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Title: Evaluating Corrosion in SAVY Containers using Non-Destructive Techniques

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Evaluating Corrosion in SAVY Containers using Non-Destructive Techniques

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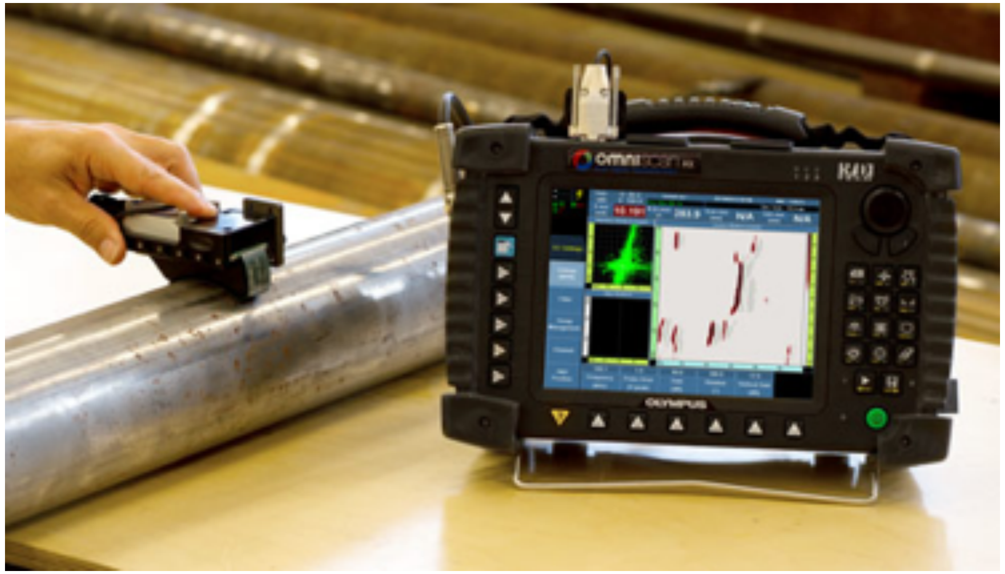
Mentor: Raj Vaidya

Ultrasonic and Eddy Current NDT

- Olympus 38DL Handheld System
  - Portable
  - One transducer
- Olympus 15 MHz Sonopen Ultrasonic Delay-line Transducer

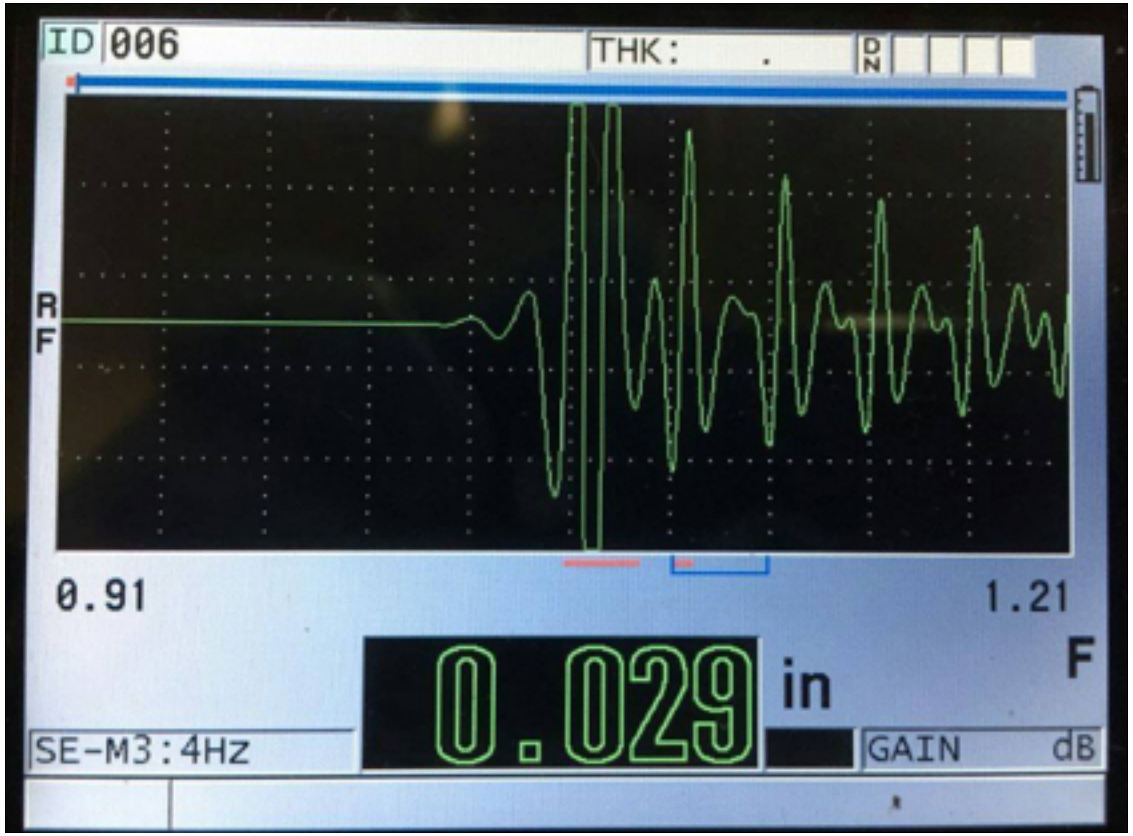


Omni Scan MX: Eddy Current Array

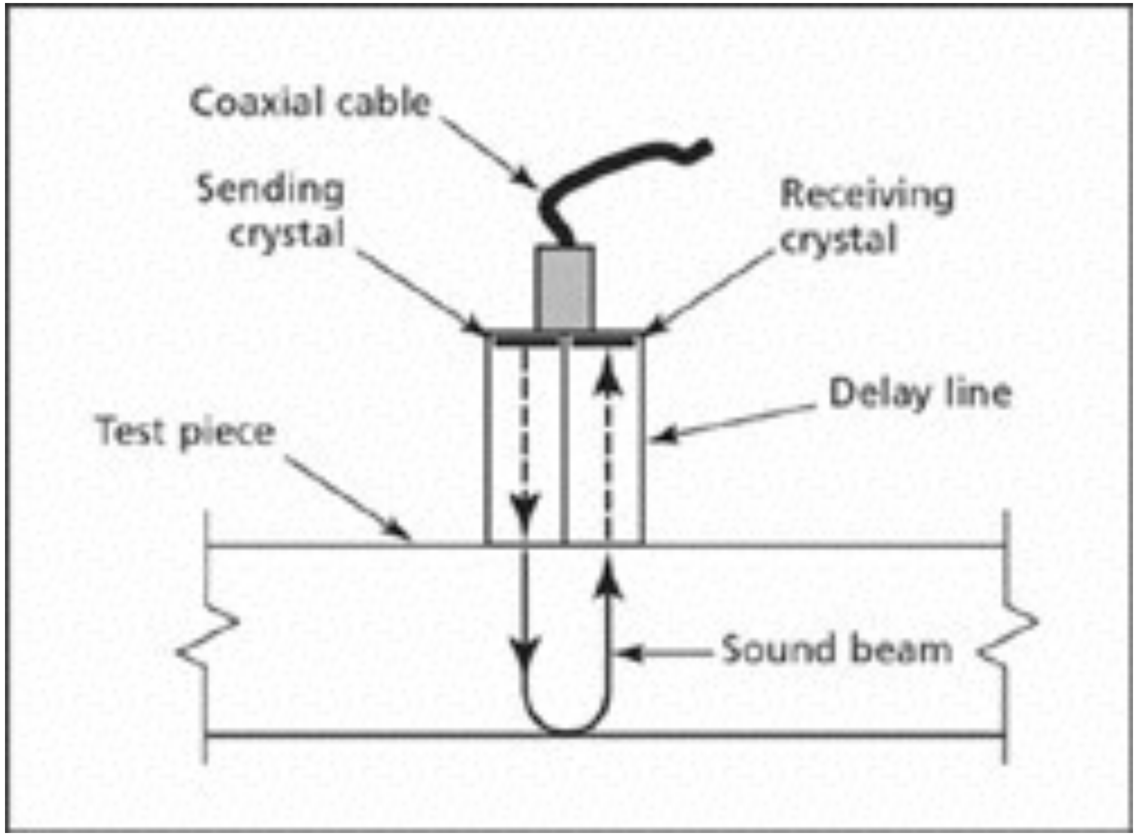
Commonly used in

- Aerospace for analysis of corrosion and defects on material
- Pipe inspection
- Railroad integrity

UT Theory

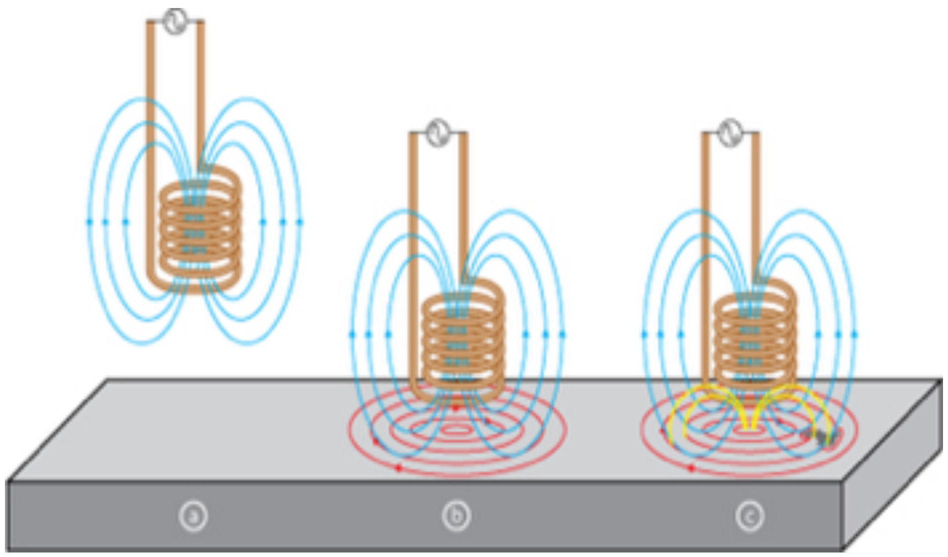


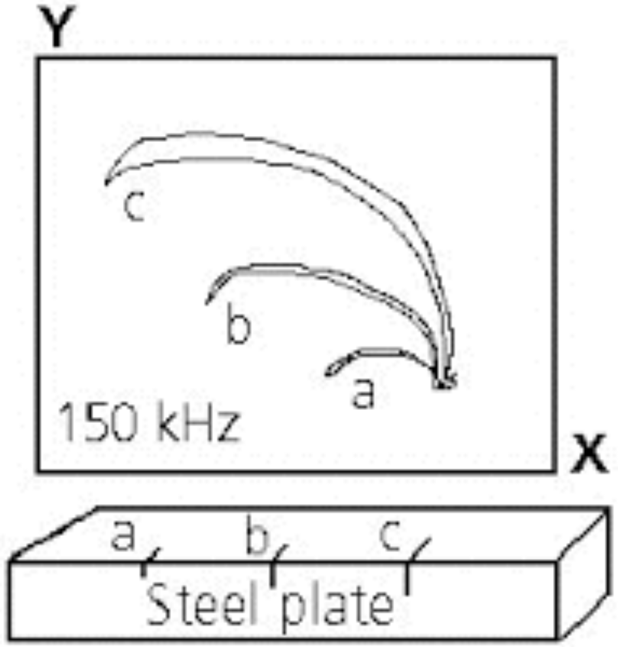
Speed of sound in 316L stainless steel: 0.230 in/μs



Measures time between pulse and backwall echo

Eddy current (ECA): How it works





a) An alternating current is introduced in coil and magnetic field is generated.

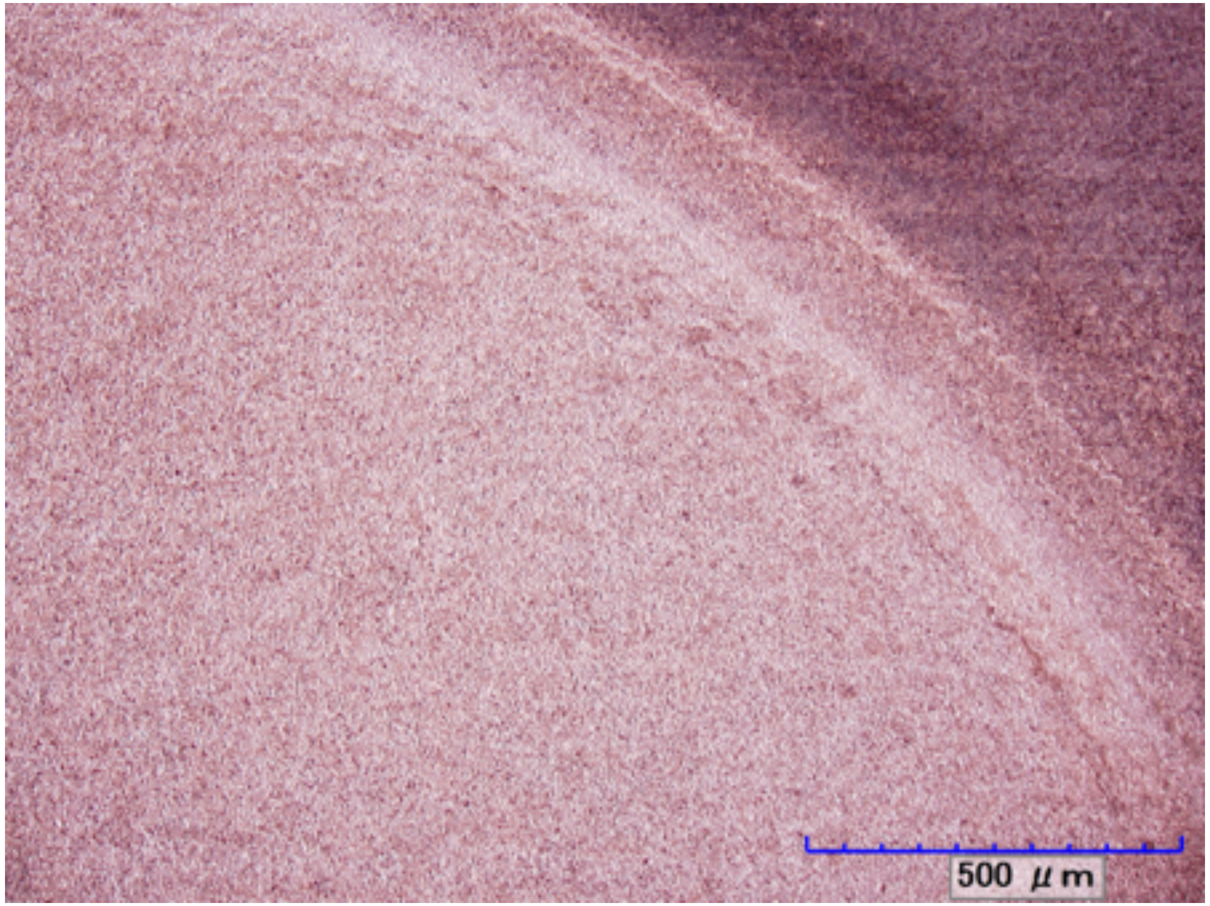
b) When placed near a electrically conductive material and eddy current is induced in material.

c) When flaw present, eddy current is disturbed and the defect is ready by reading impedance variation

Controlled Corrosion at NM Tech

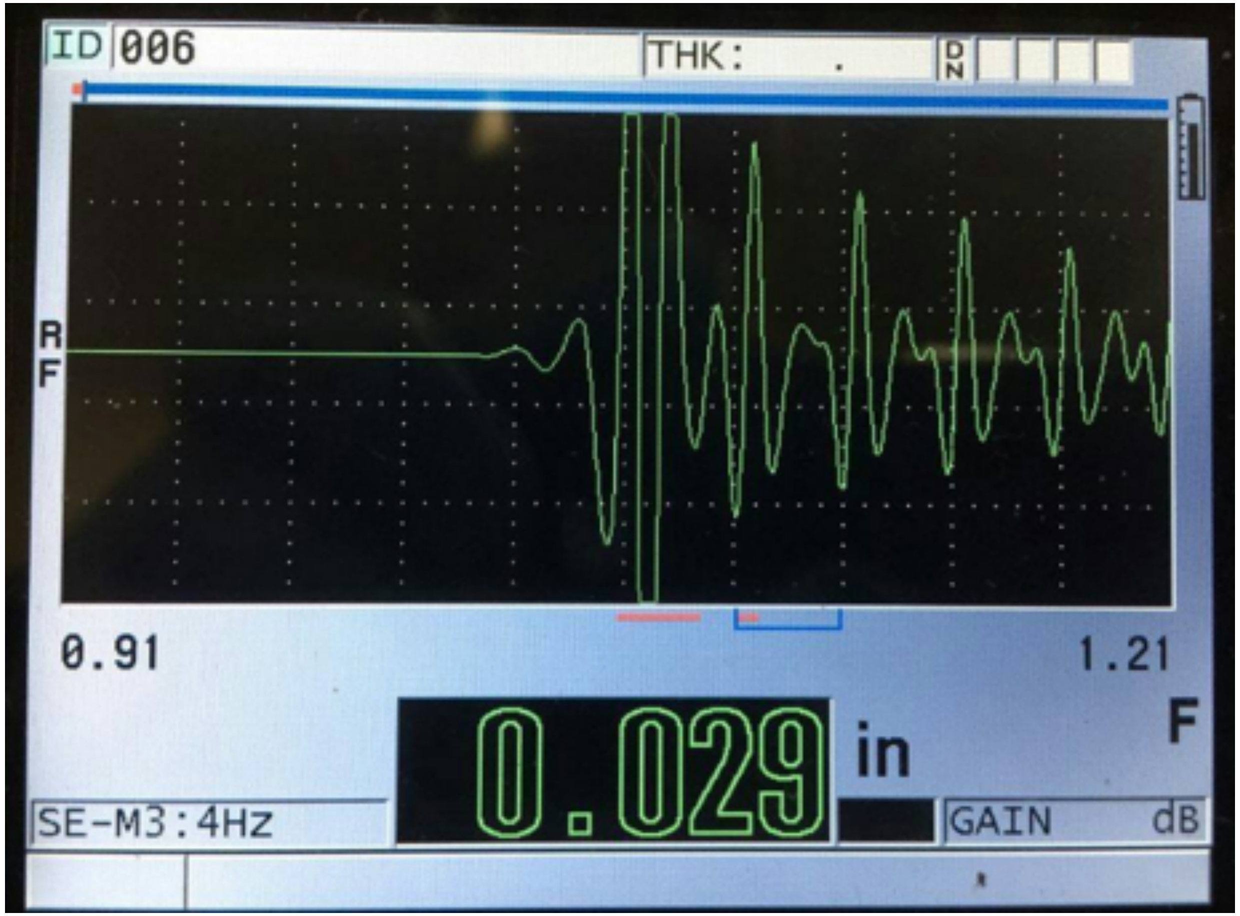
- 316L Stainless Steel, 0.030 in. thick
- Three corrosive agents
    - $FeCl_3$ (left)
    - $HCl + H_2O_2$ (center)
    - HCl (right)
- Single-side immersion test with clamped glass o-ring joints

Results – HCl Corrosion

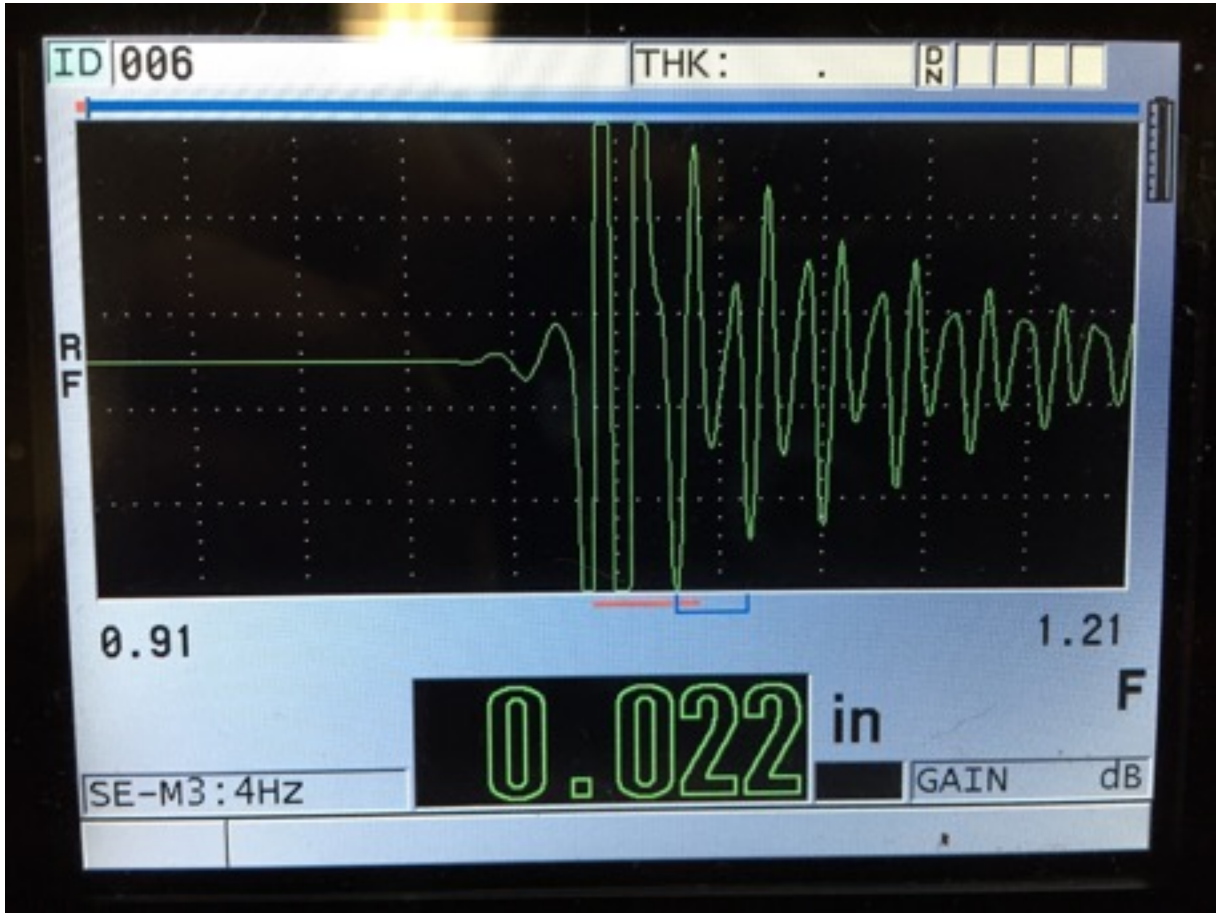


12M HCl Corroded for 7 days

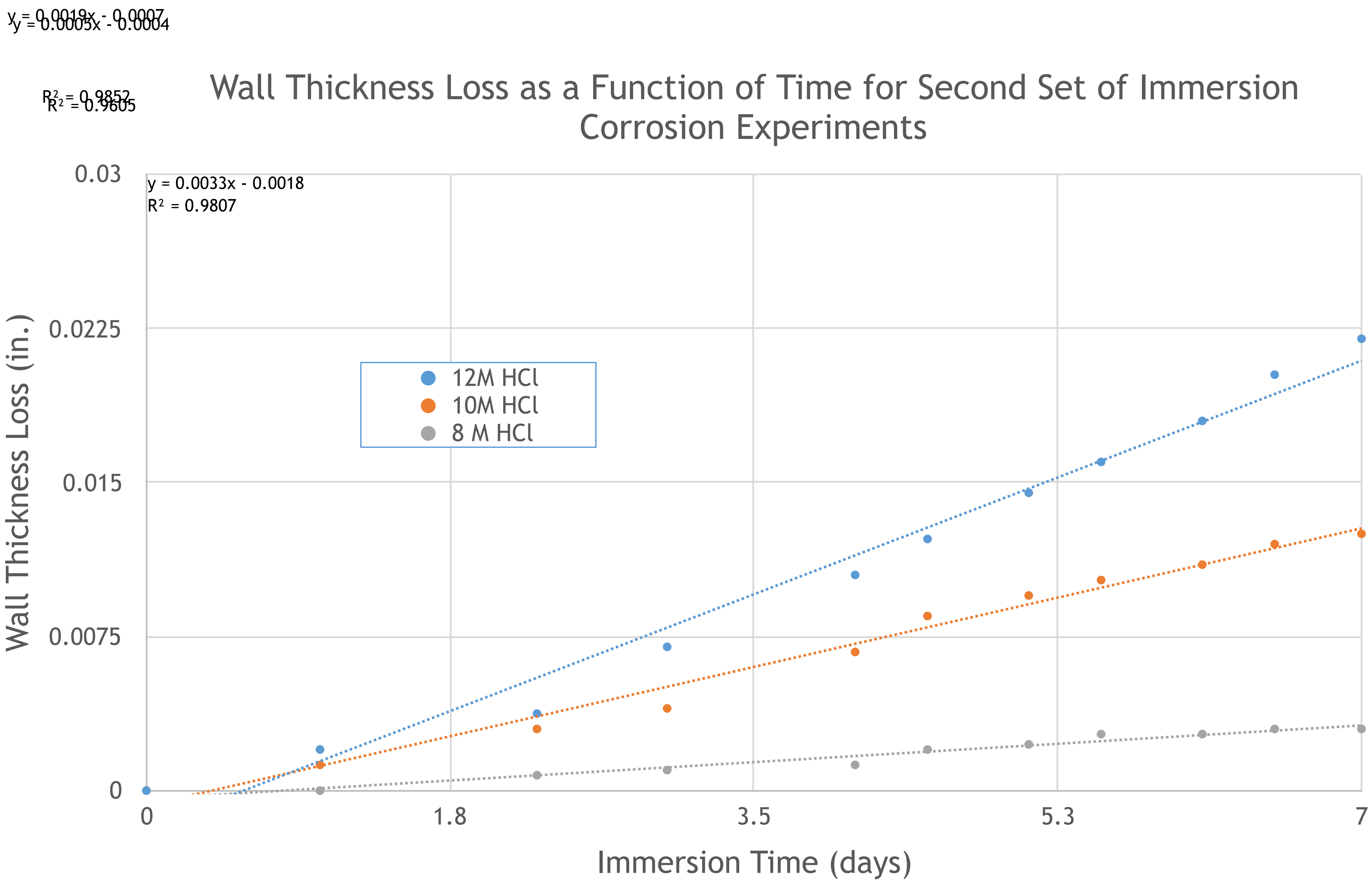
Waveform Data for 10M HCl



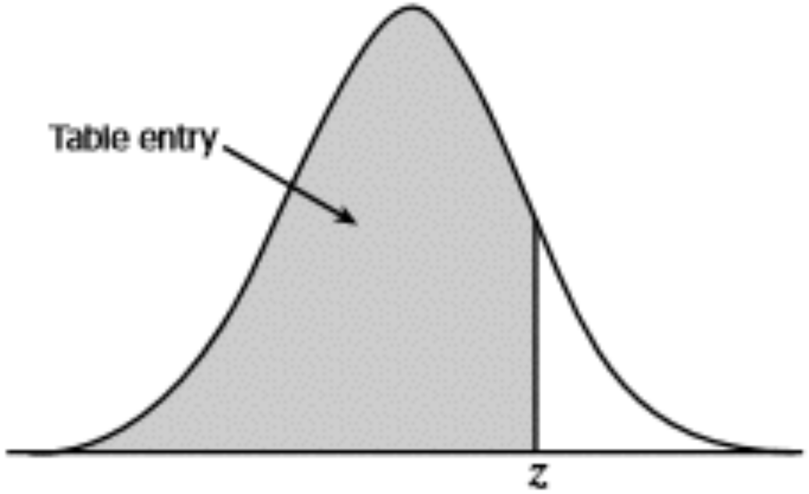
Uncorroded 316L Control



10M HCl immersed for 7 days


y = 0.0019x - 0.0007
y = 0.0005x - 0.0004
R² = 0.9852
R² = 0.9605
Wall Thickness Loss as a Function of Time for Second Set of Immersion Corrosion Experiments
y = 0.0033x - 0.0018
R² = 0.9807
12M HCl
10M HCl
8 M HCl
Wall Thickness Loss (in.)
0.03
0.0225
0.015
0.0075
0
0
1.8
3.5
5.3
7
Immersion Time (days)

Accuracy Statistics



38 measurements verified with micrometer

[n]	Mean Error (in.) [μ]	Std. Dev. [σ]
38	.00051	.00035

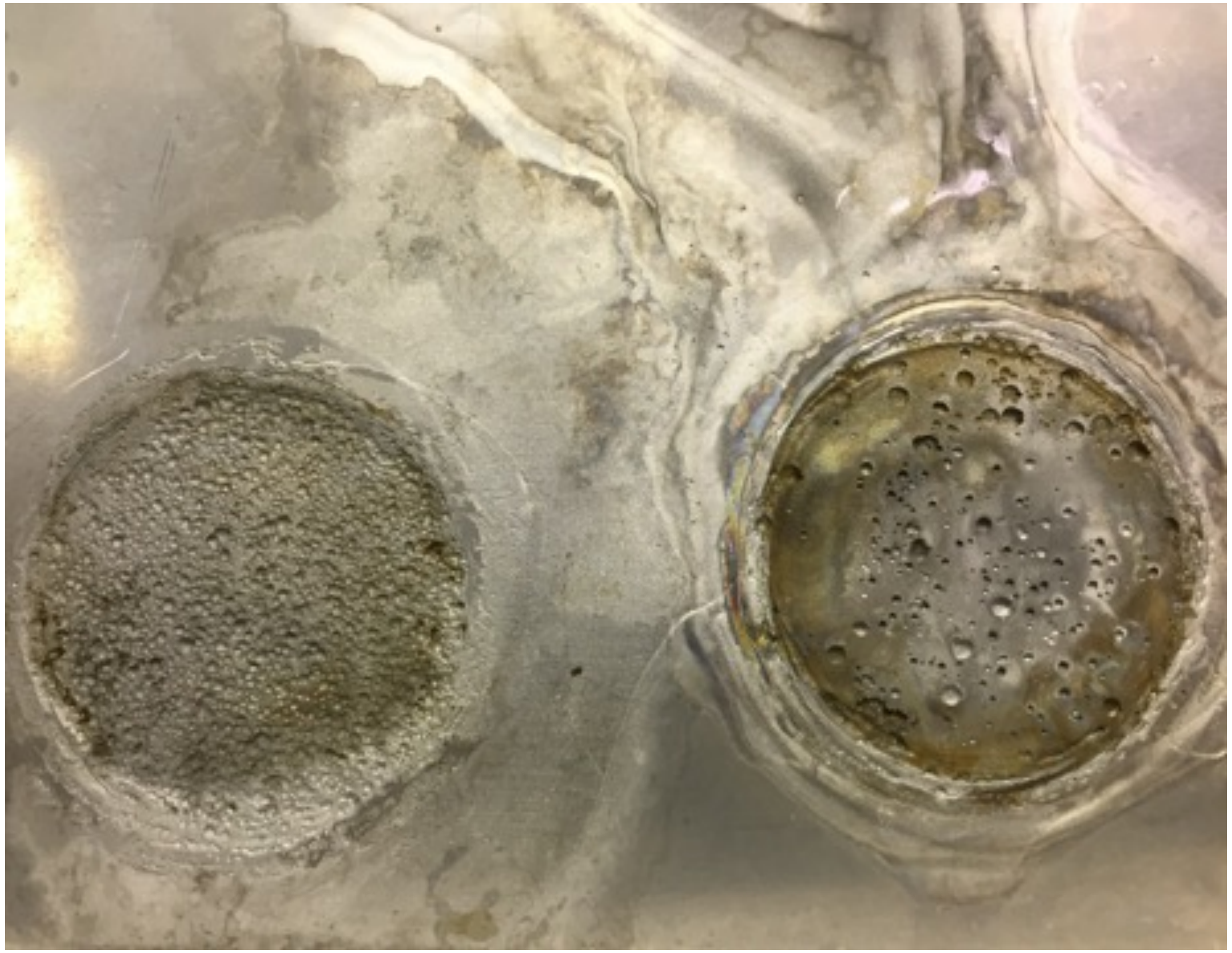
One-tailed z test to test if average error (x) is less than 0.001 in.:

$$z = \frac{\sqrt{n}(xavg - \mu)}{\sigma} = 3.35$$

Table of standard probabilities: p(z) = 0.9996

Therefore, with 99% confidence, average error is less than 0.0007 in.

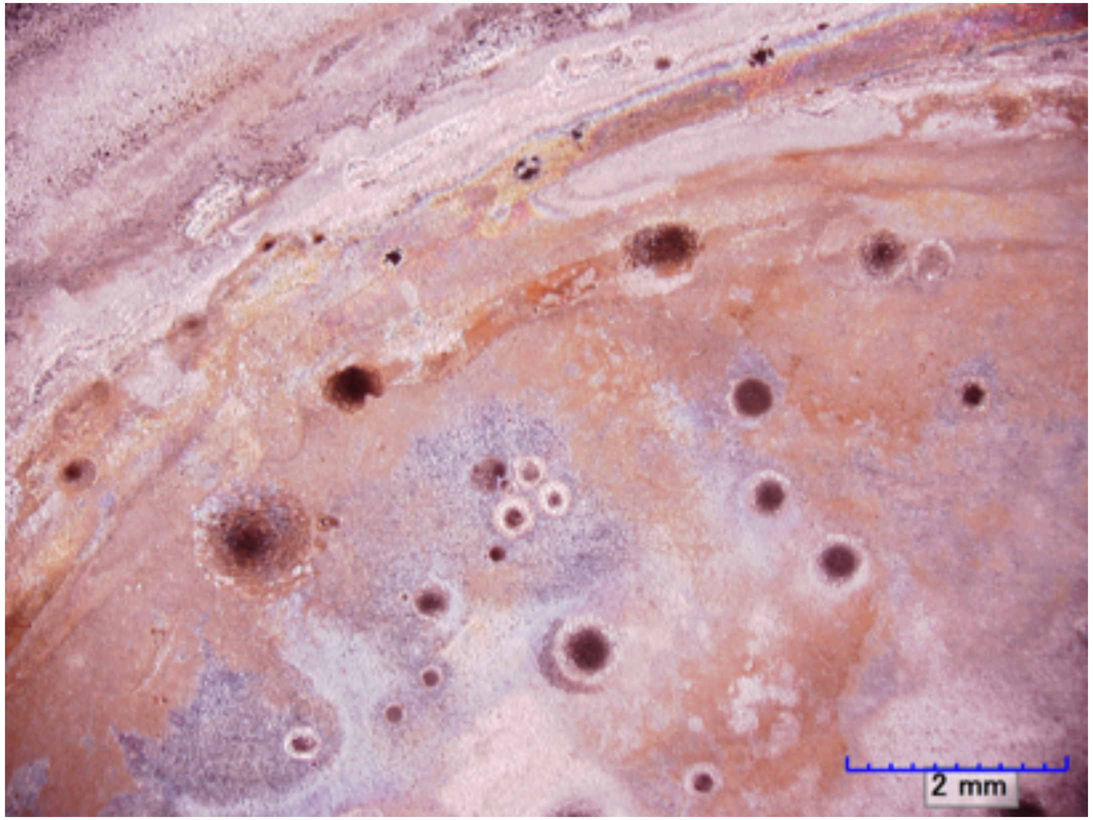
Results – $FeCl_3$ Pitting



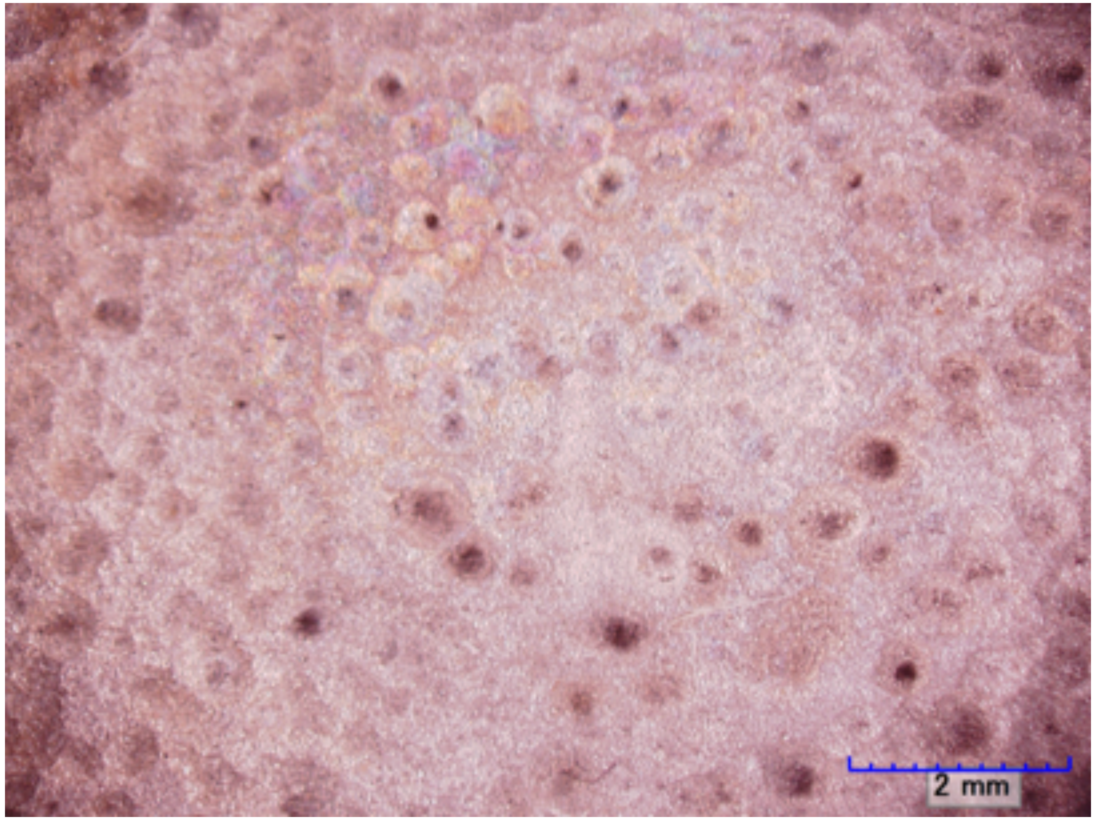
3M $FeCl_3$ Hexahydrate (left) – 7 day immersion vs. 1.5 M Anhydrous $FeCl_3$ (right) – 2.5 day immersion

- $FeCl_3$ Hexahydrate solution created small uniformly distributed pits
- Anhydrous $FeCl_3$ solution created localized deep pits and crevice corrosion under o-ring
- 1.5 M Anhydrous $FeCl_3$ solution perforated sample after 2.5 days immersion

Results – $FeCl_3$ Pitting

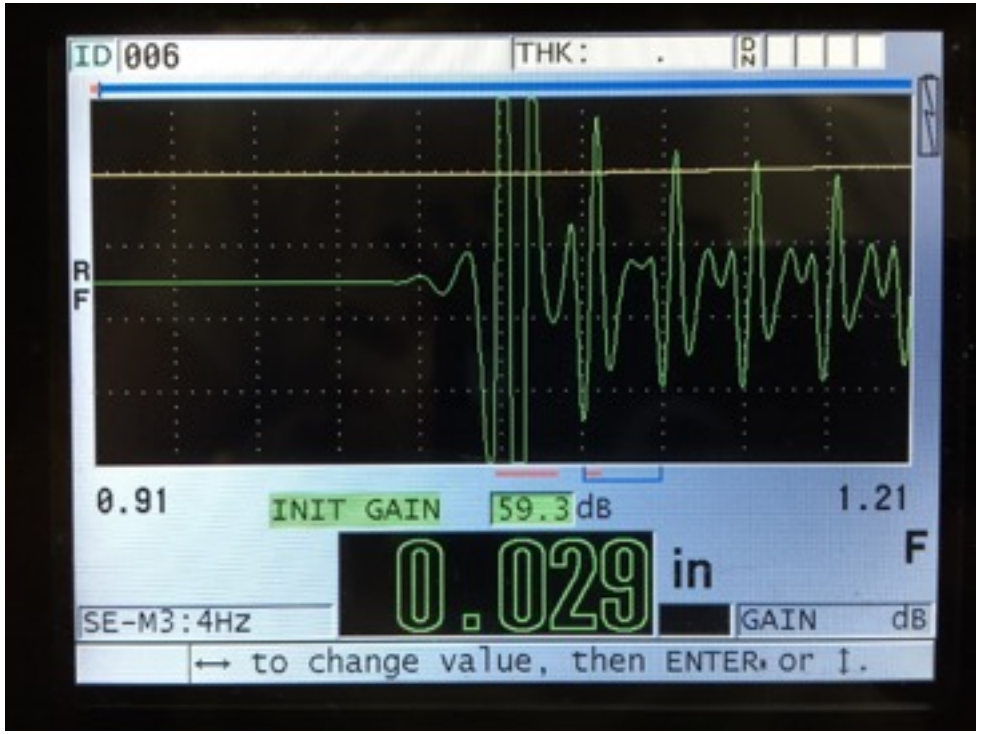


1.5 M FeCl3 with 2.5 days immersion.

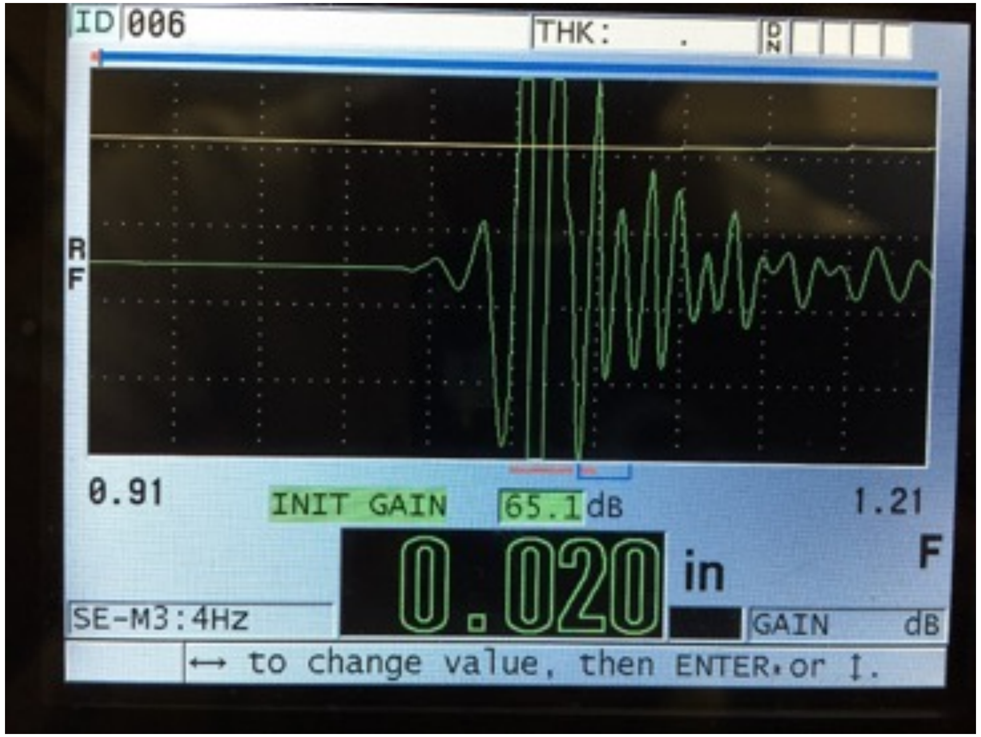


3 M FeCl3 with 7 days immersion.

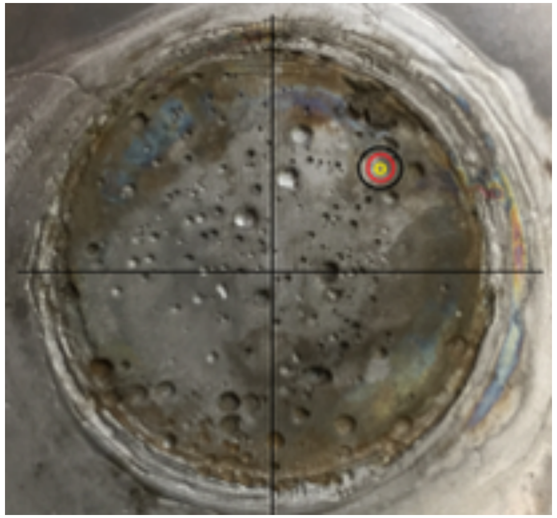
Waveforms for Anhydrous $FeCl_3$



Control: un-corroded 316L

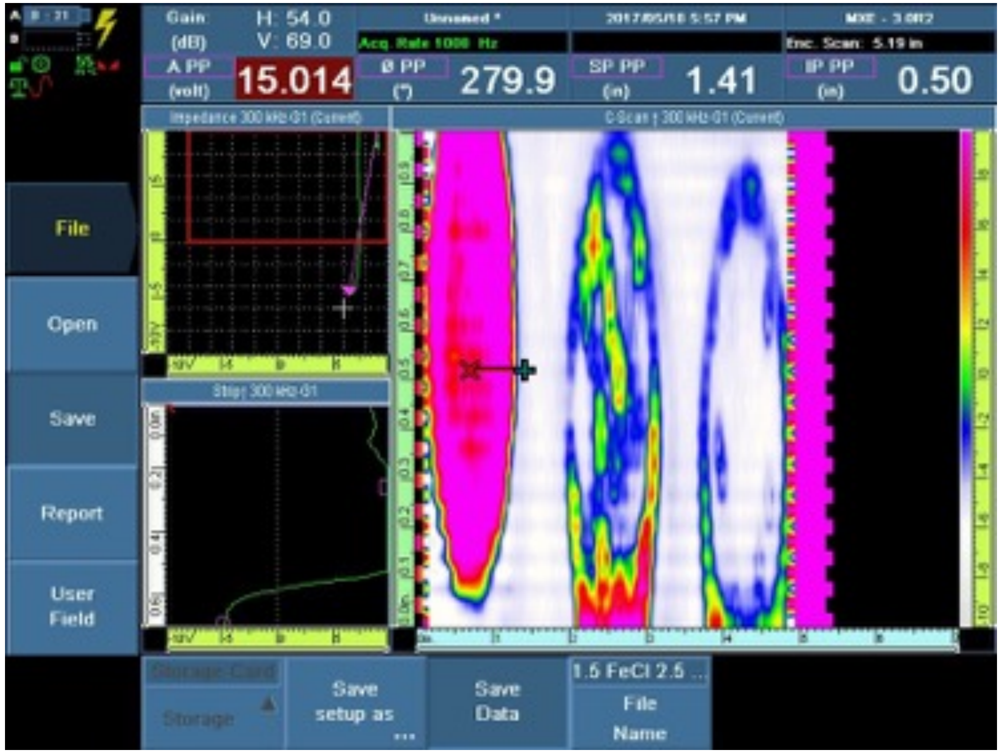


Sample corroded with Anhydrous $FeCl_3$ for 2.5 days

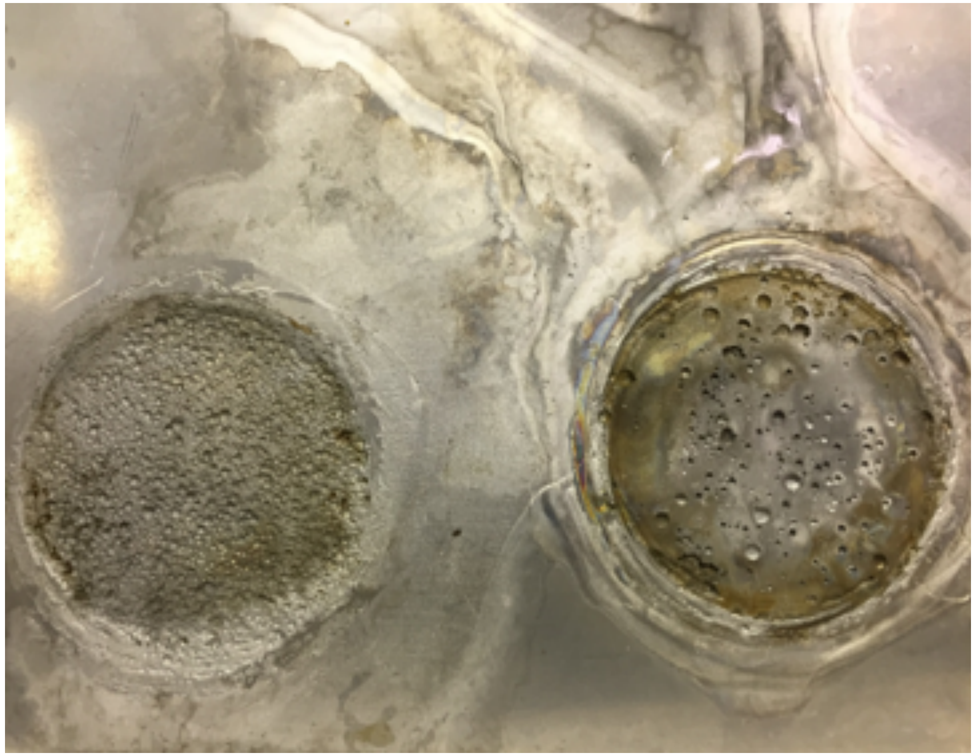


Evidence of pitting

Analyzing Corroded Stainless Steel 316L Plates

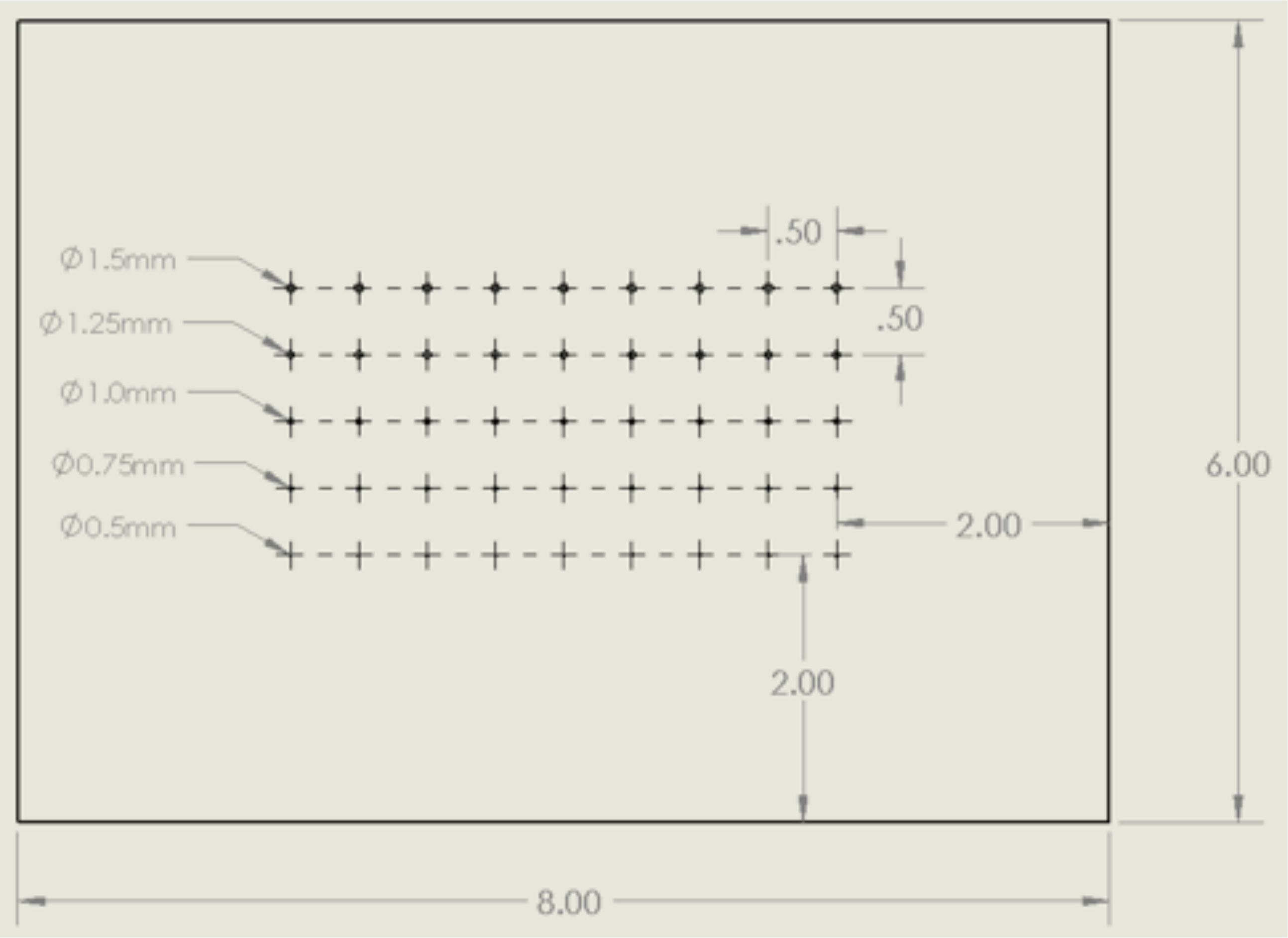


Omni Scan Mx C-Scan analysis of 2.5 M FeCl at 2.5 days (Left) and 3u FeCl3 at 7 days (Right) corroded SS316L plates



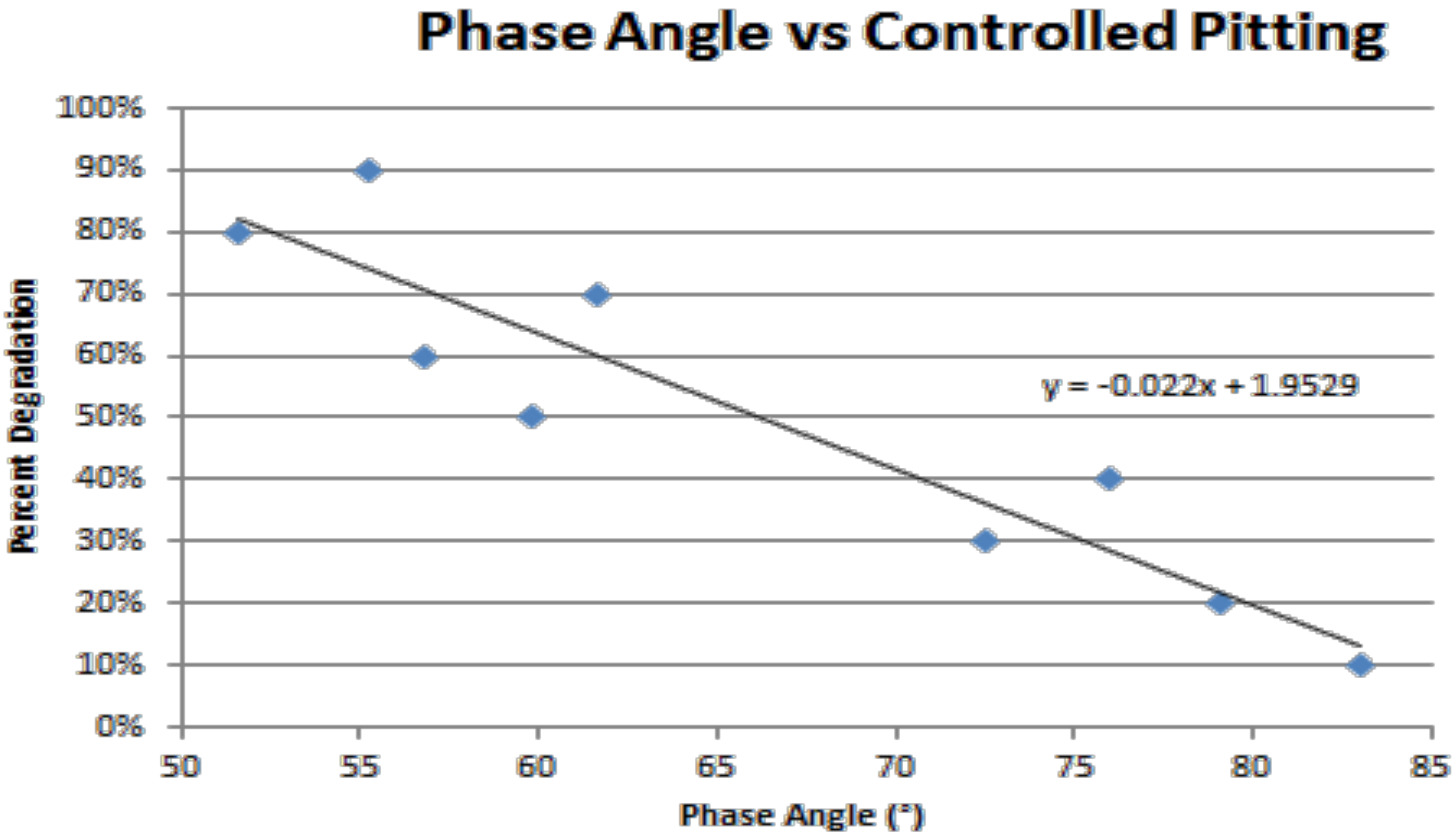
2.5 M FeCl at 2.5 days (Left) and 3u FeCl3 at 7 days (Right) corroded SS316L plates

316L Plate to Imitate Pitting

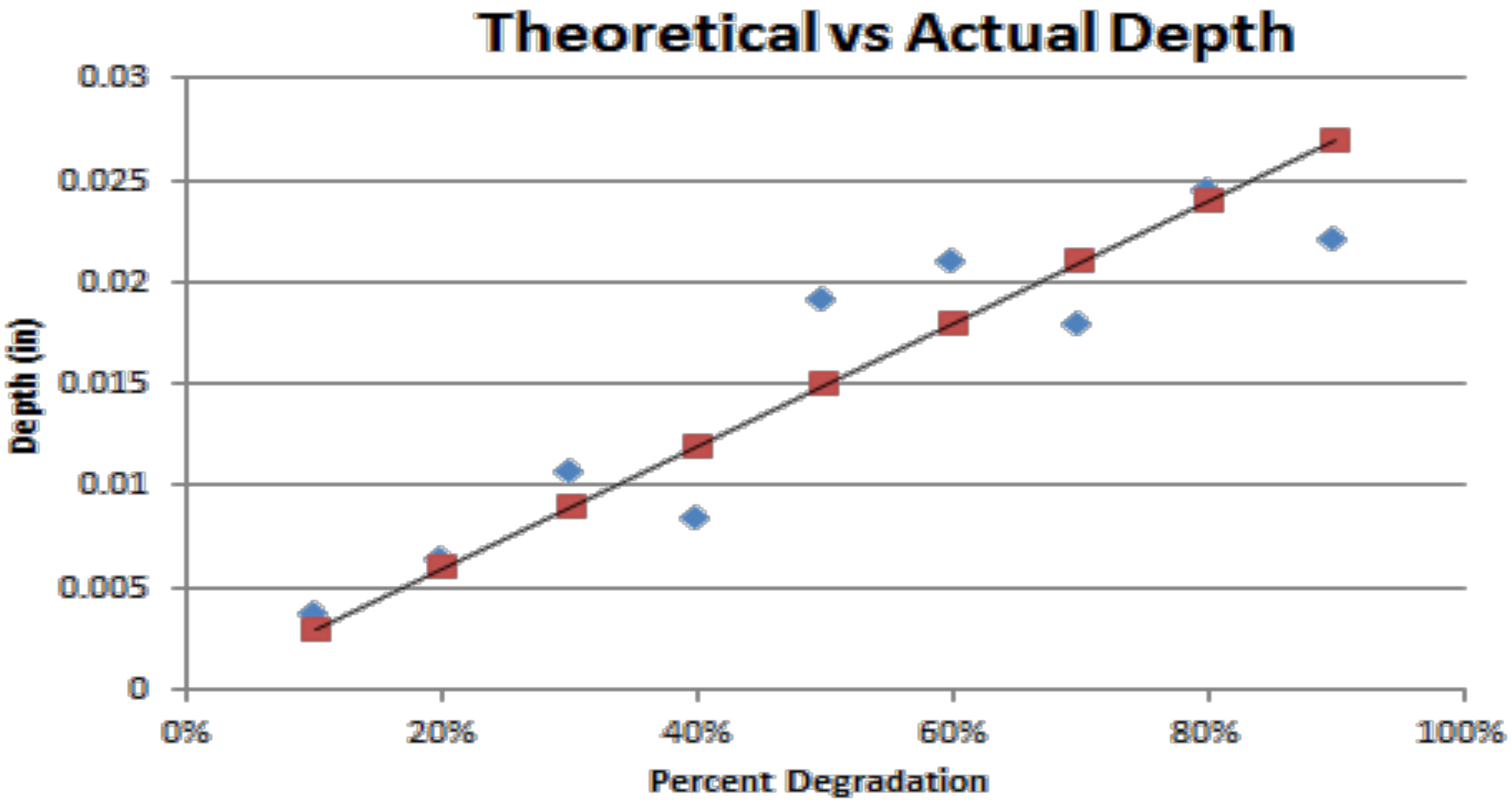


- 5 different pit diameters varying from 10% to 90%
- Diamond drill bit

ECA Pit Depth Calibration Curve



ECA Pit Depth Calibration Curve



C Scan Imaging

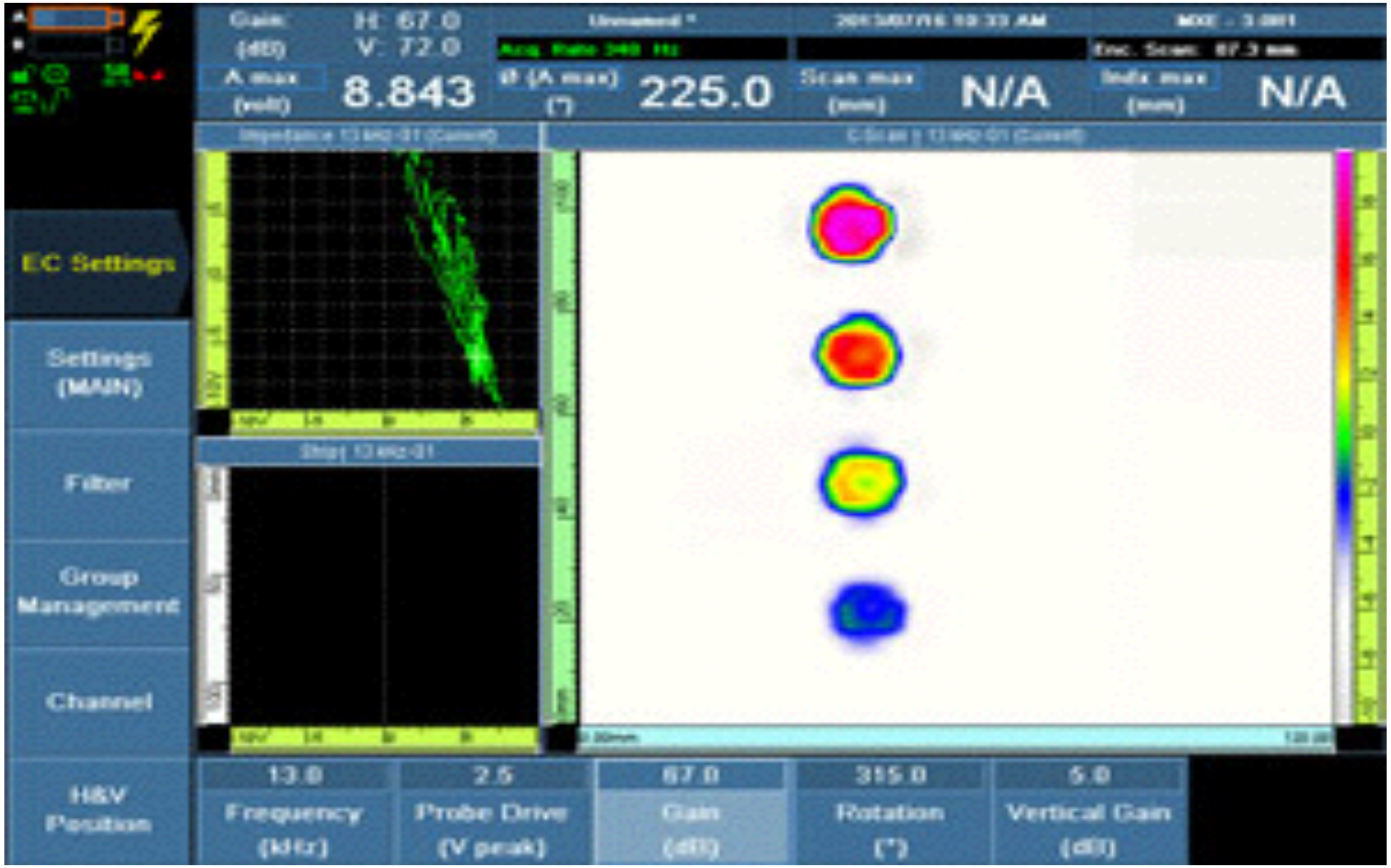


Image of calibration standard for percent depth of corrosive pitting for specific material

Variation of color imaging in relevance to depth penetration

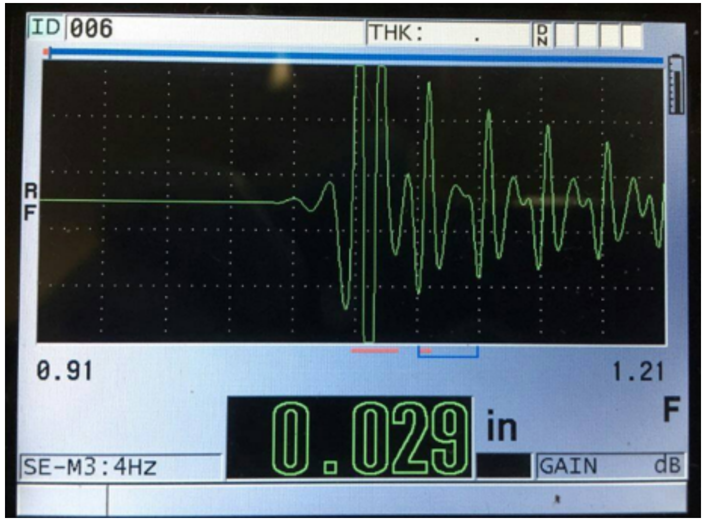
PINK= 40% corrosion depth

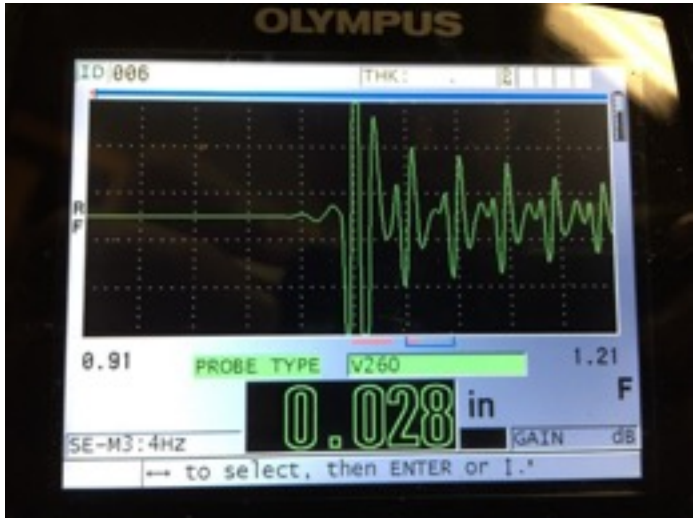
RED= 30% corrosion depth

YELLOW= 20% corrosion depth

BLUE= 10% corrosion depth

UT Pit Detection





Init. Gain:	57.0	dB								
	Depth (in.)	0.003	0.006	0.009	0.012	0.015	0.018	0.021	0.024	0.027
Diameter (mm)										
0.5						v	v	x		
0.75							x			
1				x	x					
1.25				x	x					
1.5		v	x	x	x					

SST Containers: Ultrasonic (UT) vs. CMM

- Two SAVY containers corroded with HCl and a control SAVY
- Max/min wall thickness measured by PF group using CMM
- Results replicated by NPI-2 using non-destructive (NDT) UT measurements

CMM Machine

Handheld UT System

Example UT Data:
Serial# 081305070B

Wall thickness of control subtracted from wall thickness of serial 081305070B

	Radial Measurement Location (deg.)							
Dist. From Bottom (cm.)	0	45	90	135	180	225	270	315
0	0	0	-0.001	0	0.001	0.001	-0.001	-0.001
1	-0.001	-0.001	0.001	0	-0.002	-0.001	0	0
2	-0.001	-0.001	0.001	0	-0.002	-0.001	0.001	0.001
3	-0.001	-0.001	0.001	0	0	0	0	0
4	-0.001	-0.001	0.001	0	-0.001	0	0	0
5	-0.001	-0.001	0.001	0	-0.001	-0.001	0	0
6	-0.001	-0.001	0.001	0	-0.001	-0.001	0	0
7	-0.001	-0.001	0.001	0	-0.001	-0.001	0	0
8	-0.001	-0.001	0.001	0	-0.001	-0.001	0	0
9	-0.001	-0.001	0	-0.001	-0.001	-0.001	0	0
10	0	0	0	0	-0.002	-0.002	0	0
11	-0.001	-0.001	0.001	0	-0.002	-0.002	0	0
12	-0.001	-0.001	0.001	0	-0.001	-0.001	0.001	0
13	-0.001	-0.001	0.001	0	-0.001	-0.001	0.001	0.001
14	0	-0.001	0	-0.001	-0.002	-0.002	0	0
15	-0.001	-0.001	0.001	0	-0.002	-0.002	0	0
16	0	-0.001	0	-0.001	-0.001	-0.001	0.001	0
17	-0.001	-0.002	0	-0.001	-0.002	-0.002	0	0
18	0	-0.001	0	-0.001	-0.001	-0.001	0	-0.001
19	-0.001	-0.002	0	-0.002	-0.002	-0.002	-0.001	-0.001
20	-0.001	-0.002	-0.001	-0.002	-0.002	-0.002	-0.001	-0.002
21	0	[illegible]	0	-0.001	-0.001	[illegible]	-0.001	-0.001

Sum of cells is -0.97, indicating overall loss in wall thickness

Measurements taken along 8 lines of longitude in 1 cm. increments. Steep change in wall thickness at base of container and collar. Canyons may indicate corroded areas.

UT vs. CMM Data

	Longitudinal Measurement				Bottom Measurement			
Serial #	**UT Meas. (in.)**		PF Meas. (in.)		**UT meas. (in.)**		PF Meas. (in.)	
	Max	**Min**	Max	Min	**Max**	**Min**	Max	Min
011305020B	**0.030**	**0.022**	0.0320	0.0265	**0.024**	**0.022**	0.0237	0.02331
081305070B	**0.031**	**0.021**	0.0326	0.0266	**0.023**	**0.021**	0.02339	0.02181
091205141B	**0.031**	**0.022**	0.0316	0.0266	**0.023**	**0.021**	0.02389	0.02098

Measurement	Greatest Relative Error (%)
Long. Max	6.3
Bottom Max	3.7
Bottom Min	5.6

UT measurements were taken closer to bottom than CMM, therefore measured lower longitudinal mins. Longitudinal mins. not comparable.

UT Data Analysis

Average Standard Deviation Along Each Line of Latitude		
Control	Corroded Container	Change
091205141B	081305070B	
0.00036 in.	**0.00017 in.**	**-53 %**

SAVY's have on average more uniform wall thickness along a line of latitude after being corroded.

Mass Loss Calculation

Interior surface area of 5Q SAVY: 180 in.^{2}
Average wall thickness change of 081305070B: 0.00058 in.
Density of 316L Stainless Steel: 8g/cc

$$180\ in^2 * 0.00058\ in * 16.3871 \frac{cc}{in^3} * \frac{8g\ 316L}{cc} = \mathbf{14g\ of\ 316L\ may\ have\ corroded\ away}$$

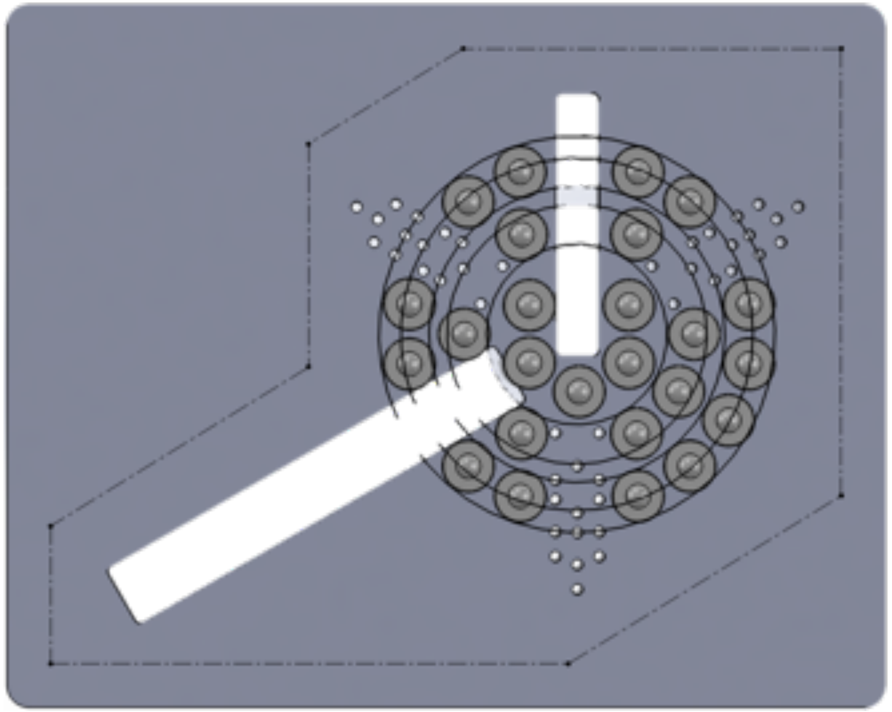
UT Conclusions and Observations

- UT technology is portable and inspections are relatively quick
- UT wall thickness measurements have low relative error when compared to CMM
- UT wall thickness measurement error for single-point measurements found to be 0.0007 in. at 99% confidence interval in previous project.
- UT supports full-container imaging
- SAVY’s have more uniform wall thickness along a line of latitude after corrosion
- SAVY’s lose more wall thickness near collar after corrosion

ECA Conclusions

- ECA can image pitted areas quickly (C-scan)
- ECA can be used to estimate pit depth with 5% error
- ECA can detect structural and mechanical flaws
- ECA is portable and has many sensor configurations

Automated System Vision



Thank you for your time