Intervention & Coiled Tubing Association

Canadian Chapter

Lunch and Learn, April 13, 2011

"COILED TUBING INSPECTION: VALUE, LIMITATIONS, INDUSTRY REQUIREMENTS"

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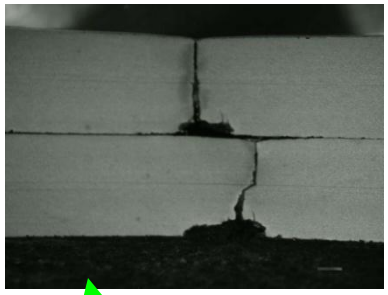
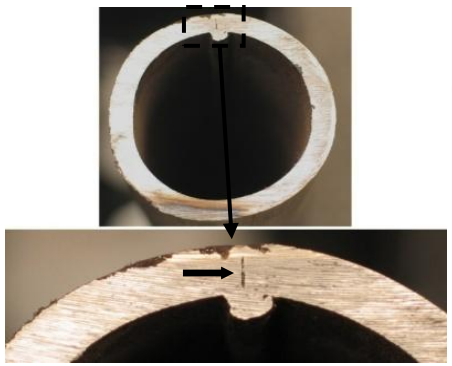
TRICAN WELL SERVICE LTD.

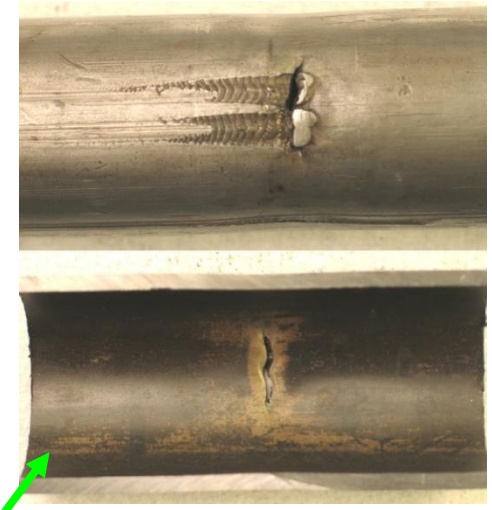
TYPICAL BREAKDOWN FOR SOURCE OF COILED TUBING FAILURES

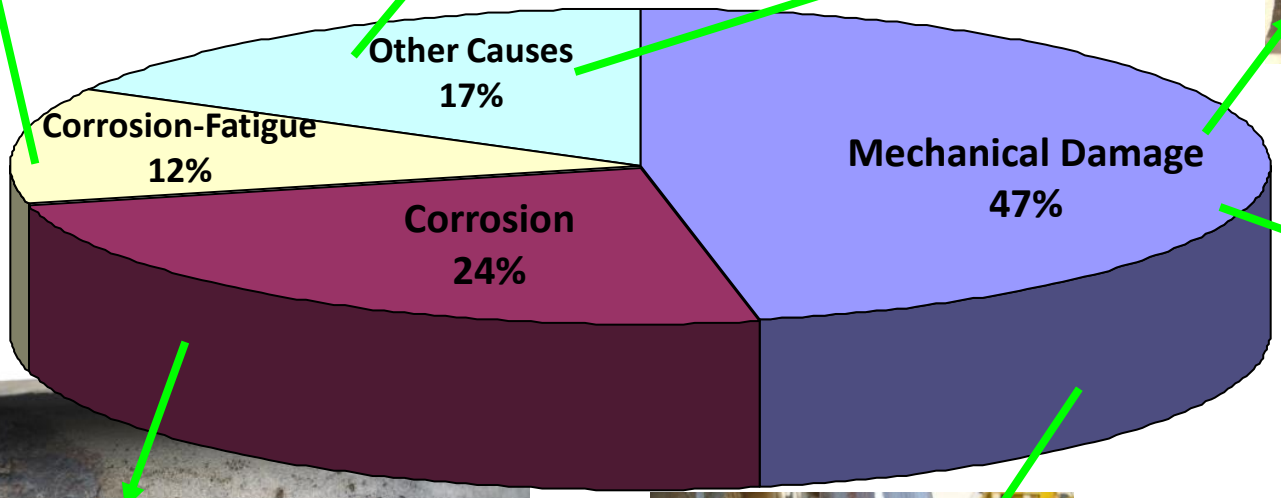


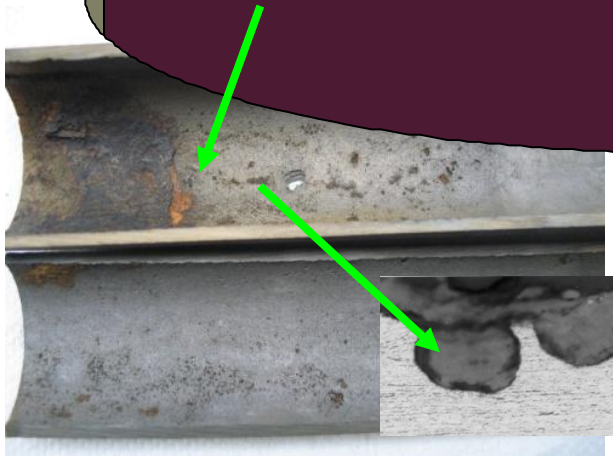


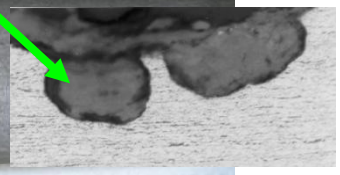
Manufacturing defect, 9%

Operator Error





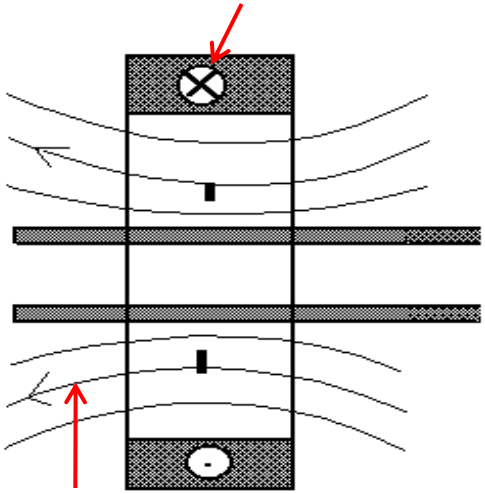




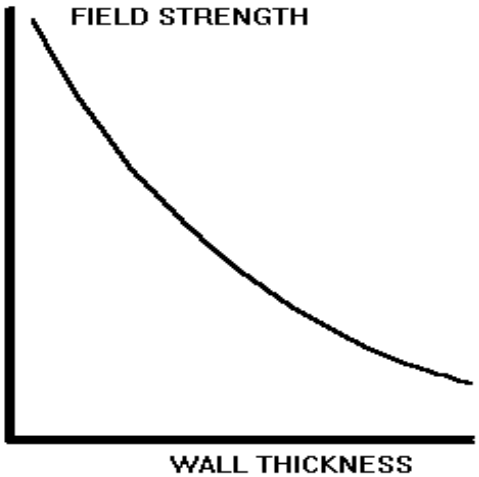
Pitting

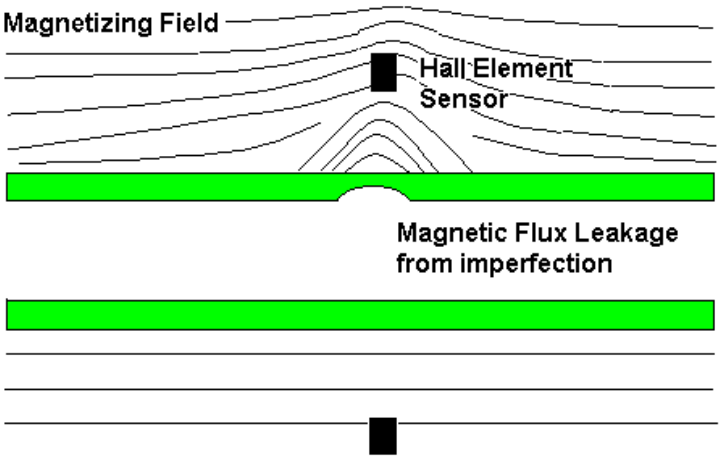
MAGNETIC FLUX LEAKAGE (MFL)

Current vector in magnetizing coil (alternatively use of permanent magnets)

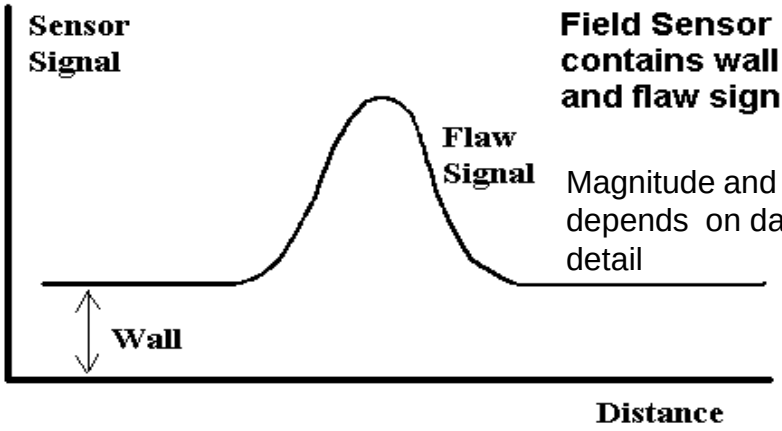


Magnetic flux or field lines

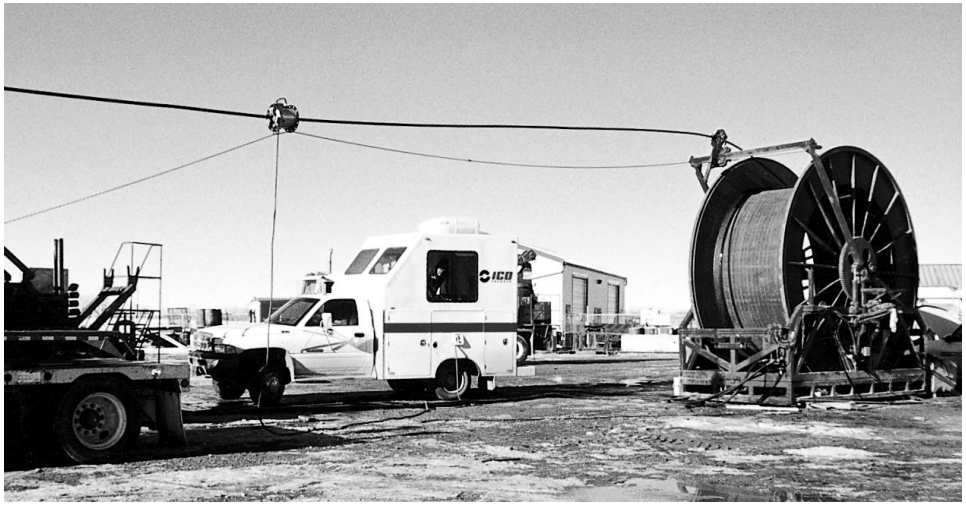




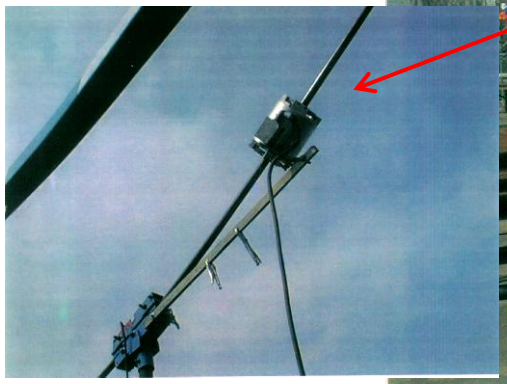
Off-line rotating magnetic pole CT inspection head for longitudinal seam weld flaws or defects and WT

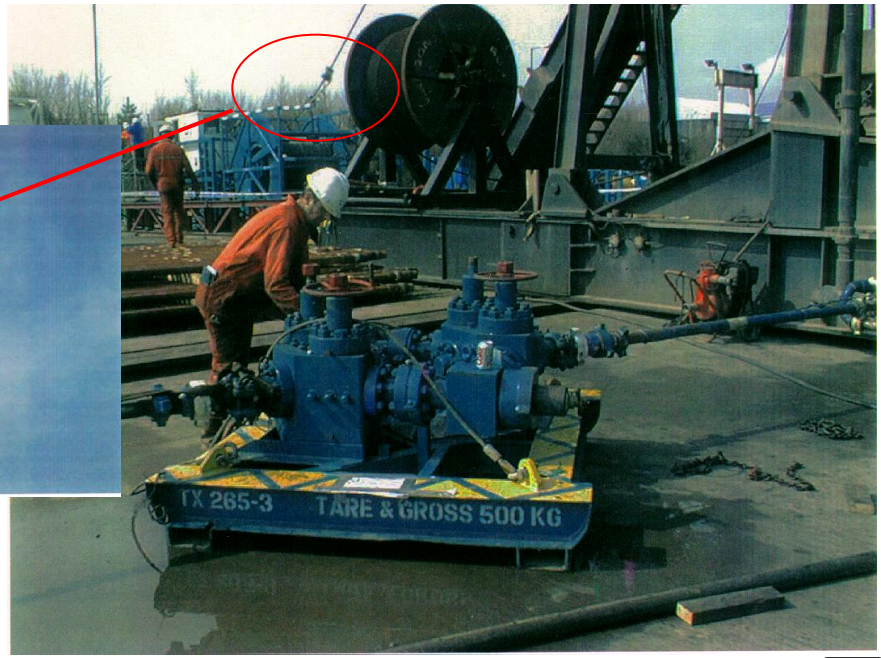


ICO-SHEARER COILED TUBING REEL TO REEL INSPECTION SYSTEM



On-Shore, Red Deer, Alberta (Circa 1995)



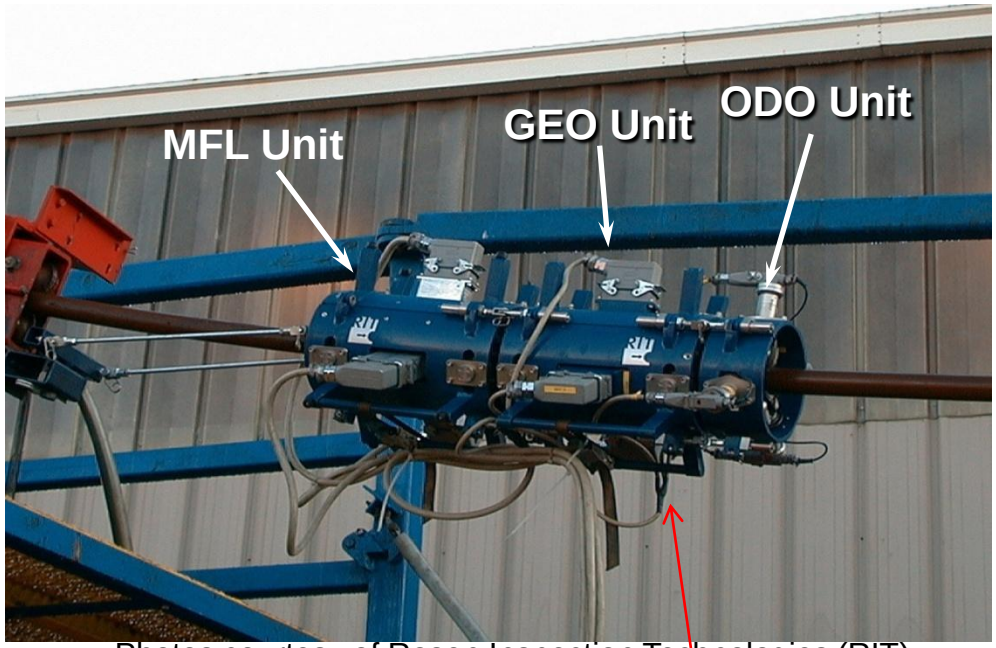


1995 used 1st generation CT inspection system to measure OD, WT and ovality

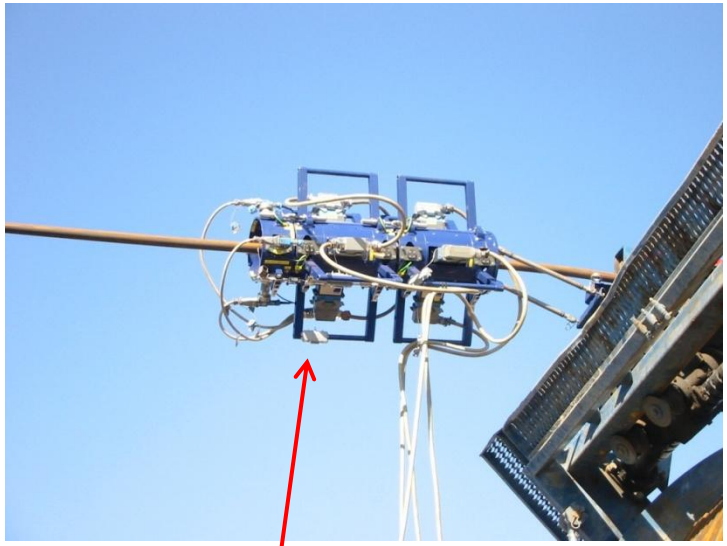
Heavy and cumbersome to mount
(not clamshell design)

Off-Shore, Aberdeen, Scotland

ROSEN AUTOMATIC COILED TUBING INTEGRITY MONITORING SYSTEM (ACIM)

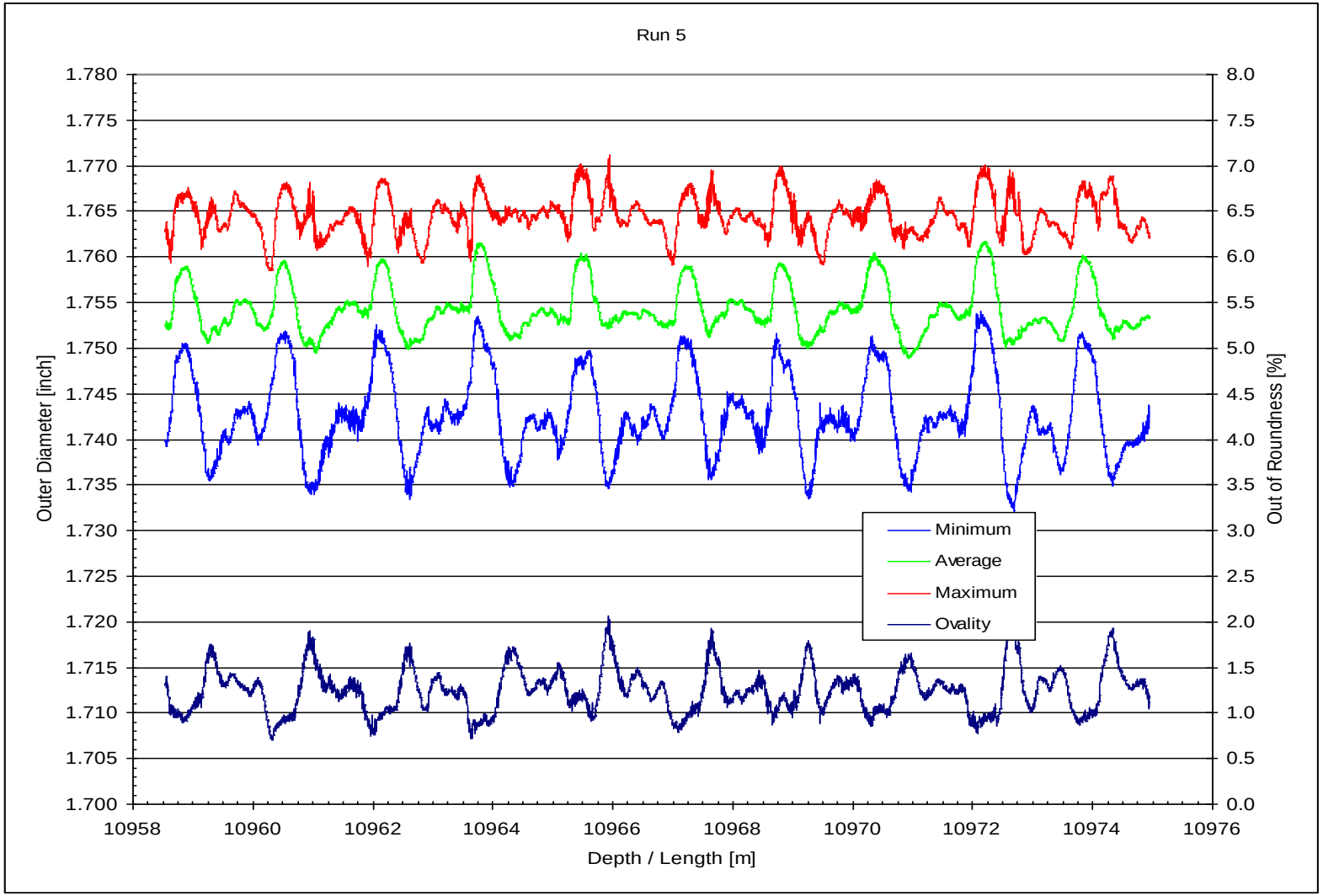


Photos courtesy of Rosen Inspection Technologies (RIT)



OUTER DIAMETER (OD) and OVALITY (O_v) SCANS

(Courtesy of Rosen Inspection Technologies (RIT))



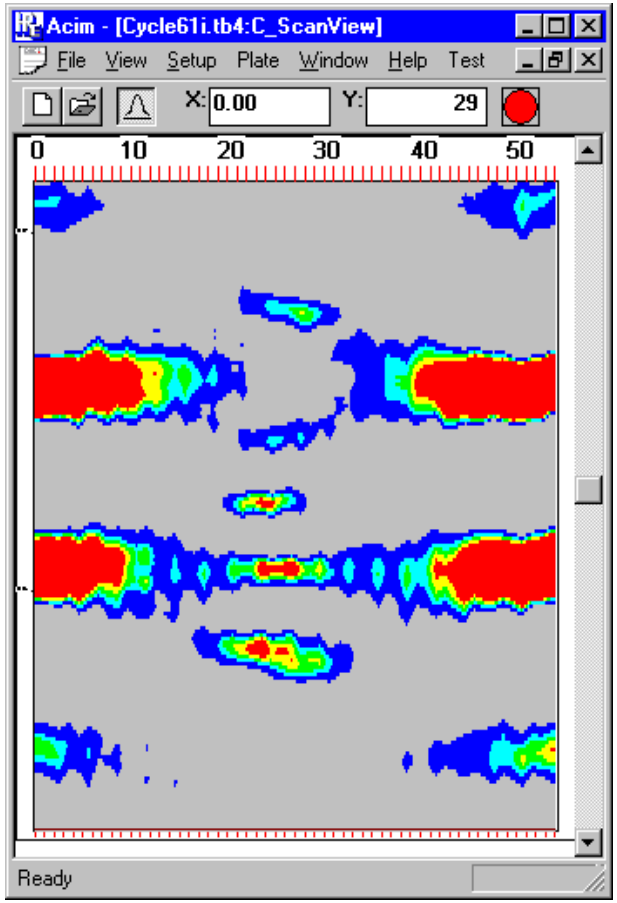
Rosen Inspection Technologies
www.RosenInspection.net

WALL THICKNESS (WT) and C-SCANS for CT PITTING

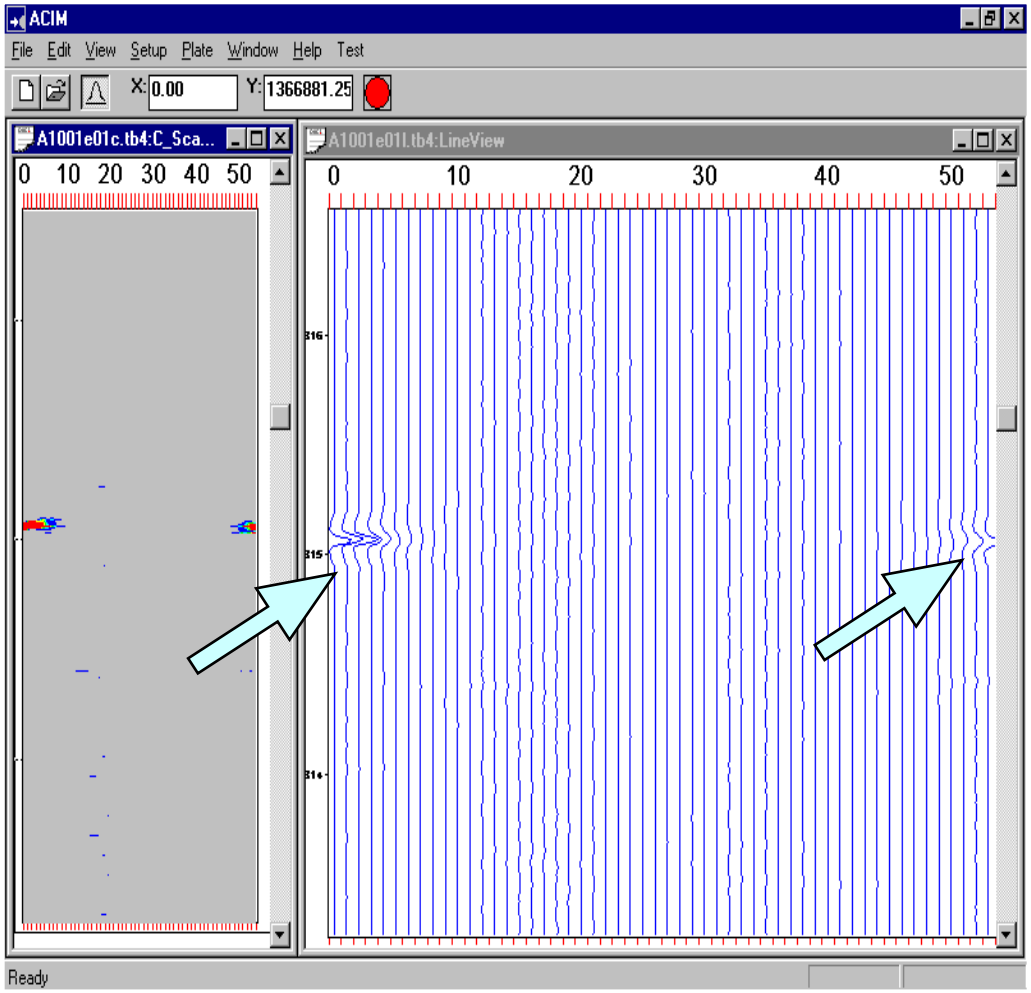
(Courtesy of Rosen Inspection Technologies (RIT))

Circumference

Depth

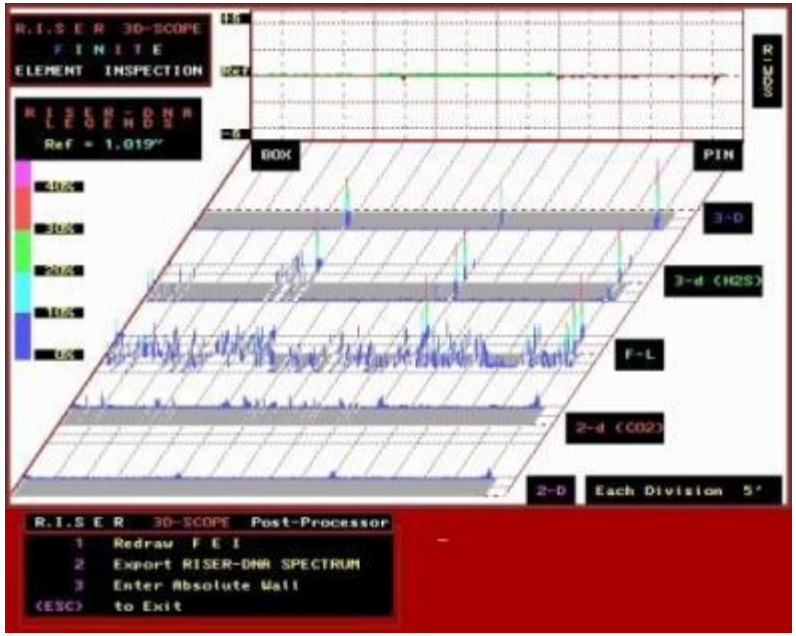


WT Scan @ cycle #61. LCF occurred at #69. Red areas show local wall thinning



C-Scan plot of corrosion pits in CT.
Red colours indicate greater pit depths

"*Stylwan*" 3D-FEI (Finite Element Inspection) SYSTEMS



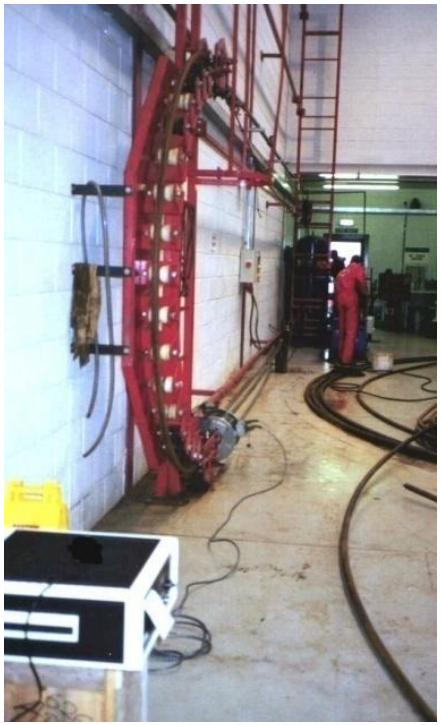
3D Rendering of MFL

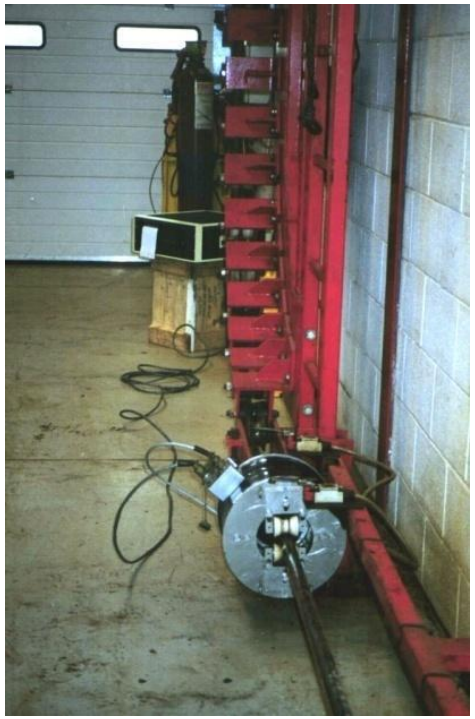
Flaw Spectrum:
Defect features through pattern recognition (not just amplitude)

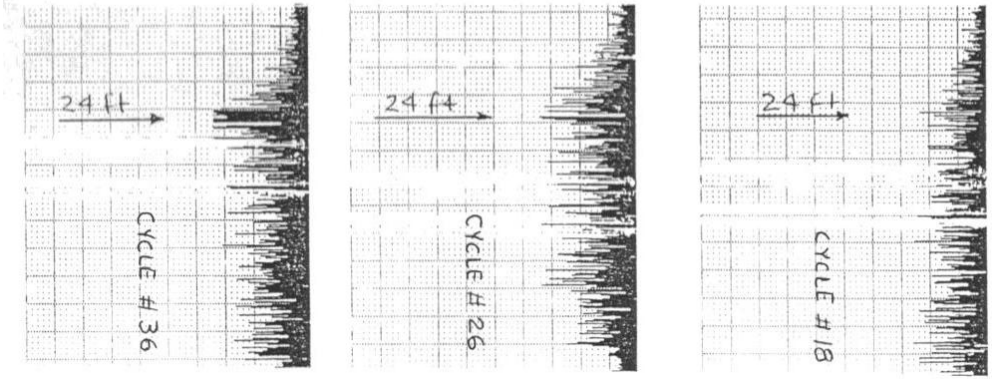
RULE:
Remaining
Useful **L**ife **E**stimation
(Not currently incorporated in standard CT inspection reports)

Stylwan's 3D-FEI (FINITE ELEMENT INSPECTION)

(*Courtesy CSM Tubular Technologies, Red Deer*)







System claimed to detect rapid fatigue consumption and identify at least 2 predominant failure locations as early as 50% of fatigue life

A CT section was cycled on a CTU at 10,000 psi.

Predicted fatigue: 45 cycles

3D-FEI detected and marked *exact failure location* according to their technical literature

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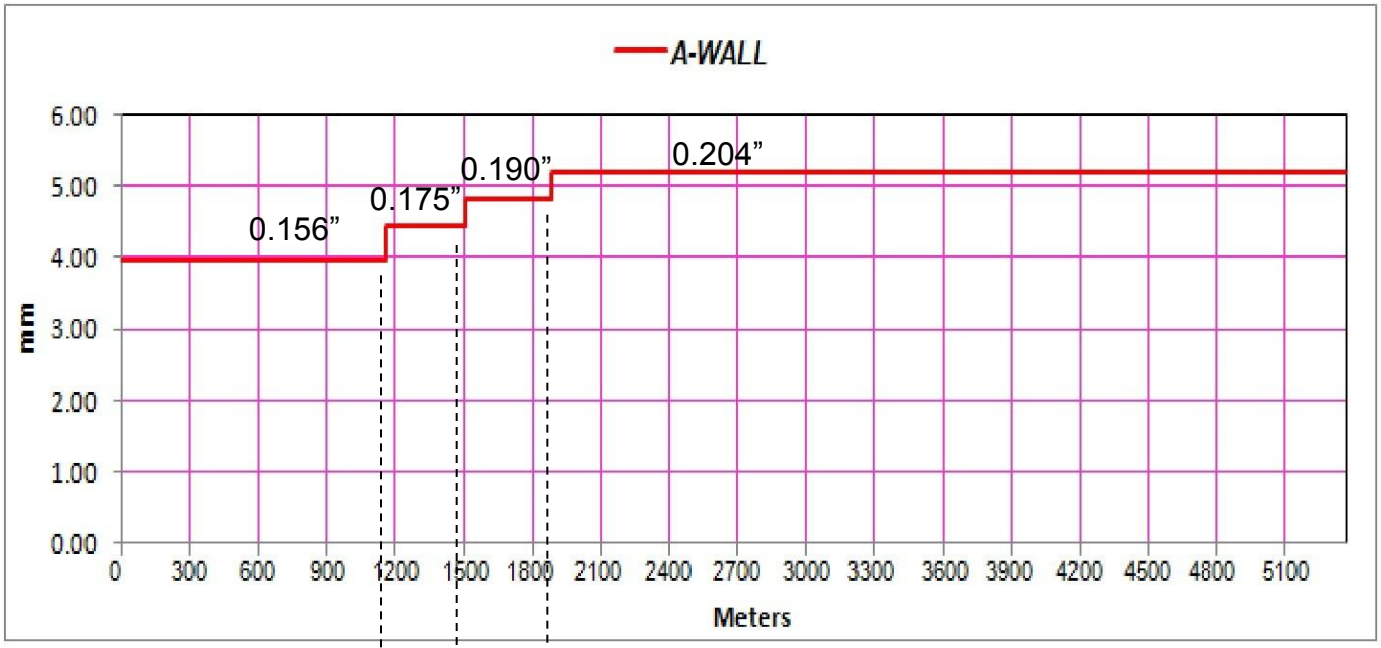
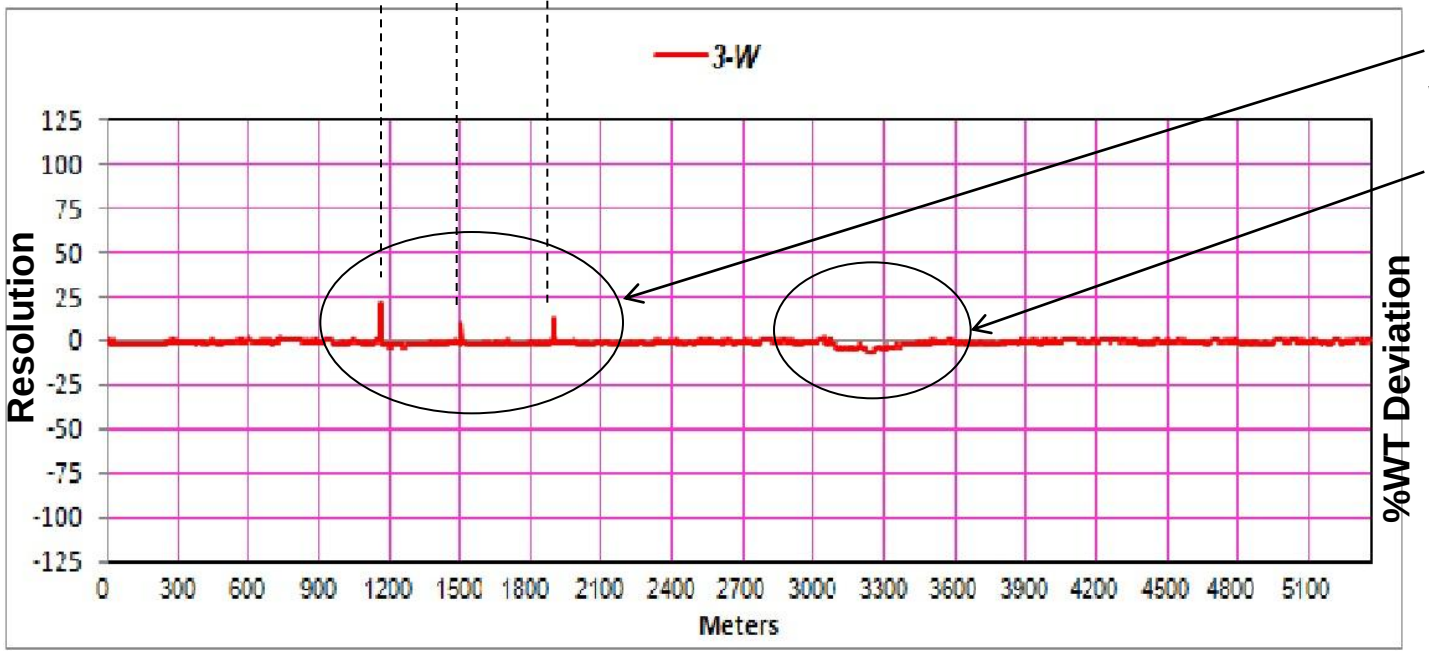
"*Stylwan*" TRACES for WALL THICKNESS and WT DEVIATIONS of TAPERED STRINGS

(*Courtesy CSM Tubular Technologies, Red Deer*)





Spikes are step changes in WT referenced after WT transition

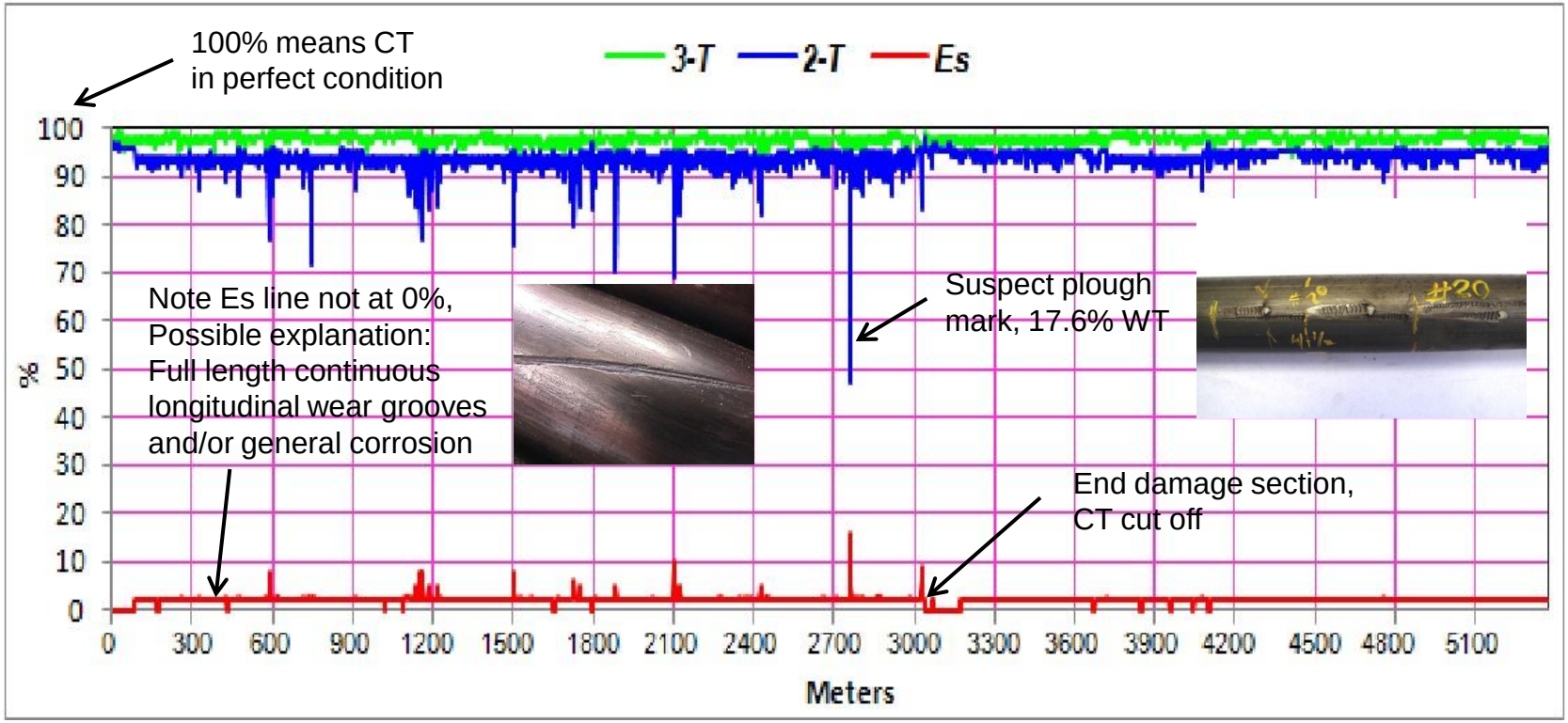
Should expand scale!

API 5ST "***NEW***" CT:
< 0.110": -0.005" to+0.010"
≤ 0.175": -0.008" to+0.012"
≤ 0.250": -0.012" to +0.012"
>0.250": -0.015" to +0.015"

IRP 21 "***USED***" CT:
max 10% loss of spec WT

"*Stylwan*" SURFACE DAMAGE INDICATION TRACES (2-T, 3-T) and RELATIVE SEVERITY of FATIGUE DEGRADATION (Es) TRACE

(*Courtesy CSM Tubular Technologies, Red Deer, Ref. CSM Report #212*)



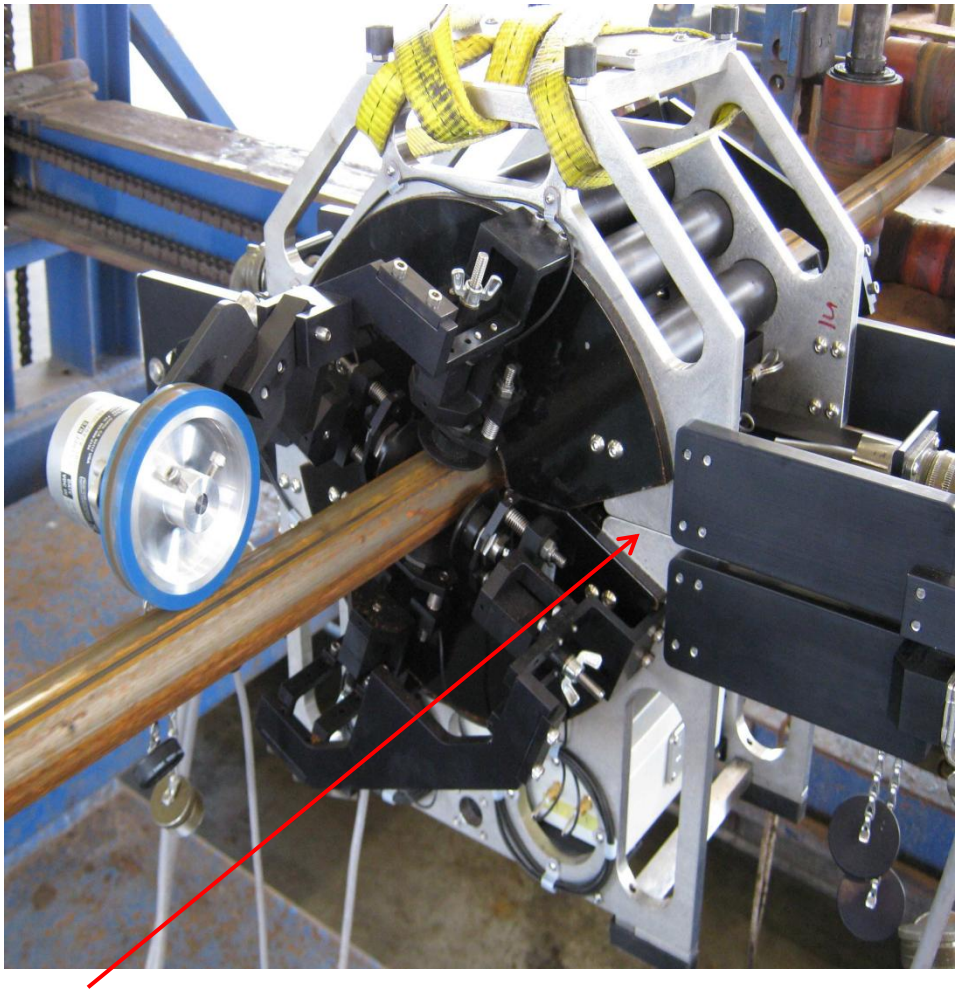
3-T Trace: Green scan from multiple sensors arranged for **3-dimensional** mensuration of corrosion pits, conical pits and gouges

2-T Trace: Blue scan from sensors used for **2-dimensional** flaws or defects such as visible cracks or edge cracks ("crack seeds")

Es Trace: Summary scan of "**E**nvironmental **S**ensitivity" provides map of ***relative*** severities to string degradation (eg. (susceptibility to fatigue failure) at various locations along string length. Also referred to as **"Fatigue Line"**

itRobotics COILED TUBING ASSESSMENT SYSTEM (CTAS)

(*Photos and graphics Courtesy Dr. Rod Stanley, itRobotics Inc.)*



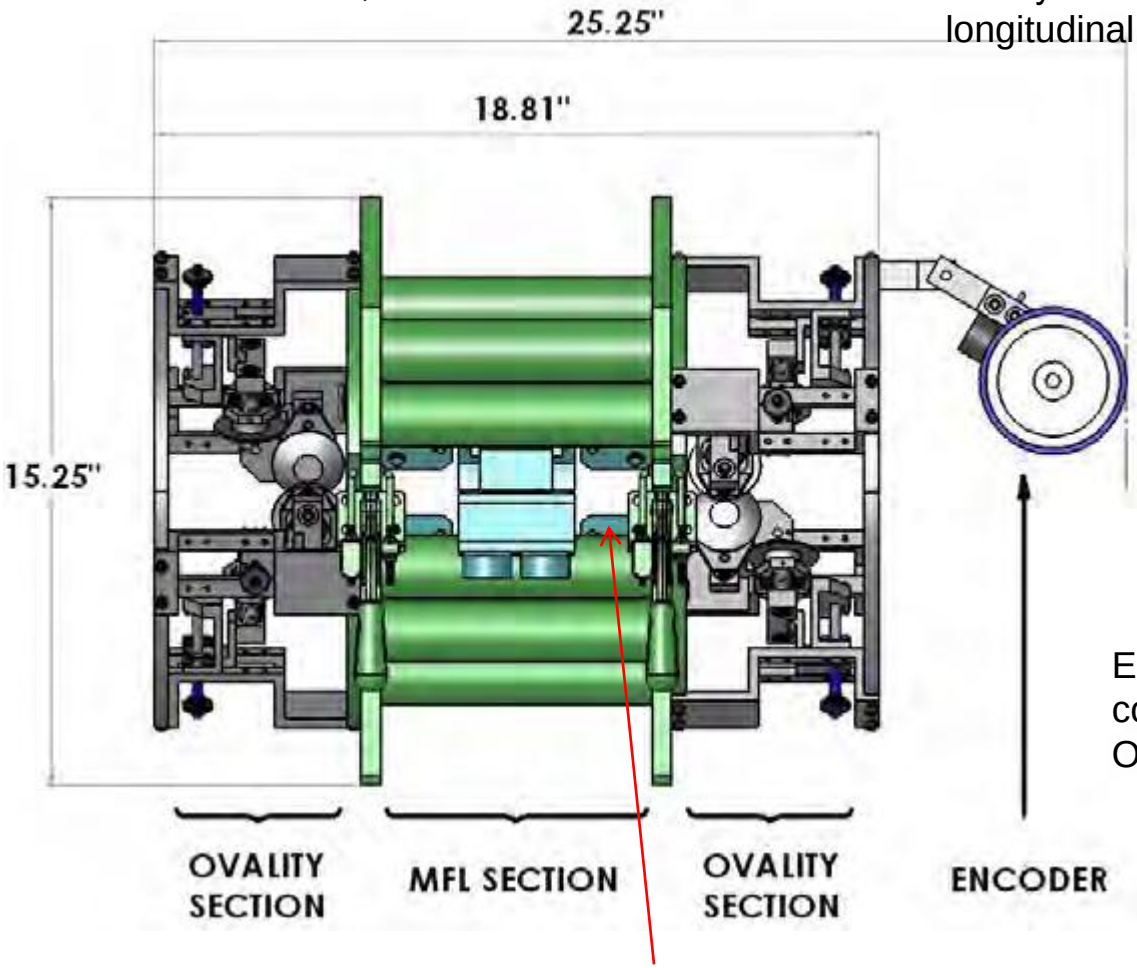
Clamshell design for mounting and inspecting shorter intermediate sections

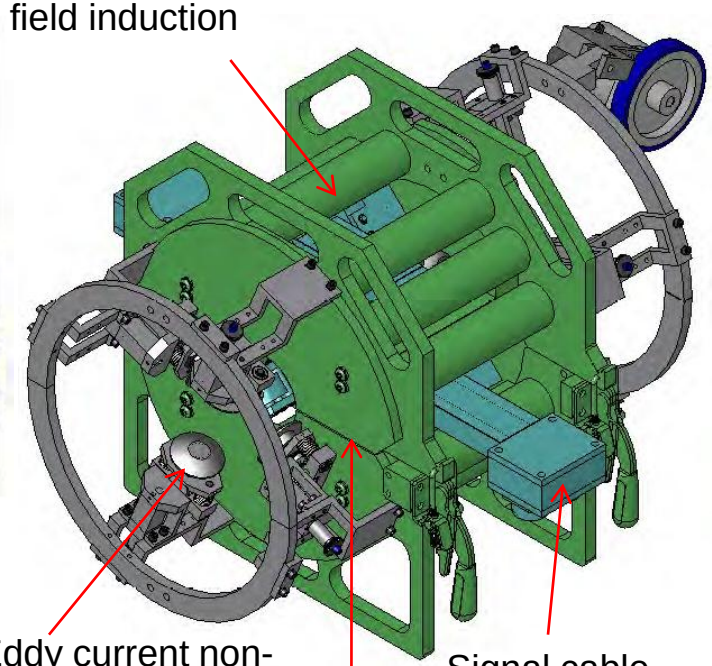
LATEST CT INSPECTION HEAD DESIGN

(exchangeable sensor rings for varying CT diameter)

Wt: ~150 lbs for 2-7/8” CT
~200 lbs for 3-1/4”, 3-1/2” CT

Neodymium “(Nd)-Fe-B” permanent magnets for longitudinal field induction





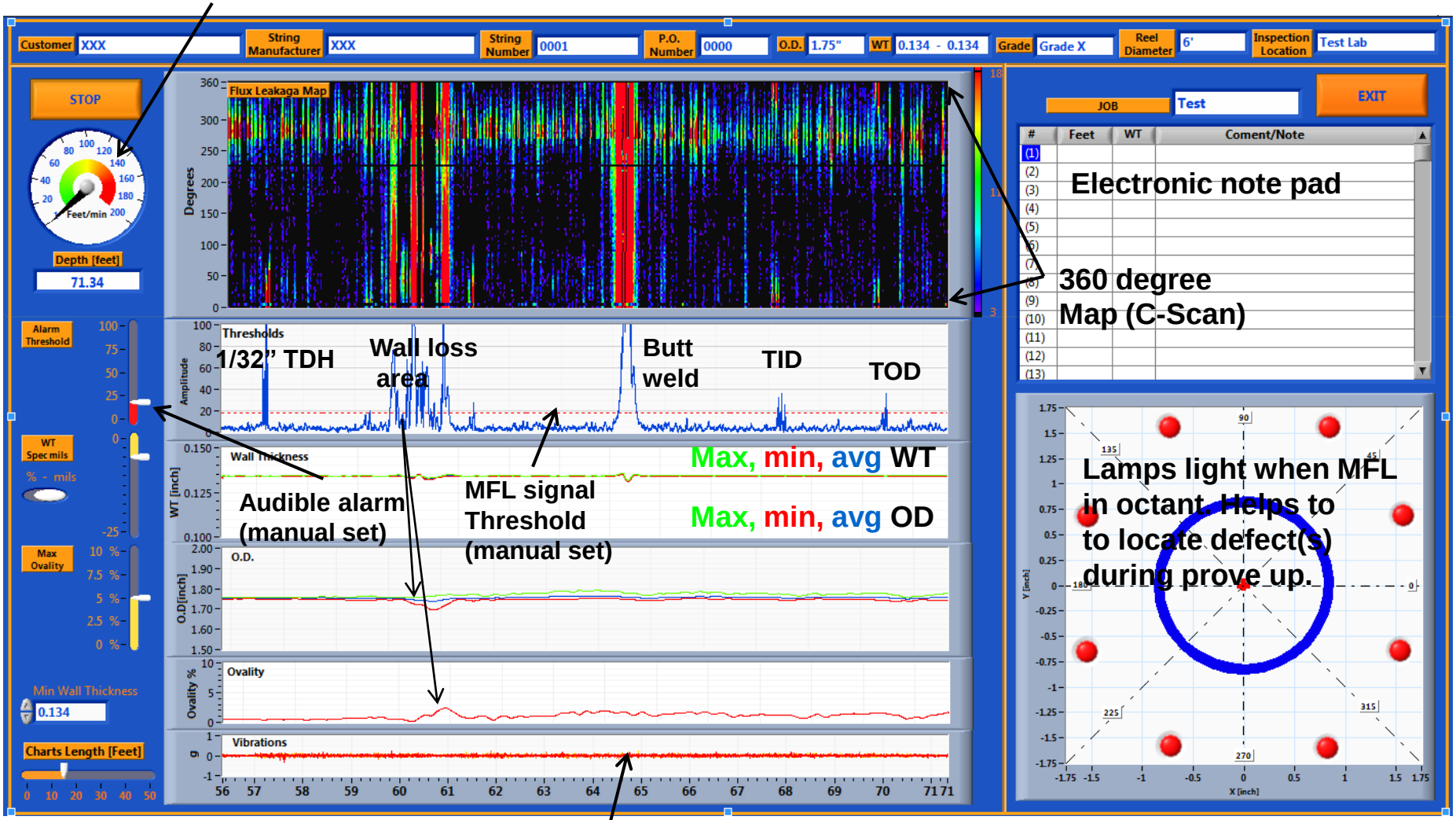
Eddy current non-contact sensors for OD and Ov measure

Signal cable junction box

Clamshell design for mounting & intermediate section inspection

Four (4) sliding CT contact shoes or wedges containing multiple Hall effect sensors encircling the CT for MFL signals to measure wall thickness and detect imperfections and defects

COMPUTER SCREEN FROM 1-3/4 X 0.134 CT

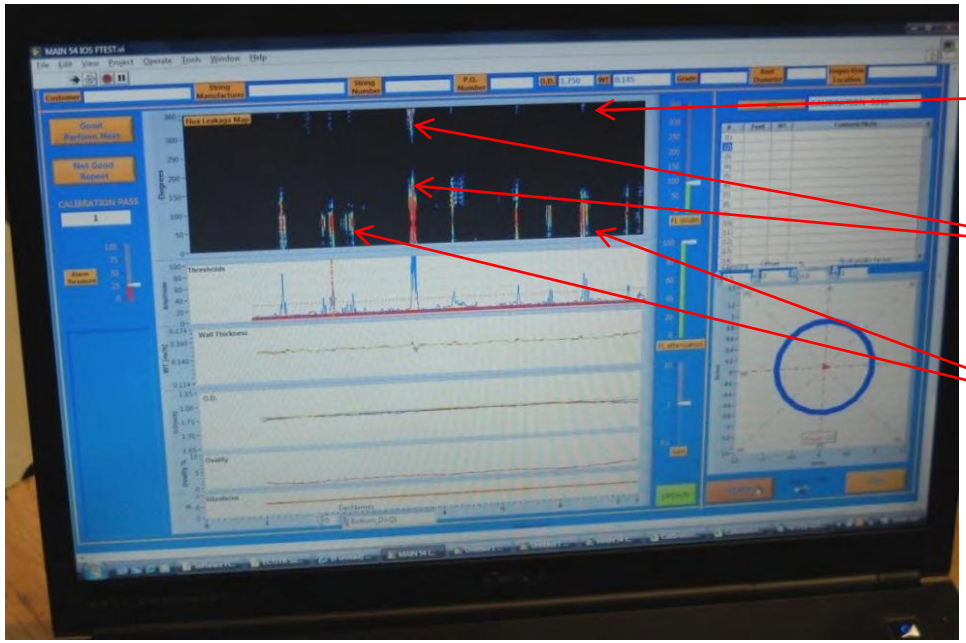


Scales show tube dimensions

Vibration scan to detect false MFL signals

CALIBRATION TO API 5ST STANDARDS AND EXXONMOBIL SPECIFICATIONS

- 10% wall thickness (WT) longitudinal and transverse notches
- 1/32” through drilled hole (new CT)
- 1/16” through drilled hole (used CT)
- Wall thickness reduction



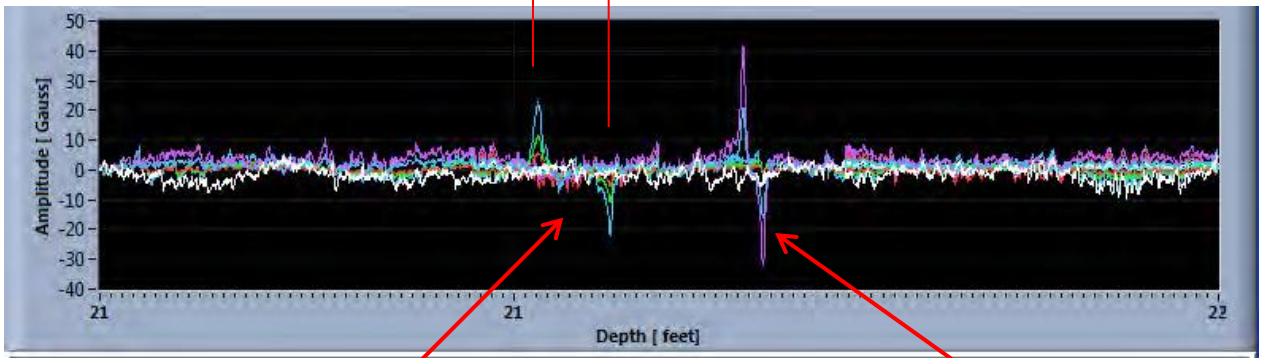
1/32” Through drilled hole (TDH) in seam weld

Butt weld

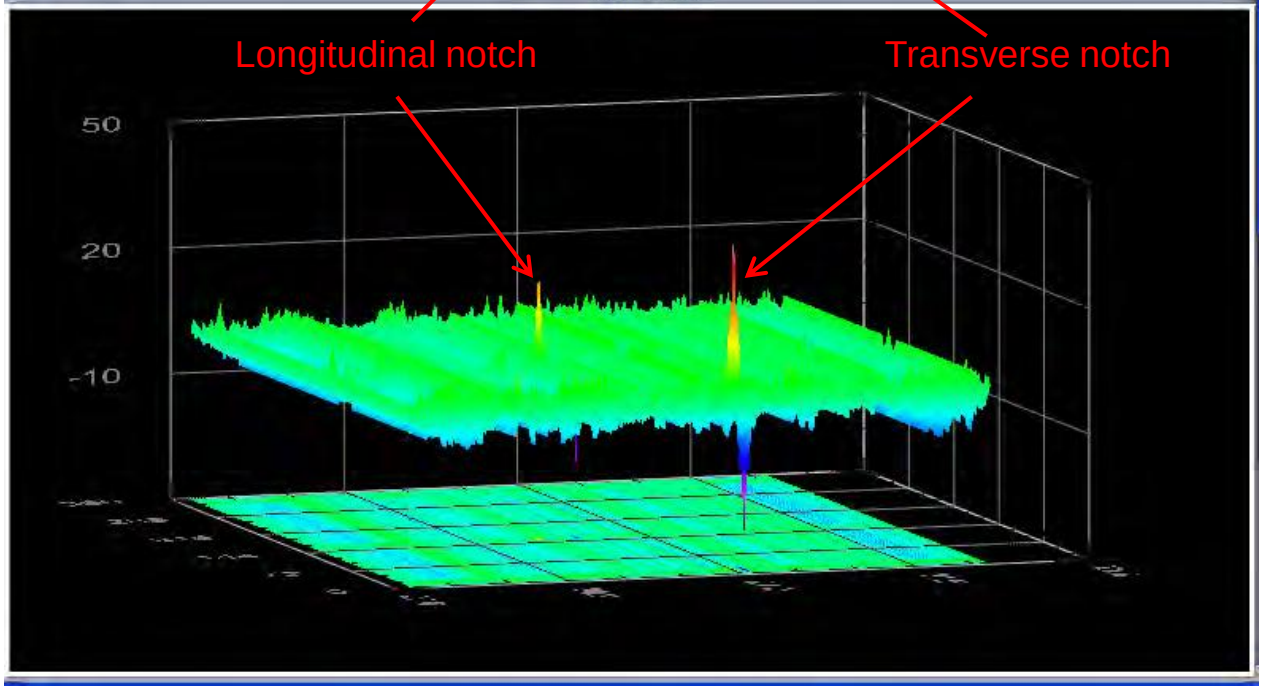
OD and ID transverse (TOD,TID) and longitudinal (LOD, LID) EDM reference notches

DIGITIZING, 3D RENDERING AND ARCHIVING OF MFL SCANS FOR SUBSEQUENT ENGINEERING CRITICAL ANALYSES (ECA)

Measures length of longitudinal flaw or defect
(MFL peaks emanate from ends of longitudinal OD & ID notches)

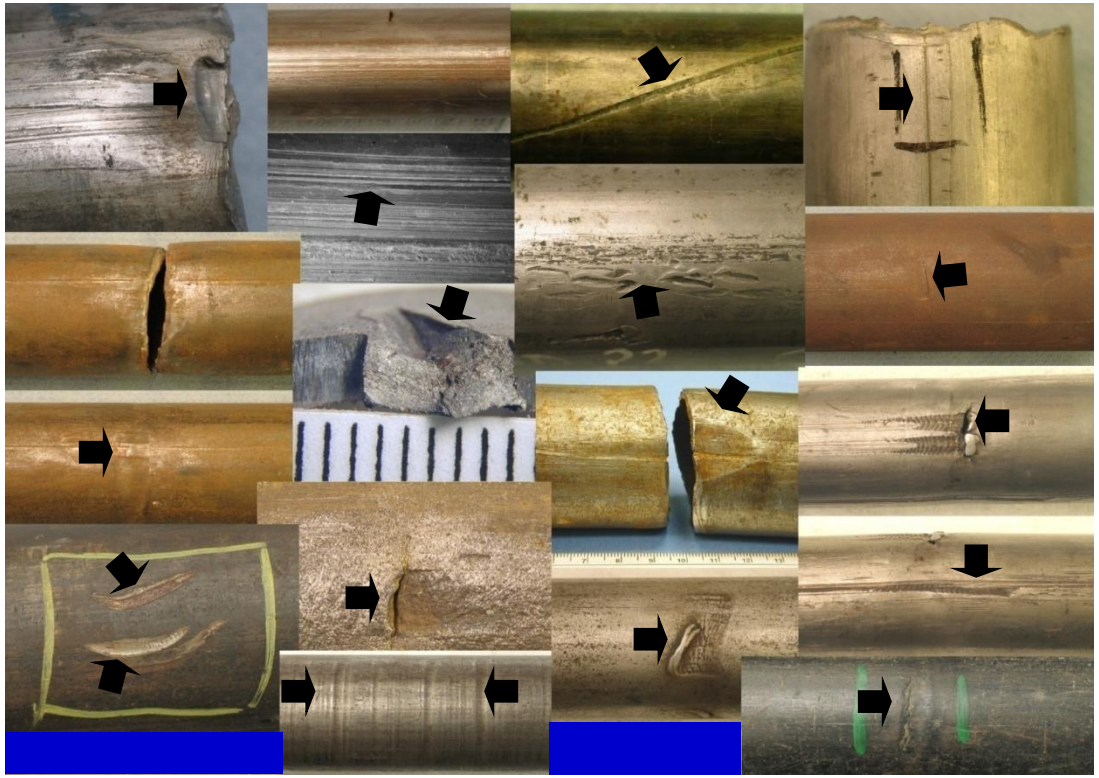


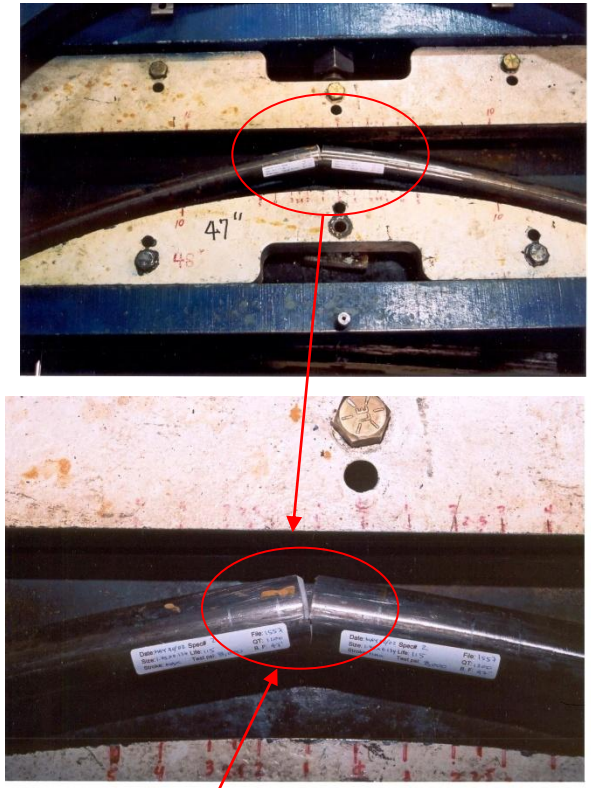
MFL Hall sensor signals from all four (4) shoes or wedges. (Digitized every 0.5 mm)

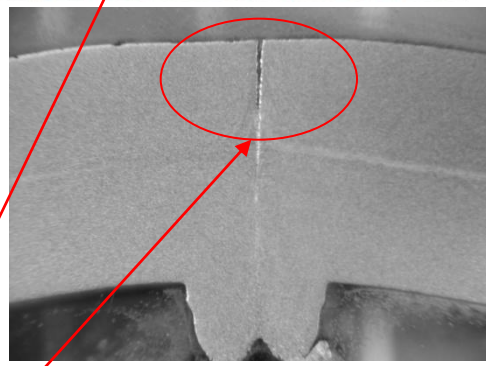


MFL map can be rotated to Measure length of *longitudinal* notches

VALUE, BENEFITS AND IMPORTANCE OF CT INSPECTIONS







✓All mechanical and corrosion damage reduce fatigue life to varying degree. Need to predict remaining safe working life.

✓ Economics: want to maximize service life of expensive consumables

✓Safety: want to avoid catastrophic failures such as large fatigue cracks in high pressure operations and/or higher strength CT.

✓Verify integrity of newly manufactured “high profile” or critical strings

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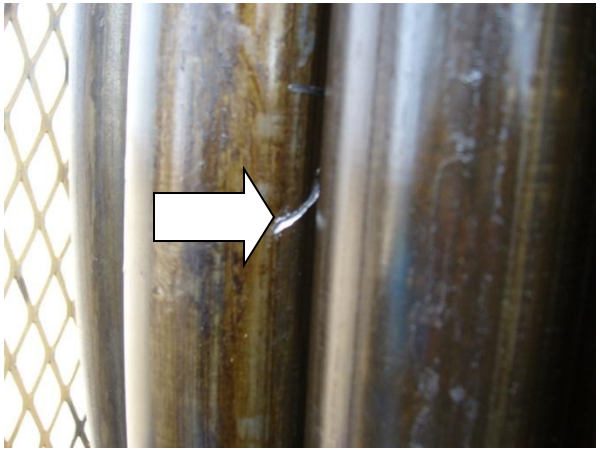
QUANTIFYING LOSS OF CT FATIGUE FROM MECHANICAL DAMAGE

Artificial Damage Detail



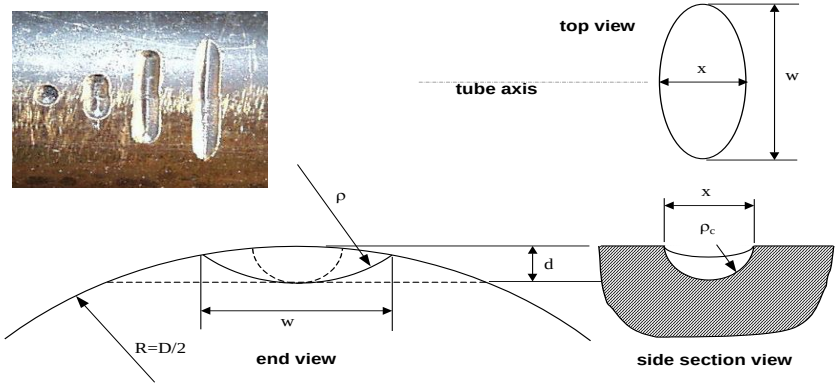


Fig. 6 – Geometry of defects milled with ball-nose cutter. (Inset photo shows the four actual 0.625" deep cuts on a 2.375" diameter sample.)

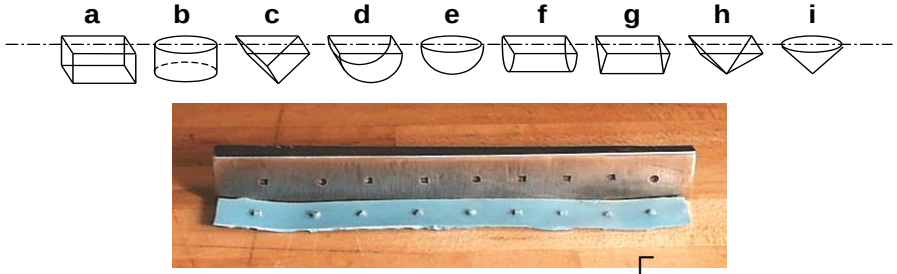
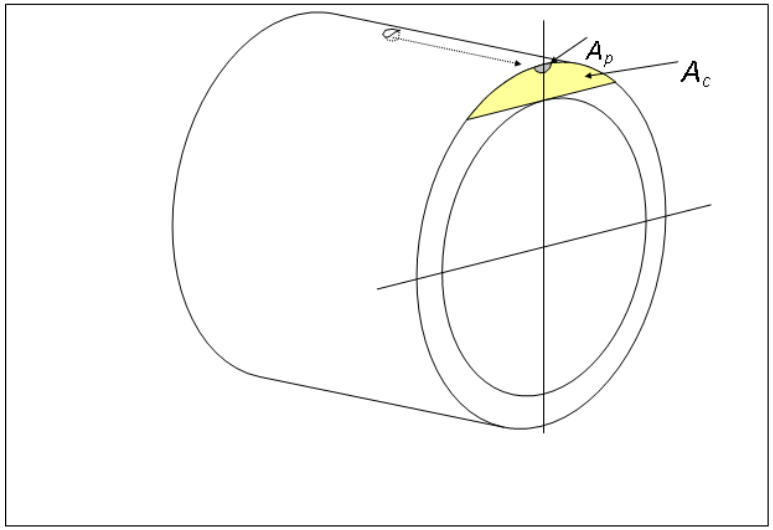


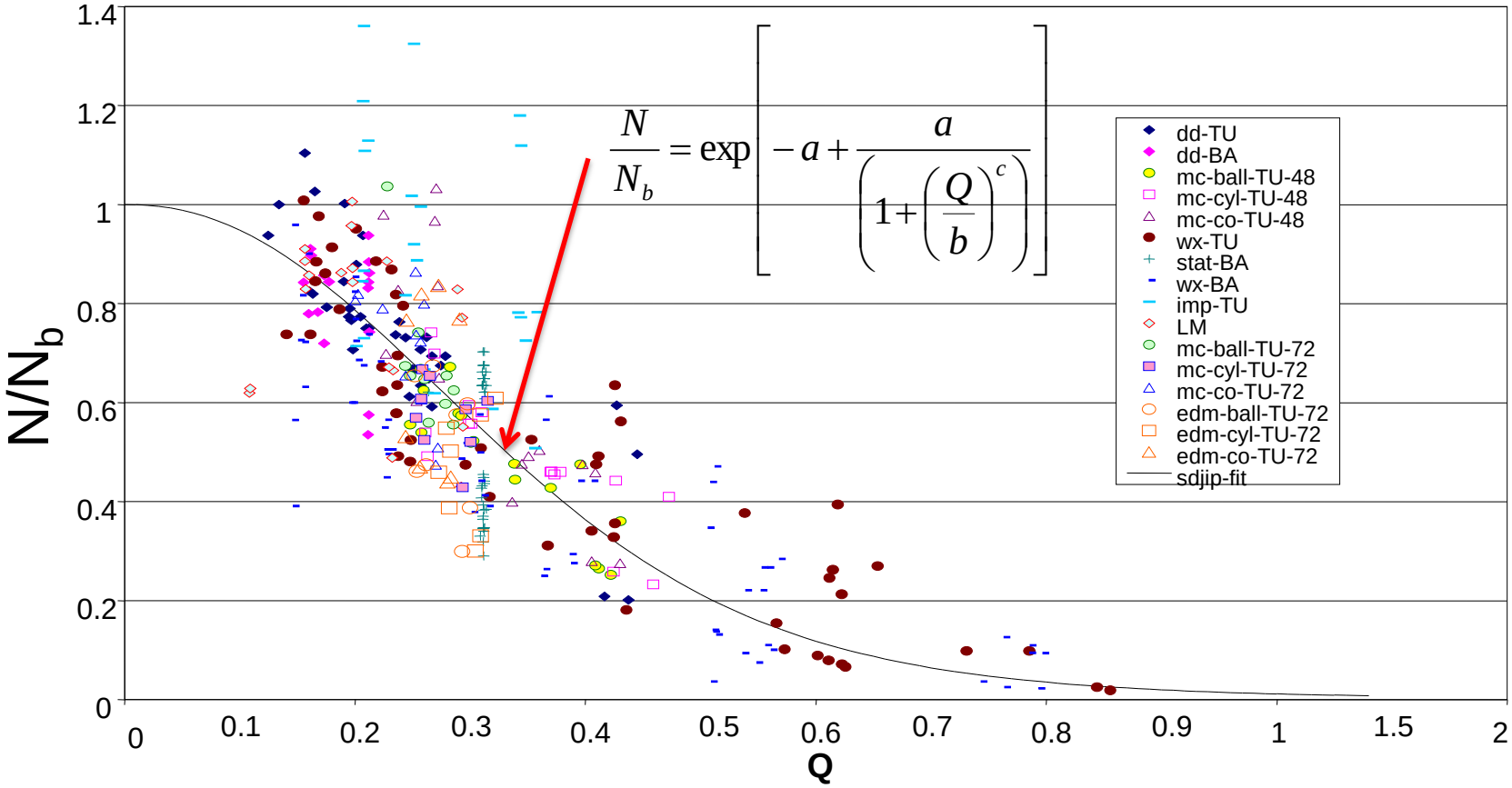
Fig. 1 – Defect geometries and EDM samples.



$$Q = \left[\left(\frac{d}{t} \right) \left(\frac{w}{x} \right) \sqrt{\frac{A_p}{A_c}} \right]^{\frac{1}{3}} \qquad \frac{N}{N_b} = \exp\left[-a + \frac{a}{\left(1 + \left(\frac{Q}{b} \right)^c \right)} \right]$$

a = 9.222 b = 1.0339 c = 2.20735

DETERMINE CT FATIGUE DE-RATING FACTOR (N/Nb) or DEFECT INTENSITY FACTOR (DIF = Nb/N)



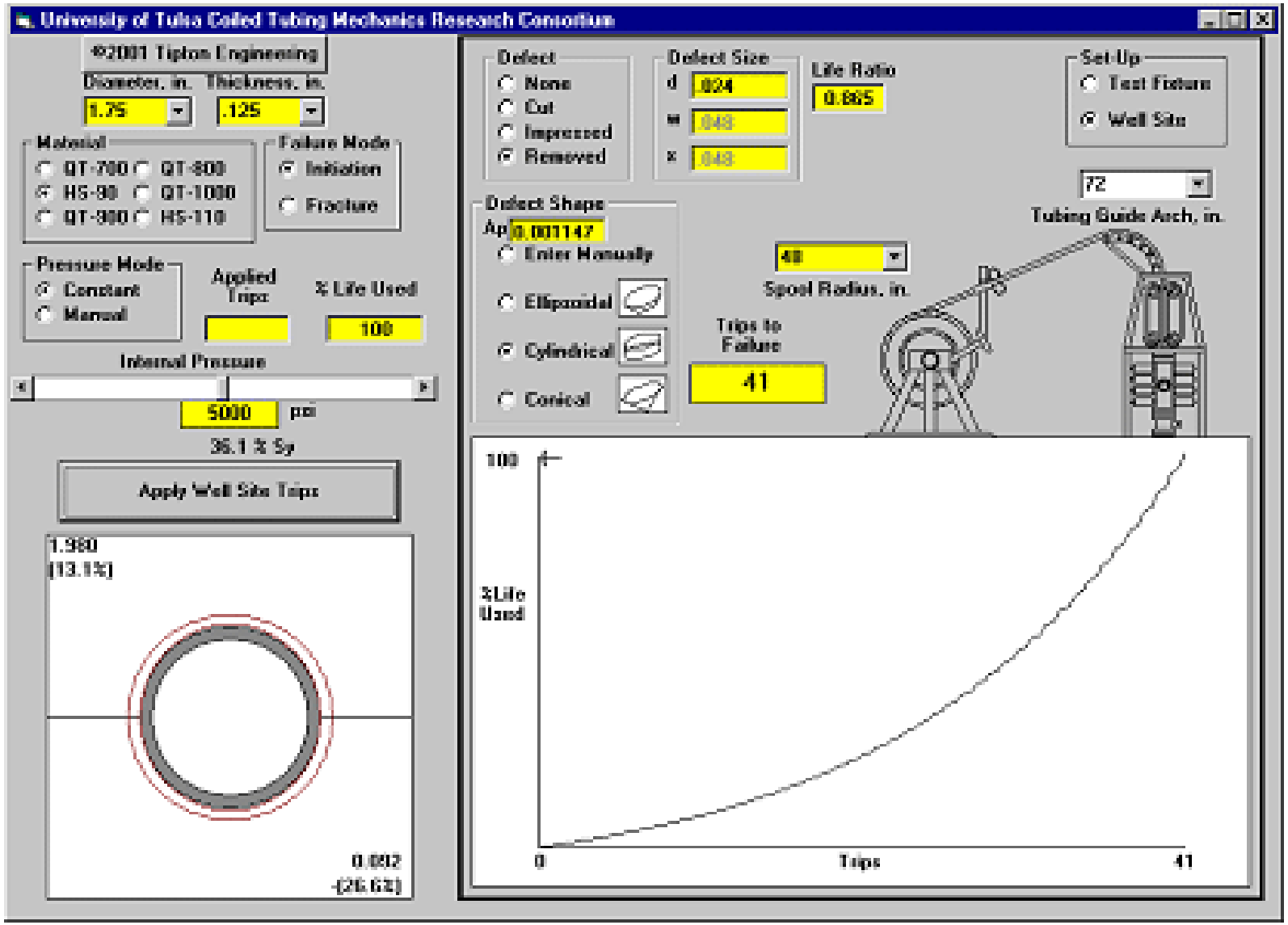
N = CT fatigue cycles with surface damage

Q = Damage parameter

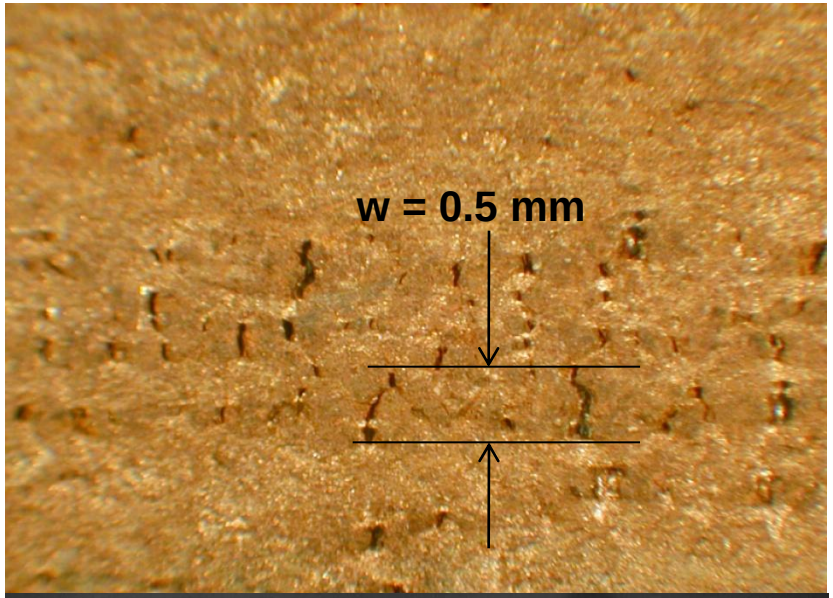
N_b = Baseline CT fatigue cycles without damage

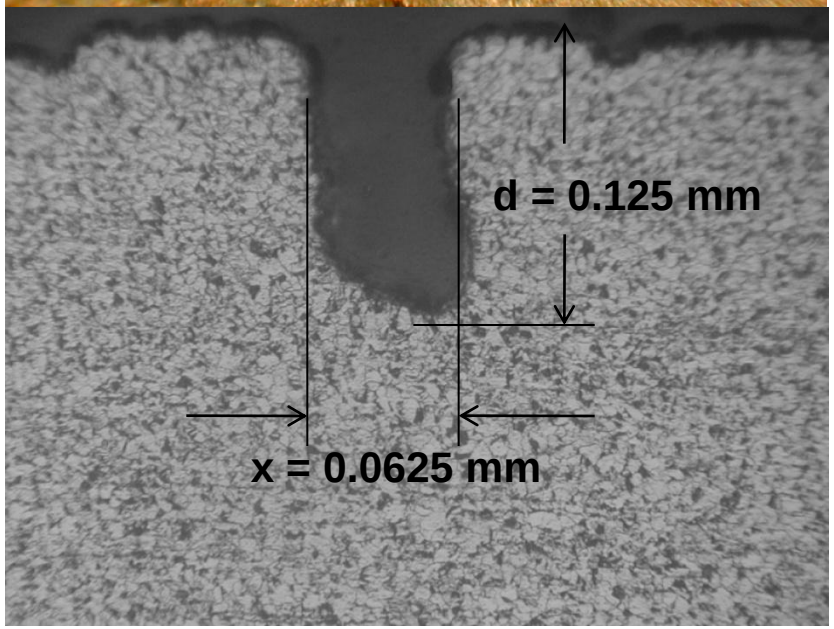
N/N_b = Fatigue de-rating factor

"FLEXOR TU" SOFTWARE INTERFACE FOR NEW AND DAMAGED CT FATIGUE PREDICTIONS



ECA Example Using Flexor TU-Corrosion Pits – Test Case #1





CT AND DAMAGE DETAILS:
•1-1/4" X 0.095" (31.2 mm X 2.41 mm) CT80
•18% working life consumed
•Transverse OD surface corroded edge cracks

PHYSICAL MEASUREMENTS:
•0.5 mm (0.0197") long (w), 0.0625 mm (0.0025") wide (x), 0.125 mm (0.0049") deep (d)
•%WT = d/t X 100 = 5.2%
•w/x = 0.5/0.0625 = 8

PREDICTION OF FATIGUE DEGRADATION:
•Defect Intensity Factor @ 1000 psi = 1.42. Divide remaining fatigue life by1.42 (i.e. remaining fatigue life is reduced to 1/1.42 or 70.4% of non-damaged fatigue)

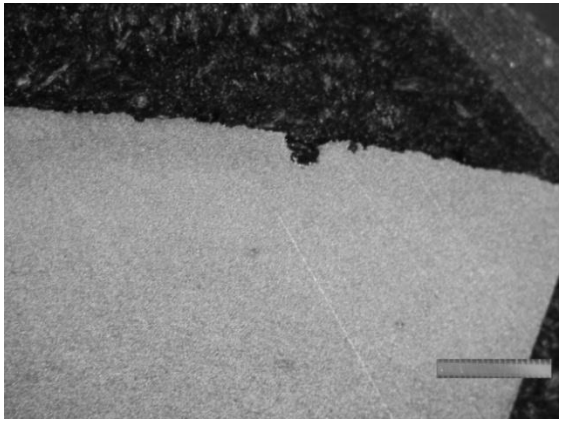
•Defect Intensity Factor @ 6000 psi = 1.21. Divide remaining fatigue life by1.21(i.e. remaining fatigue life is reduced to 1/1.21 or 82.9% of non-damaged fatigue)

BFM FATIGUE TEST RESULTS:
Fatigue loss at 1,000 psi: 31.7%, at 6,000 psi 15.6%

RECOMMENDATION:
Reduce remaining fatigue by 25%

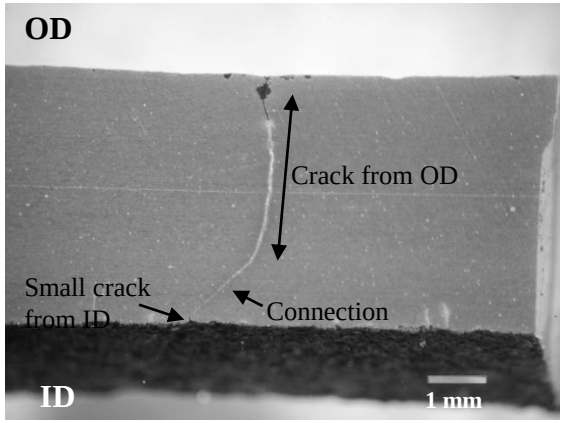
ECA Example Using Flexor TU-Corrosion Pits - Test Case #2

- 1-1/2” diam x 0.175” thick, CT100
- CT exposed to sea environment. Pitting corrosion on OD and ID surfaces
- BFM Test Parameters: 72” Bend Form Radius; 500 psi internal pressure

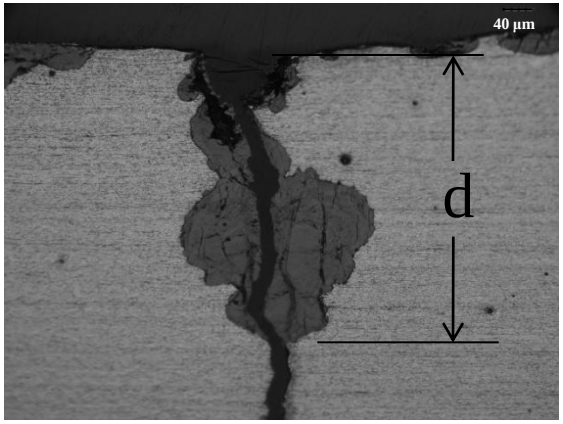


EXAMPLE OF “Flexor TU” APPLICATION-CORROSION PITS ON BOTH INTERNAL AND EXTERNAL SURFACES

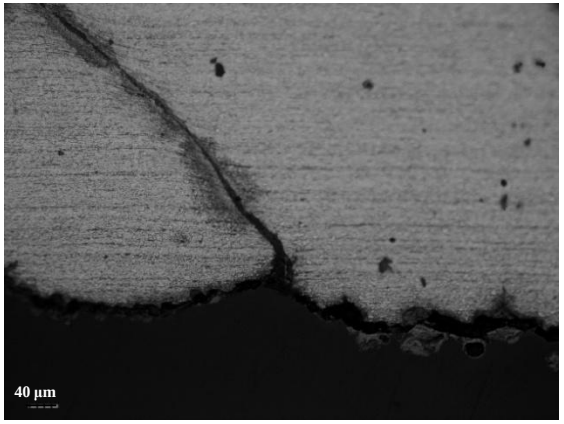
Pinhole Longitudinal Section



External Pit Detail



Internal Pit Detail

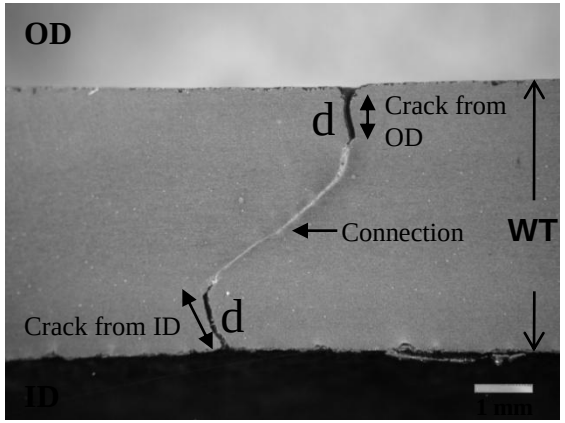


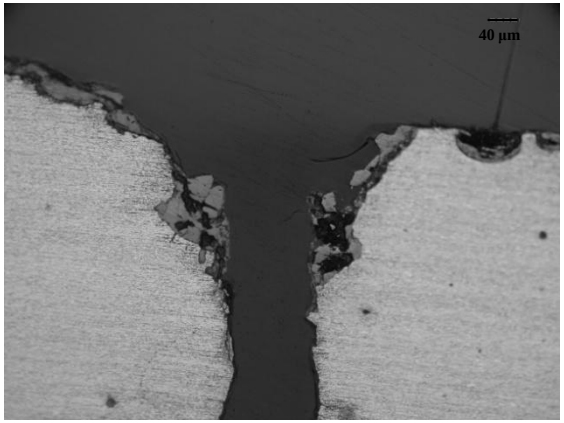
Sample S12

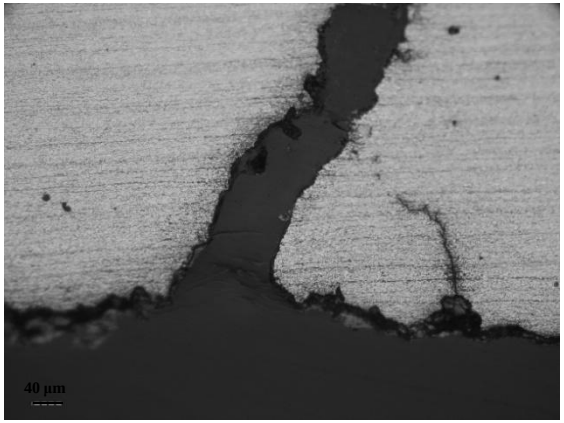
External Pit		Internal Pit	
d (mm)	D (mm)	d (mm)	D (mm)
0.42	0.247	0.07	0.2

D: pit diameter; d: pit depth

EXAMPLE OF “Flexor TU” APPLICATION-CORROSION PITS ON BOTH INTERNAL AND EXTERNAL SURFACES







Sample S6

External Pit		Internal Pit	
d (mm)	D (mm)	d (mm)	D (mm)
0.31	0.565	0.09	0.502

D: Pit Diameter; d: pit depth

COMPARISON BETWEEN BFM TESTS AND "FLEXOR TU" PREDICTIONS

Often conservative but sometimes optimistic estimates of remaining fatigue life

Sample	N predicted[1] (cycles)	N_f BFM test[2] (cycles)	Difference[3] (%)
S12	877	804	+9.1 (i.e. optimistic)
S6	885	997	-11.2 (i.e. pessimistic)

(1) Predictions assuming simultaneous crack propagation from OD & ID pits. Cut defects, cylindrical shape, constant pit diameter to full depth of pit

(2) N_f = Failure cycles measured with BFM

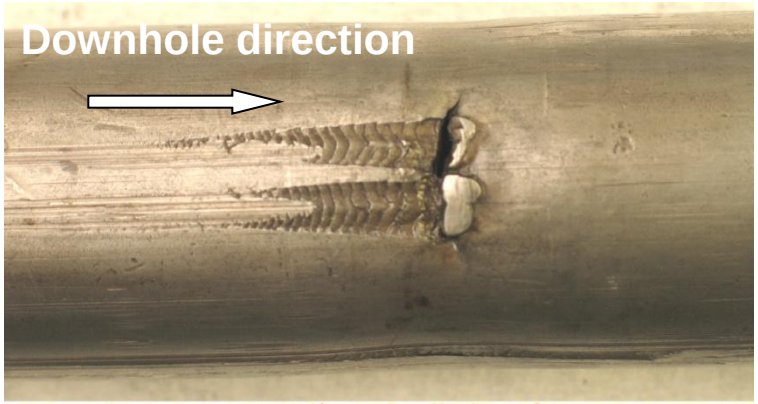
(3) Difference: $[(N \text{ predicted} - N_f) / N_f] \times 100$

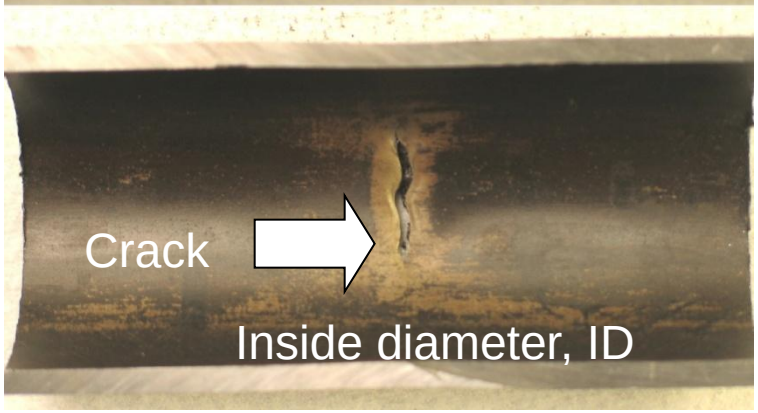
EXAMPLE OF MECHANICAL DAMAGE – "PERF BURNS" (2" X 0.175" or 50.8mm X 4.45 mm CT80)

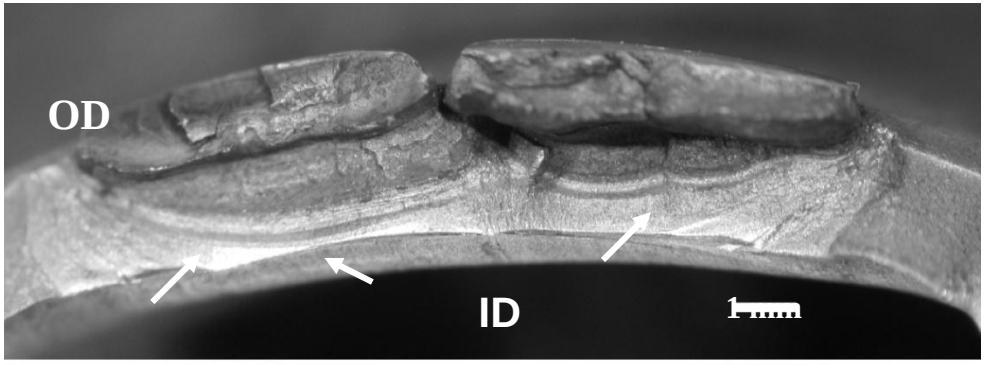
Summary of CT Damage ECA: (Pressure = 3,000 psi (21 MPa), BFM Bend Form: 72"R)

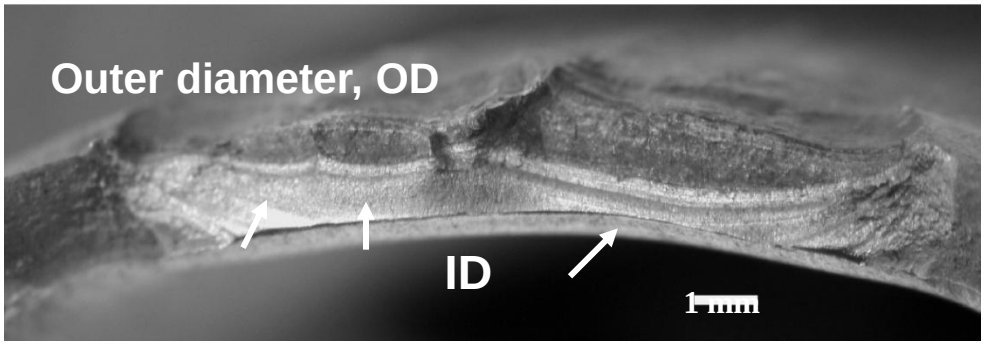
Hemispherical, x = w = 0.32" (scaled from photo), d_{max} = 0.012" , Nf/Nb = 426/504 = 0.845 (DIF = 1.182)
Hemispherical, larger diameter, x = w = 0.5", d_{max} = 0.012" , Nf/Nb = 411/504 = 0.815 (DIF = 1.226)
Hemispherical, greater depth, x = w = 0.32", d_{max} = 0.015" , Nf/Nb = 403/504 = 0.801 (DIF = 1.249)
Ellipsoidal, Longitudinal (w/x < 1), x = 0.5", w = 0.32", d_{max} = 0.012", Nf/Nb = 450/504 = 0.892 (DIF = 1.121)
Ellipsoidal, Transverse (w/x > 1), x = 0.32", w = 0.5", d_{max} = 0.012", Nf/Nb = 375/504 = 0.744 (DIF = 1.344)

SOME LIMITATIONS OF *REEL TO REEL* CT INSPECTIONS





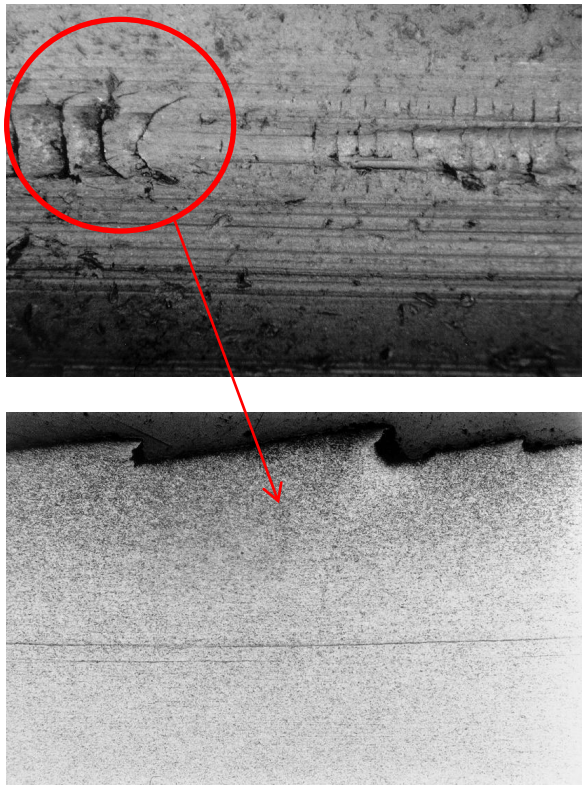


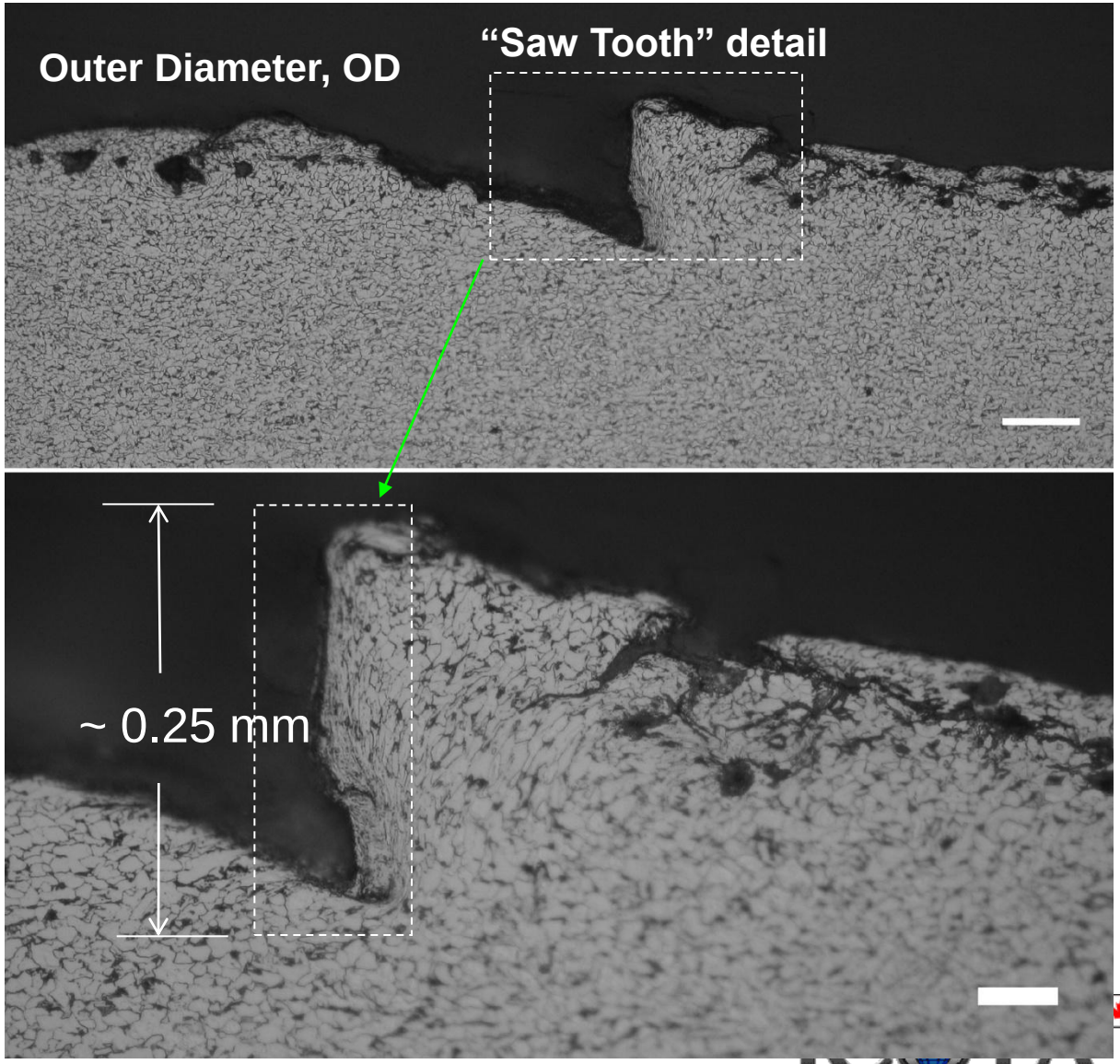


Severe plough marks

- Severe ploughing or scraping causes large plastic distortion of grains and **transverse edge cracks (see arrows).**
- Tests have shown that fatigue propagation to pinhole failure can occur in only 1 or 2 trips into and out of the well.
- More laboratory testing required on realistic defects such as deep plough marks. Present example would call for cut out and butt weld repair

SOME LIMITATIONS OF *REEL TO REEL* CT INSPECTIONS

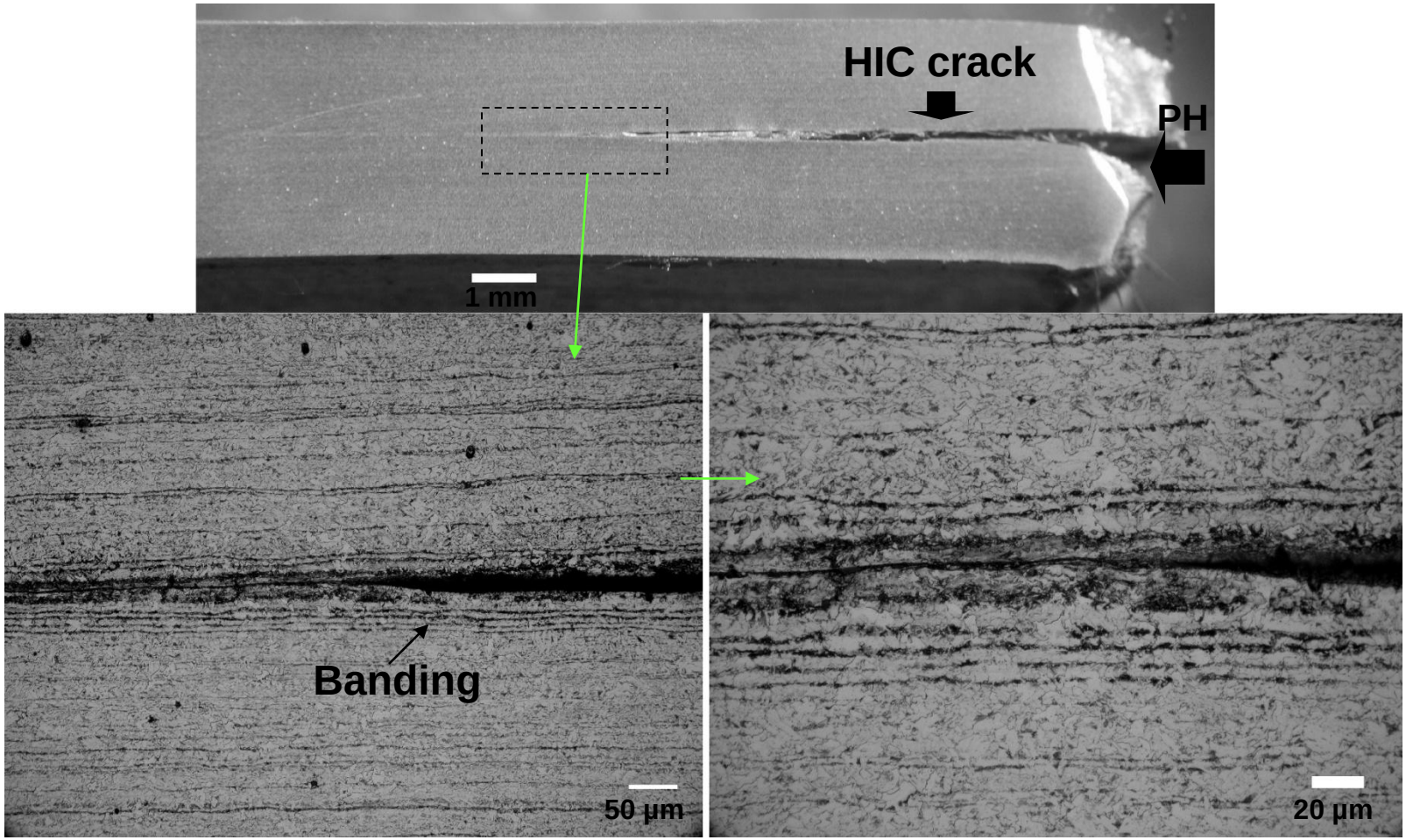




- Sharp notch effects. Depth of only 0.25 mm or can reduce fatigue by 25%.
- Resolution of inspection system may be too low

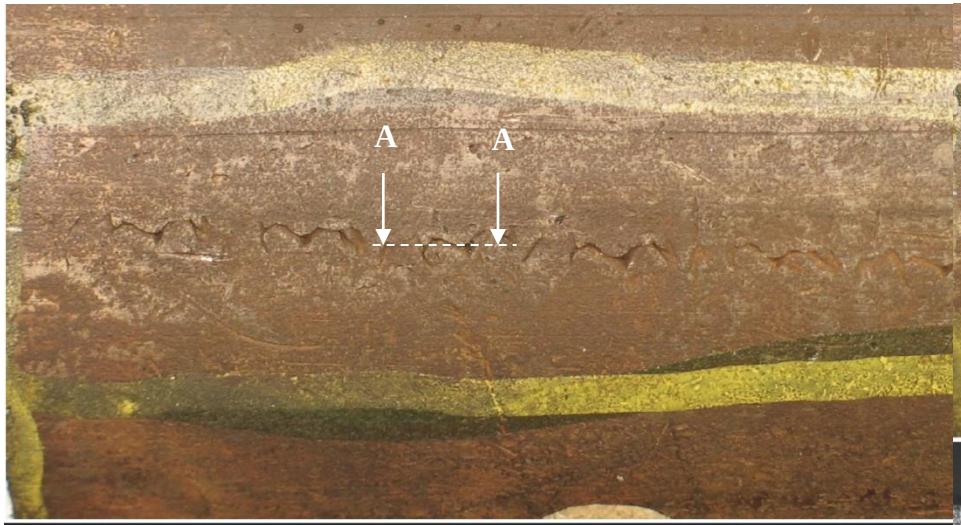
SOME LIMITATIONS OF *REEL TO REEL* CT INSPECTIONS

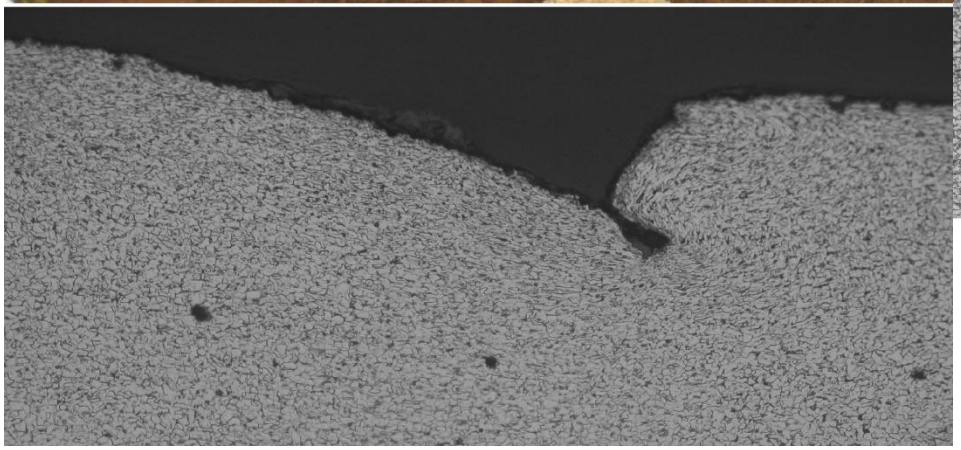
Mid-wall planar Hydrogen Induced Cracks (HIC) from Sour Well Exposure

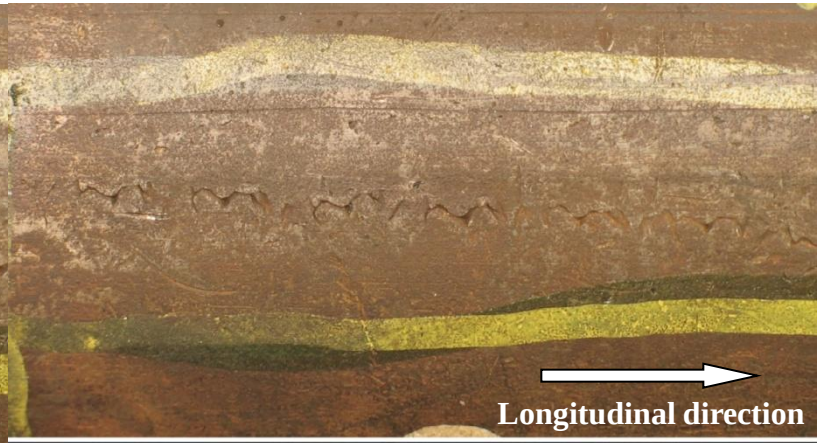


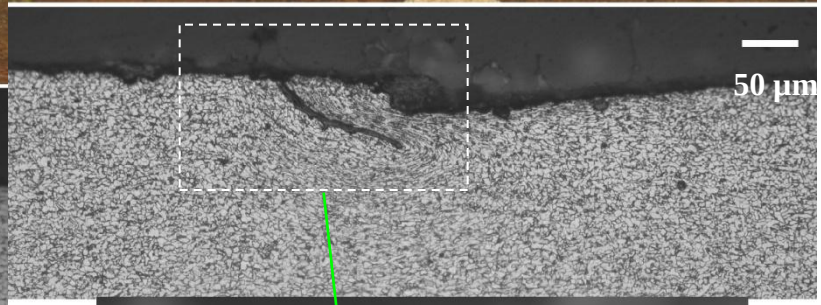
PH = Pinhole – Longitudinal section
Cracking associated with banding

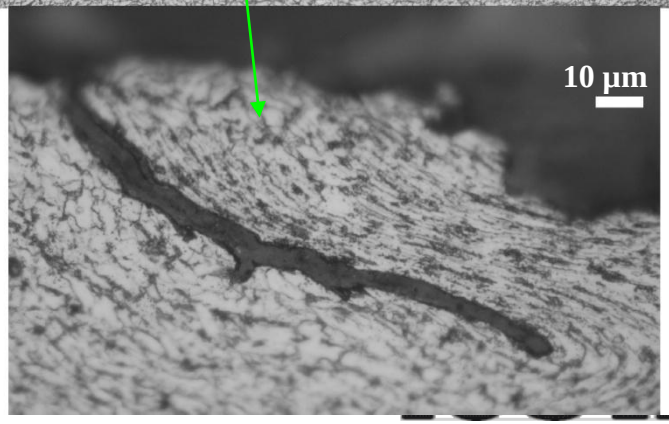
EXAMPLES OF DAMAGE DETAILS REQUIRING MORE ENGINEERING JUDGEMENT AND/OR TESTS ON REALISTIC DEFECTS





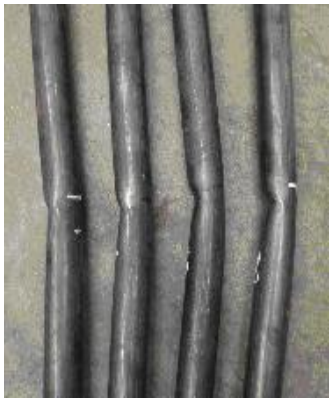


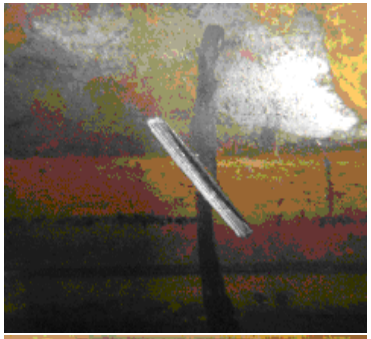


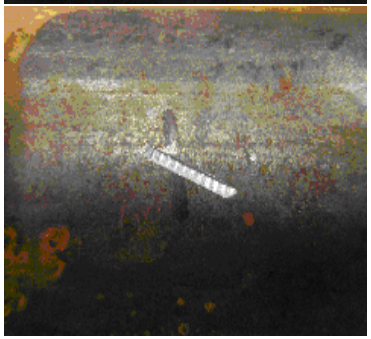


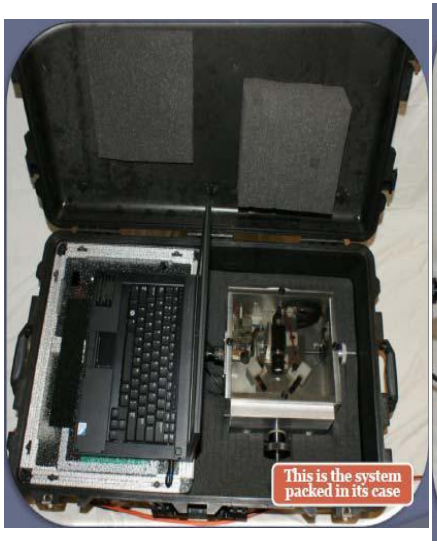
Mechanical Damage (irregular shape or with micro-cracks and plastically deformed grains)

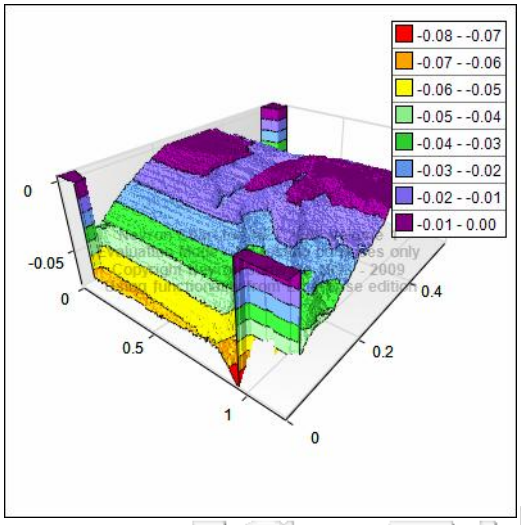
ON-GOING OR CURRENT CT INSPECTION RESEARCH AND DEVELOPMENT











REMAINING INDUSTRY NEEDS AND ON-GOING R & D

- Standardization on different defect terminology –
  (Some definitions already standardized in API 5ST.
  Incorporate in API 5C8 currently under development?)

- Atlas of relative defect severity with respect to fatigue
  (Incorporate in API 5C8 currently under development?)

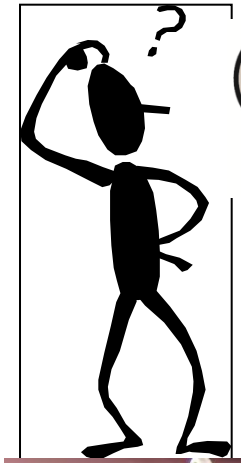
- Efficient prove-up tool for measuring critical defect dimensions
  (Currently under development at TU CTMRC i.e. Laser Scanning Measuring Tool)

- Increased BFM tests on realistic defects and comparison with FLEXOR TU
  (Currently under development at Tulsa University CTMRC)

- Increased resolution for on-line detection of cold weld/penetrator defects
  (Possibly non-contact divergent eddy current technology)

- Additional training of CT string inspectors

- Check out Aradia Consulting web site ***www.ctfatigue.com***



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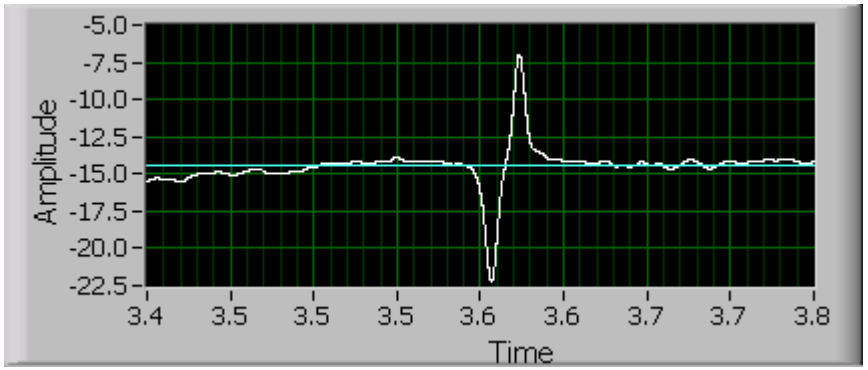
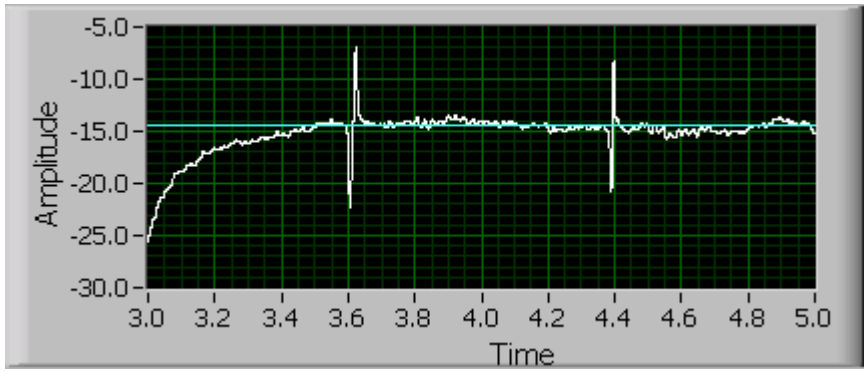
QUESTIONS?

ICoTA

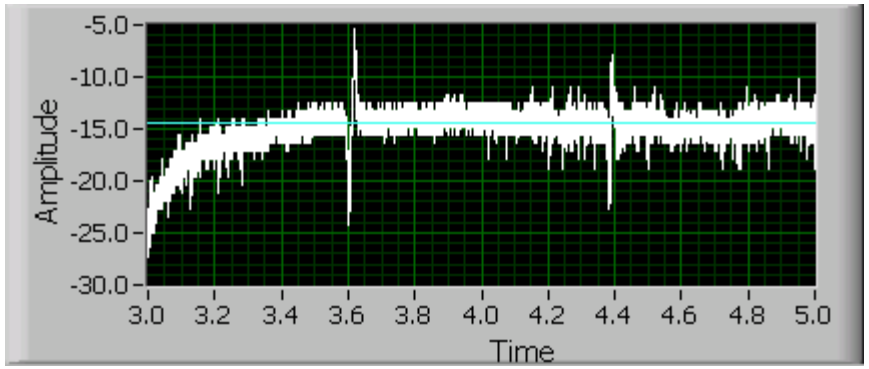
TYPICAL MFL SIGNALS



Transverse notch



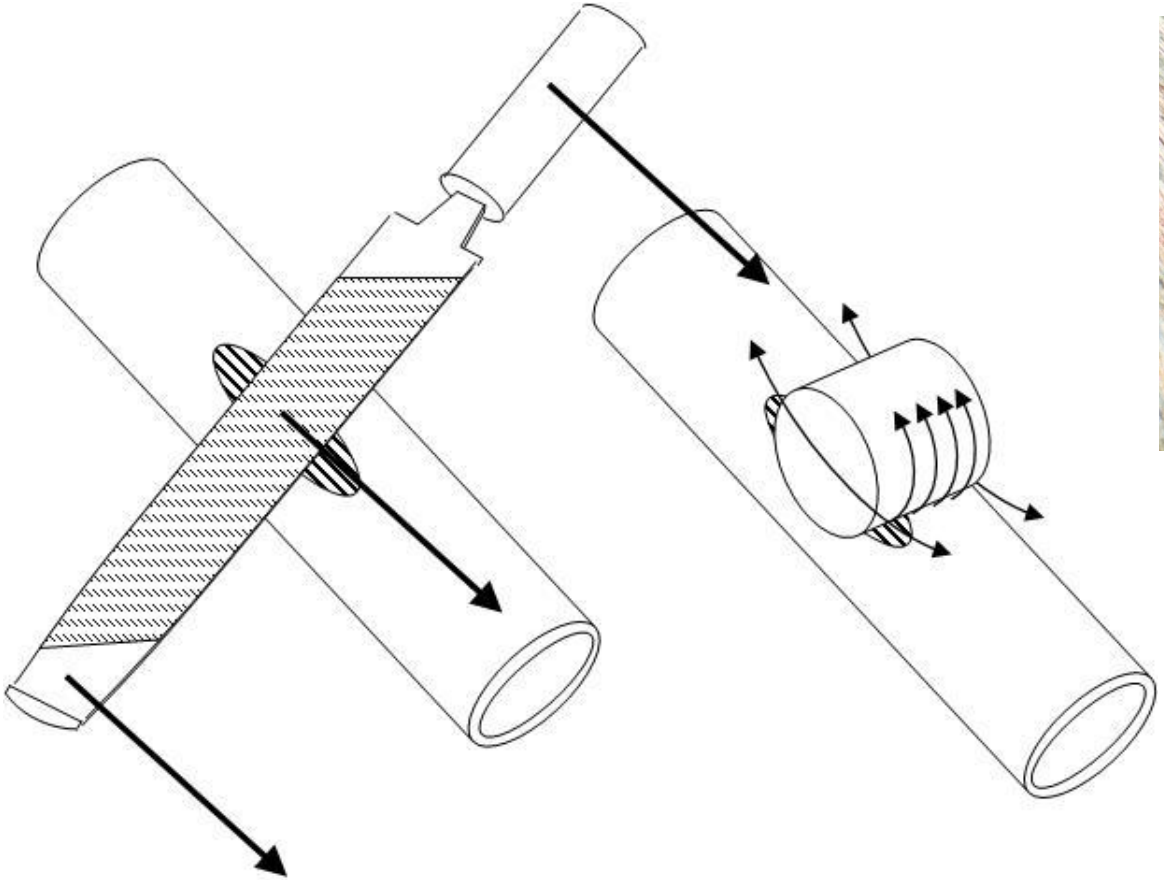
Longitudinal notch

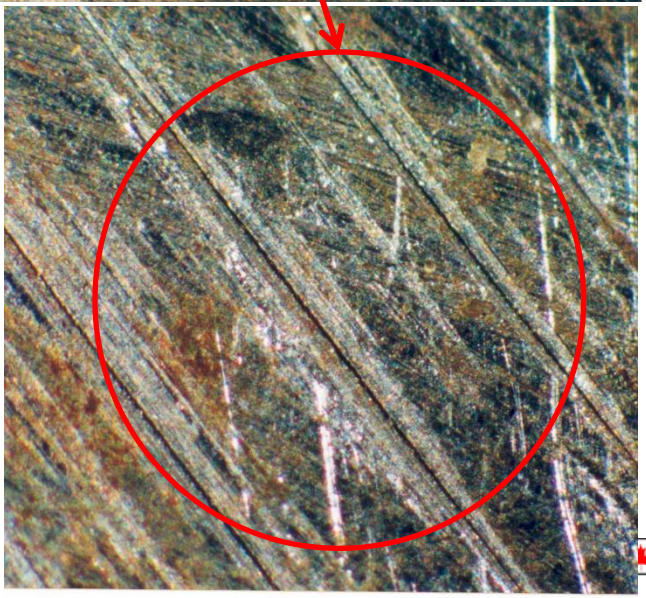


Detectable notches with background “white” noise

SURFACE REPAIR PROCEDURE FOR COILED TUBING

(Ref. Tipton, S. M. et al, "Repairing Surface Flaws in Coiled Tubing", SPE/ICoTA, 10th European Coiled Tubing and Well Intervention Round Table, Nov. 16-17, 2004)

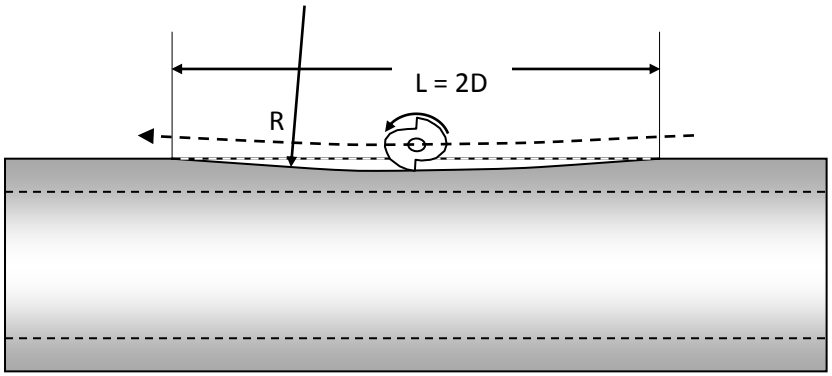




Direction of filing and surface finish is very important.

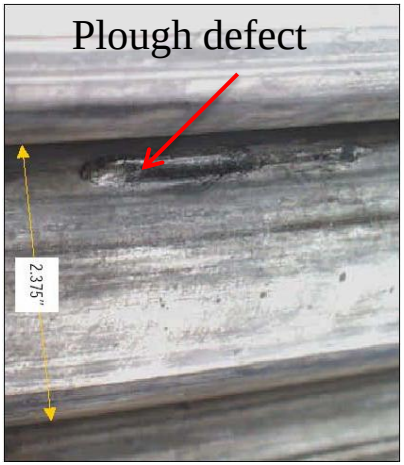
Visible grind marks can lead to early fatigue

SIMULATED SURFACE REPAIR OF PLOUGH MARK IN 60.3 X 3.9 mm



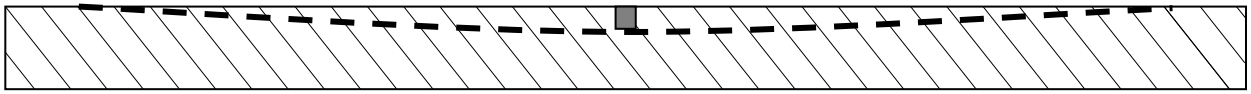
D = CT diameter

Tested at high pressure,
4840 psi (33.4 MPa)

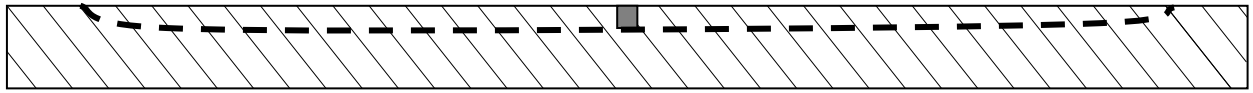


Transverse cutter marks
Life: 14 cycles

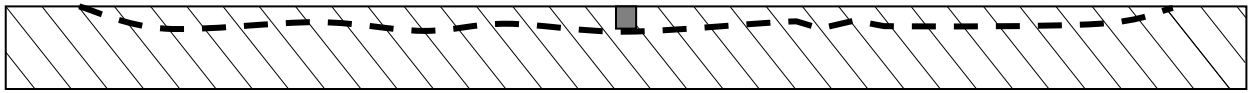
Optimum profile: gradually increasing wall thickness away from defect

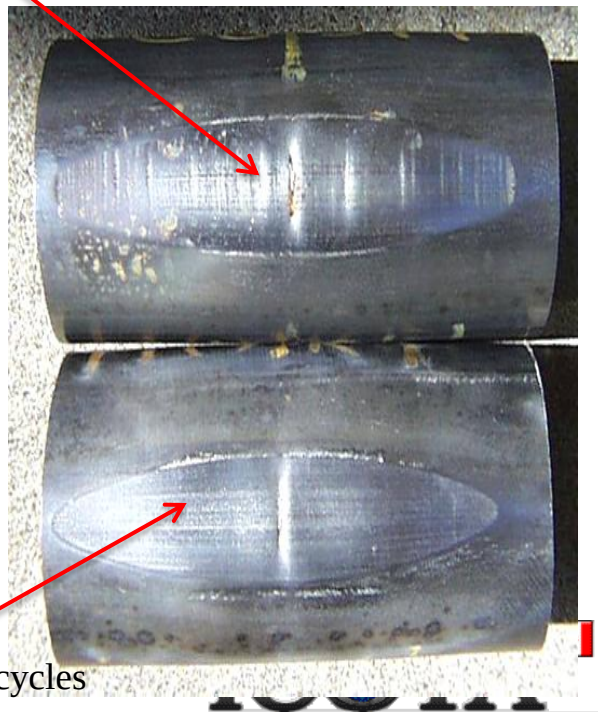


Poor profile: too much wall thickness removed along tubing length



Poor profile: abrupt changes/waviness in wall thickness

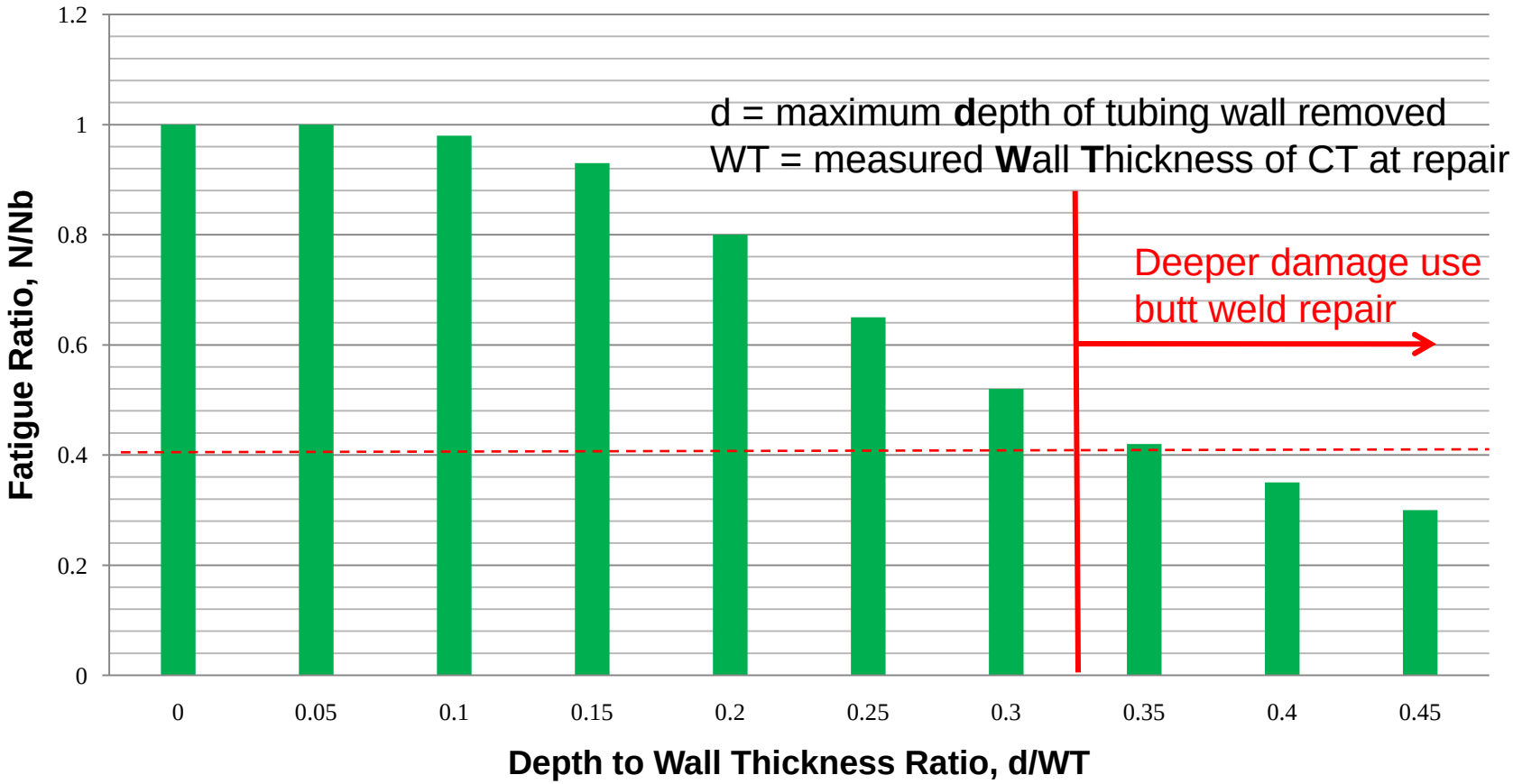




Longitudinally filed
smooth surface, Life: 28 cycles

FATIGUE RECOVERY OF SURFACE REPAIRS IN COILED TUBING

Ref. Tulsa University CT Materials Research Consortium (TUCTMRC)

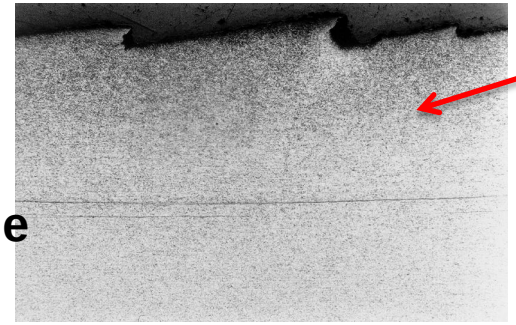


N = Fatigue cycles to failure with surface repairs

N_b = Fatigue cycles to failure without damage (baseline fatigue)

EXAMPLES OF CT MECHANICAL DAMAGE SUITABLE FOR SURFACE REPAIR

“Plough” marks



Isolated and shallow damage

“Sawtooth” marks