 6 | 50 | 56 | 62 |

# Other Parameters in the Model

## Material & Notch

| | | | |
|---|---|---|---|
| **Thickness:** | **3 mm** | **Lift-off:** | **0.2 mm** |
| **Notch:** | **9x0.2, 0.5 and 1 mm** | **Core $\mu_r$:** | **200** |

## Absolute Probe

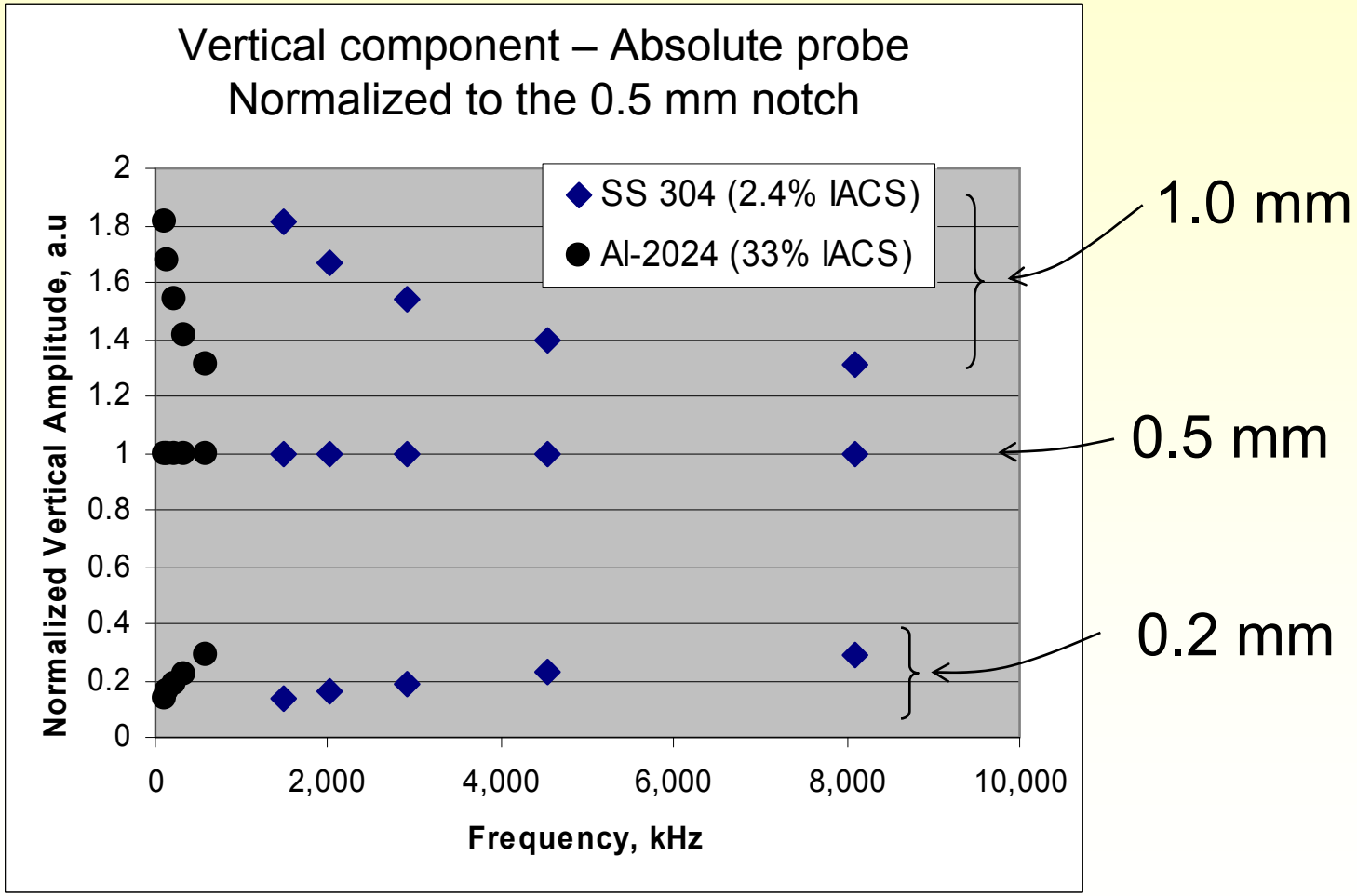
| | | | |
|---|---|---|---|
| **Coil ID:** | **1.5 mm** | **Coil OD:** | **1.8 mm** |
| **Coil length:** | **0.3 mm** | **Coil height:** | **1.0 mm** |
| **Core ID:** | **1.4 mm** | **Core height:** | **2 mm** |

## Differential Probe

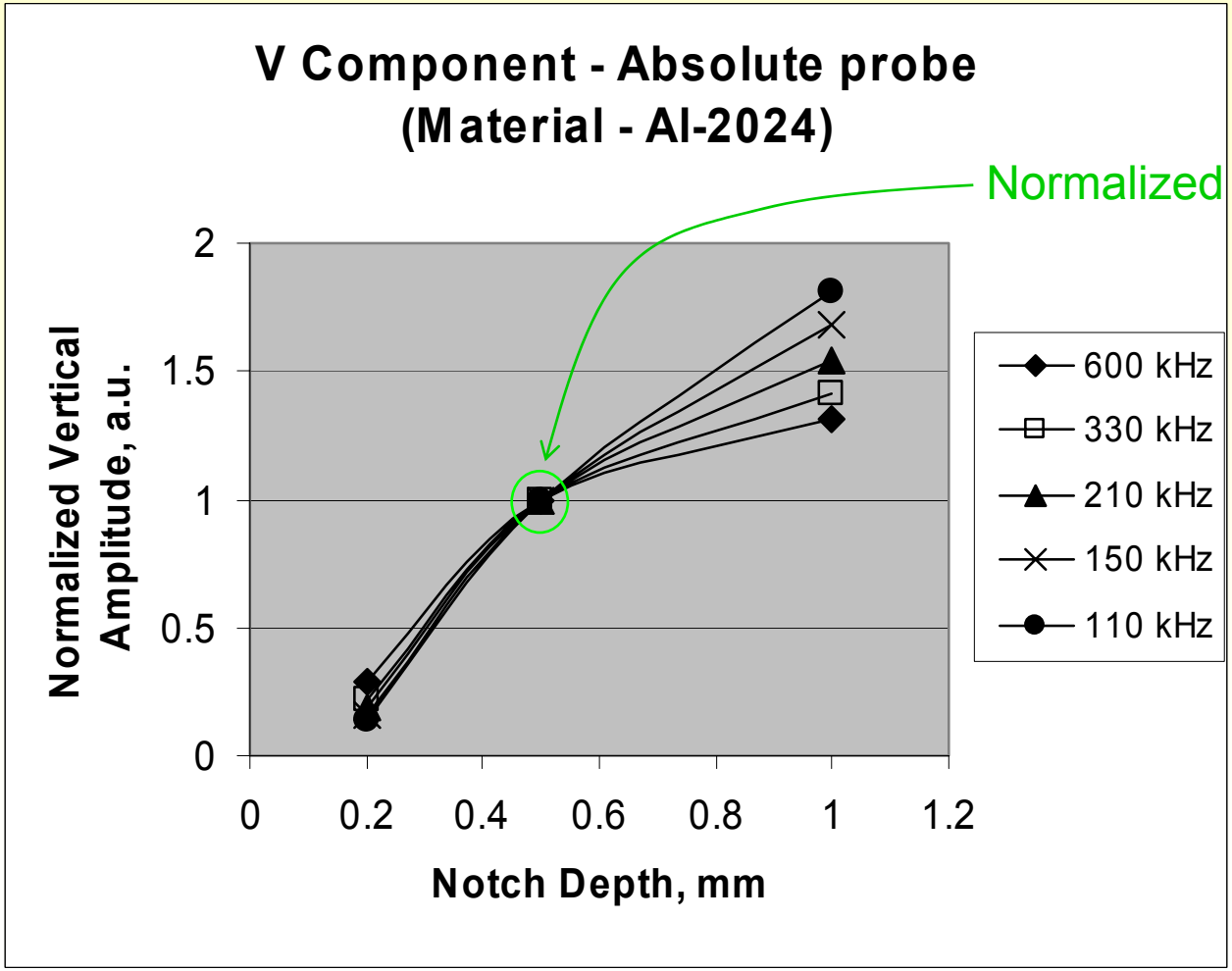
| | | | |
|---|---|---|---|
| **Coil ID:** | **1.5 mm** | **Coil OD:** | **1.8 mm** |
| **Coil length:** | **0.15 mm** | **Coil height:** | **1.0 mm** |
| **Split ID:** | **1.4 mm** | **Height:** | **2 mm** |

**Split Cores Gap: 0.3 mm**

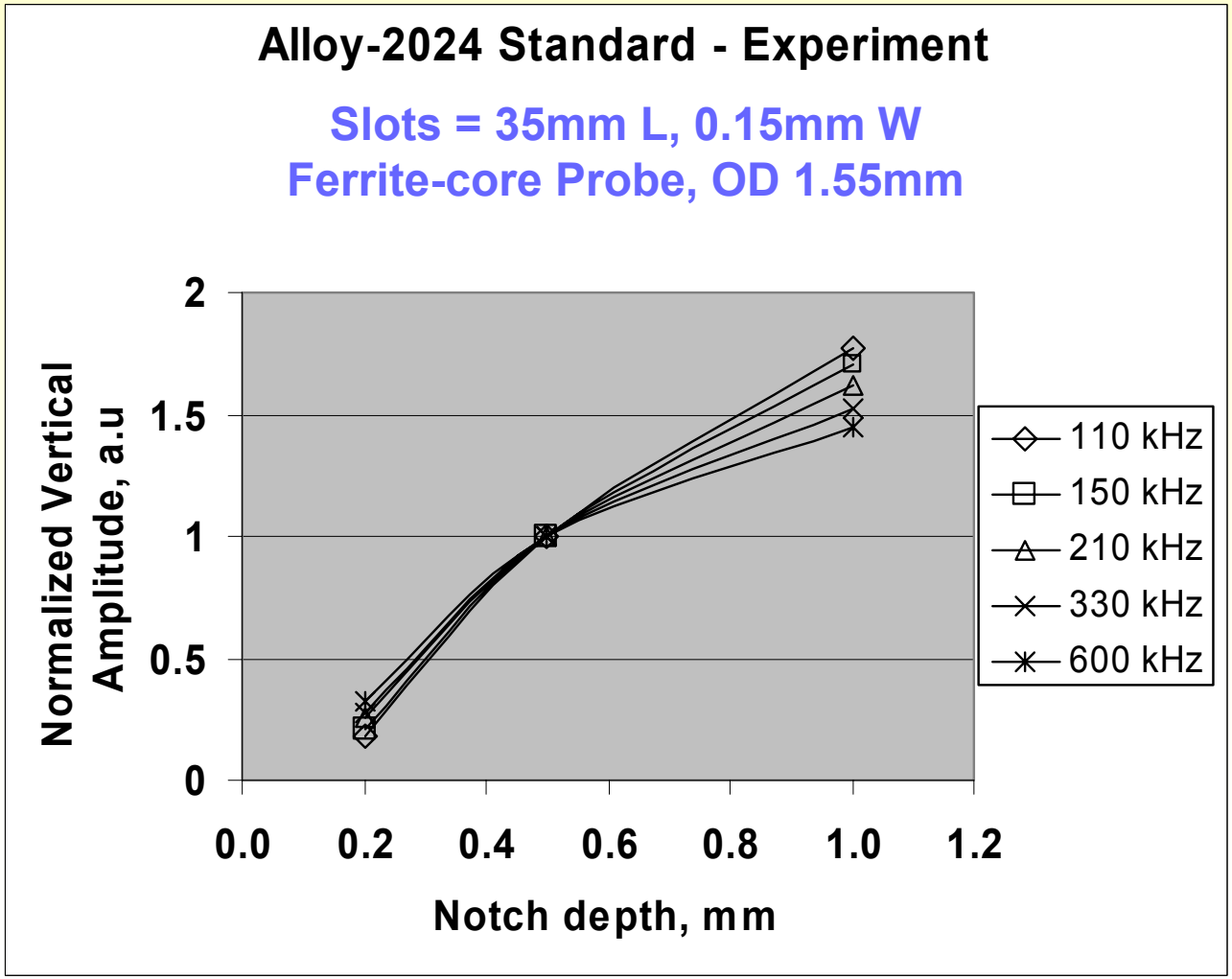
# Predicted Signal Ranges vs. Frequency



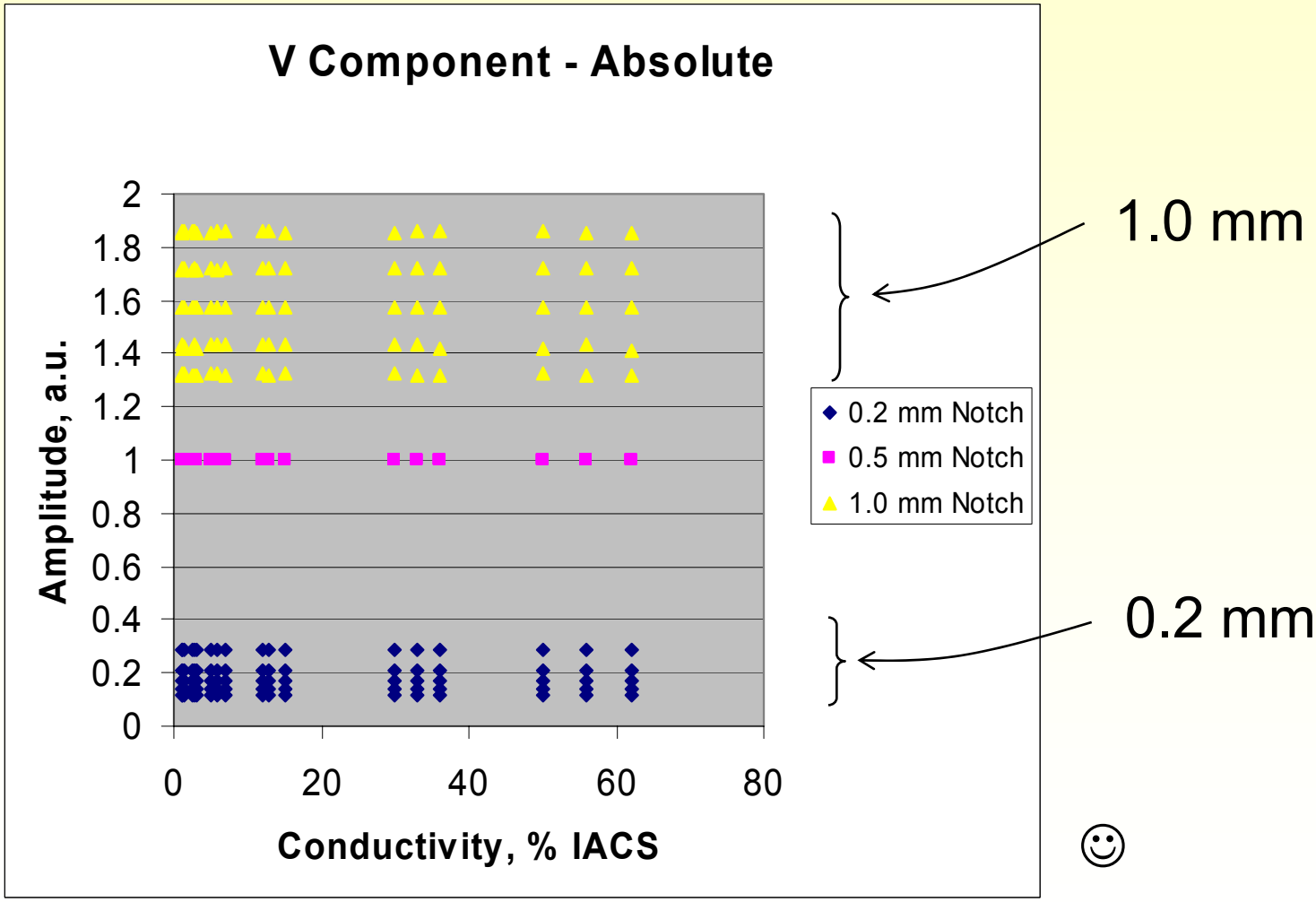
# Predicted Signal Ranges vs. Notch Depth



# Measured Signal Ranges vs. Notch Depth



# ‘Expected Amplitude Range’ for 1st Set predicted for Absolute Probes

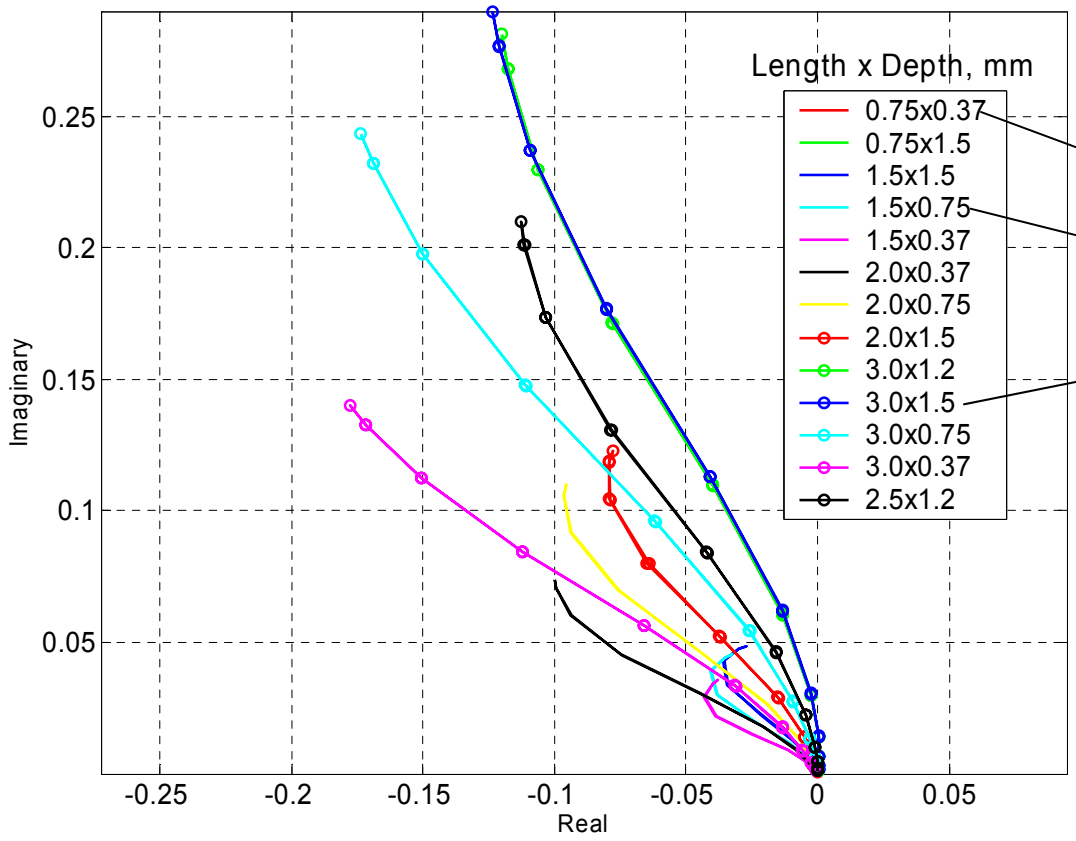


# Snapshot of Model Predictions

| BEM Model Predicted Results* | Absolute Probe | | Differential Probe | |
|---|---|---|---|---|
| | Expected Range | | Expected Range | |
| | 0.2 mm Notch | 1.0 mm Notch | 0.2 mm Notch | 1.0 mm Notch |
| V. Amplitude | 22±8% | 156±25% | 19±6% | 153±23% |
| Phase Angle | 35±2% | 70±2% | 35±1% | 70±1% |
| H. Amplitude | 61±23% | 106±18% | 56±18% | 116±16% |

*0.5 mm deep reference notch amplitude is 100% and phase angle is 45º

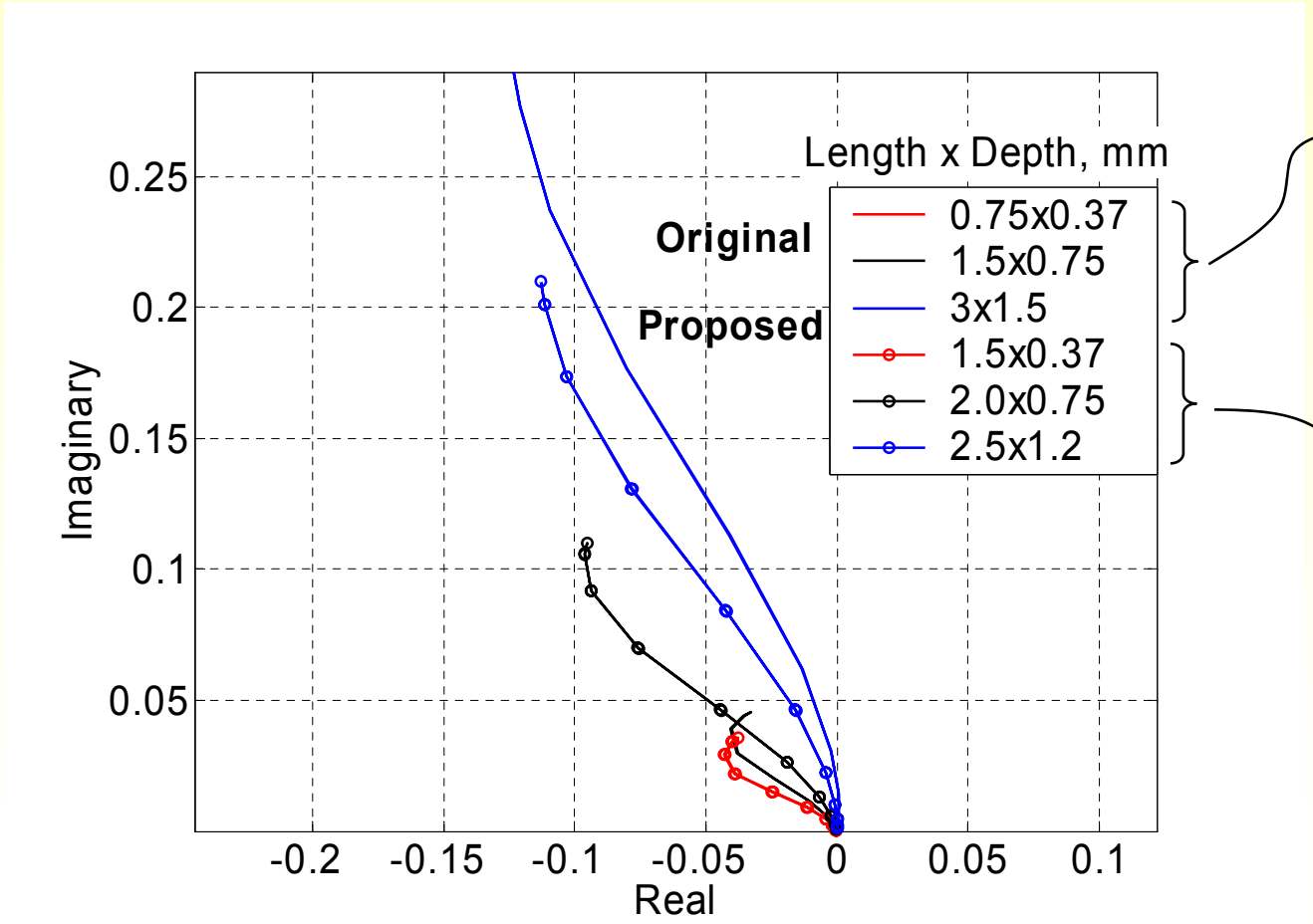
# Second set of Notches Analysis




**SPECIFIED NOTCH SIZES**

**0.75 x 0.37 mm**
**1.5 x 0.75 mm**
**3.0 x 1.5 mm**

# 2nd Set of Notches; Proposed Revision



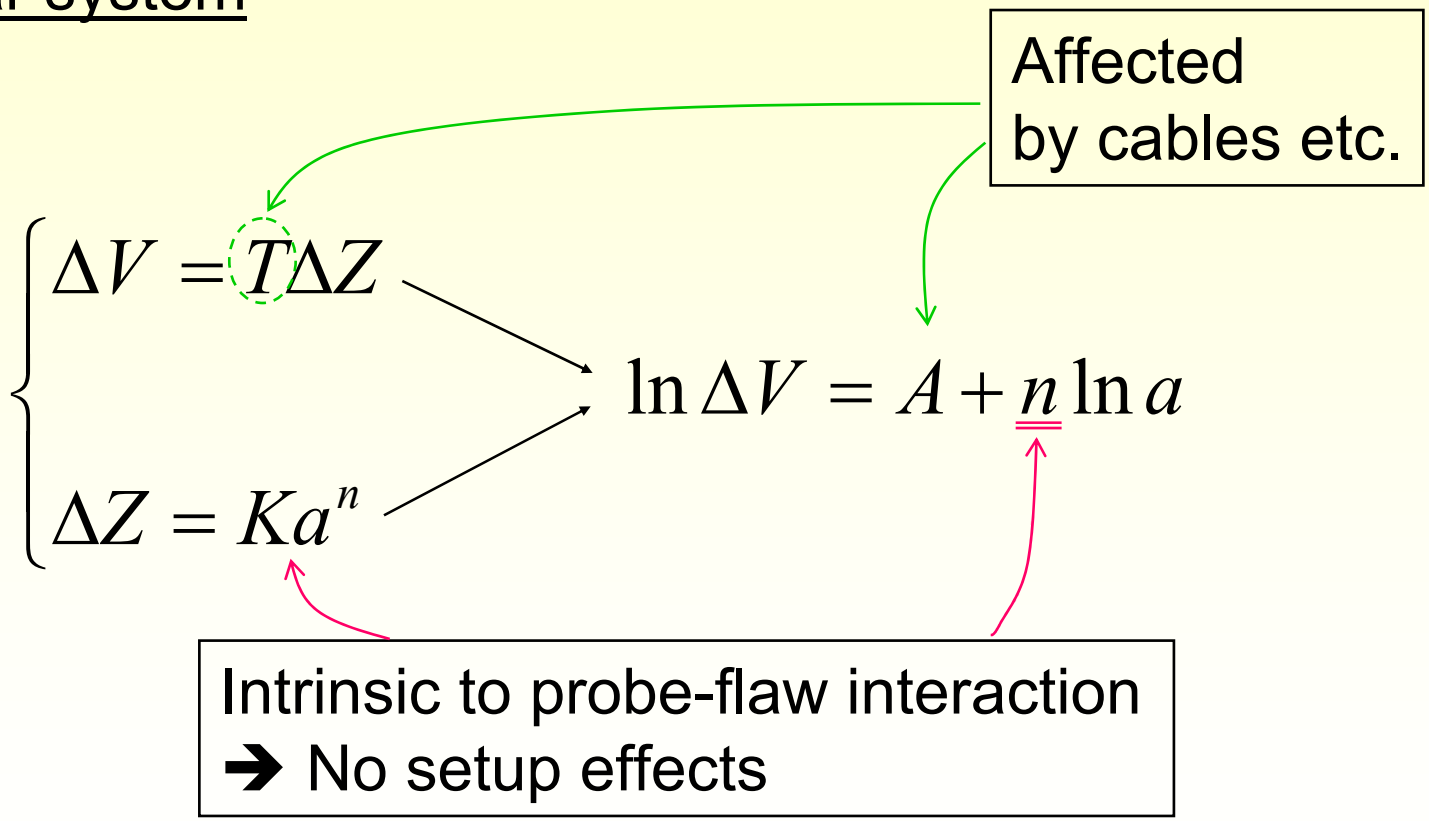
# Summary of Notch Size Selection Study

- Three-point calibration standard procedure analyzed using BEM numerical simulations.
- Material conductivity and test frequency influence eddy current signal response in an apparently non-linear manner as also validated experimentally.
- ‘Expected Ranges’ determined for amplitudes and phase angle from lift-off.
- Quantitatively established that vertical amplitude can be reliably used for all materials and display types covered in the recommended procedure.
- Modifications proposed for second set of notches based on the model predictions

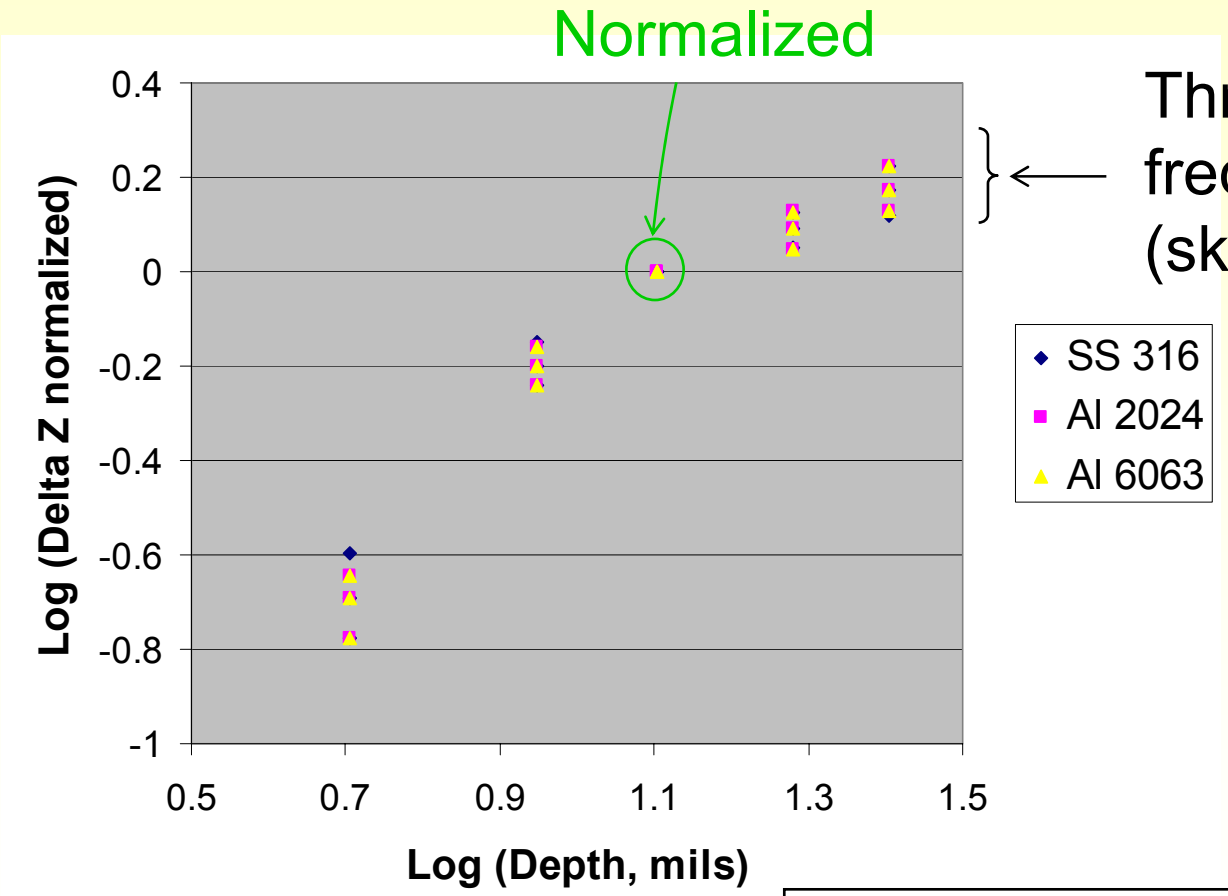
# Comment
# on Possible Need for Non-Linear Models

# Consideration to "<a> vs. a" Relation

Linear system



# Predictions for "Power Law" $\Delta Z = Ka^n$




"Approximately log-linear"

# Possible Source of Slope Variation

- Observed setup dependence of the slope “n” is likely due to non-linear effects

$$\ln \Delta V = A + \underline{n} \ln a$$

- Origin of non-linearity?
  - Cables/connectors themselves are passive and highly linear
  - Ferrite cores may lead to non-linear behaviors
    - Voltage-driven electronics ➔ The longer the cable, the lower the drive voltage applied to the probe element.
    - Experimental tests to be performed.
      - Change cable lengths
      - Change drive voltage; use current drive

# Conclusions

- A role of models
  - Have demonstrated that CNDE EC model provides help in selecting 3pt calibration notch sizes properly.
  - The 2nd set of the selection in the draft "Committee K" document may need revision.

- Toward Advanced Role
  - Need to examine the ferrite non-linearity.