

Applications of Motorized Rotational RFEC Probes in Thick and Multilayer Structure Crack Detection

Innovative Materials Testing Technologies, Inc.

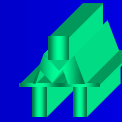
**3141 W. Torreys Peak Drive, Superior, CO 80027
Tel. 303 554 8000; Fax. 303 554 8001**

(The Complete Version)



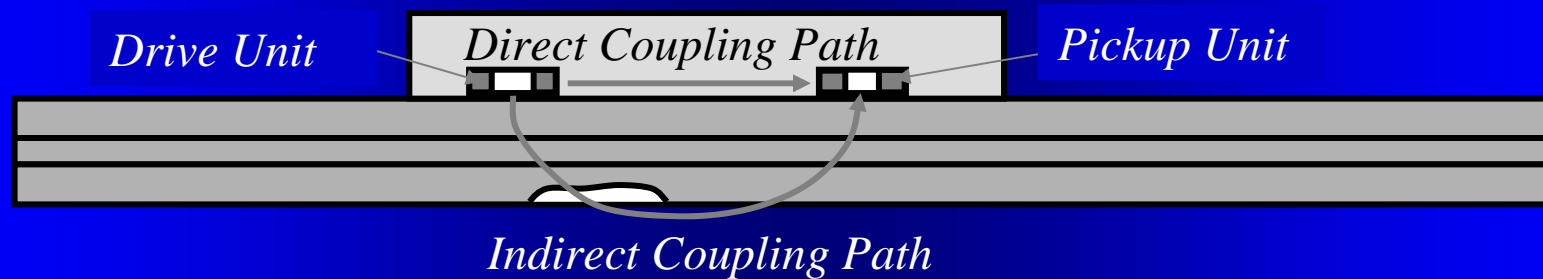
Challenges

- 1. Requirement of deep penetration in multilayer structure**
- 2. Structure variations around a fastener – background noise comparable or greater than crack signal**
- 3. Material property variations, such as permeability variation of a steel fastener.**
- 4. Extremely weak crack signal submerged in background noise and structure variation signals**



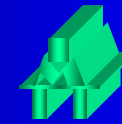
RFEC Probe

A solution for Deep Penetration

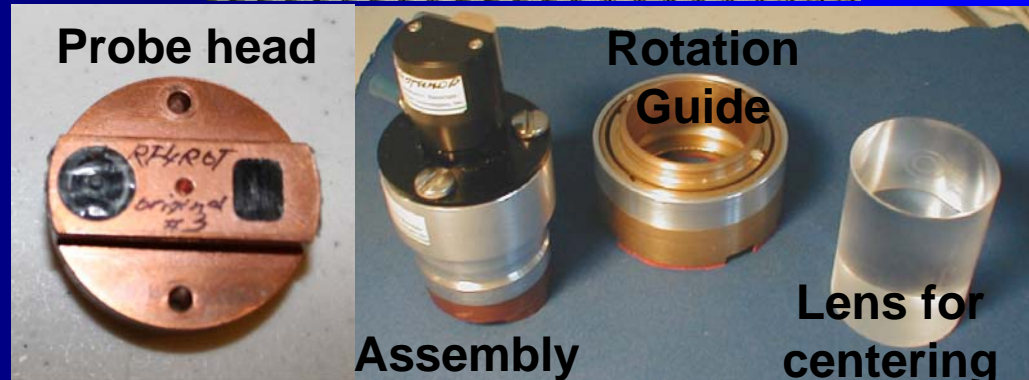
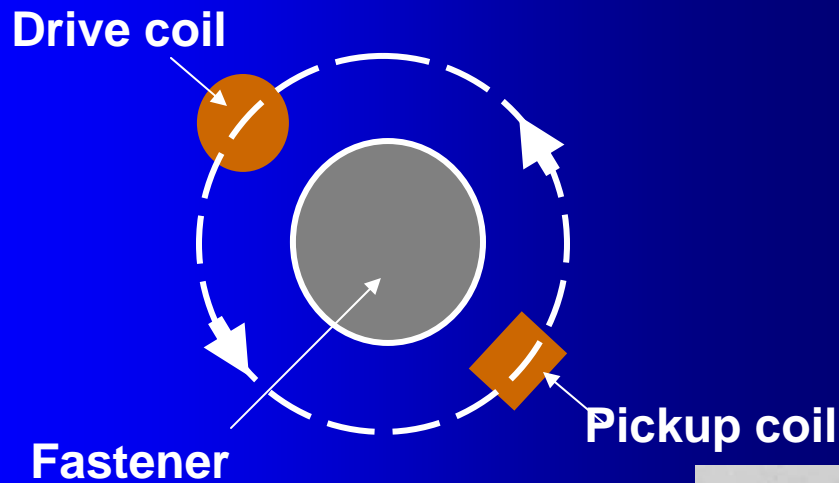


The probe blocks the direct coupling path. The energy released from the drive unit is forced to go along the indirect coupling path.

Therefore, the entire signal received by the pickup unit has passed the wall twice and carries the whole information about the wall condition.

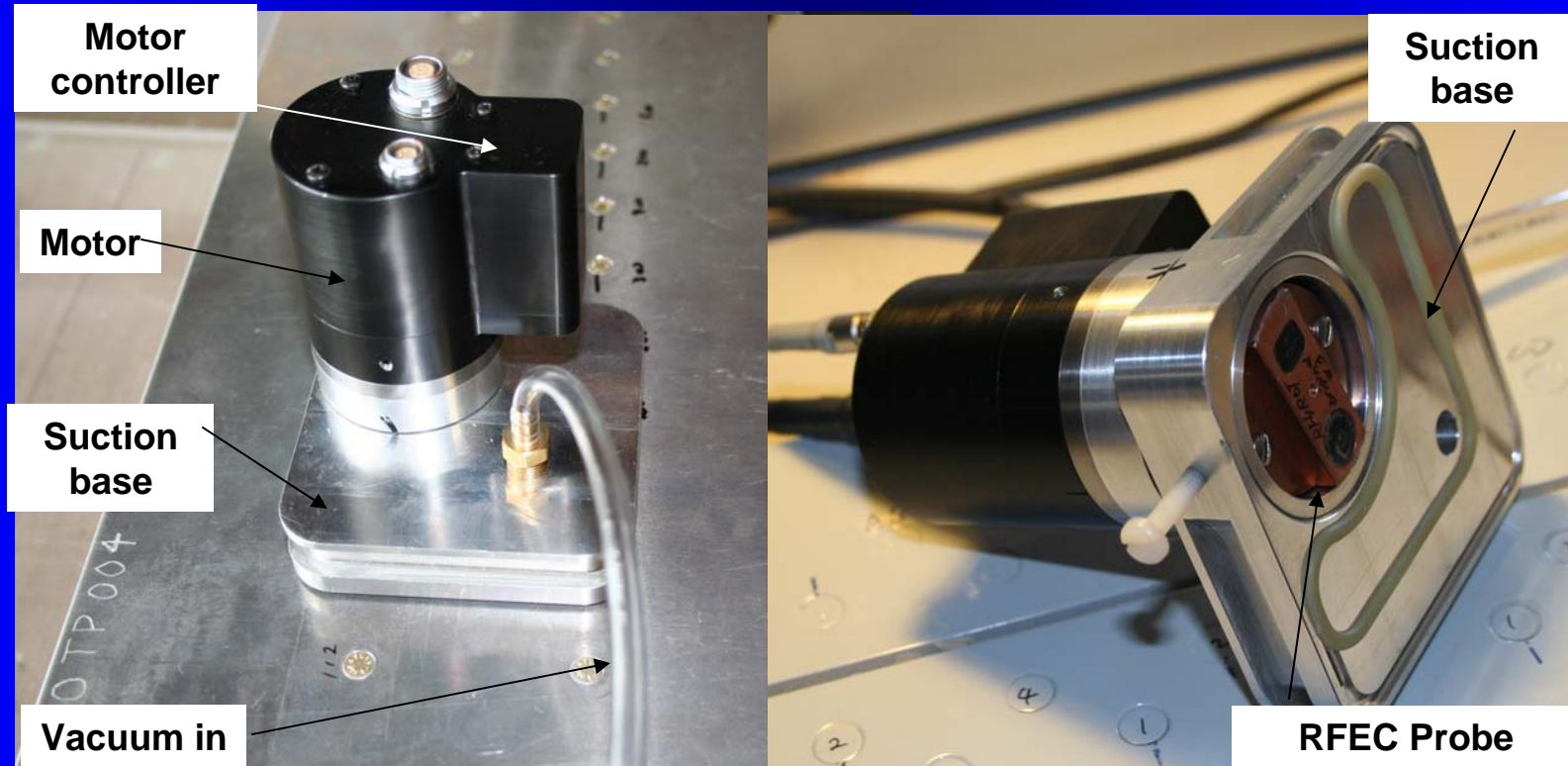


Rotational RFEC Probe Minimizing Noise from Fastener





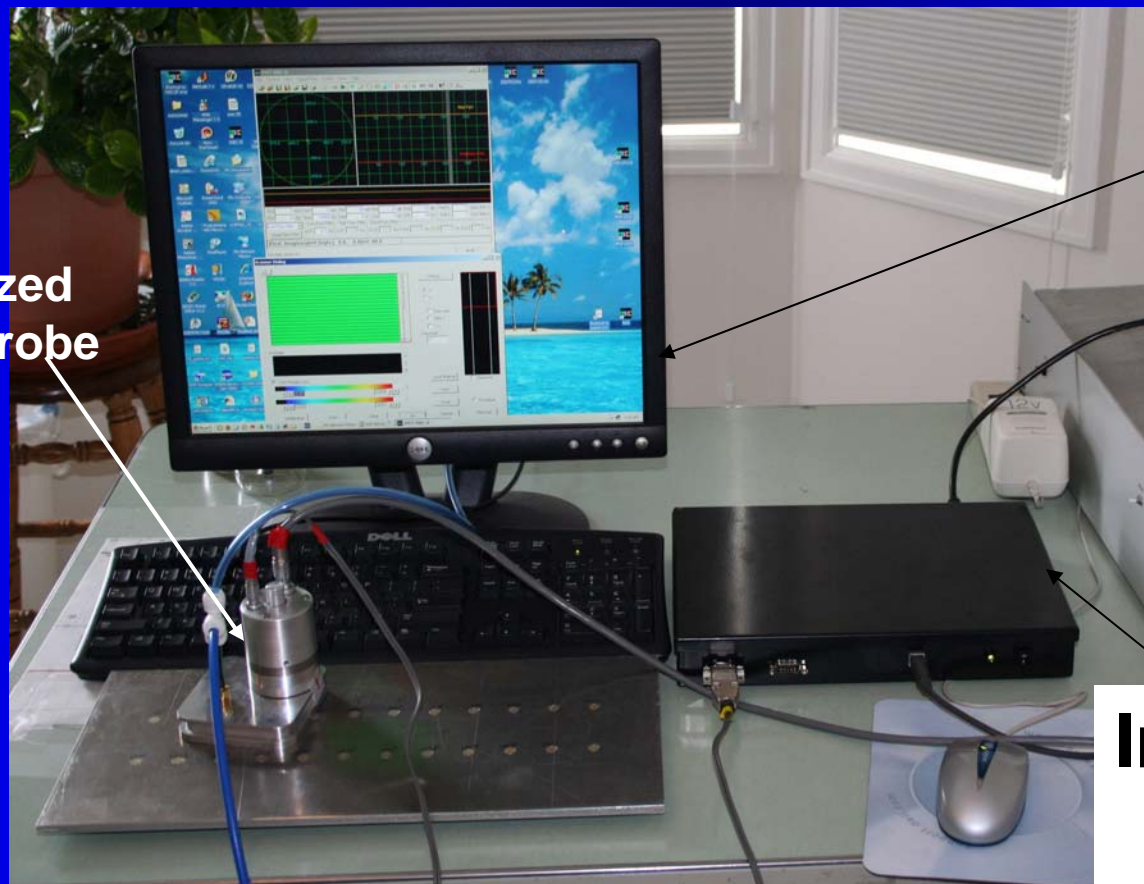
Motor-Controlled Rotation Ensuring Repeatable Signal for Online Signal Processing





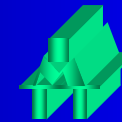
Computerized SSEC Instrument Enabling Online Signal Processing

Motorized
RFEC Probe



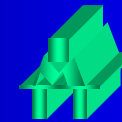
PC Monitor
or Laptop

Instrument
SSEC



Purpose of This Study

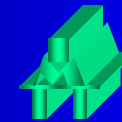
- 1. Investigate influence of 1st & 2nd layer edges on 2nd layer crack detection while the 1st layer is thick**
- 2. Investigate influence of steel fastener on 2nd layer crack detection at different edge conditions**
- 3. Improving 2nd layer crack detect-ability using motorized rotational RFEC probes with online signal processing and/or pattern recognition**



Study # 1

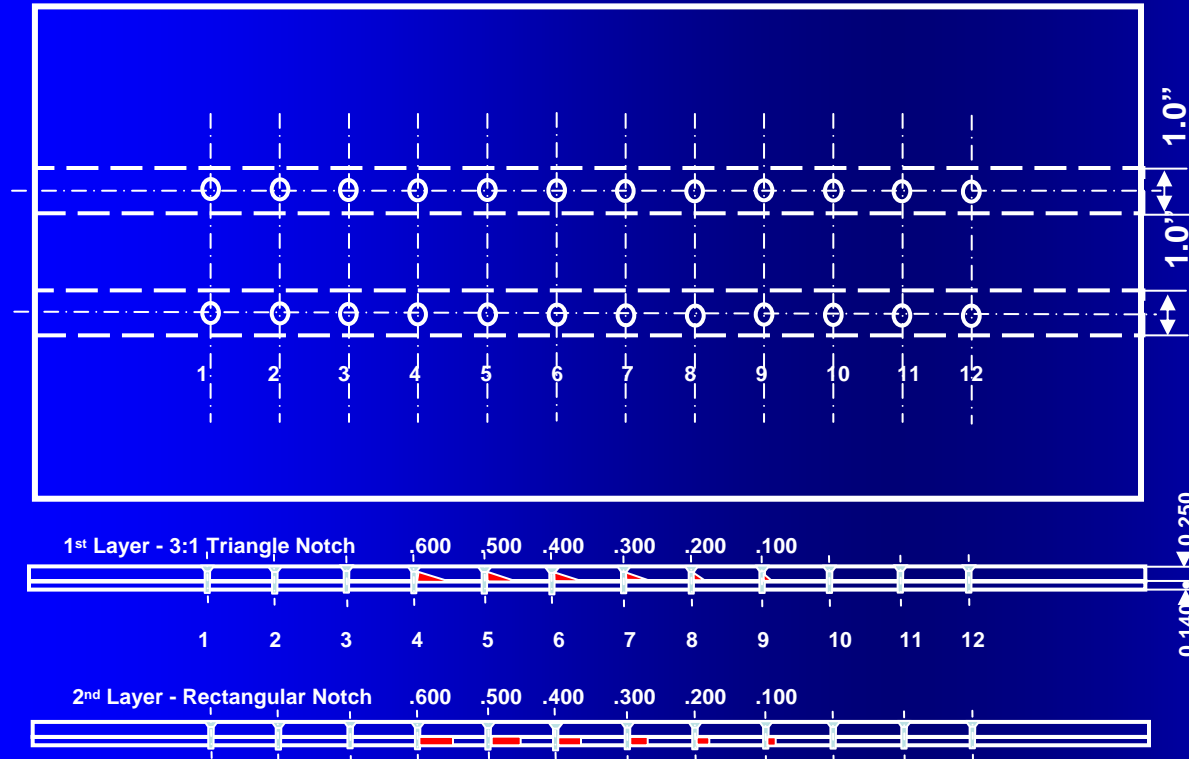
**1st or 2nd layer edge effect, but crack is a
little away from edge**

**Ferromagnetic or non-ferromagnetic
fastener**



Example 1

Detection 2nd layer horizontally oriented cracks C-130 center wing box standard with steel fasteners



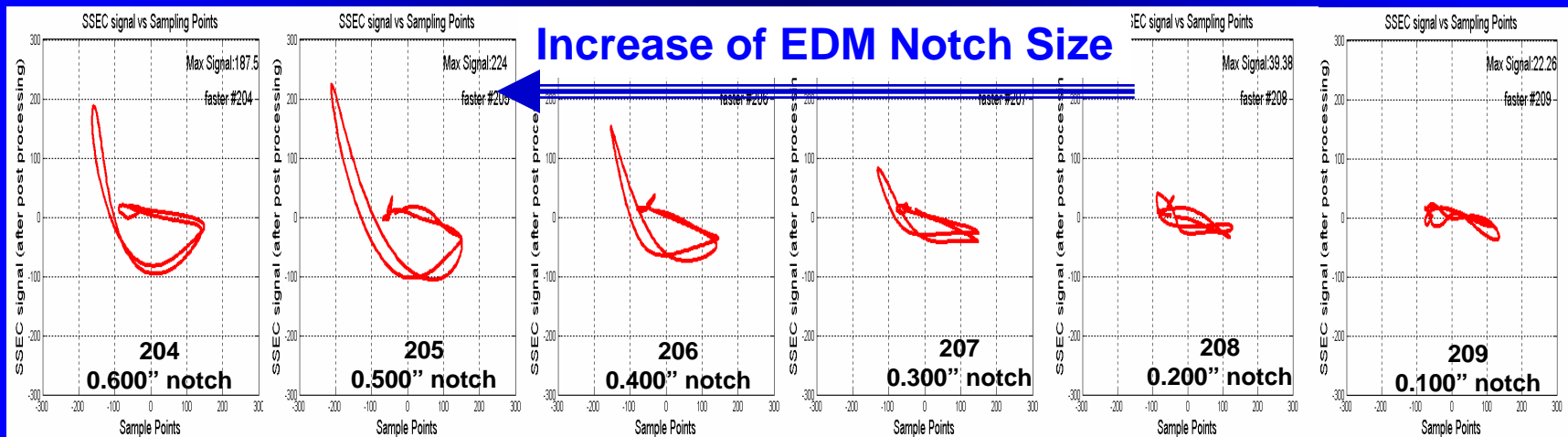
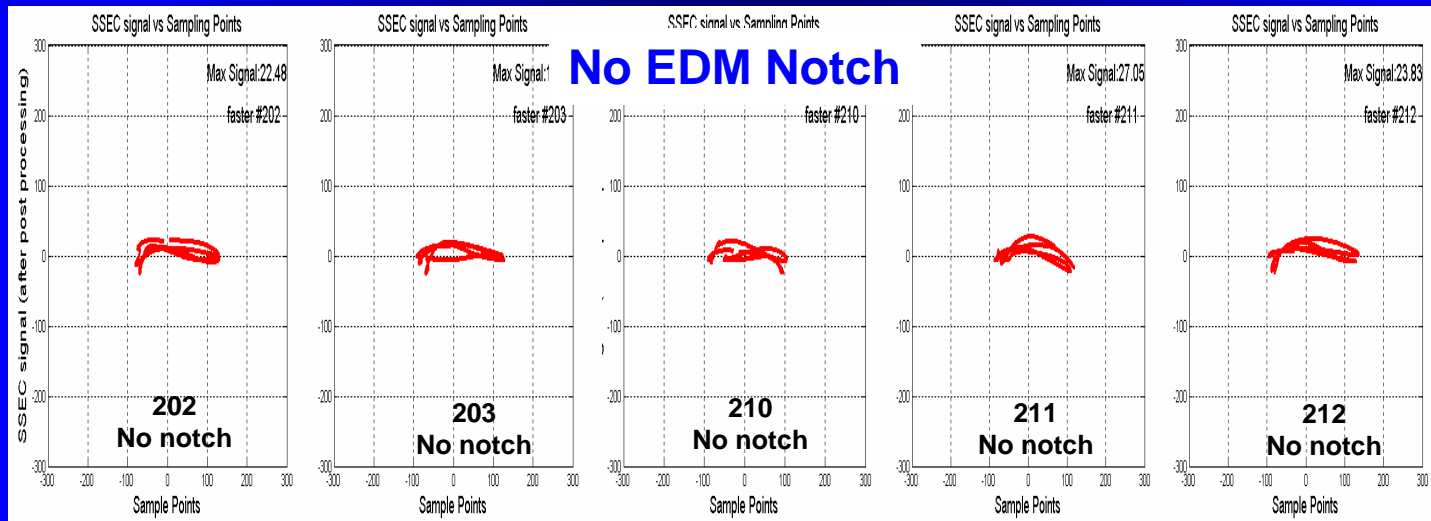
1st layer –
 0.250”
 Aluminum

2nd layer –
 0.140”
 Aluminum
 Width = 1.000”

2nd layer EDM
 notches –
 0.100” - 0.600”

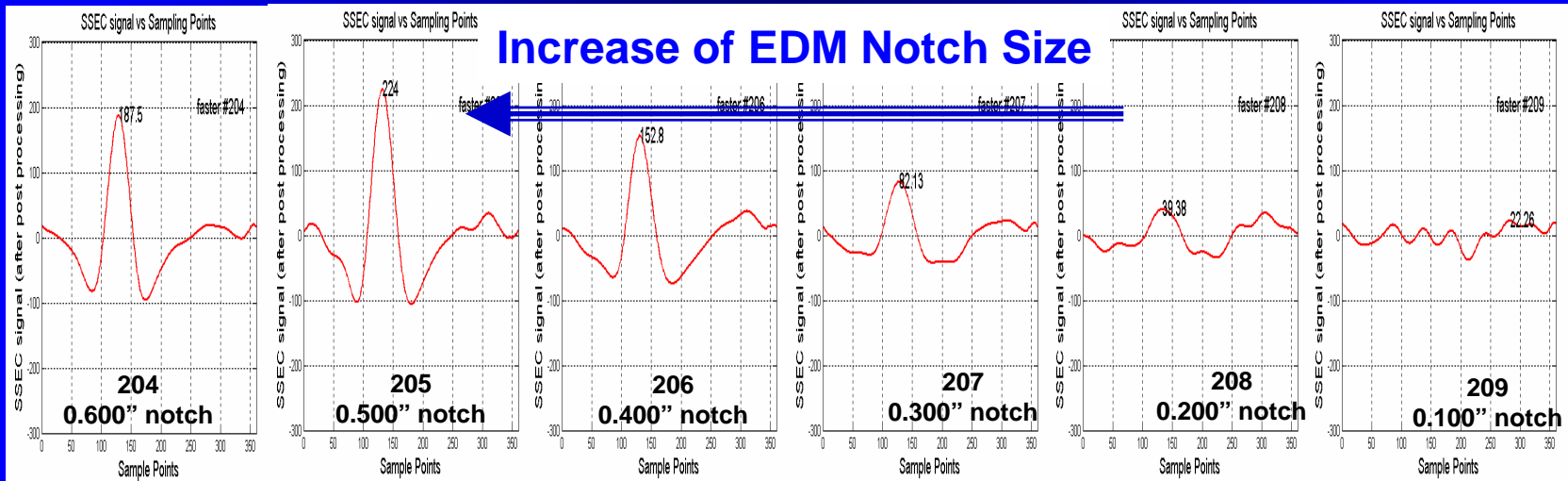
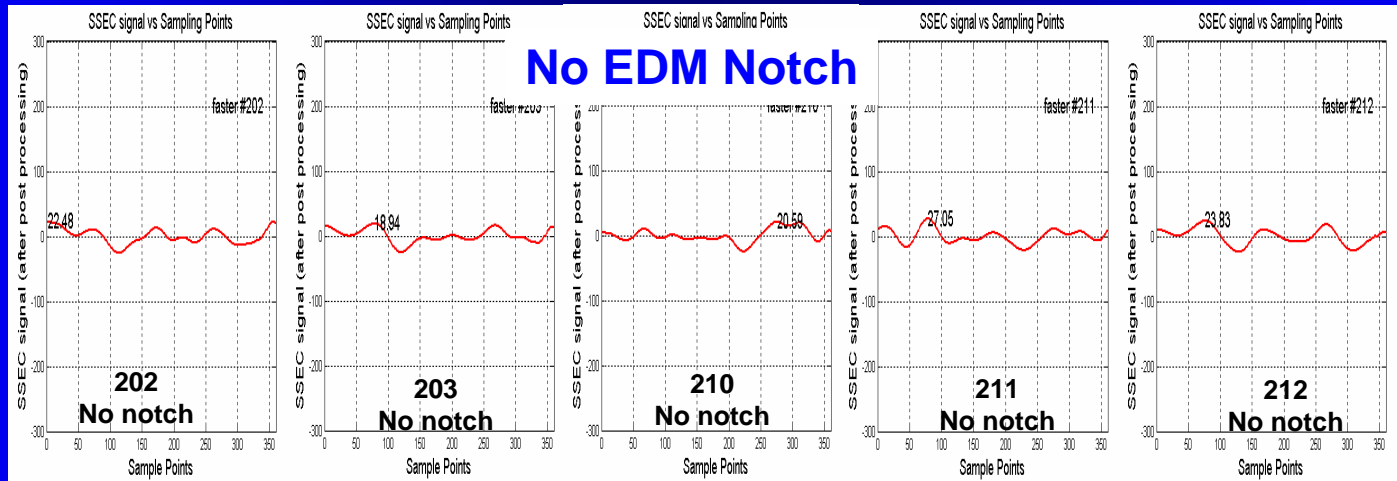


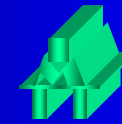
Detection of 2nd Layer Notches—impedance plane (row data)



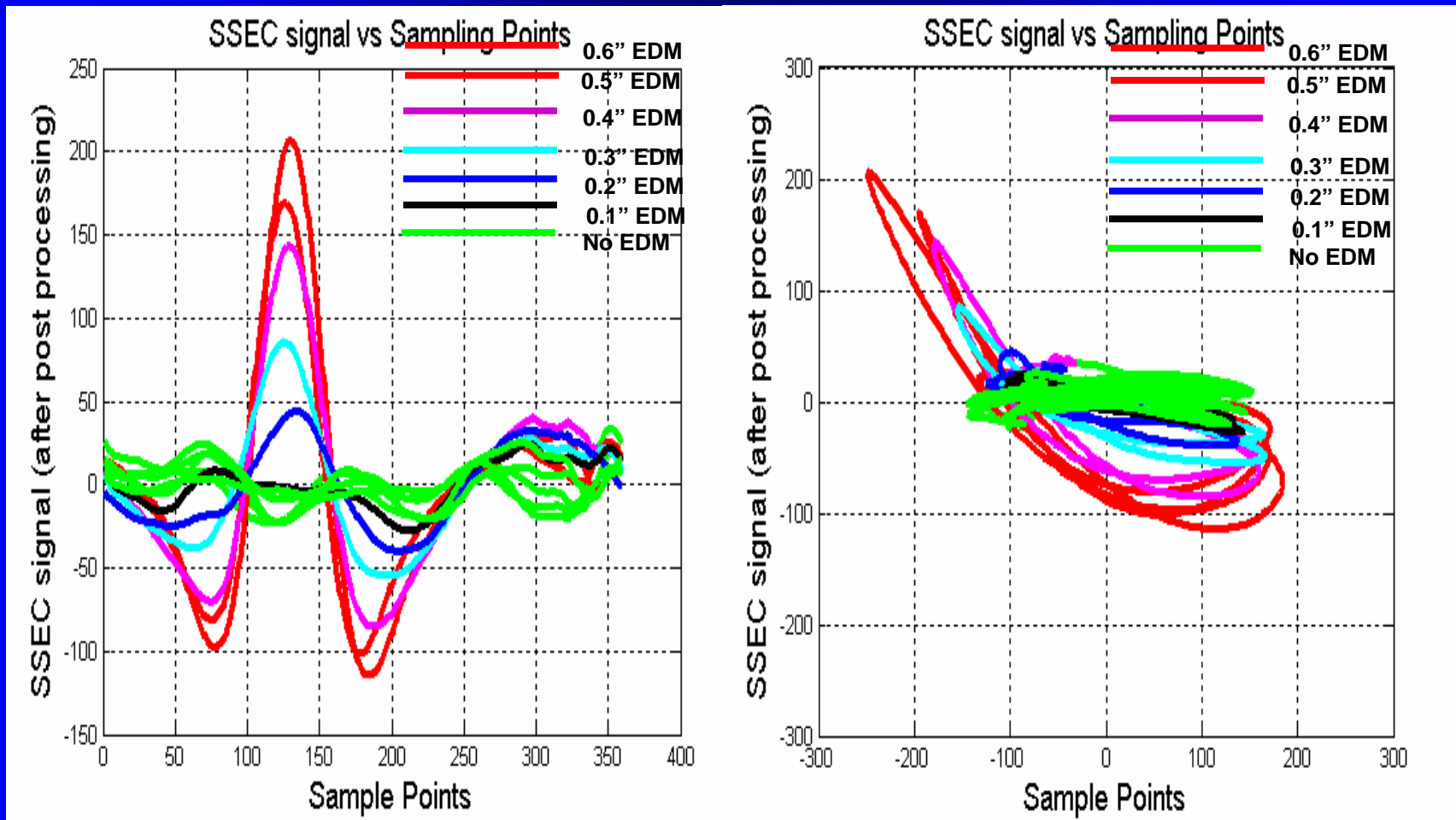


Detection of 2nd Layer Notches—imaginary (row data)



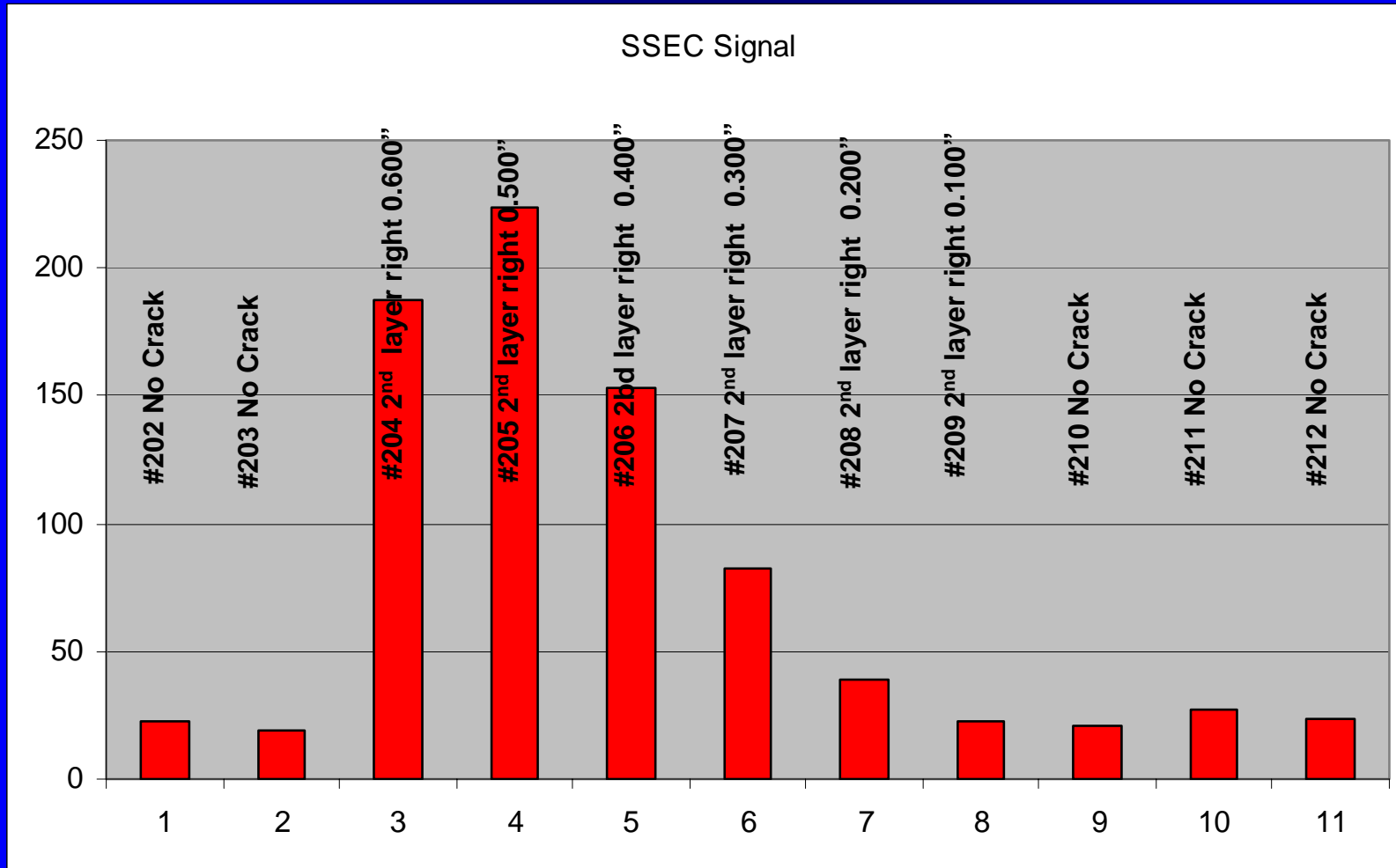


Detection of 2nd Layer Notches—Comparison (1) Before signal processing

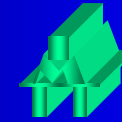




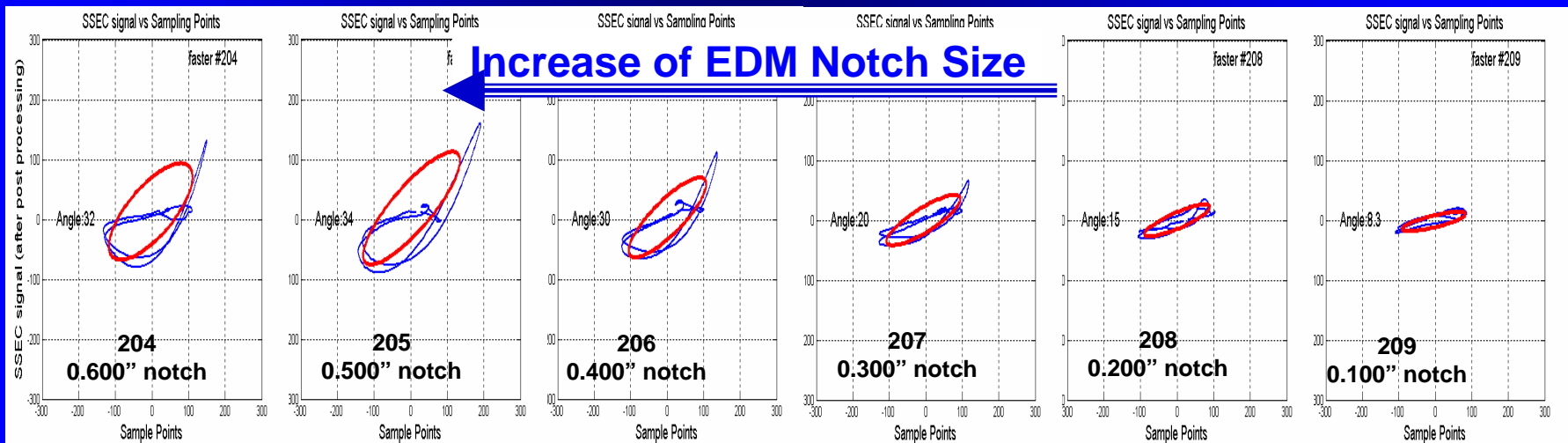
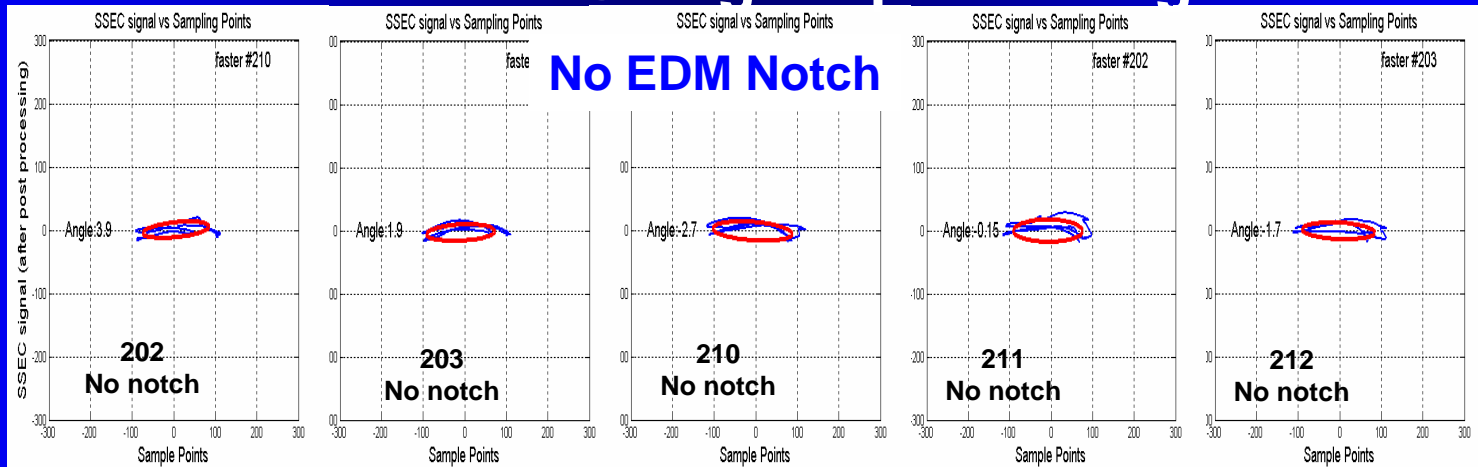
Detection of 2nd Layer Notches—Comparison (2) Before Signal Processing

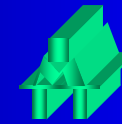


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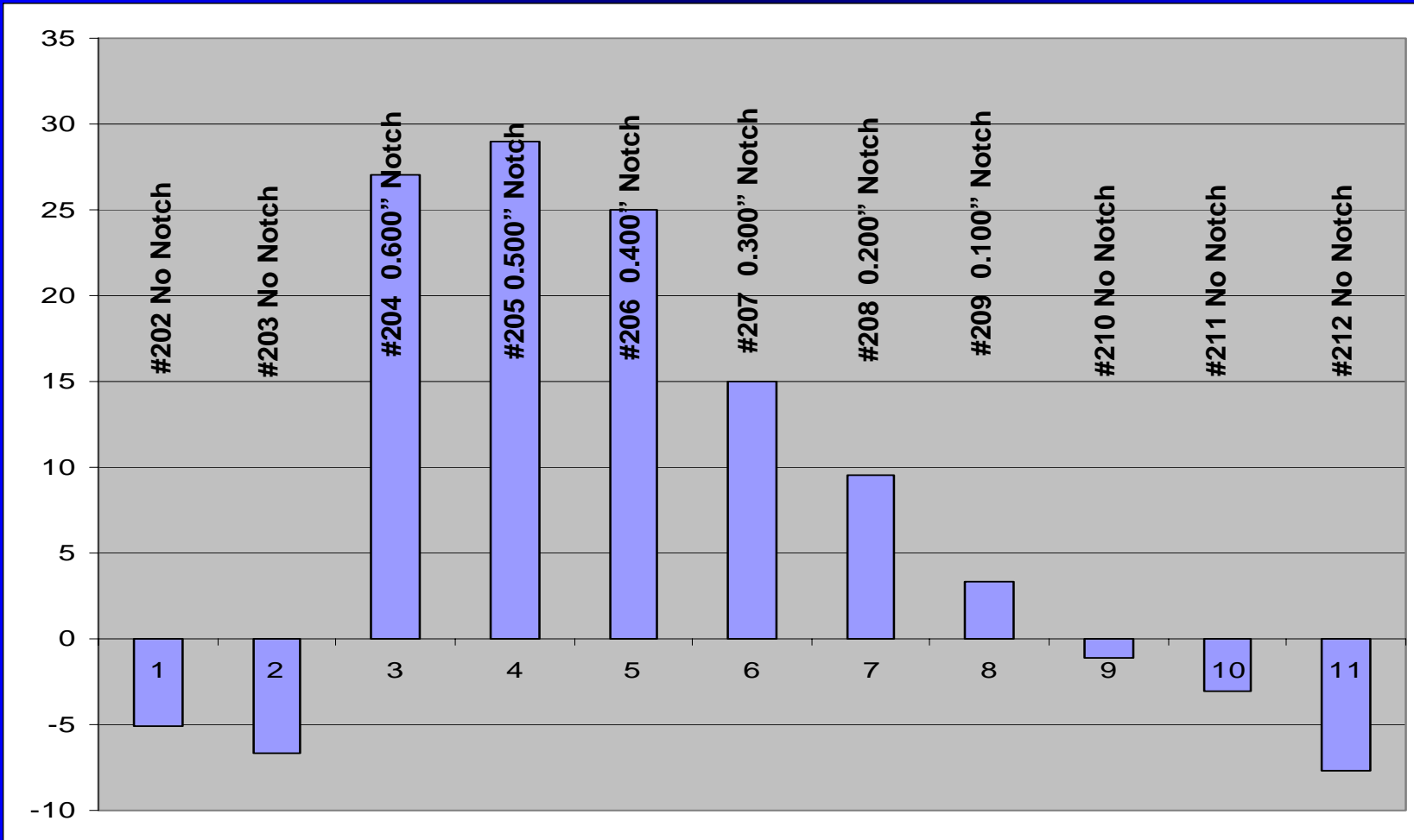


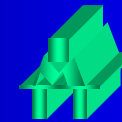
Detection of 2nd Layer Notche Processed Using Ellipse Fitting





Detection of 2nd Layer Notches - After Ellipse Fitting All Cracks Detected

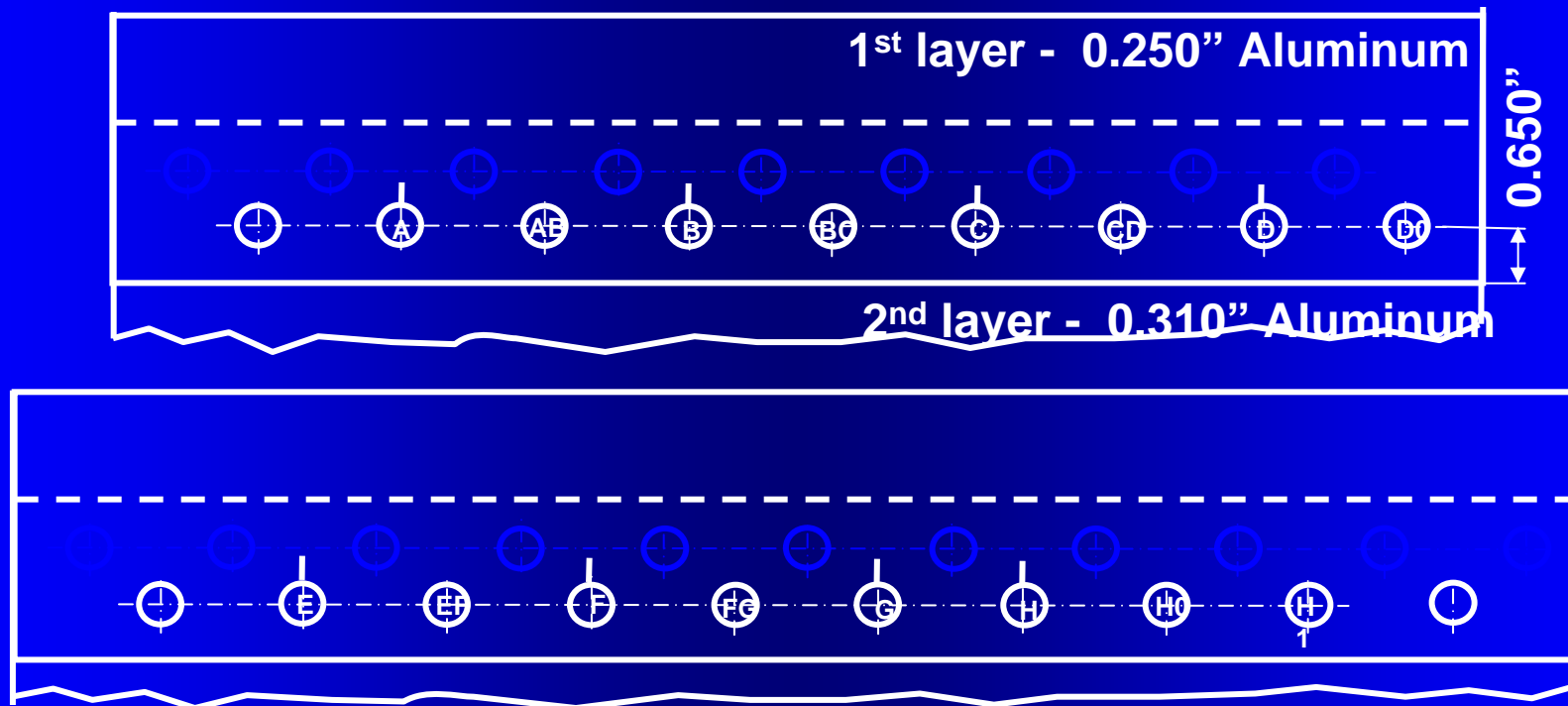




Example 2

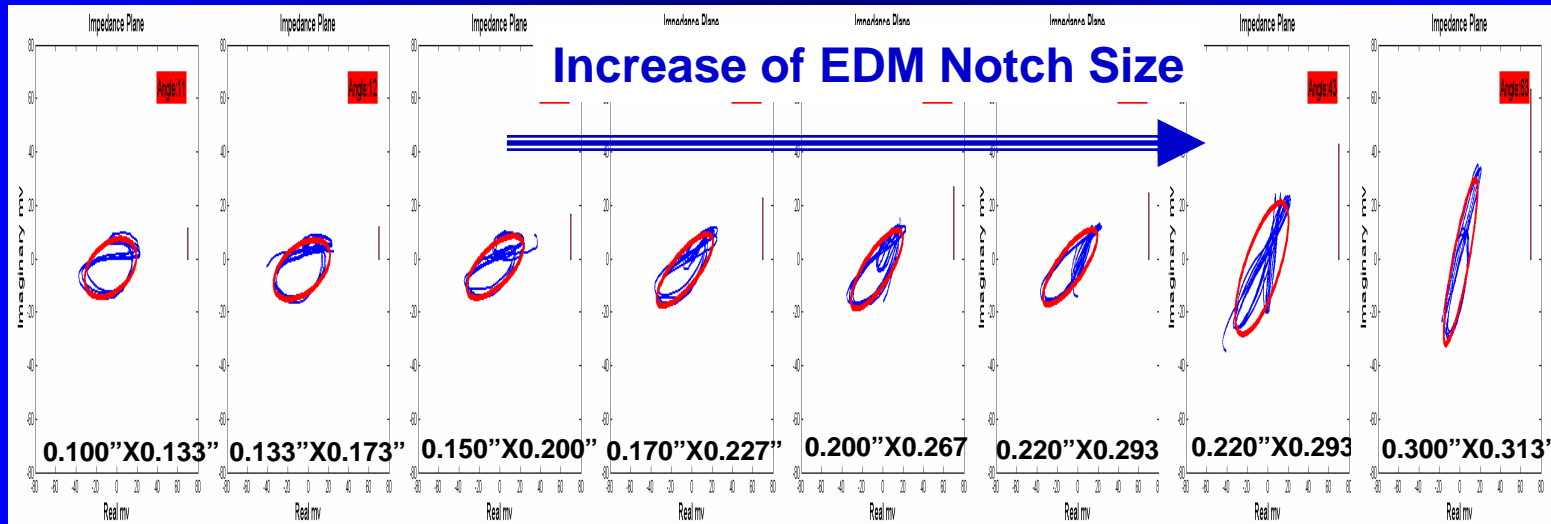
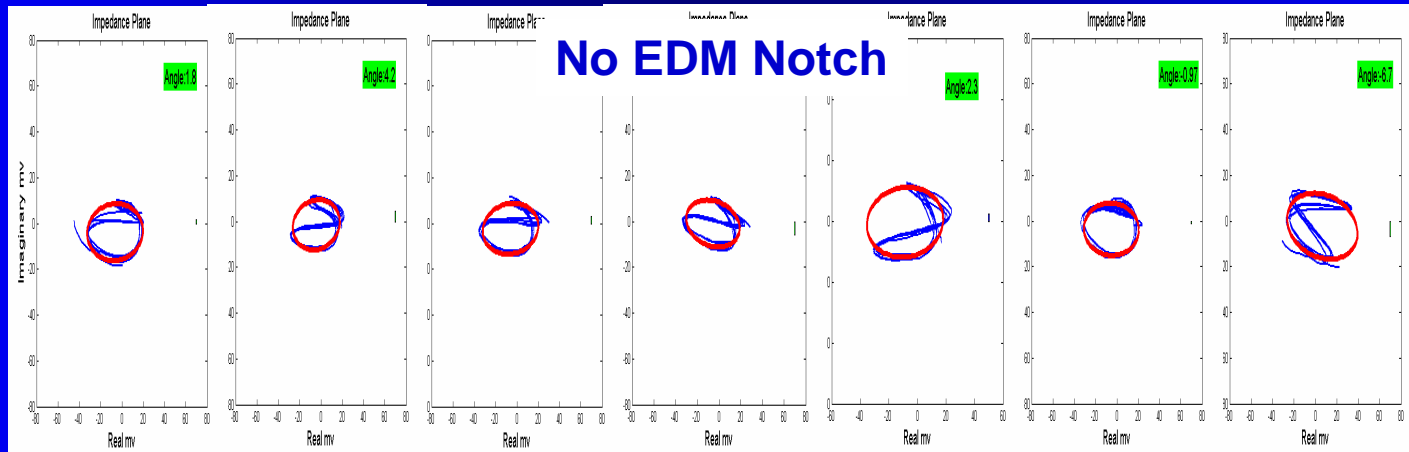
Detection 2nd layer vertically oriented cracks with titanium fasteners

+Thicker 2nd layer +Close 1st edge +Triangle EDM notches



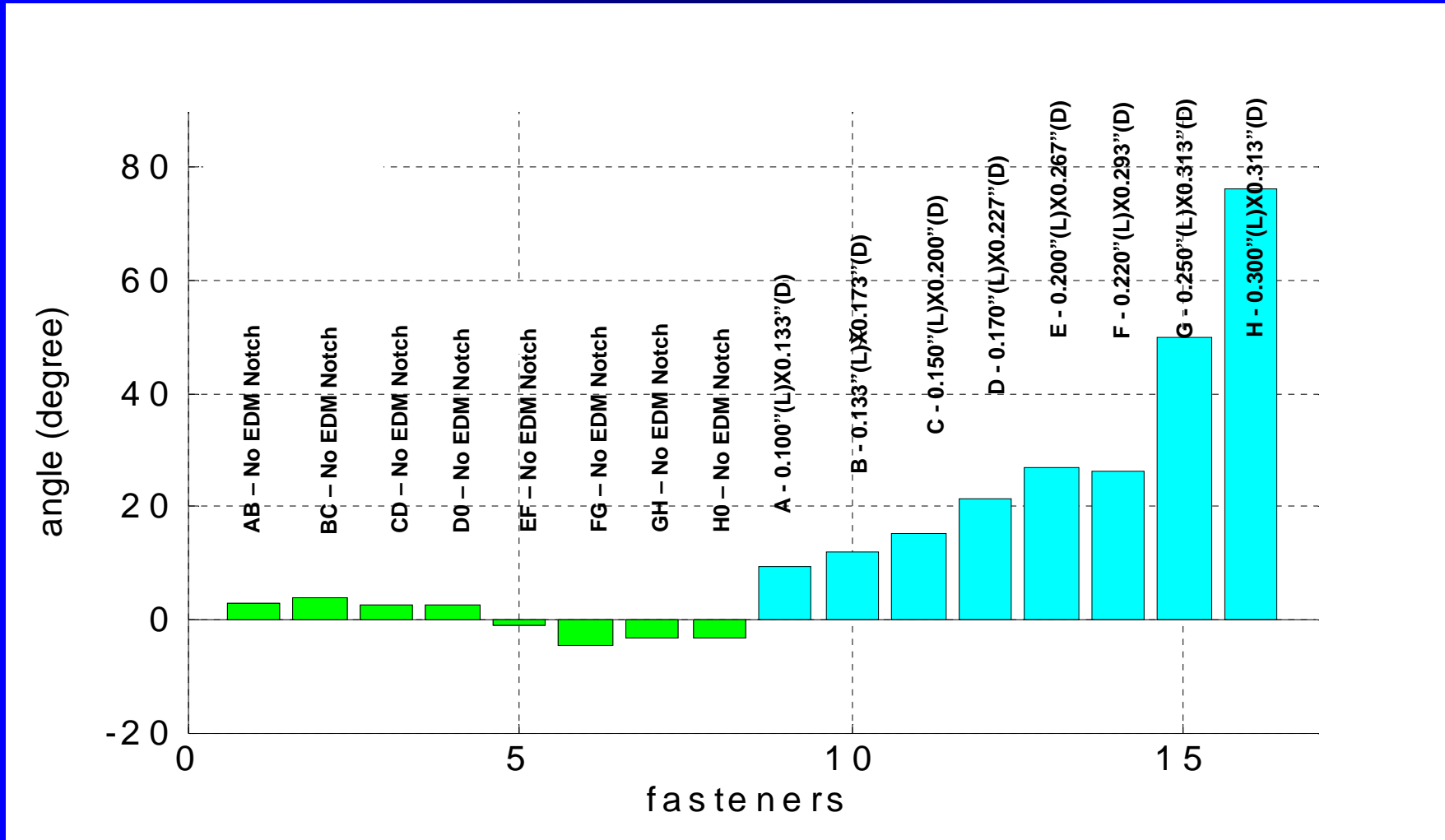


2nd Layer Vertical Notches, Titanium Fastener



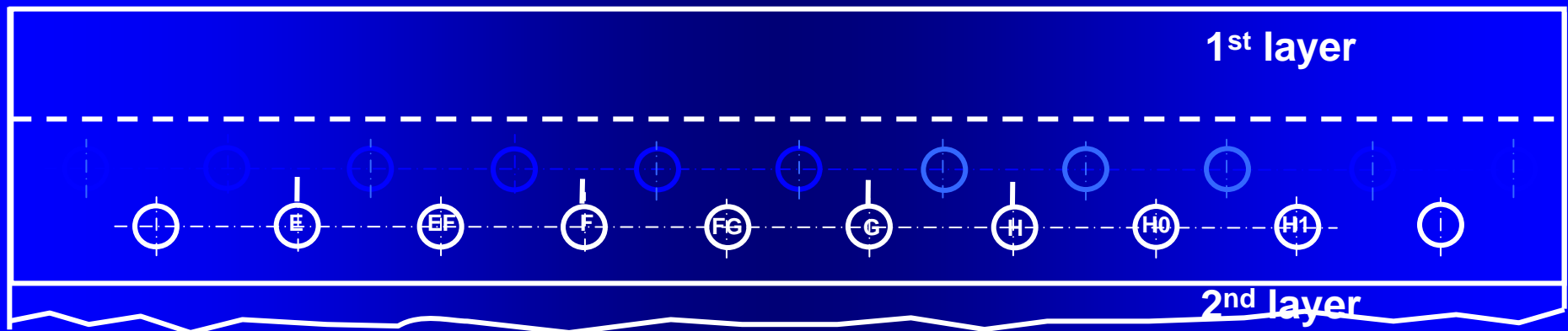
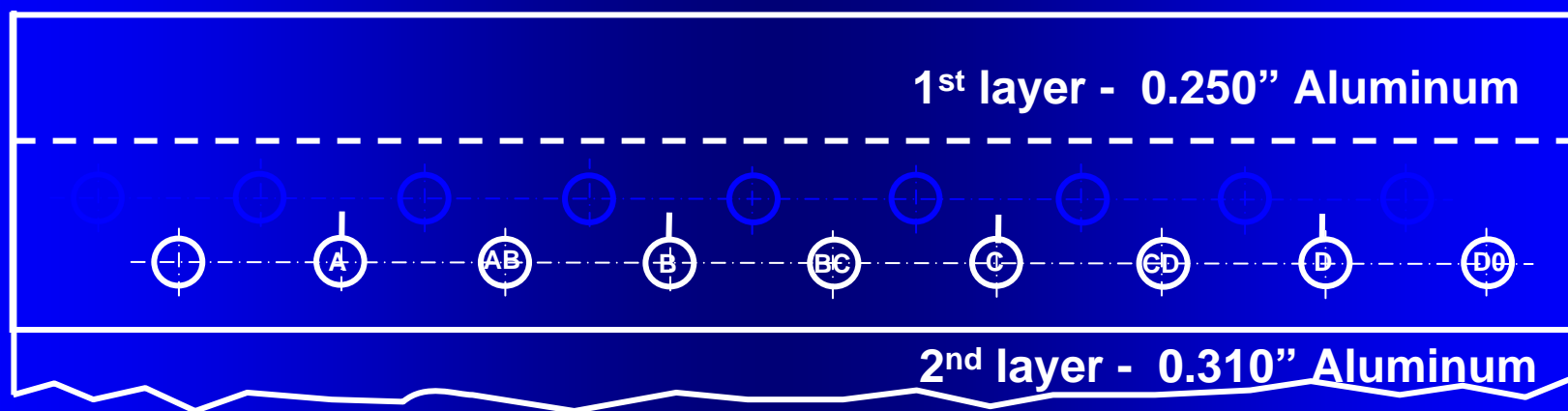


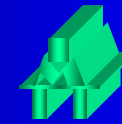
Signal Rotation Angle - All Cracks detected





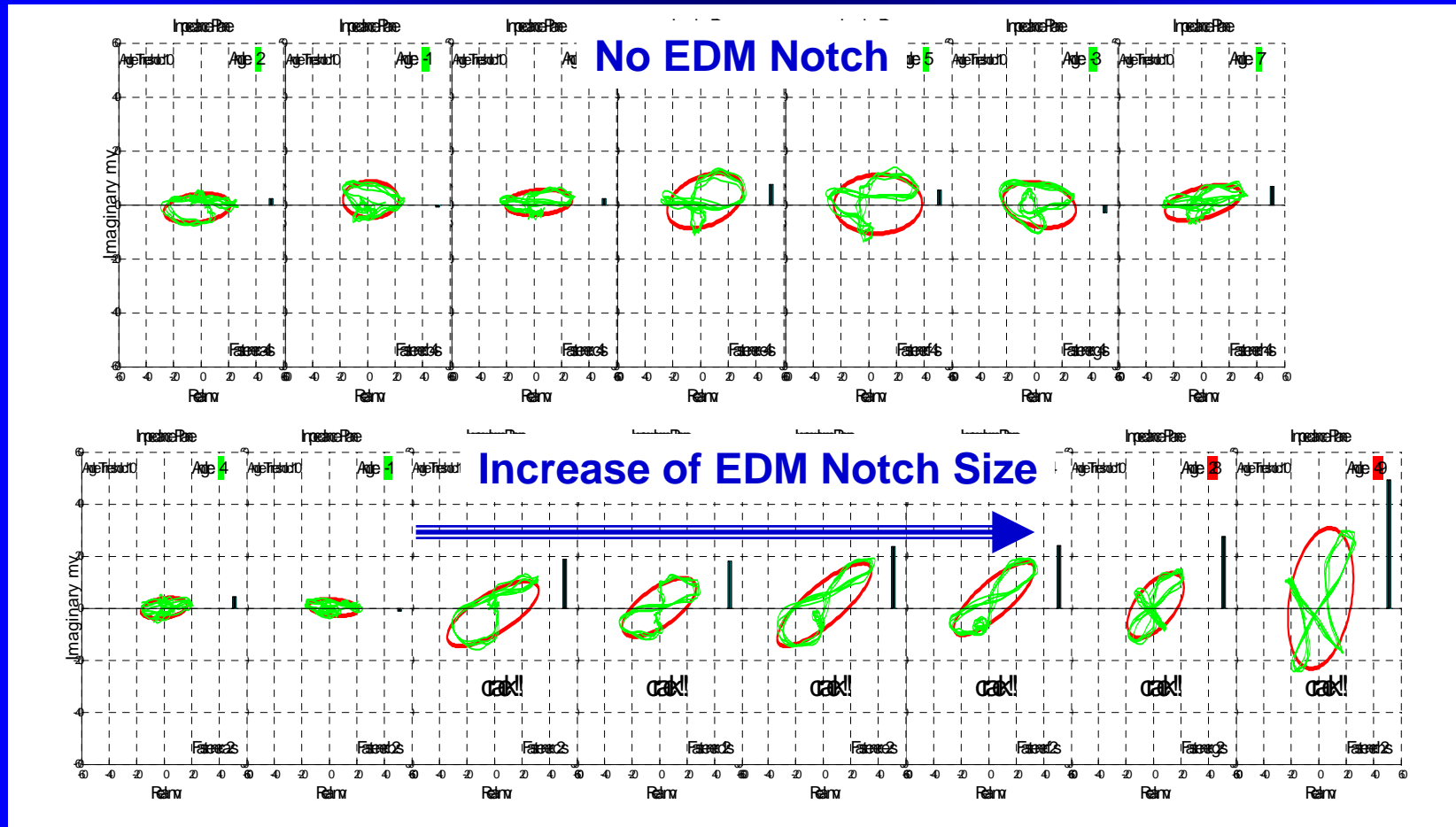
Example 3 Detection 2nd layer vertically oriented cracks with steel fasteners





2nd Layer Vertical Notches, Steel Fastener

Greater variation in the size of impedance plane

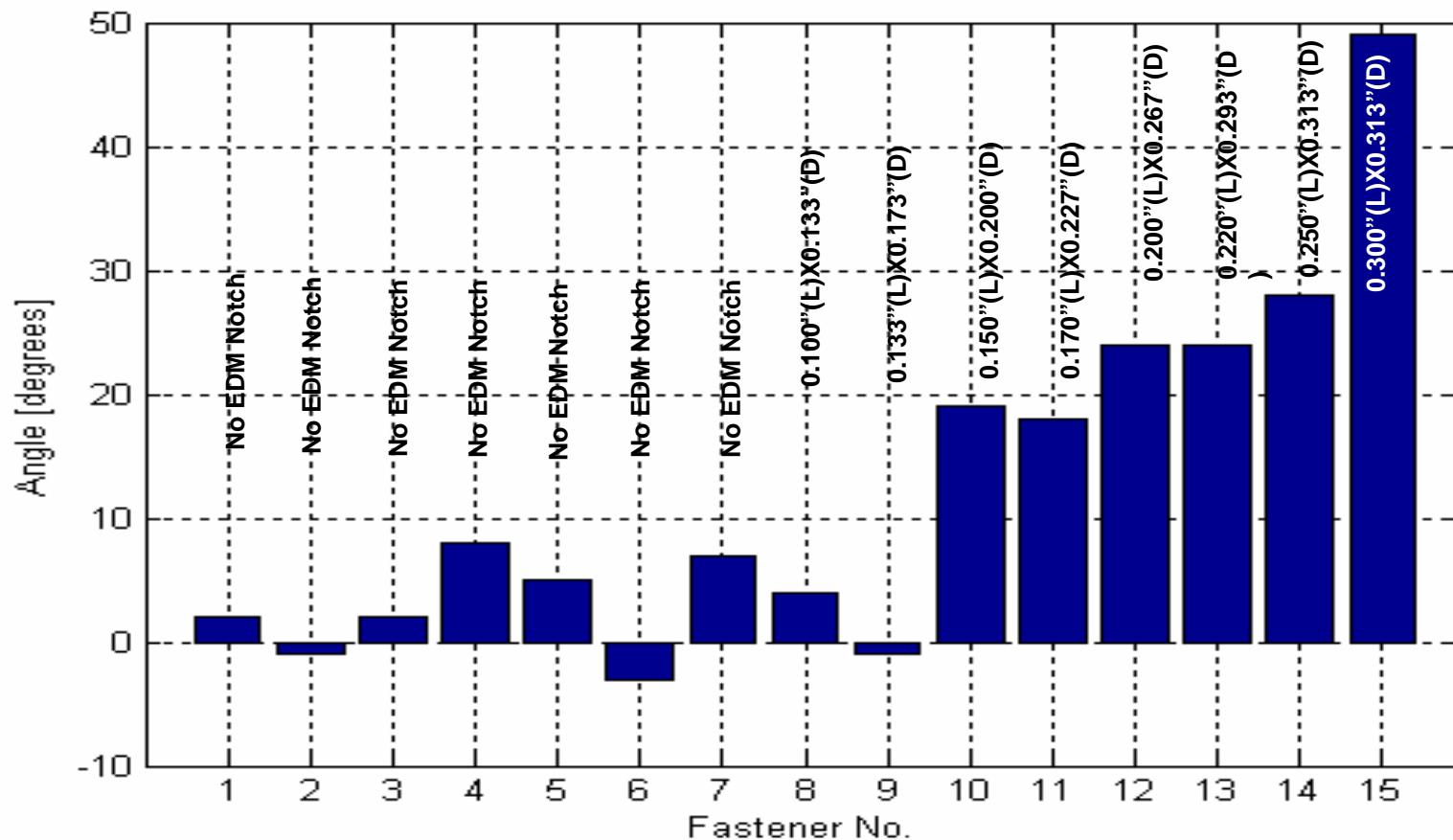


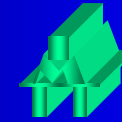
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Signal Rotation Angle

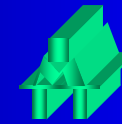
Detect-ability: Notch $\geq 0.150''$





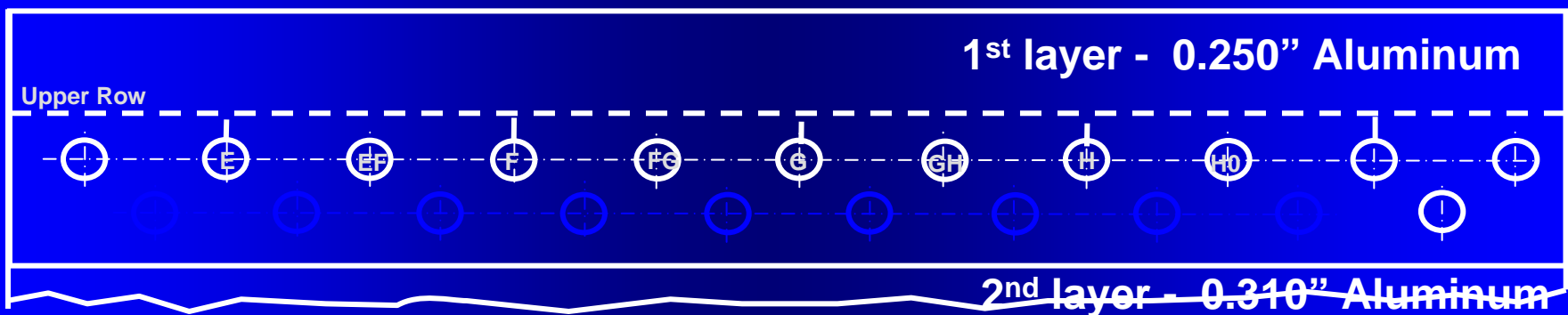
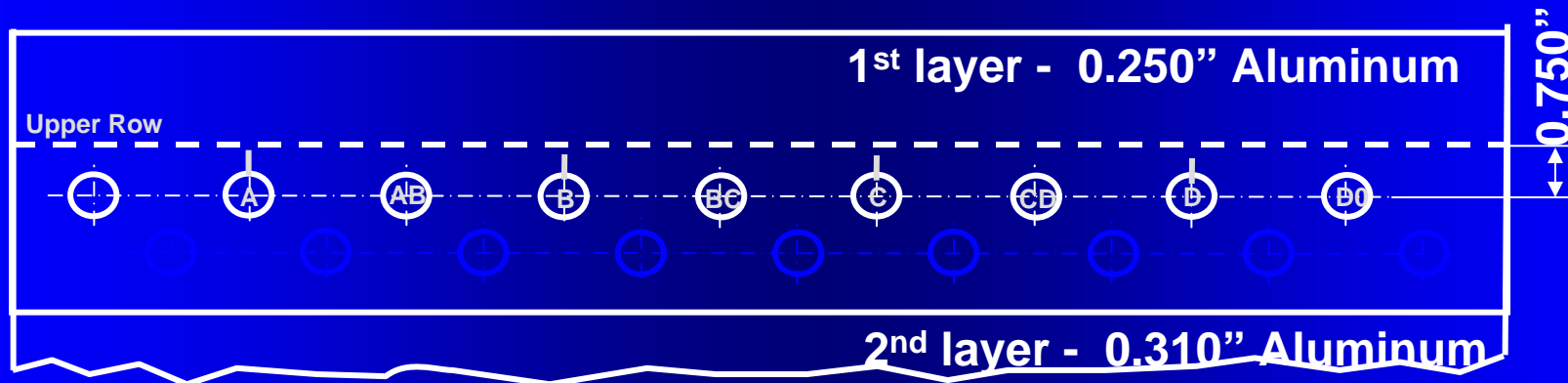
Study # 2

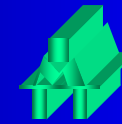
2nd Layer Crack near 2nd Layer Edge Non-ferromagnetic Fastener



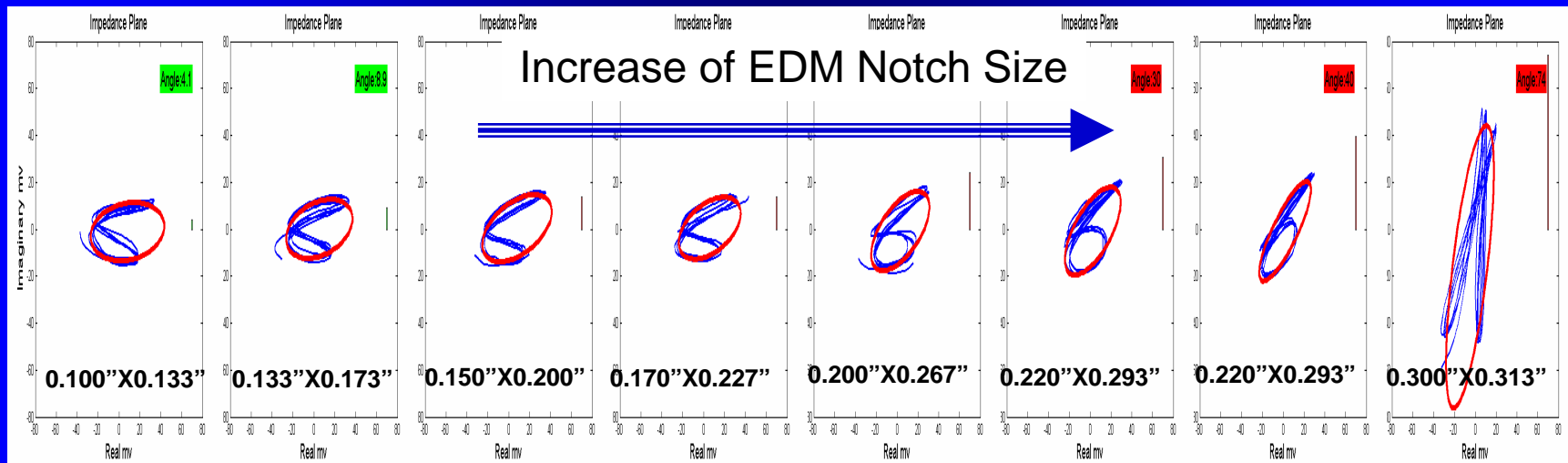
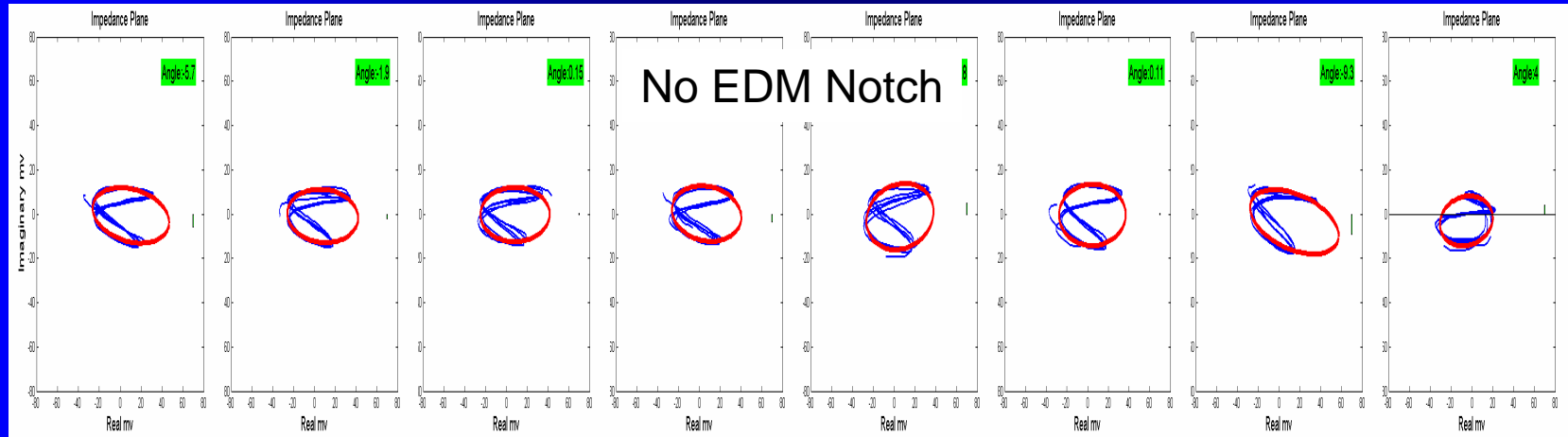
Example 3

Detection 2nd layer vertical cracks with Ti fasteners, crack close to 2nd layer edge





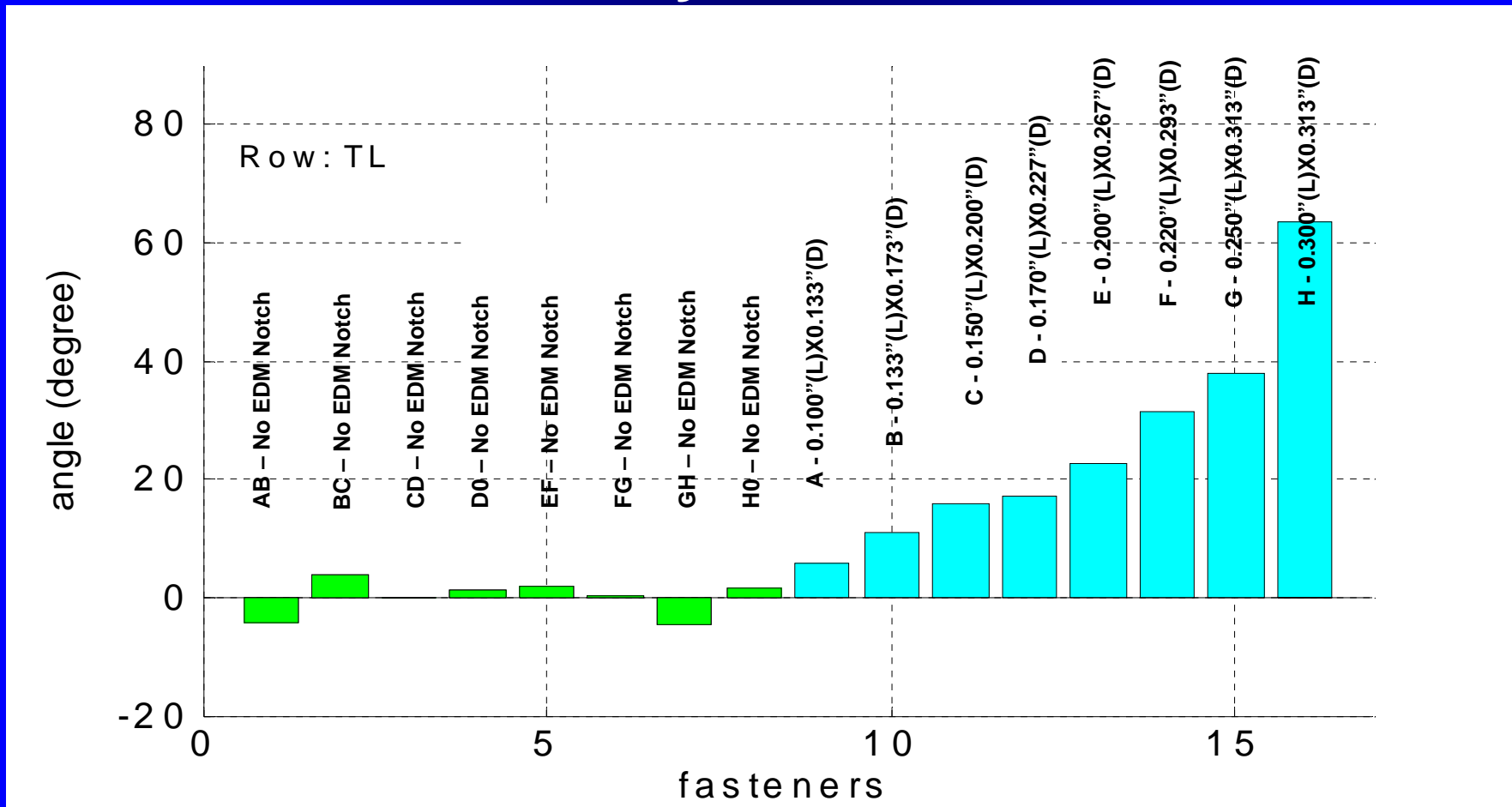
Detection of 2nd Layer Notches impedance plane & ellipse fitting





Signal Rotation Angle

Detect-ability: Notch $\geq 0.133''$

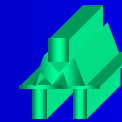




Study # 3

2nd Layer Crack near 2nd Layer Edge

Ferromagnetic Fastener



Example 3

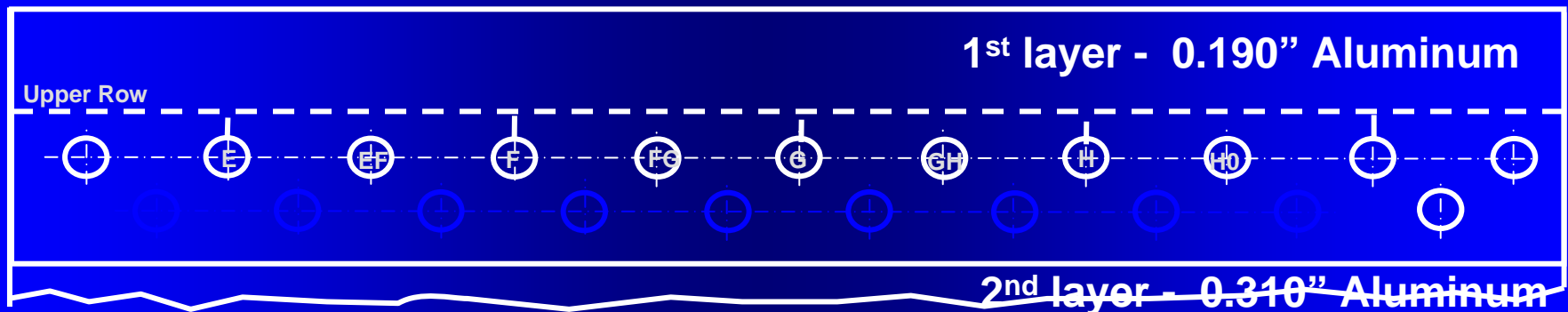
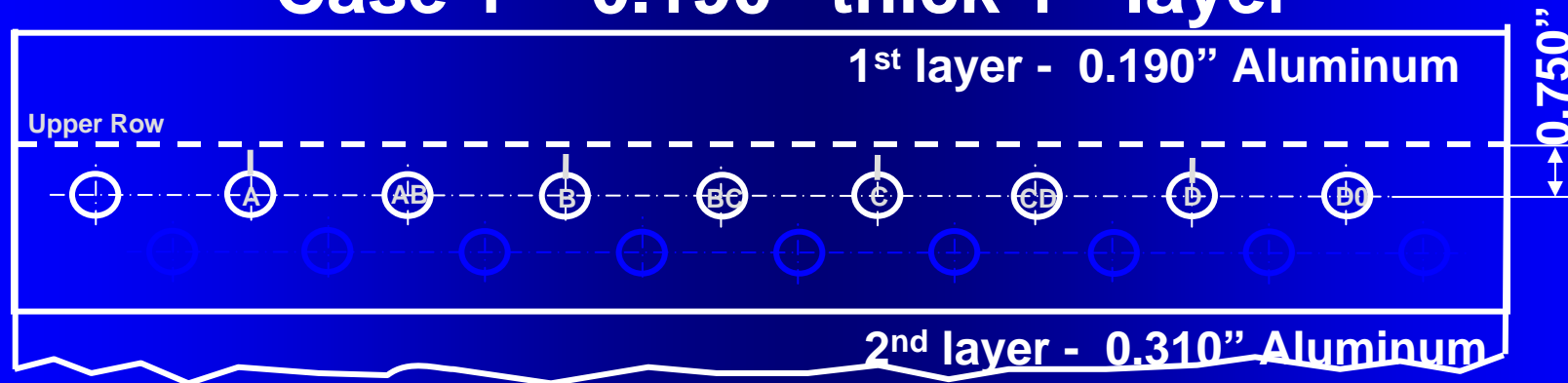
Detection 2nd layer vertically aligned cracks
with steel fasteners & crack close to 2nd layer edge

Challenges:

1. Fastener head shortens drive - pickup coil distance – possible less penetration
2. No-crack fastener signal may vary from one fastener to other due to ferromagnetism.
3. 2nd layer crack is on the same layer and same side with 2nd layer edge and crack signal is much smaller than edge effect.

Example 3

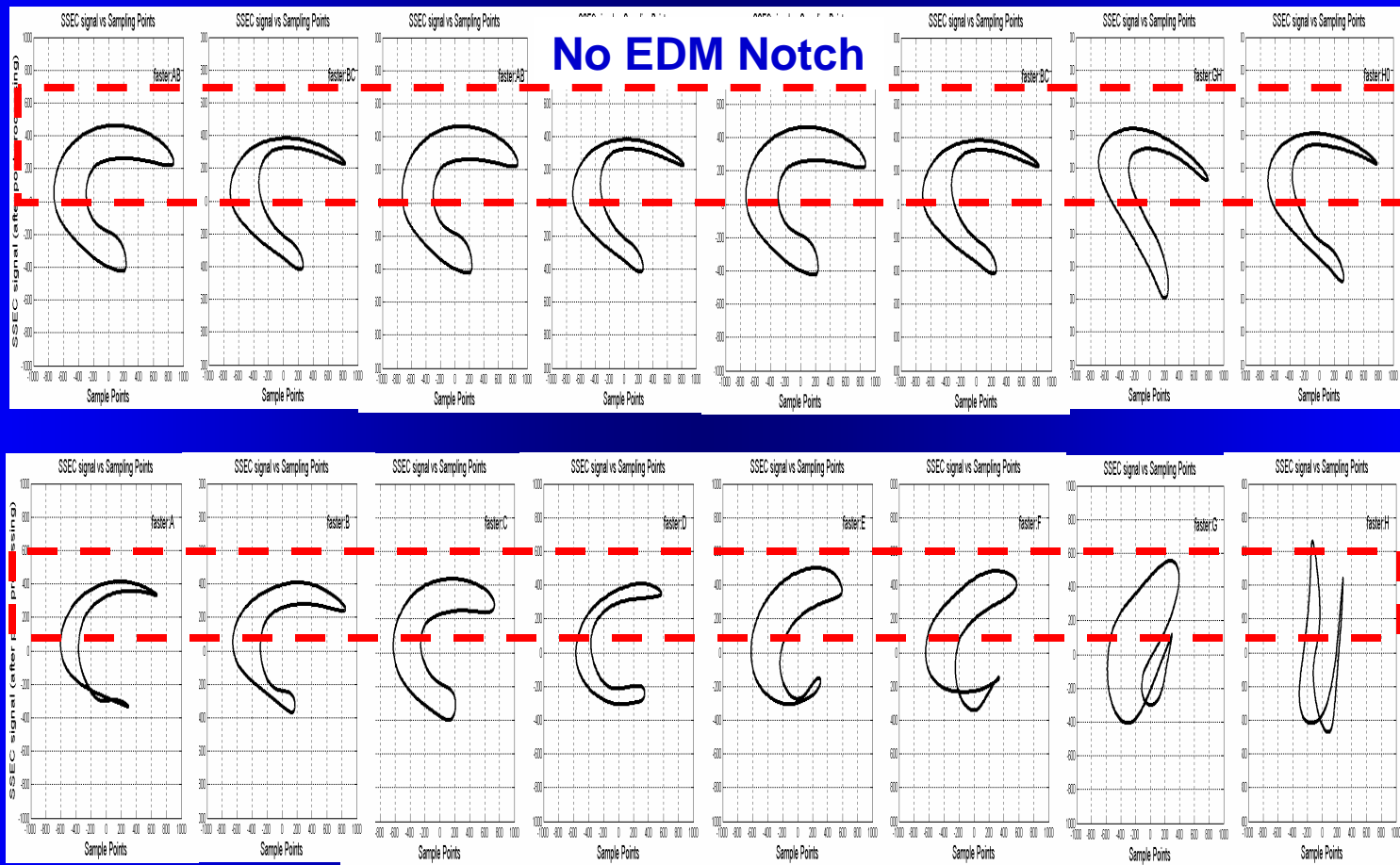
Detection 2nd layer vertically oriented cracks
with steel fasteners, crack close to 2nd layer edge
Case 1 – 0.190” thick 1st layer





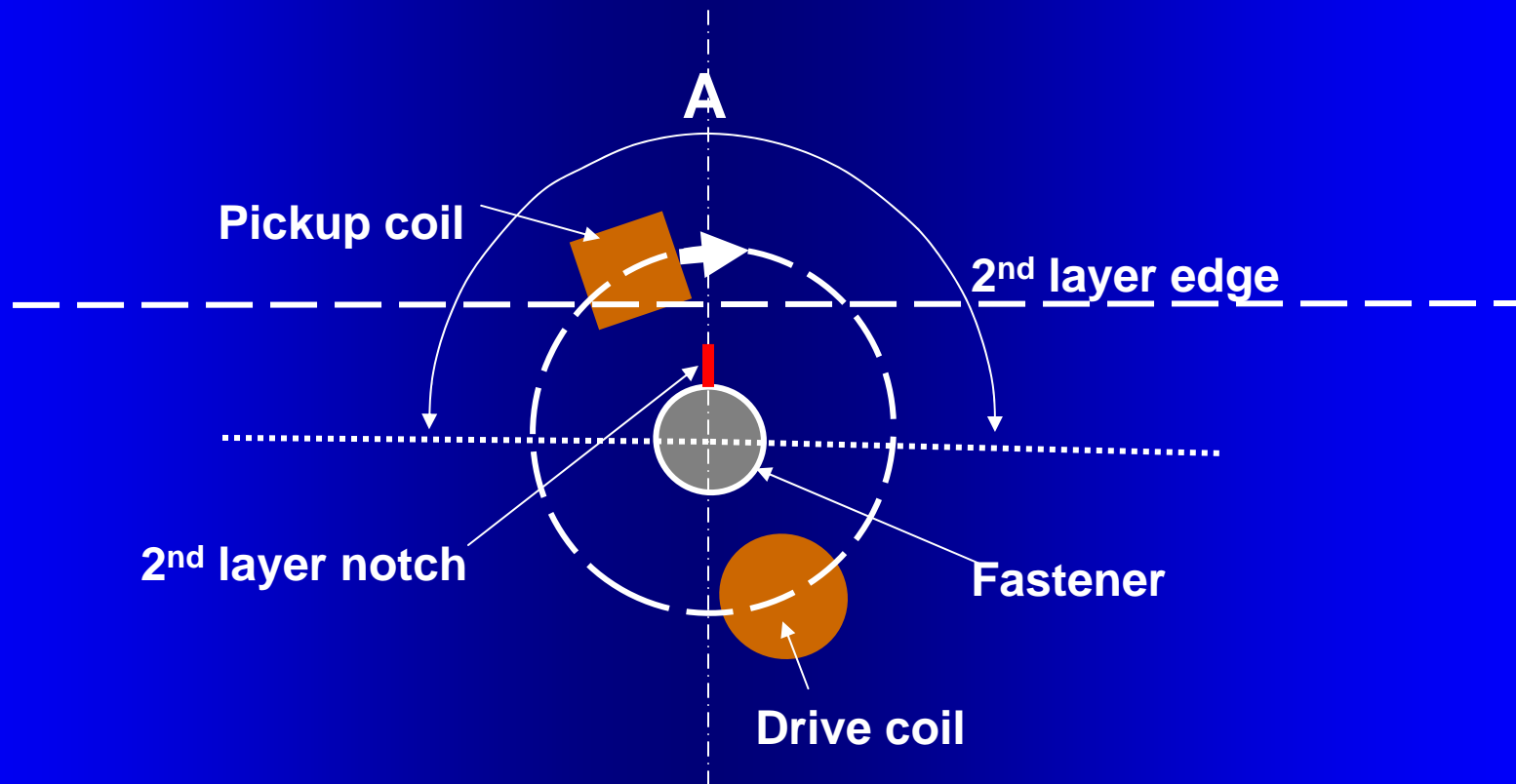
Signals from Fastener Holes

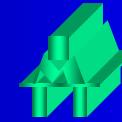
Major difference between no-crack and crack signals is on the top half of the impedance planes – when pickup coil passing the 2nd layer edge



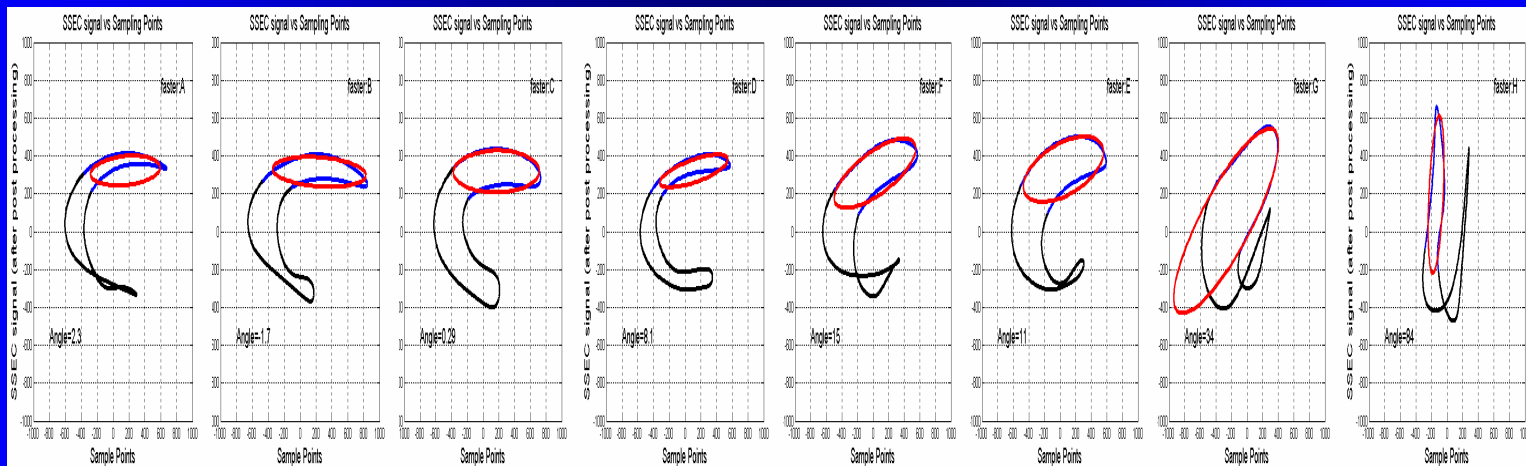
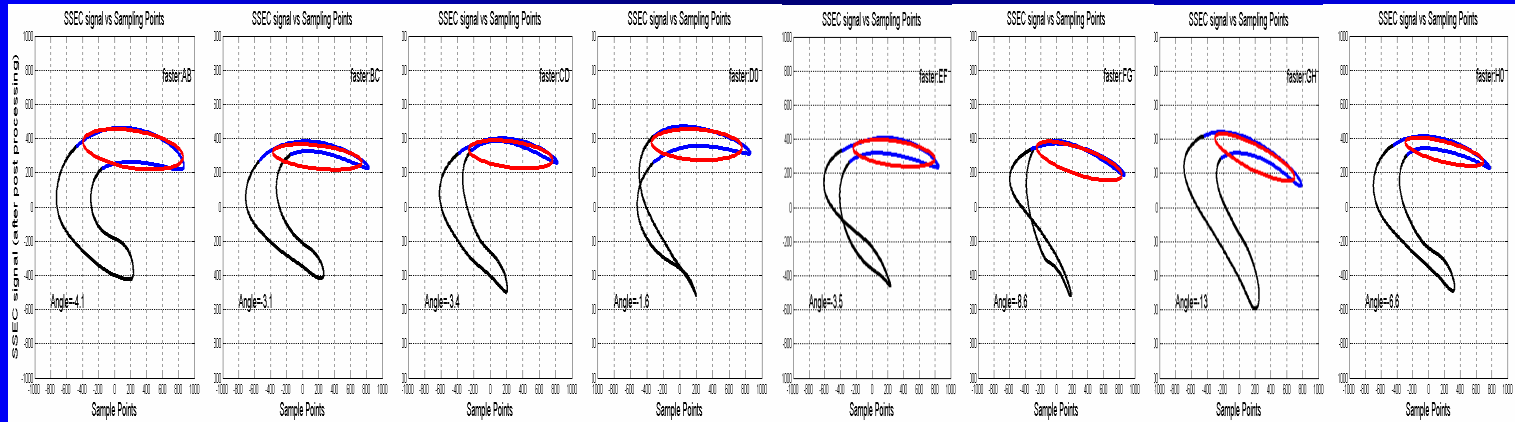
Yushi Sun, Weiqiang Wan, Changhong Sun, Xinle Yang, Haiou Zhu & Tianhe Ouyang, IMTT

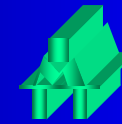
Limited Area, A, where Crack Signal Can Be Observed



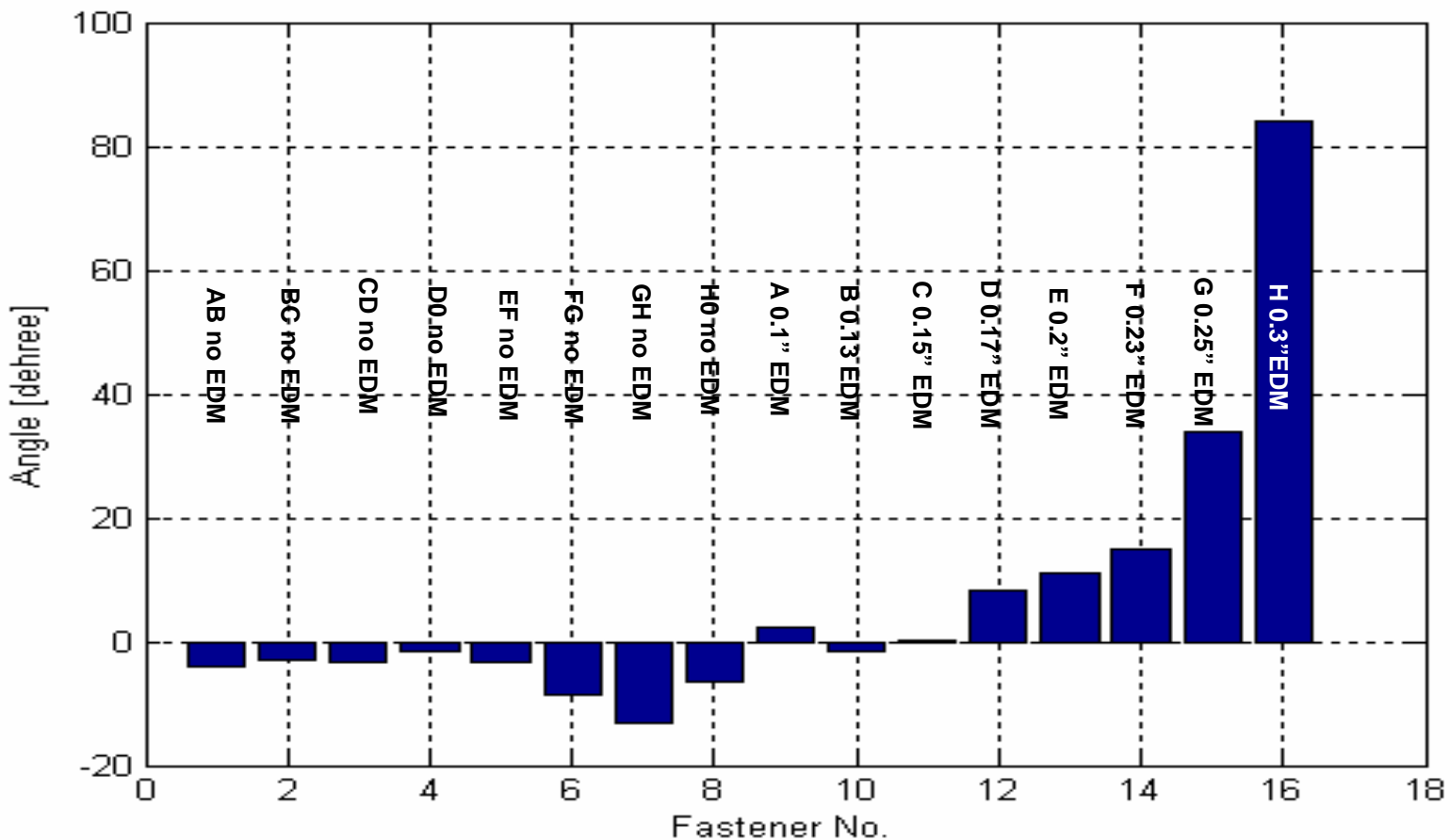


Apply Ellipse Fitting only on Area A of the impedance planes



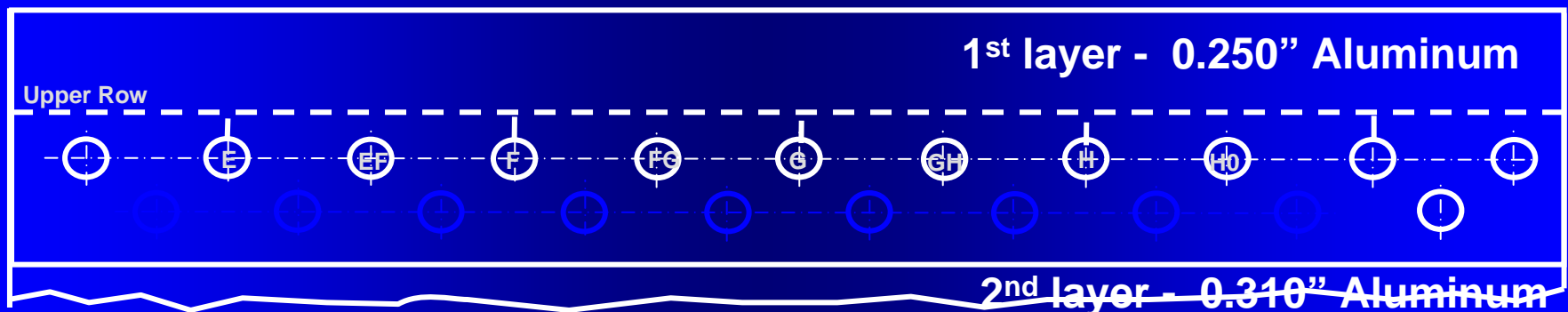
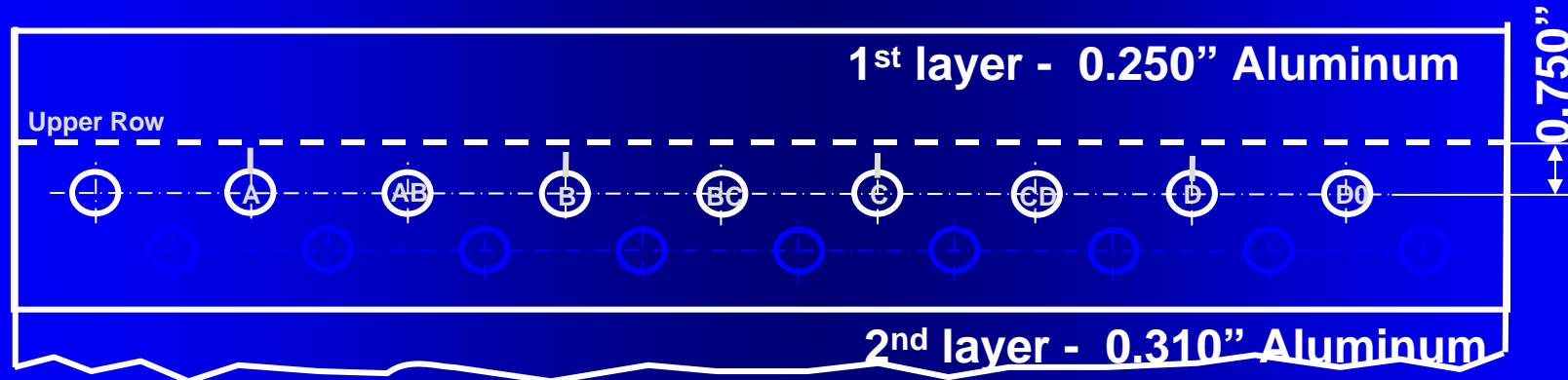


Signal Rotation Angle Detect-ability: Notch ≥ 0.170 "



Example 3

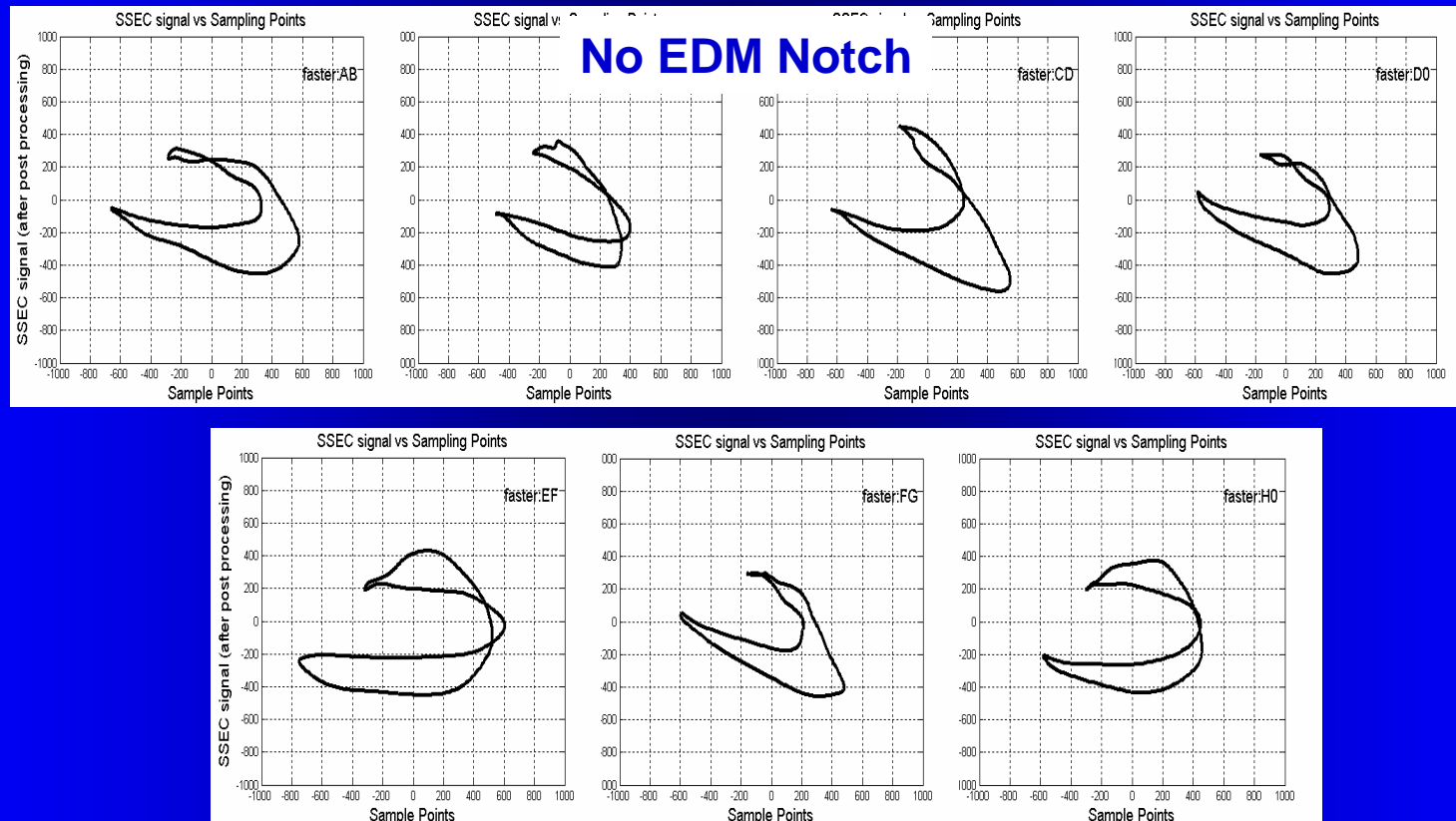
Detection 2nd layer vertically oriented cracks
with steel fasteners, crack close to 2nd layer edge
Case 2 – 0.250” thick 1st layer





Signals from Fastener Holes without Notch

Signal varies in its size and shape

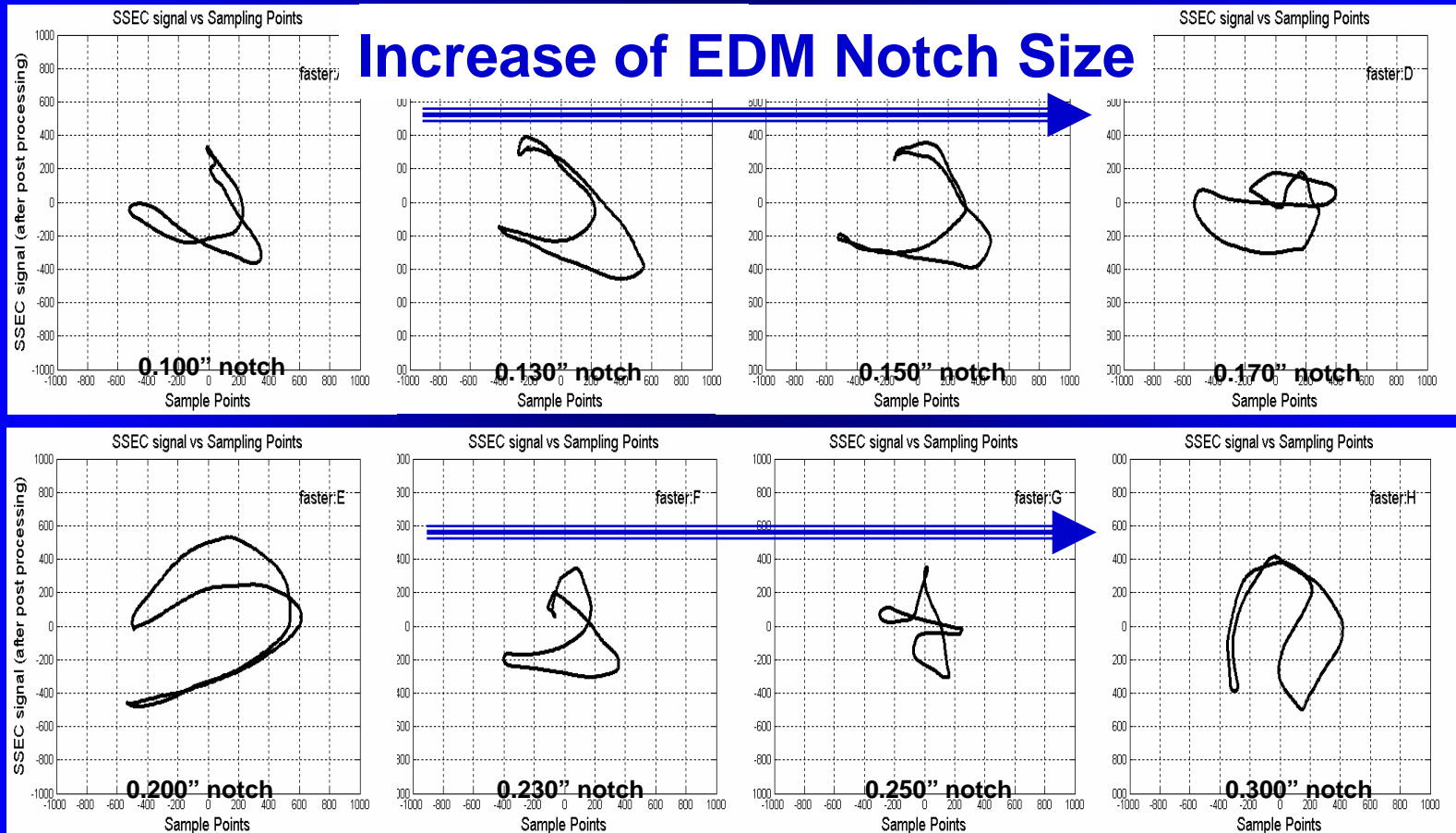




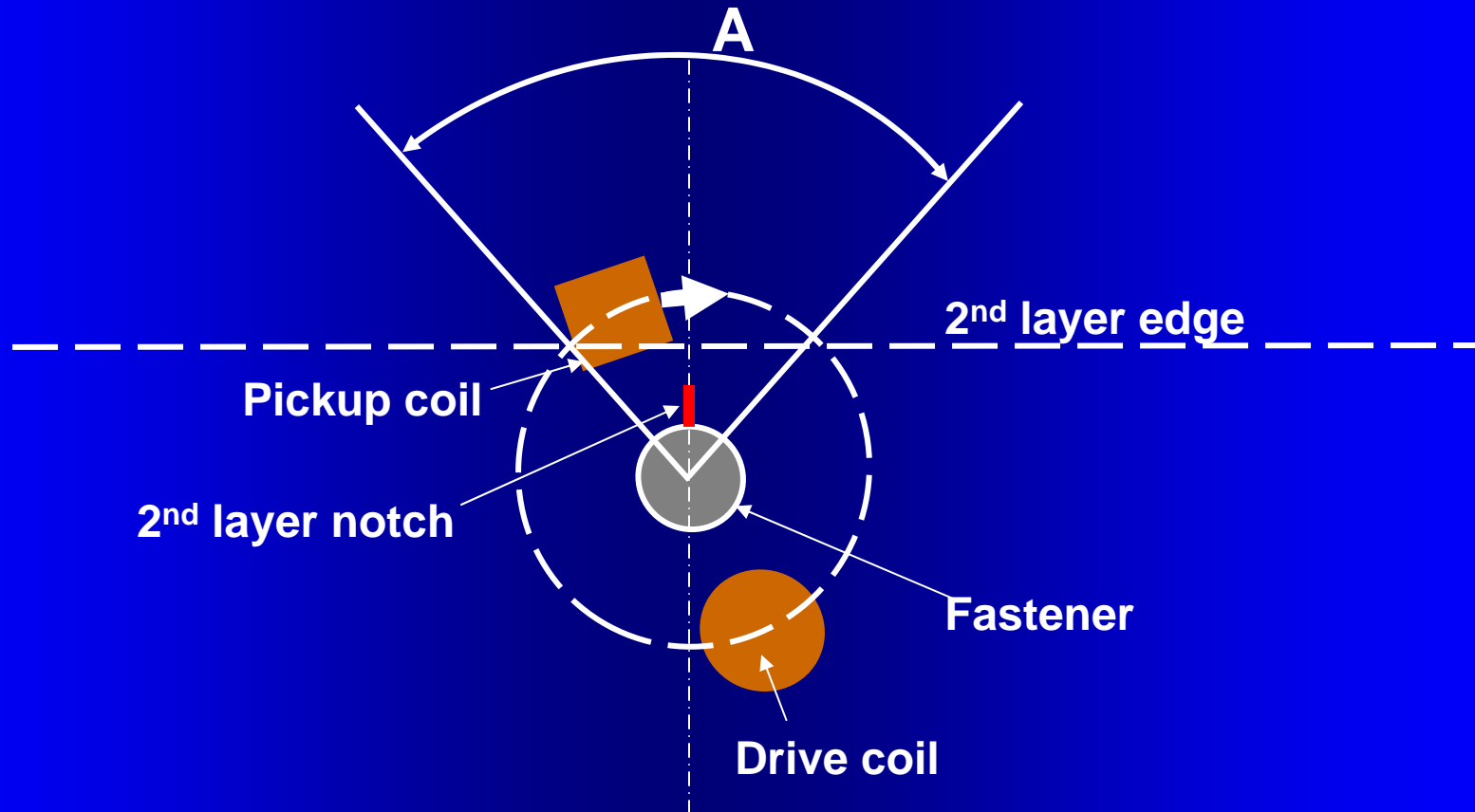
Signals from Fastener Holes with Notch

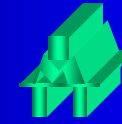
Signal changes in irregular way

Increase of EDM Notch Size

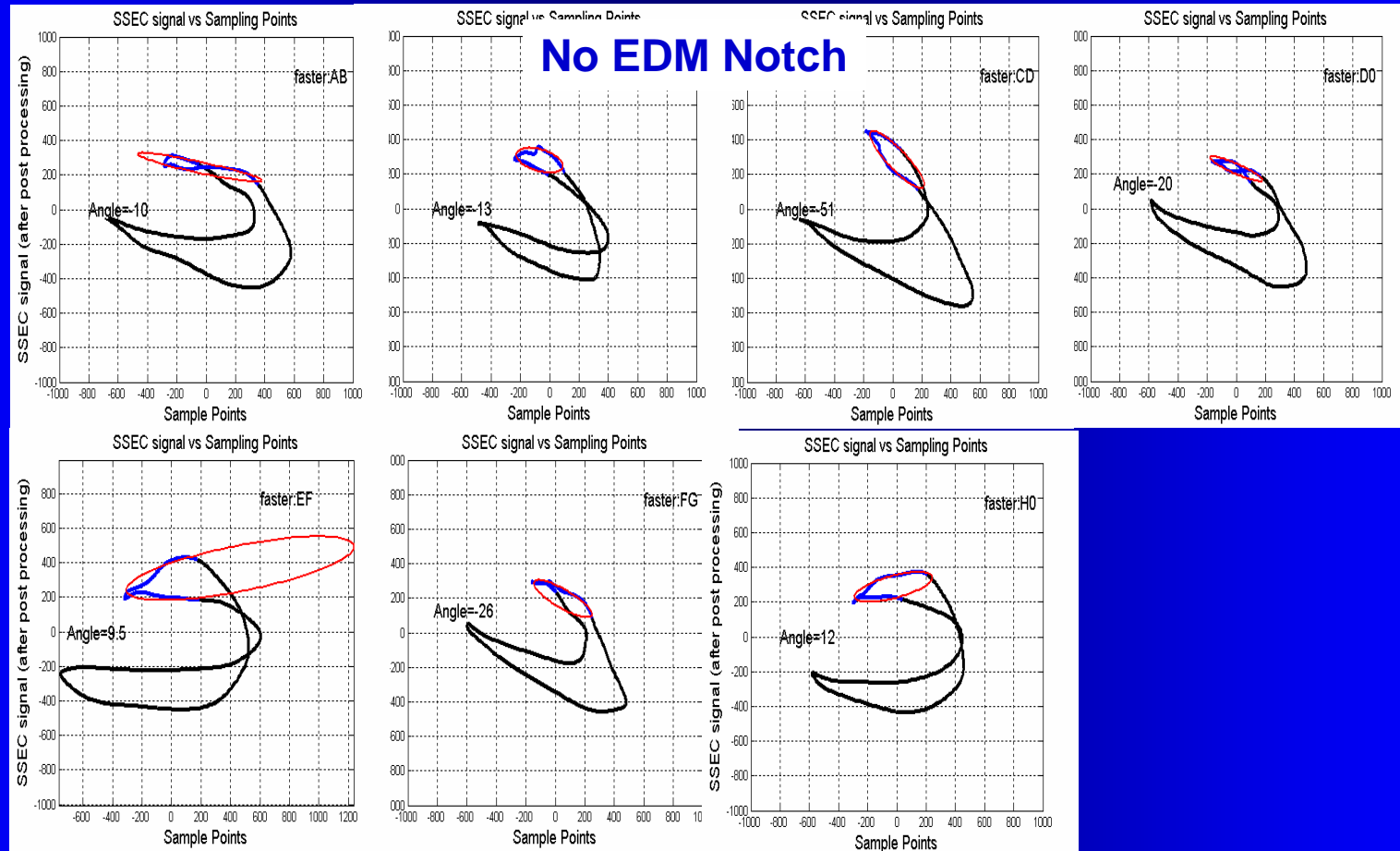


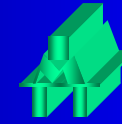
Limited Area where Crack Signal Can Be Observed



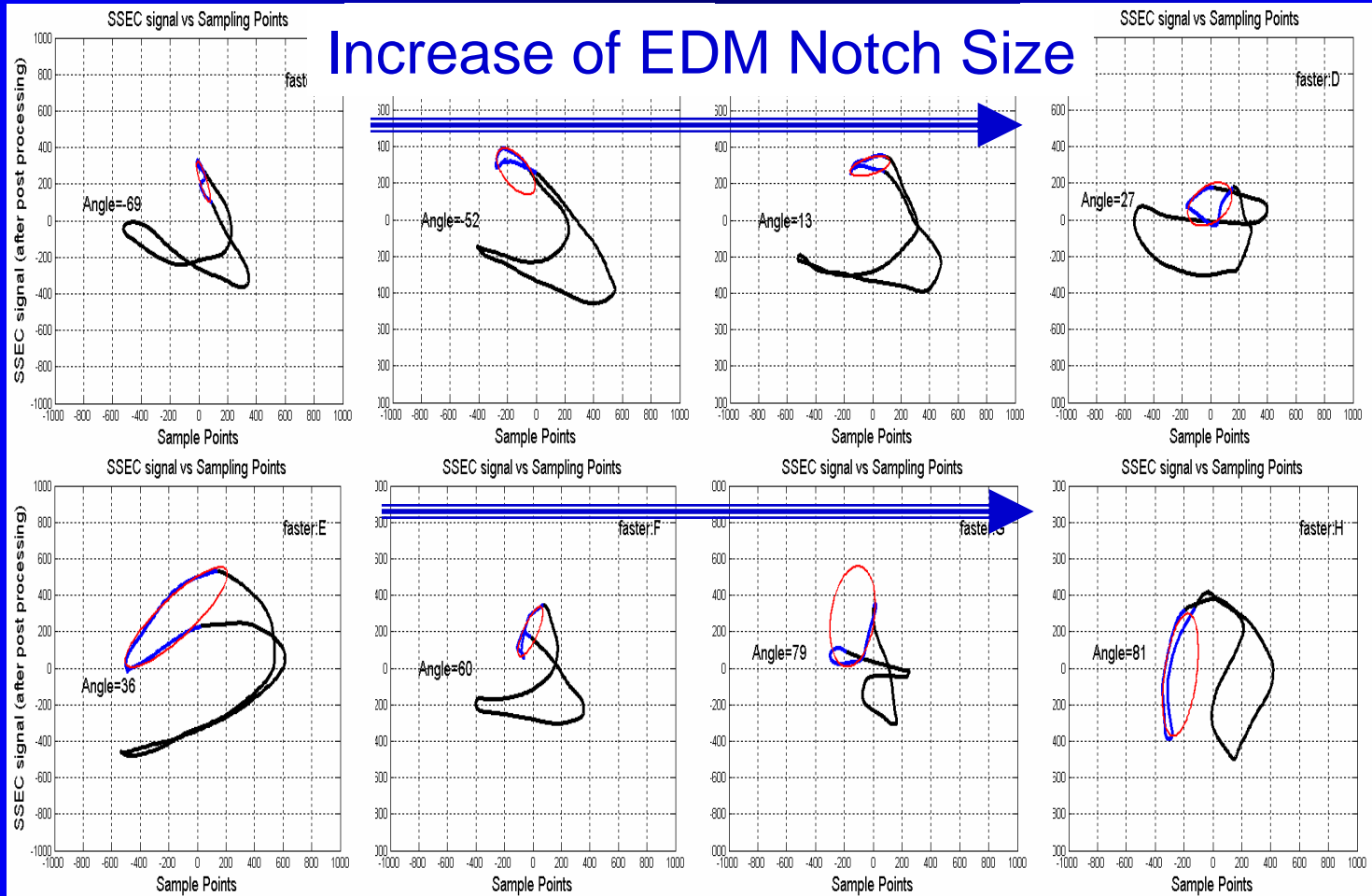


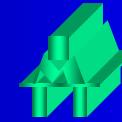
Signals from Fastener Holes without Notch



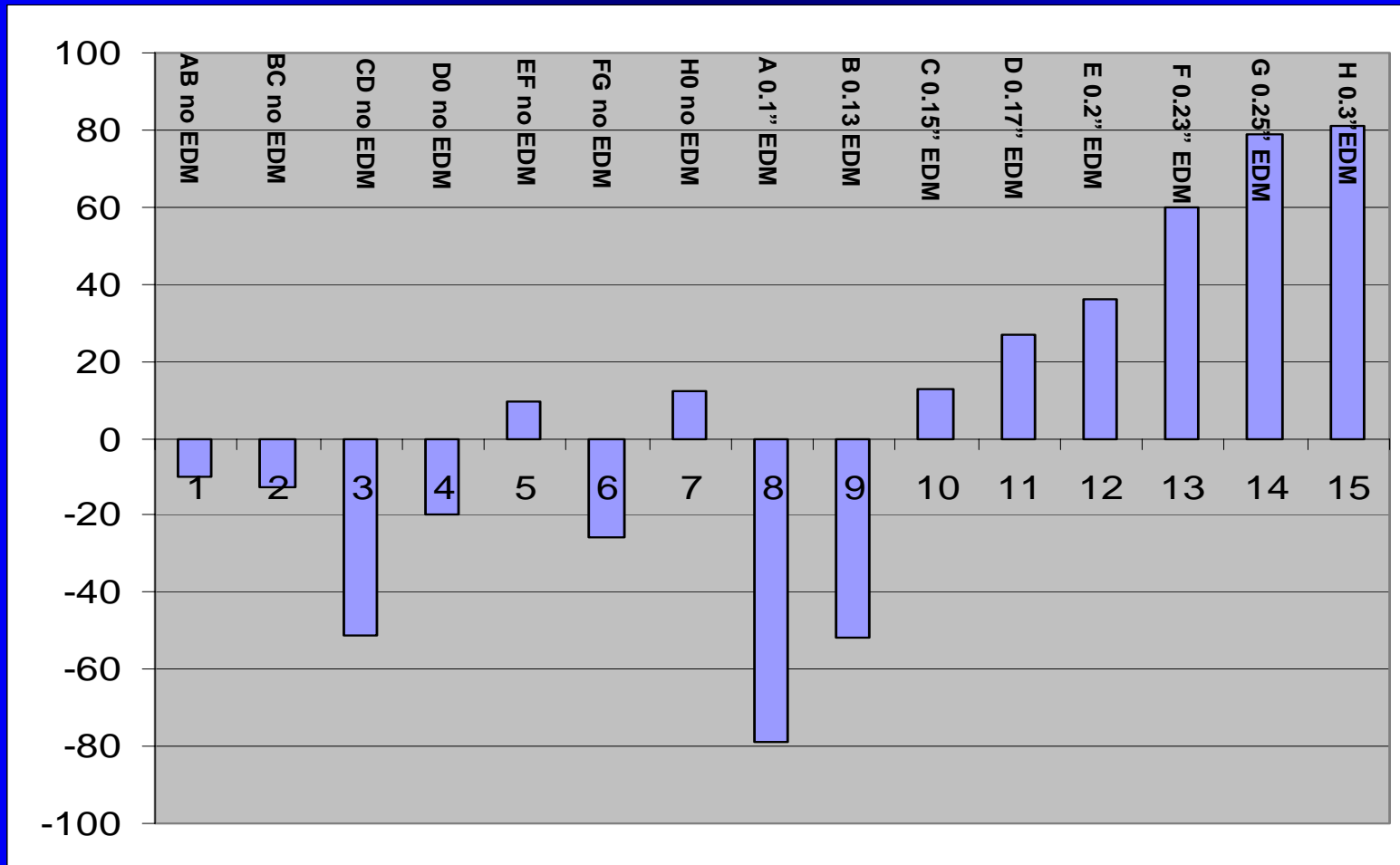


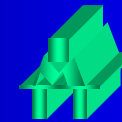
Signals from Fastener Holes with Notch





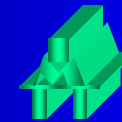
Signal Rotation Angle Detect-ability: Notch $\geq 0.170''$





Pattern Recognition – An Alternative Approach

A couple of pattern recognition algorithms have been tried to identify cracks located at different layers and locations in two three-layer 0.690” thick aluminum samples. The samples are provided by Sandia Labs and Cessna Aircraft. The first test results are encouraging. However, a large number of samples and a huge amount of work are needed for the training the scheme. The project is now pending.



Conclusions

- 1. Motorization of rotational RFEC probe provides highly repeatable signal that enables the use of online signal processing and pattern recognition.**
- 2. As a consequence motorized rotational probe is capable of detecting some cracks that are undetectable using regular manual probes.**
- 3. Selection of appropriate signal processing algorithm improves overall sensitivity and reliability of RFEC rotational probes in cracks detection in thick multilayer structure with complex geometry.**