DETECTING CRACKS UNDER BUSHINGS WITH ROTATIONAL REMOTE-FIELD EDDY CURRENT PROBES

Yushi Sun, Tianhe Ouyang, Jie Long
Innovative Materials Testing Technologies, Inc.
2501 N. Loop Drive, Ames, IA 50010

Jeff Thompson, Jeff Kollgaard
Boeing Commercial Airplanes
635 Park Avenue North, Renton, WA 98055

Michael Harper, Terry Herrman
Ames Laboratory, 167 Metal Development
Iowa State University, Ames, IA 50011-3020

Acknowledgements

Innovative Materials Testing Technologies, Inc.

BOEING

Innovative Materials Testing Technologies, Inc. (IMTT):

Developed prototype probe for the IMTT Super Sensitive Eddy Current (SSEC) system.

Ames Laboratory's Engineering Services:

Assisted in probe design and fabrication

Boeing Commercial Airplanes:

Provided specimens, requirements, and guidance for the inspection

FAA

Provided funding to support development of this technology

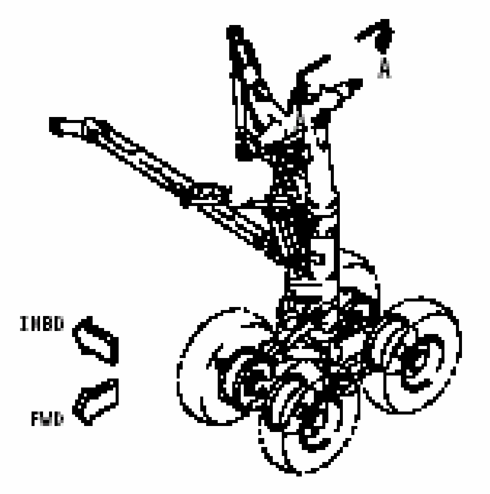
Detection of Cracks Beneath Installed Bushings

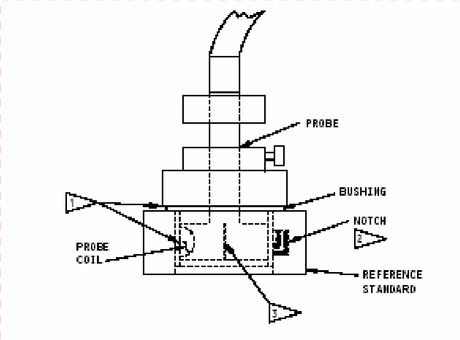
- **Cracks propagate quickly in high-strength steel, requiring timely detection**
  - Low frequency eddy current (LFEC) lacks required sensitivity
  - Ultrasonic shear wave inspection requires special fixtures to direct the sound beam
- *Methods are needed that can inspect 360 degrees around a bore without removal of installed bushings*

Current 767 Inspection

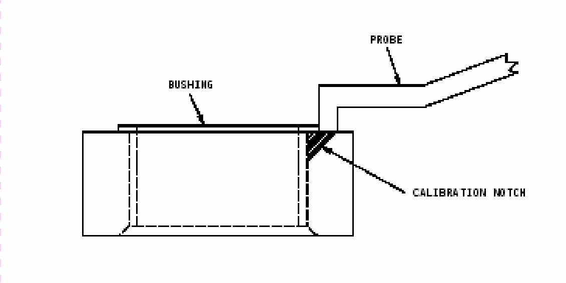
Innovative Materials Testing Technologies, Inc.

BOEING

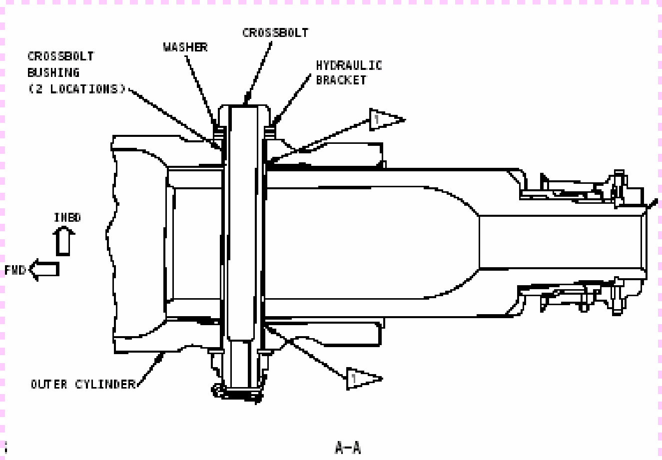




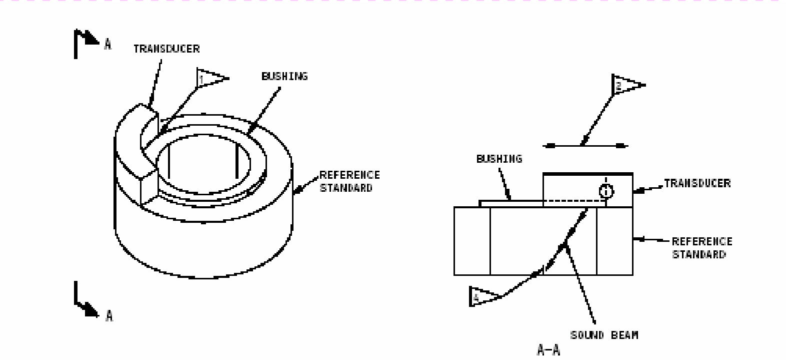
Rotational LFEC probe
Lndi = 0.4" long x 0.25" deep



High frequency eddy current probe around flange perimeter
Lndi = 0.3" triangular



Three separate NDT inspections required



Ultrasonic shear wave
Lndi = 0.15" triangular

RFEC FG Technique[1] with SSEC system[2]

Innovative Materials Testing Technologies, Inc.

BOEING

- Deep penetration – up to 0.8” into a multi-layer structure
- High sensitivity – it detects 0.004” deep and 0.092” diameter hole on the backside of a 0.125” thick aluminum structure
- Simple to use – similar to conventional EC technique
- AUTOCURRENT function helps to automatically set drive current & pre-gain at optimal values
- RDIFF[3] mode minimizes background noise
- Low cost – similar to conventional EC systems
- Portable

---

1 Remote Field Eddy Current technique for inspecting conductive objects of Flat Geometries.

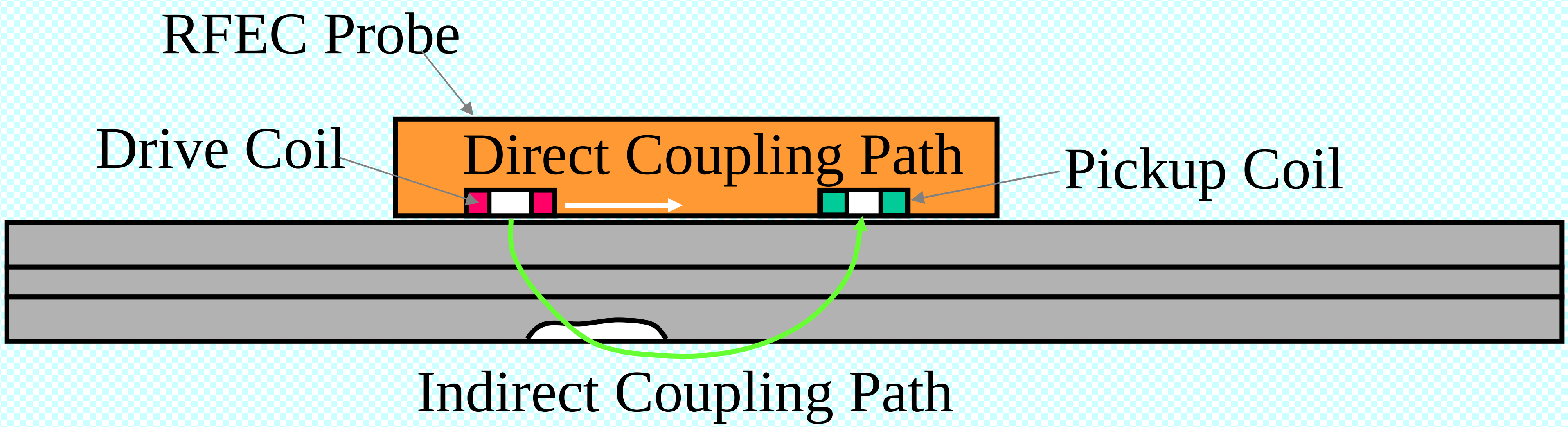
2 Super Sensitive Eddy Current System.

3 Reflection differential mode.

RFEC Phenomenon in Flat Geometries

Innovative Materials Testing Technologies, Inc.

BOEING



- In the absence of a test part, only direct coupling from the drive coil is detected, i.e., No RFEC signal is present
- The RFEC probe is designed to minimize signal from direct coupling and focus on the indirect coupling path

LFEC vs. RFEC

Innovative Materials Testing Technologies, Inc.

BOEING

LFEC

- Impedance (Z) is proportional to total flux, (Φ).

  In a reflection probe induced voltage (V) is proportional to Φ
- Flaw causes *very limited* change in Φ, also in Z or V.
- Change in Φ caused by a deeply hidden flaw may be less than 0.01% - 0.001%.
- Different approaches have been used to cancel the normal signal and separate out the flaw signal. Perfect separation is impossible.

RFEC

- V is proportional to a portion of the flux, Φ_{RF}, that has passed through the test object twice
  - Represents the local condition below and between the driver and receiver.
- The presence of a discontinuity results in a *large* change in Φ_{RF}, and also in V.
- Change in phase of Φ_{RF} has a linear relation with the wall thickness.

LFEC vs. RFEC

LFEC

- Nominal signal levels are high, but flaw-induced variations are low, so flaw-signal/normal-signal ratio is low.
    - Limits the gain to be used in an instrument.

RFEC

- Signal level is low, but flaw-signal/normal-signal ratio is high.
    - Allows higher gain for a given flaw signal.

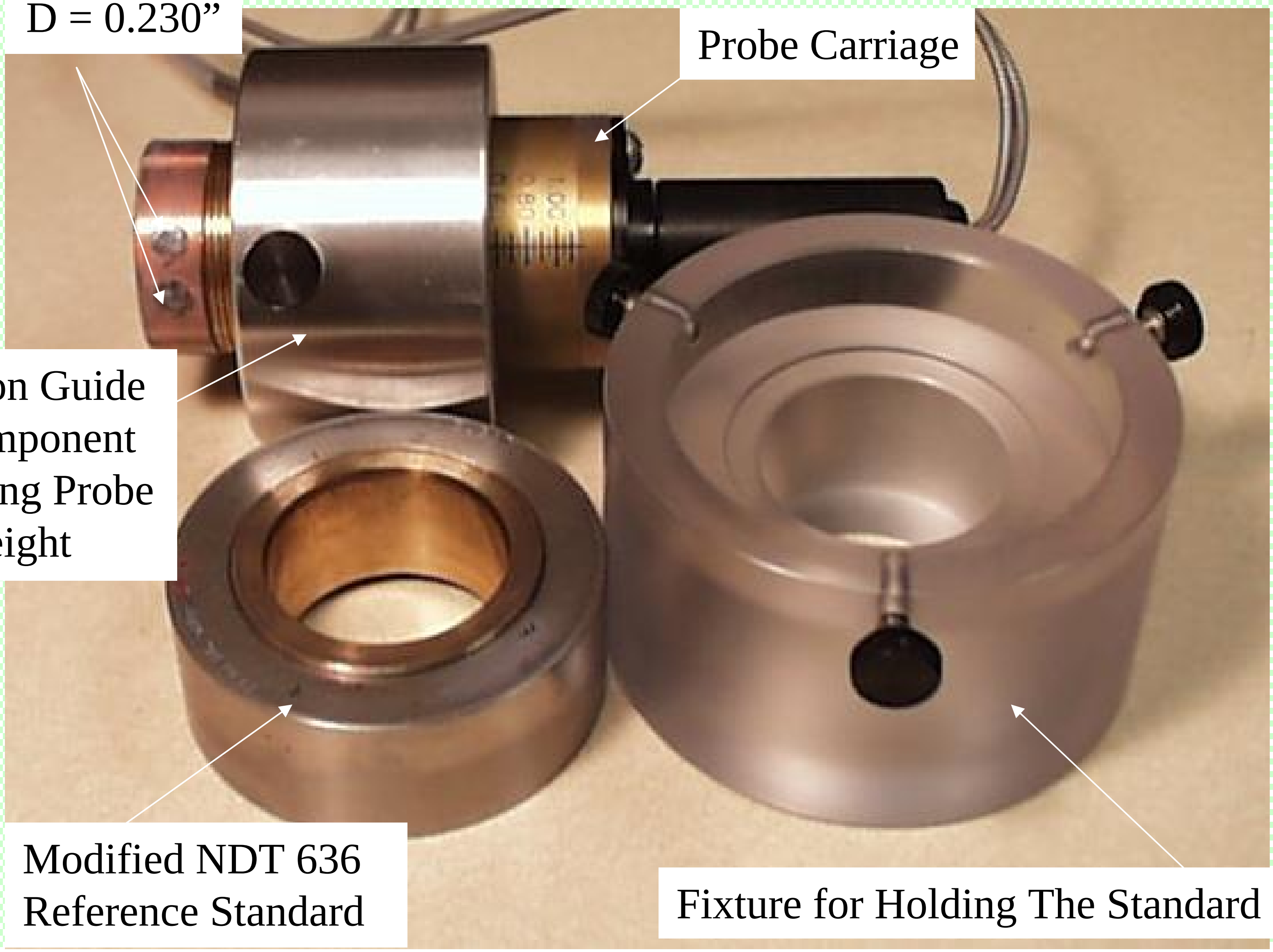
SSEC System [2]

Unique Features Compared to Conventional ECT system:

- Higher sensitivity - Deeper penetration
- Lower power requirement
  - Current drive power is ~ 0.4 [Ampere-Volt]
- Capable of accommodating alternative, non-coil, types of magnetic sensors
- Capable of driving multi-phase traveling/rotating magnetic wave probes.
- Display is similar to that of a conventional ECT system.

[2] Super Sensitive Eddy Current System.

Probe & Accessories



Working Probe

Innovative Materials Testing Technologies, Inc.

BOEING

Cable Strain Releaser

Slip Ring

Probe Carriage

Rotation Guide and Component Adjusting Probe Location

Rotation Handle

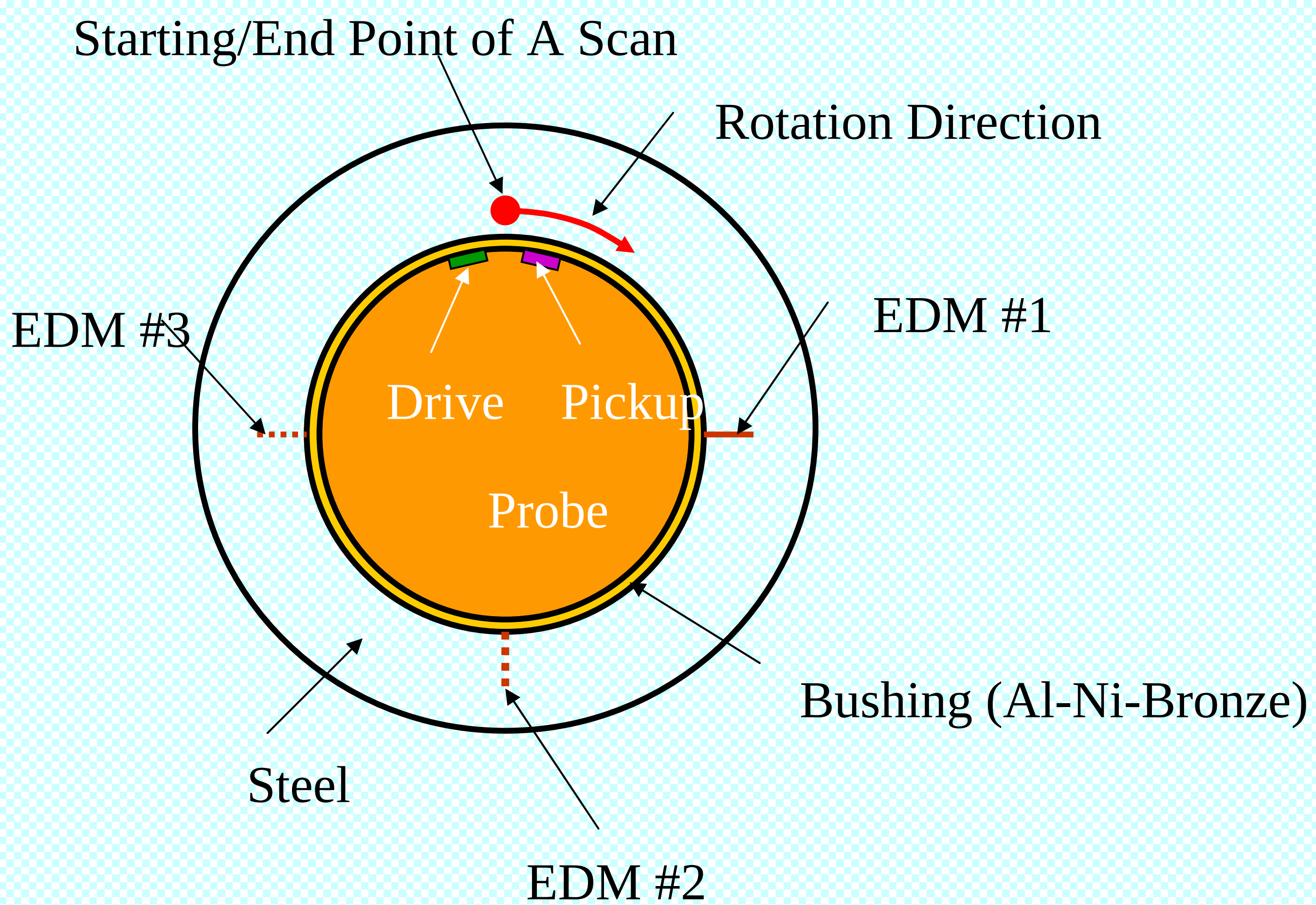
Modified NDT 636 Reference Standard

Fixture Holding The Standard

Reference Standard NDT636 – Top View

Innovative Materials Testing Technologies, Inc.

BOEING



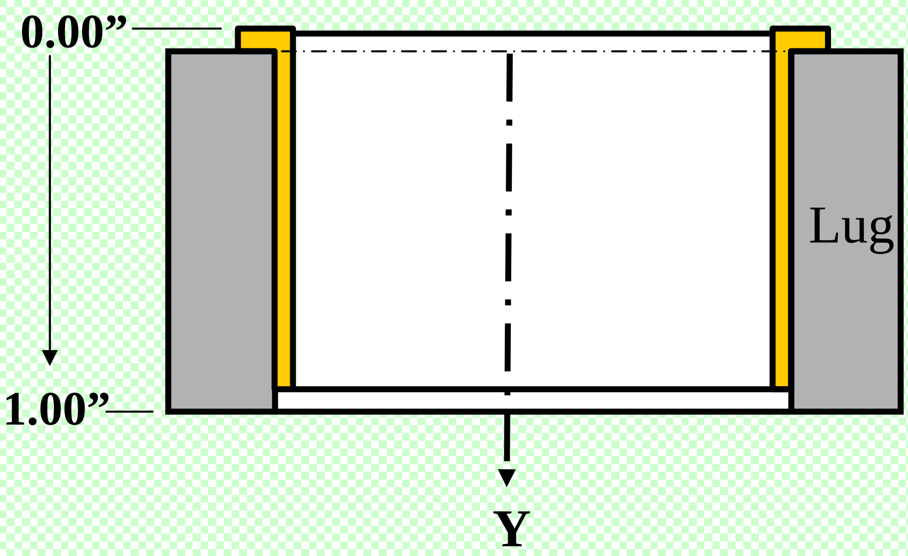
Probe is inserted without removing the bushing and rotated in the bore

RFEC probe and SSEC system minimize the background noise and maximize detectable crack signal.

Vertical Locations of EDM Notches

Innovative Materials Testing Technologies, Inc.

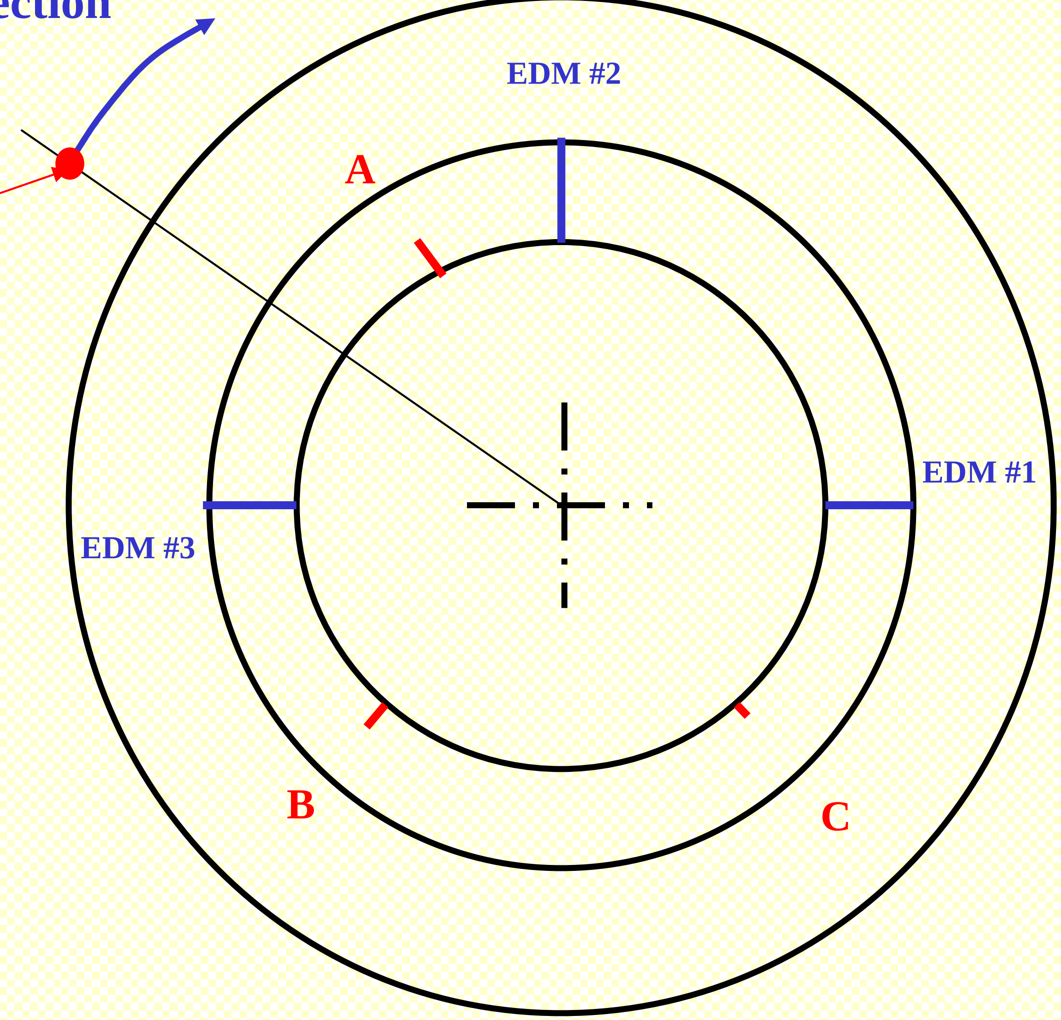
BOEING



- **Originally 3 EDM notches, EDM #1, EDM #2 & EDM #3, built in Reference Standard NDT636.**
- **Smaller EDM notches, A, B, and C, added to Reference Standard**

Vertical Locations			
EDM #	**Length**	**Depth**	**Location in Y**
EDM #1	0.30”	0.30”	0.000” - 0.300”
EDM #2	0.40”	0.25”	0.375” - 0.625”
EDM #3	0.150”	0.150”	0.850” - 1.000”
A	0.150”	0.075”	0.425” - 0.575”
B	0.100”	0.050”	0.450” - 0.550”
C	0.050”	0.025”	0.475” - 0.525”

Circumferential Location of EDM Notches



SSEC System Settings

Innovative Materials Testing Technologies, Inc.

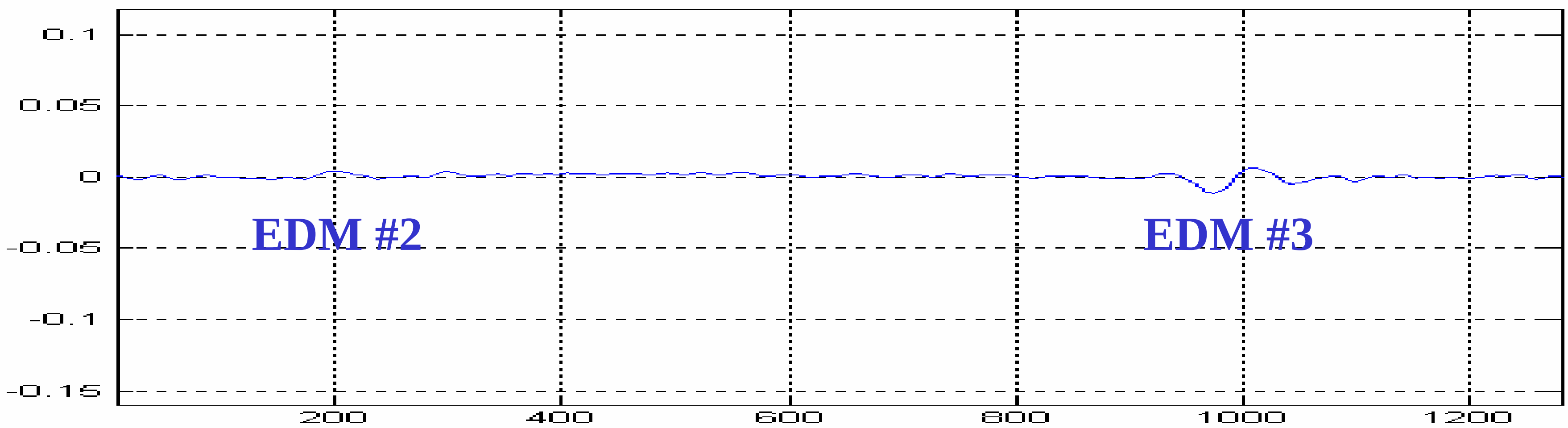
BOEING

Option I - A		Option I - B	
(for inspecting all locations but the ends of the lug)		(for inspecting the two ends of the lug only)	
Drive Frequency:		4.00 kHz	
Reference Current:		94.97mA	
PreGain:	37 dB	PreGain:	26 dB
PostGain:	25 dB	PostGain:	35 dB
LPF Cutoff Frequency:		30.00 Hz	
Current Angle:		320°	
Probe Mode:		RDIFF	
Differential Step:		2	
Band Pass Filter:		3 Hz/6 Hz	
Rotation Speed:		8 seconds per rotation	

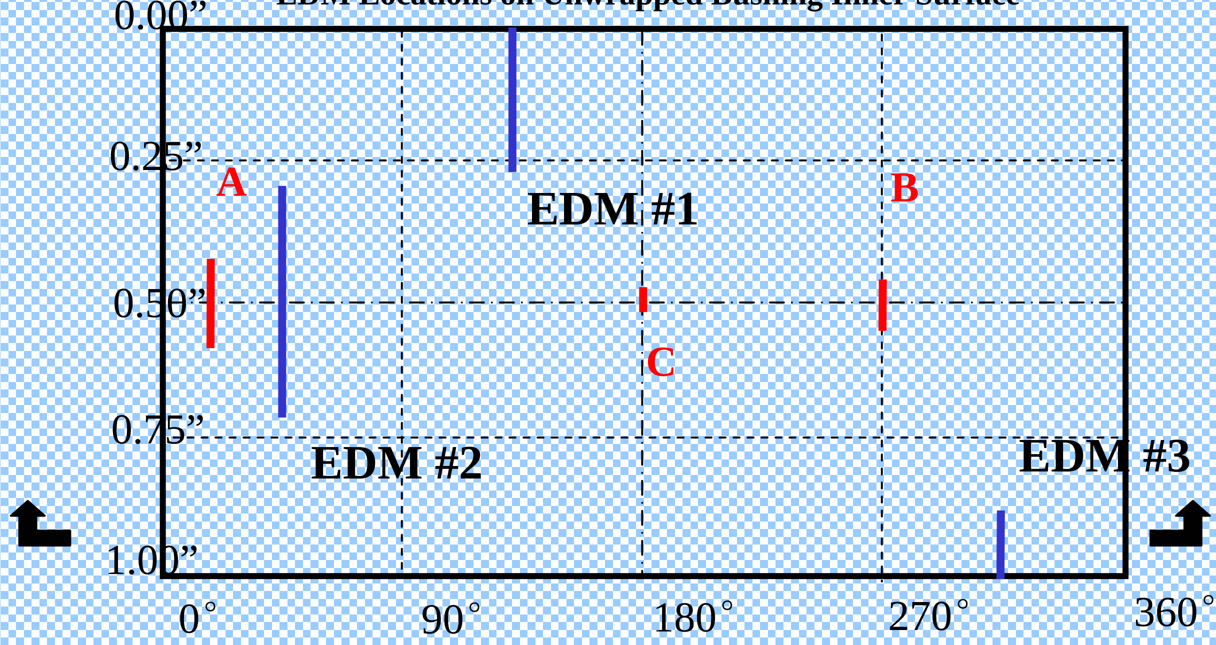
Results at 0.95” depth (SSEC Settings I-B)

Innovative Materials Testing Technologies, Inc.

BOEING



EDM Locations on Unwrapped Bushing Inner Surface



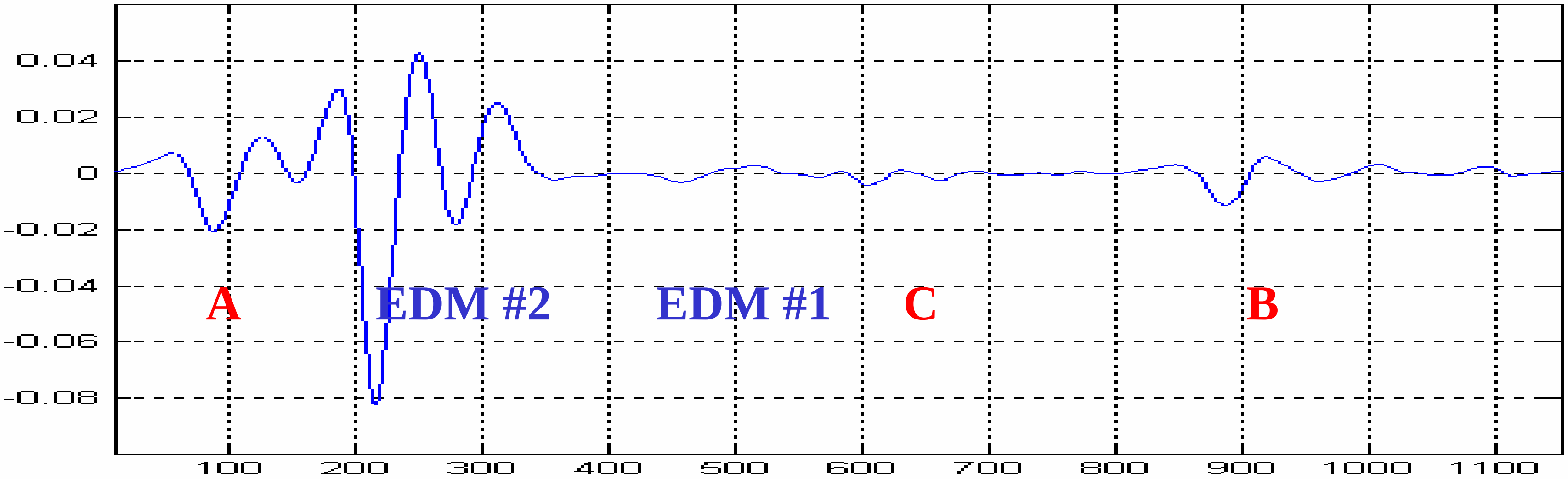
EDM Notch Dimensions

EDM #	Length	Depth
EDM #1	0.30”	0.30”
EDM #2	0.40”	0.25”
EDM #3	**0.150”**	**0.150”**
A	0.150”	0.075”
B	0.100”	0.050”
C	0.050”	0.025”

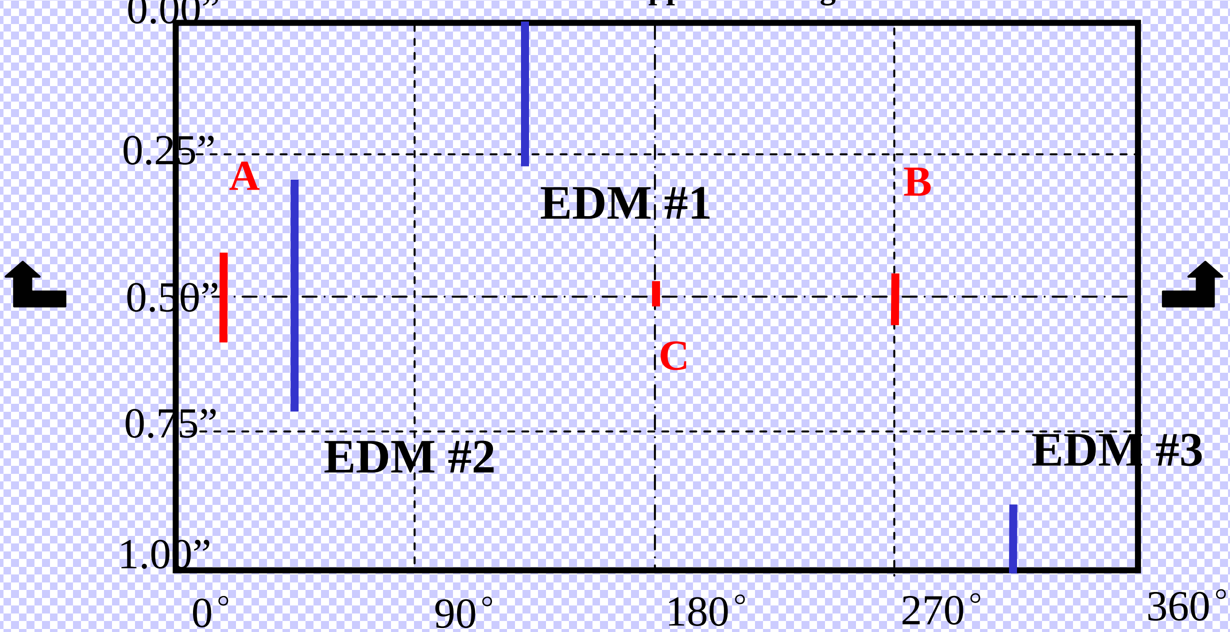
Results at 0.50” depth (SSEC Settings I-A)

Innovative Materials Testing Technologies, Inc.

BOEING



EDM Locations on Unwrapped Bushing Inner Surface



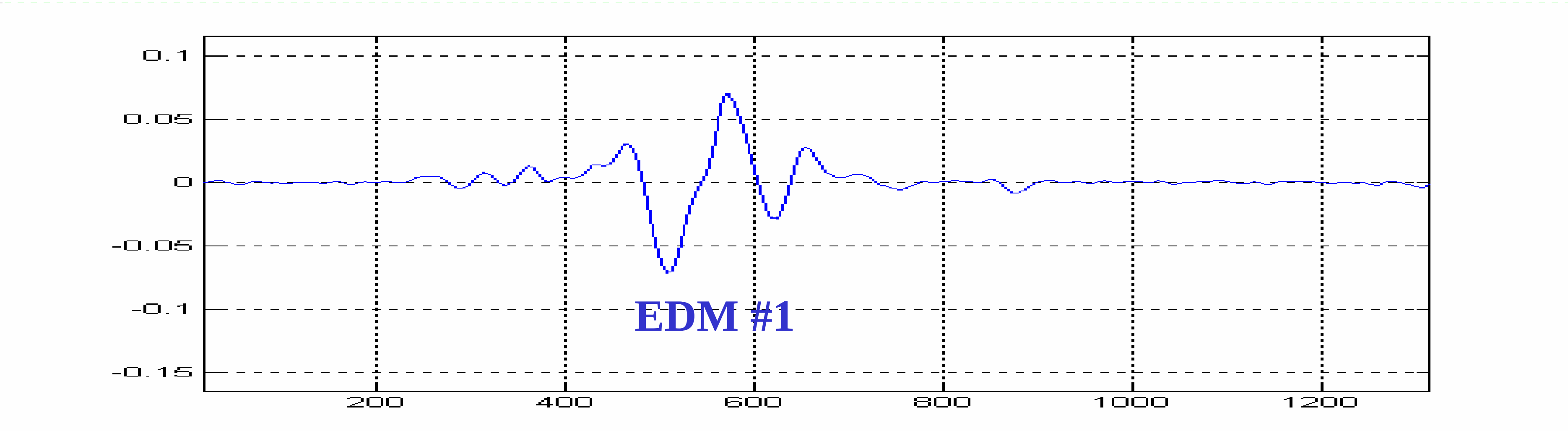
EDM Notch Dimensions

EDM #	Length	Depth
EDM #1	0.30”	0.30”
EDM #2	**0.40”**	**0.25”**
EDM #3	0.150”	0.150”
A	**0.150”**	**0.075”**
B	**0.100”**	**0.050”**
C	**0.050”**	**0.025”**

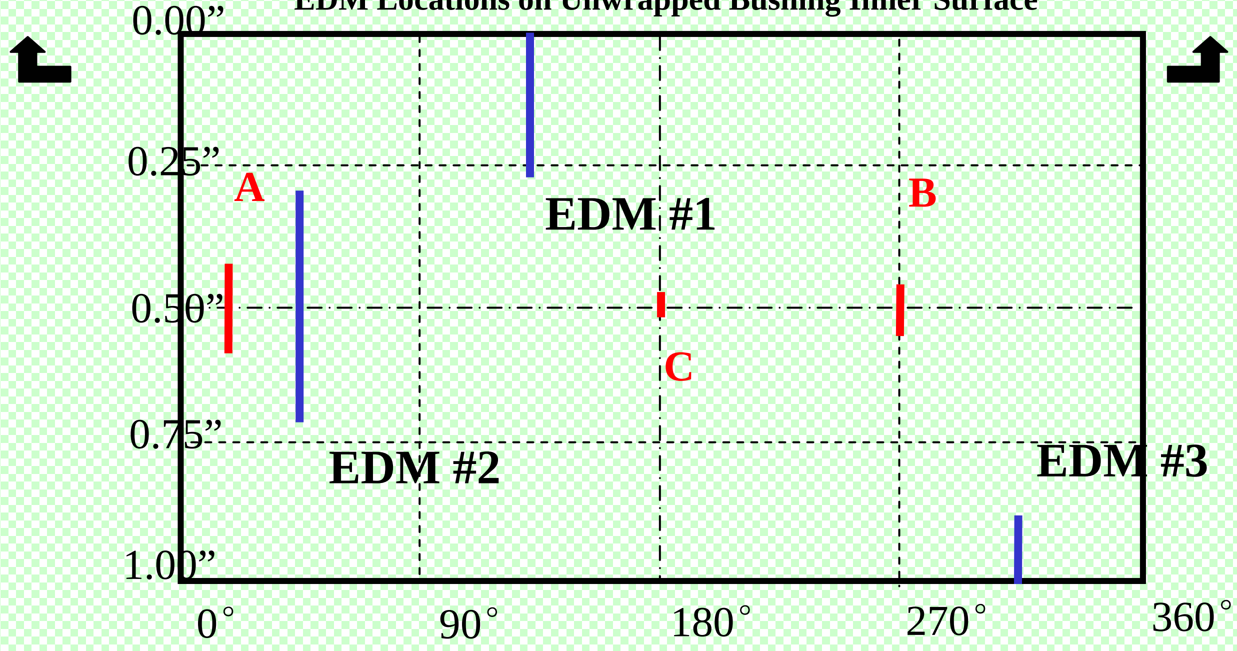
Results at 0.05” depth (SSEC Settings I-B)

Innovative Materials Testing Technologies, Inc.

BOEING



EDM Locations on Unwrapped Bushing Inner Surface



EDM Notch Dimensions

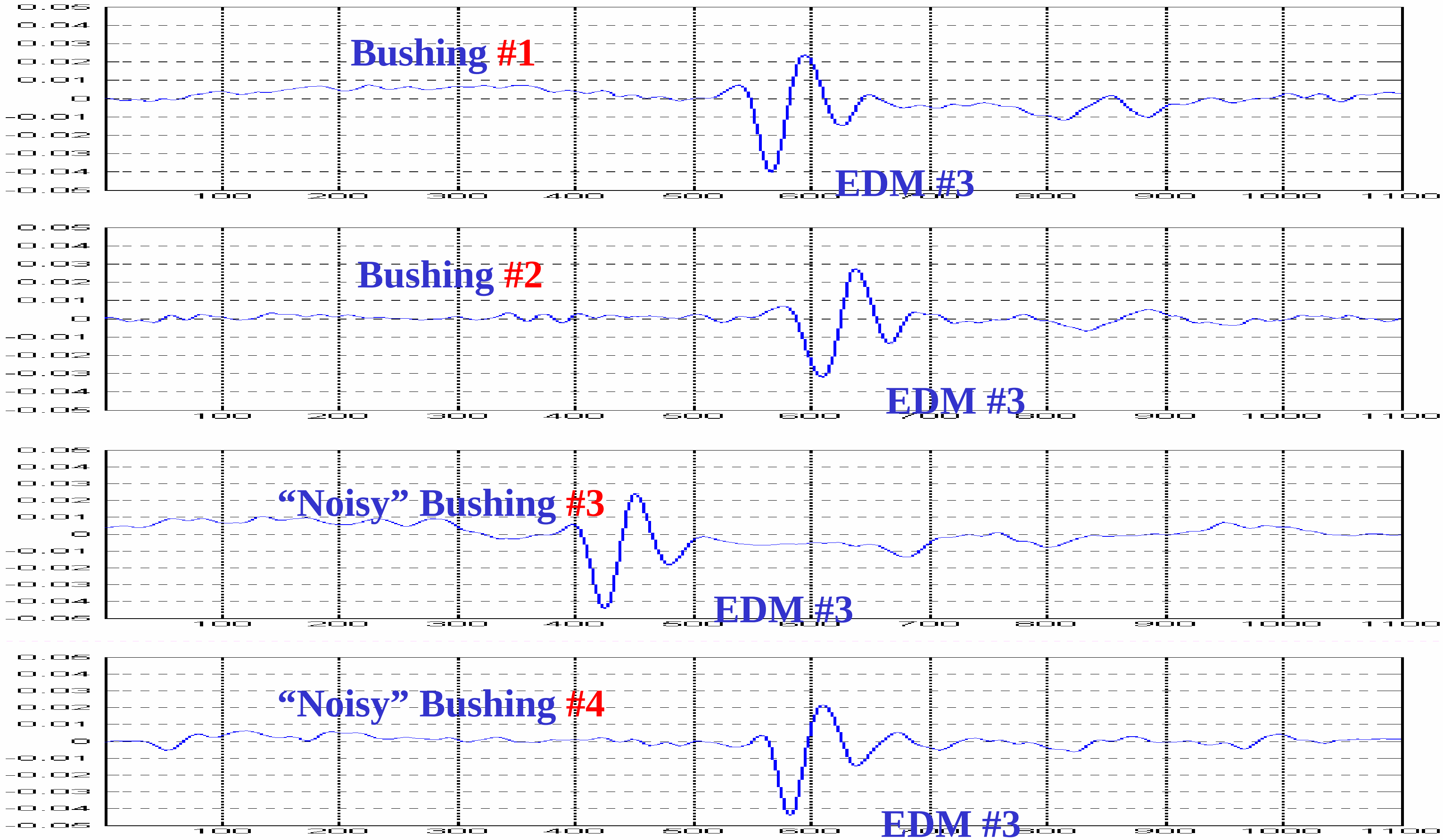
EDM #	Length	Depth
EDM #1	**0.30”**	**0.30”**
EDM #2	0.40”	0.25”
EDM #3	0.150”	0.150”
A	0.150”	0.075”
B	0.100”	0.050”
C	0.050”	0.025”

Minimization of Background Noise

Innovative Materials Testing Technologies, Inc.

BOEING

- Significant background noise seen in LFEC signals;
- RFEC FG & SSEC system almost removed noise



Conclusions

Innovative Materials Testing Technologies, Inc.

BOEING

- SSEC with RFEC probe can detect small cracks under installed bushings
- Bushing noise is minimized
- The probe works for a large frequency range, from 1 kHz to 8 kHz
  - Will accommodate other bushing thicknesses
- Greater crack sensitivity will allow less frequent inspections