

# JOHNSON MATTHEY

HYDROGEN & SYN GAS TECHNICAL TRAINING SEMINAR

FAILURE MECHANISMS & INSPECTION TECHNIQUES IN STEAM METHANE REFORMERS

NOVEMBER 28<sup>TH</sup> - 30<sup>TH</sup>, 2023

FLORIDA, UNITED STATES



- Innovative Processes
- Reliable Products
- Technology Leader
- System Partner
- Solution Provider

**Employees**

600 Worldwide

**Export**

80 %

**Annual Revenue**

> 100 Mio. EUR

## FIVE SPECIALIZED BUSINESS UNITS



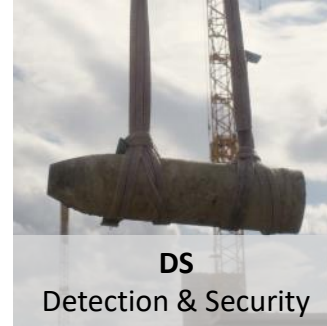
- Testing of semi-finished products such as wire, rod, tube and sheet metal for the smallest defects



- Component testing for surface defects and cracks
- Material testing to avoid material mix-ups
- Qualification of materials



- Mobile testing devices for the detection of material fatigue and cracks caused by abrasion
- Mobile hardness testing of metallic components



- Detection of contaminated sites
- Archaeological explorations
- Detection of magnetic fields



- Non-destructive testing of reformer tubes in chemical plants



**Metals Industry**



**Automotive**



**Aeronautics & Aerospace**



**Medical Technology**



**Geophysics**



**Petrochemical Industry**



**Oil & Gas Industry**



**Fasteners & Connectors**

## OUR MOST IMPORTANT MEASURING AND TESTING METHODS

### Eddy Current Technology



Testing of metallic parts for defects like cracks, voids, and other defects

### Magnetic Inductive Technology



Determination of the material properties of semi-finished products, soft magnetic materials, hard metals and components using the hysteresis curve

### Ultrasonic Technology



Detection of defects and inhomogeneities in plates and tubes as well as wall thickness measurement for tubes

### Magnetic Flux Leakage Technology



Testing of metallic semi-finished products for surface defects using magnetic flux

### Heat Flux Thermography



Testing of steel billets and -tubes for surface defects by infrared cameras

### Magnetometer Technology



Measuring disruptions in the Earth's magnetic field caused by ferromagnetic objects

### UCI Hardness Method



Minor-destructive, mobile hardness measurement of metallic materials

## TOPICS TO BE DISCUSSED

- Foerster Group / MP - MP merged with the Foerster Group in January 2021
- Foerster Group / MP Activities / Services - Institut Dr. Foerster GmbH & Co. KG (IFR)
- Latest Acquisitions are US Thermal Technology (USTT) & Quest Lotis & Mantis Technology
- External Inspection of Reformer Tubes - Laser Eddy-current Outside (LEO-SCAN)
- Internal Inspection of Reformer Tubes - Laser Eddy-current Inside (LEO-iScan)
- Failures - Cause and Effect Relations
- Baseline Inspection
- Inspection Results & Documentation
- Remaining Life Assessment
- Summary

- History:
- 1950 Prof. Foerster developed the scientific basis of the electromagnetic test methods
  - 1963 the first magnetic field measuring equipment from Foerster was installed in a satellite. The Mariner II was researching the magnetic field of the planet Venus using this technology.
  - There is also a Foerster probe on the moon.
  - Professor Foerster received the highest distinction from NASA in 1992 for his work. ([www.foerstergroup.de/History](http://www.foerstergroup.de/History))



FRIEDRICH FOERSTER

1948

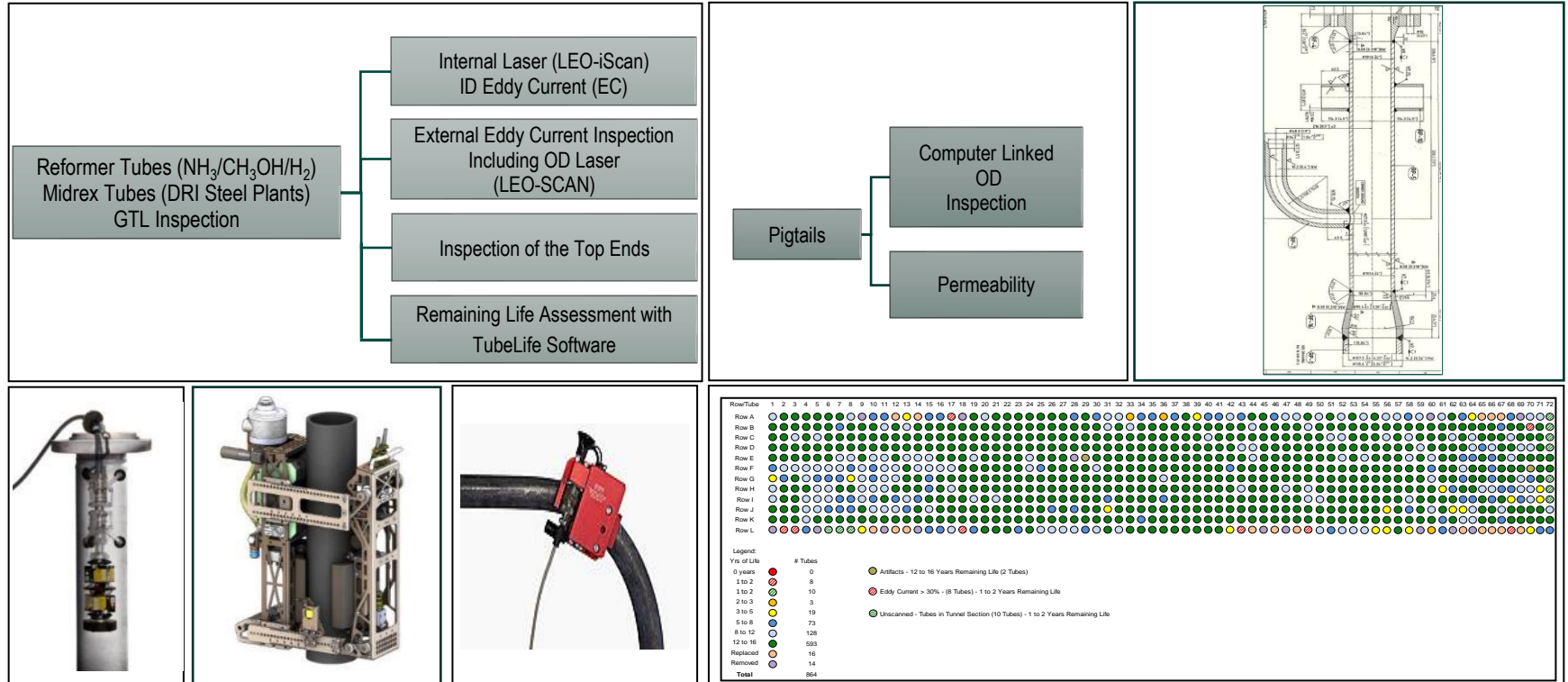




**Head Office,**  
in Reutlingen, Germany

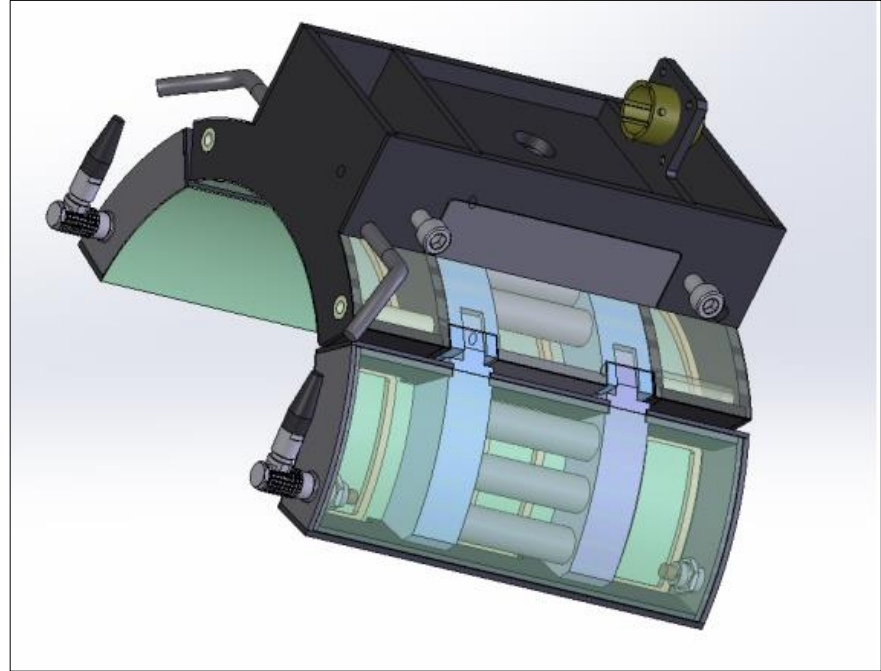
**2023**





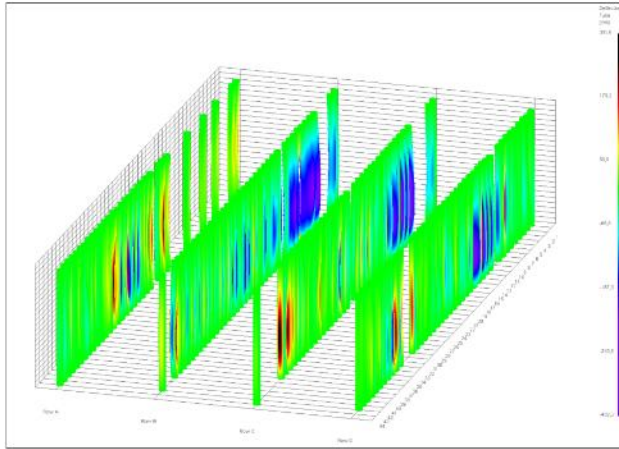


ID ROTATING PROBE 360° COVERAGE

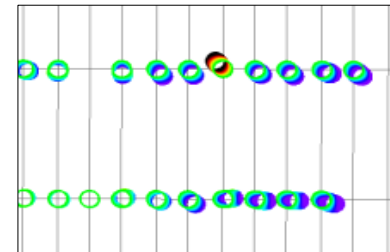
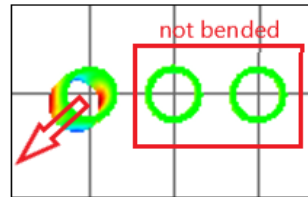
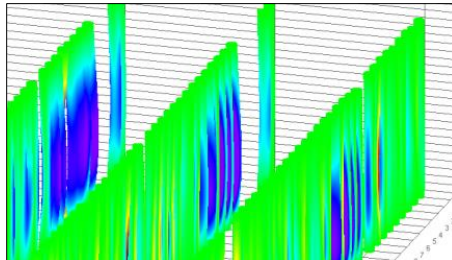
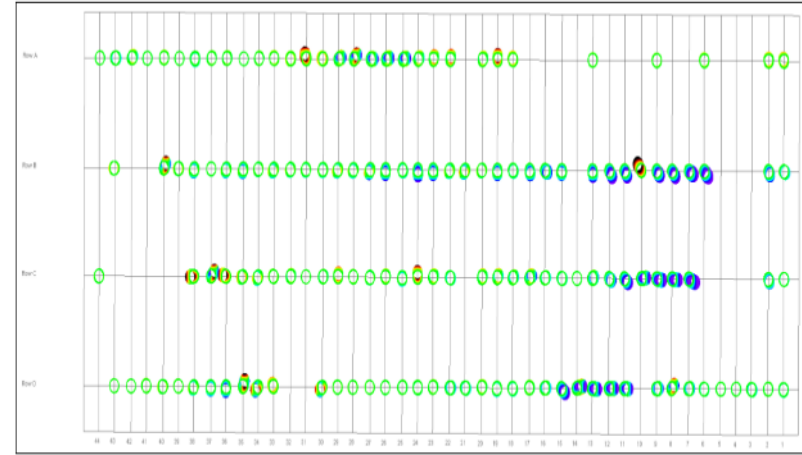


360° EDDY CURRENT PROBE COVERAGE OF THE REFORMER TUBE OD

# LATEST DEVELOPMENTS FOR REFORMER TUBE TESTING



INCLINOMETER





Global contracts with companies like Air Liquide, Linde / Praxair, BAPCO, OQ, OCI, Air Products. Foerster accounts for more than 85% of the world market share on Reformer Tube Testing.

- 400 Customers
- 60 Countries
- More Than 200 Inspections Annually

Shell, Chevron, ExxonMobil, BPAmoco, ConocoPhillips, Valero, PCS, Air Liquide, Air Products, Praxair, Linde, Repsol, Metor, Petronas, Syncrude, Suncor, BASF, IPSL, Bayer, Petrobras, CF Industries, Agrium, Koch, S-Oil, SK Energy, Formosa, Pemex, Celanese, Yara, Methanex, Supermetanol, etc..

Sabic, Safco, Al Bayroni, Ar Razi, IBN Sina, Hadeed, Maaden, Aramco, GPIC, Qafco, Sipchem, OPSL, Salalah Methanol, Qafac, Omifco, Sirte Oil, Mopco, Midor, Abu Qir, AMOC, AlexFert, Helwan, EBIC, OryxGTL, Qasco, KNPC, PIC, SUICI, Fertil, Takreer, Kharg, Fanavaran, Chemanol, Petro Rabigh, Sorfert, etc.

MRPL, BORL, IFFCO, Pupuk Kaltim, Kaltim Methanol, Kaltim Perna, Pupuk Kujang, Pertamina (Dumai / Balongan / Balikpapan), Panca Amara Utama, Formosa, JXTG, etc..

SKW, BASF, Bayer, Lotos, Grupa Azoty, PKN Orlen, PCK Schwedt, Degussa, Evonik, Caloric, Hellenic Refinery, Holborn, Solvay, Gunvor, Miro, Shell Wessling, etc..

# NDT SERVICE FOR STEAM METHANE REFORMERS

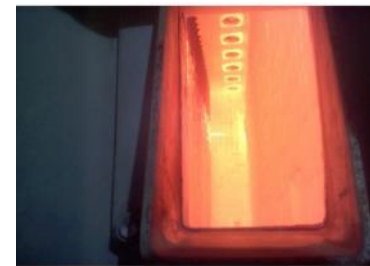
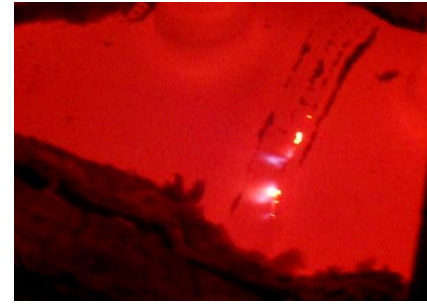


- Burner Operation
- Catalyst Issues
- Spring Support Issues
- Flue Gas Distribution Issues
- Overheating Issues
- TMT Related Issues
- Tunnel Brick Proximity
- Tunnel Brick Design
- Etc.

## LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES



## MP Successful External Eddy Current Technique



In Service Tube and Header Failures

## LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES



## MANTIS & LOTIS TECHNOLOGY

### MANTIS™ External Crawler Inspection Technology

- External tube crawler system with creep strain detection sensors
- Ideal for use between catalyst changes
- Maximizes efficiency and accuracy
- Rapid deployment and inspection rate
- Fits into tight spaces, currently 1" clearance (25 mm) between tubes required, bowed tubes are less of a challenge
- Typically 15,000 strain readings per tube at 0.25" intervals along tube length



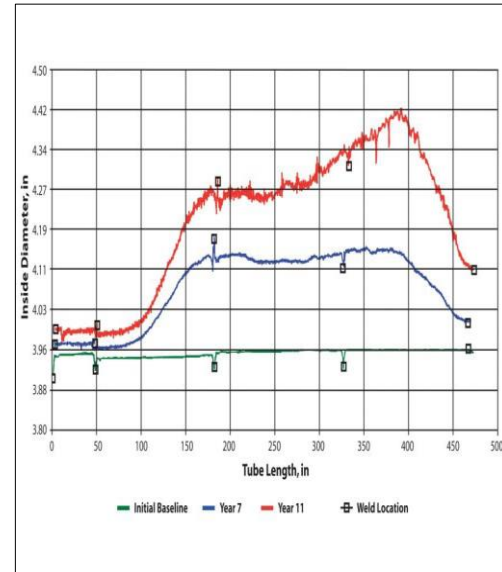
## MANTIS & LOTIS TECHNOLOGY

### MANTIS™ External Crawler Inspection Technology

- Robust lightweight design and portability
- The MANTIS produces results in several formats including diametrical line graphs, 3-Dimensional (3D) single tube and full reformer tube color graphics.
- The automated tube crawler system employs an automated computer-controlled motion system that provides synchronization of the sensors and the associated axial and circumferential positions, thus enabling the computer to reconstruct an accurate topographical map of the target surface.



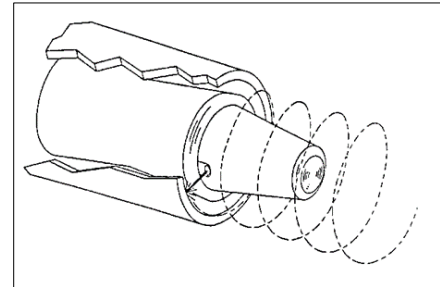
MANTIS CRAWLER



## MANTIS & LOTIS TECHNOLOGY

### LOTIS® Examination Method

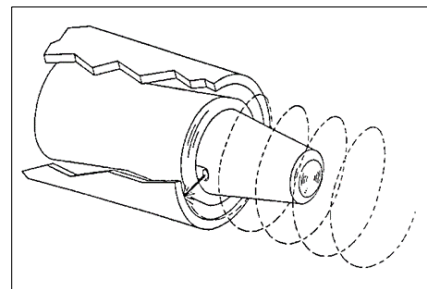
- Laser-Optic Tube Inspection System (LOTIS) with laser-mapping probe.
- The laser-based surface mapping system utilized by LOTIS is based on the principle of optical triangulation.
- LOTIS was originally designed for the inspection of military marine boilers and has been used for regular inspections since 1987.
- The probe (see below) projects a small laser beam (typically 0.5 mm (0.020 in.) in diameter) onto the target surface at near normal incidence.
- Receiving optics focus this reflection of light on a single-axis, lateral-effect photo detector.
- Because the transmitting and receiving optics are at different angles, changes in target proximity are converted to lateral movement on the photo detector.



## MANTIS & LOTIS TECHNOLOGY

### LOTIS® Examination Method

- By calibrating the system for non-linearities that are introduced by the optical configuration and the photo detector, the sensor can provide precise radius measurements of the inside surface of the tube at each sample point.
- The optics housing rotates at 1,800 rpm, depending on the desired mapping resolution, and is drawn through the tube so that a helical sampling pattern is generated (see picture).
- The system typically samples several hundred thousand data points during an inspection and therefore, a very detailed map of the inside surface of the tube is generated.
- The LOTIS produces results in several formats including diametrical line graphs, 3-Dimensional (3D) single tube or full reformer tube color graphics.
- Upon completion of the LOTIS inspection of each tube, the diametrical data is immediately ready for viewing and analysis. No post processing is necessary.



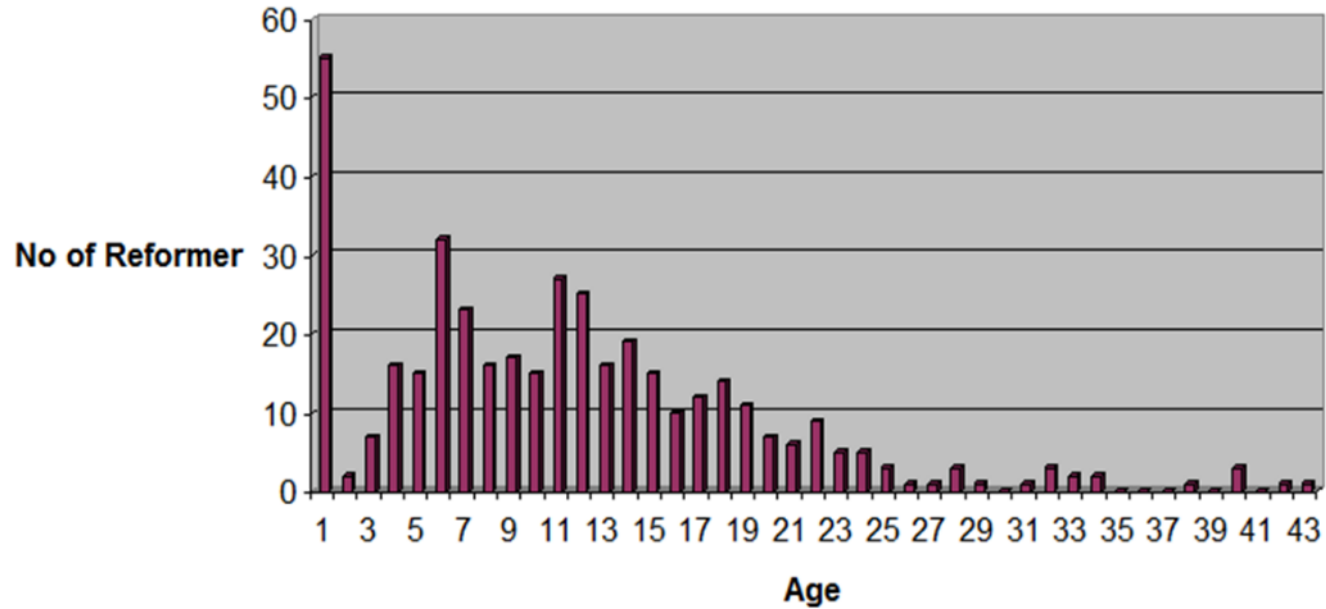
## LEO - SCAN (Laser Eddy Current Outside Scanning of Reformer Tubes)



- Proven, Accurate and Reliable
- EC probes penetrate up to 23.5 mm
- Dual axis laser measurement
- Starting point is 20 mm from the floor
- High Speed - 250 tubes / shift
- Inspection with or without catalyst

# LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Average Age of the Tubes in 400 Reformers Sampled Since 2012

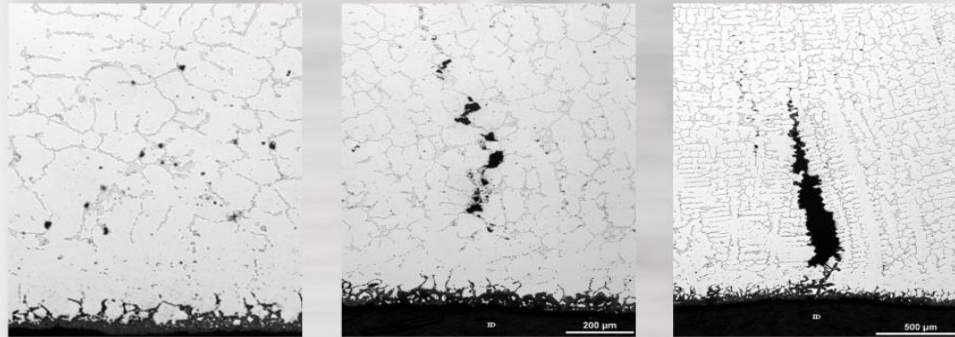


### Creep Damage



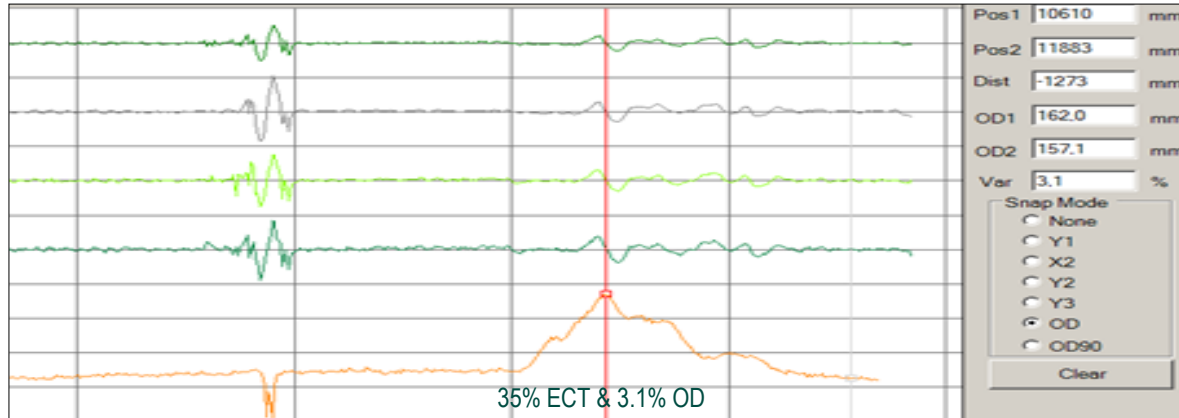
LEO-SCAN will detect damage

LEO-SCAN will detect damage



Creep damage

## CRACKING AND EXPANSION CORRELATED AT NORMAL CREEPING



CREEP DAMAGE OCCURS OVER DESIGN LIFE TIMESCALES!

VGB-TW-507 - MICROSTRUCTURE RATING CHARTS FOR EVALUATING CREEP DAMAGE

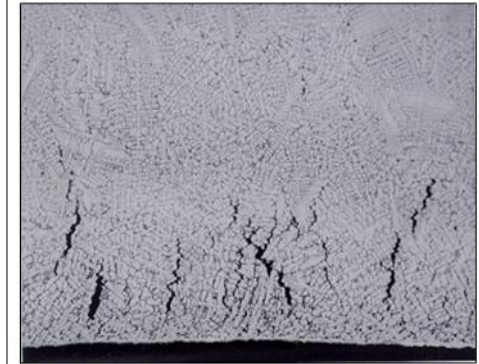
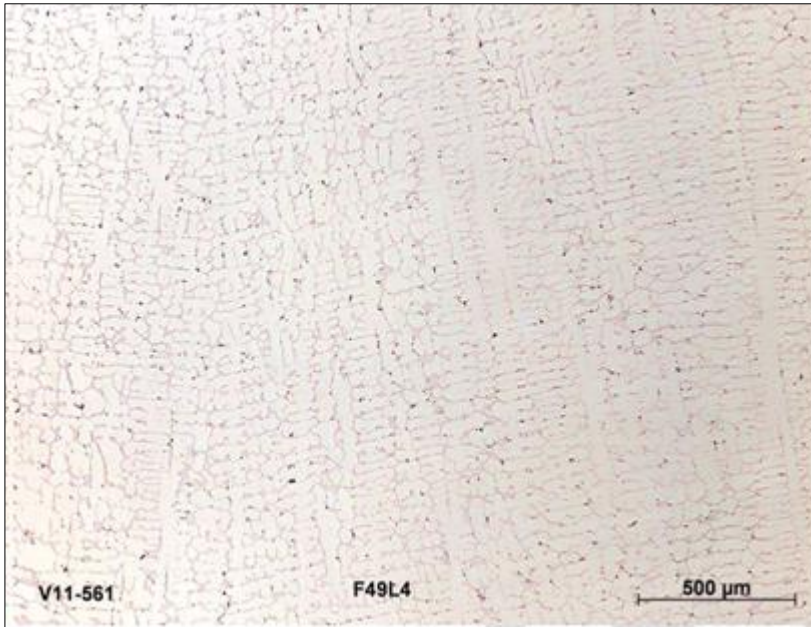


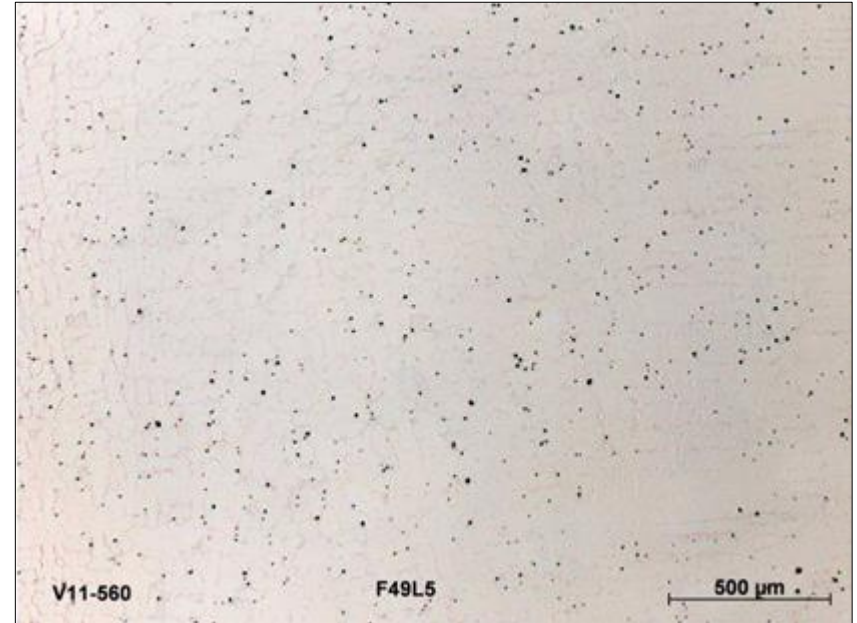
Figure 1. Photomicrograph of creep damage near the ID of Terra tube A-3  
Magnification 25 X Etchant: Oxalic Acid

Class 0	: As received, without thermal service load;
Class 1	: Creep exposed, without cavities;
Class 2A	: Isolated cavities;
Class 2B	: Numerous cavities without preferred orientation;
Class 3A	: Numerous oriented cavities;
Class 3B	: Chains of cavities and/or grain boundary separations;
Class 4	: Micro cracks;
Class 5	: Macro cracks.

## CREEP DAMAGE CLASSIFICATION

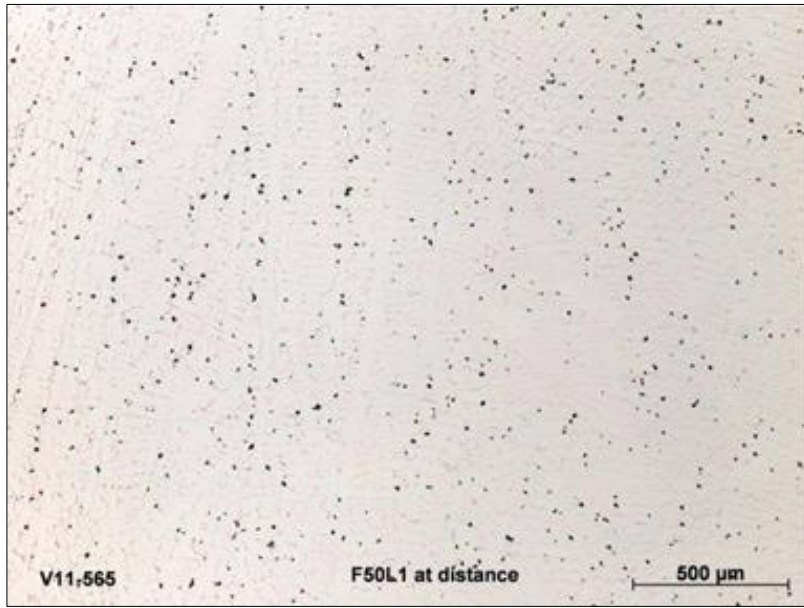


CREEP CLASSIFICATION - NO CREEP DAMAGE - CLASS 1

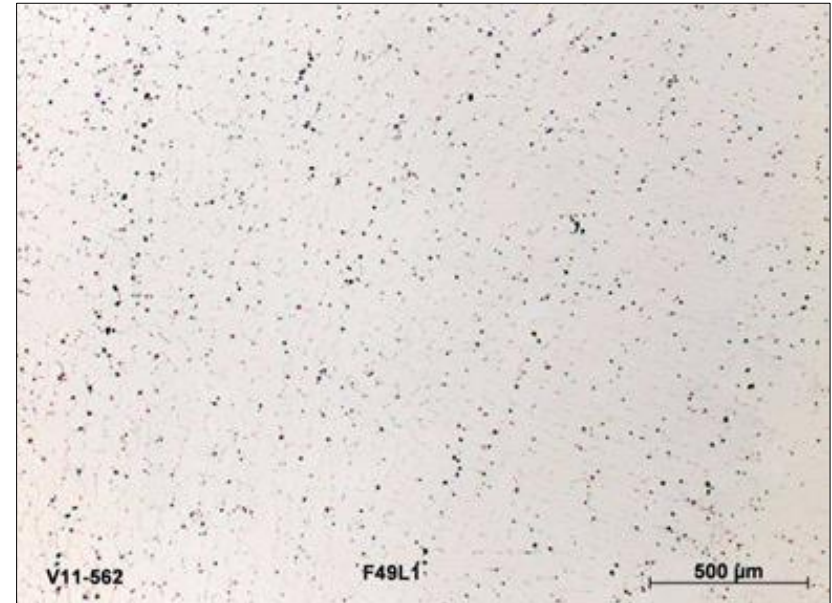


CREEP CLASSIFICATION – CREEP DAMAGE (BLACK SPOTS) - CLASS 2A

## CREEP DAMAGE CLASSIFICATION

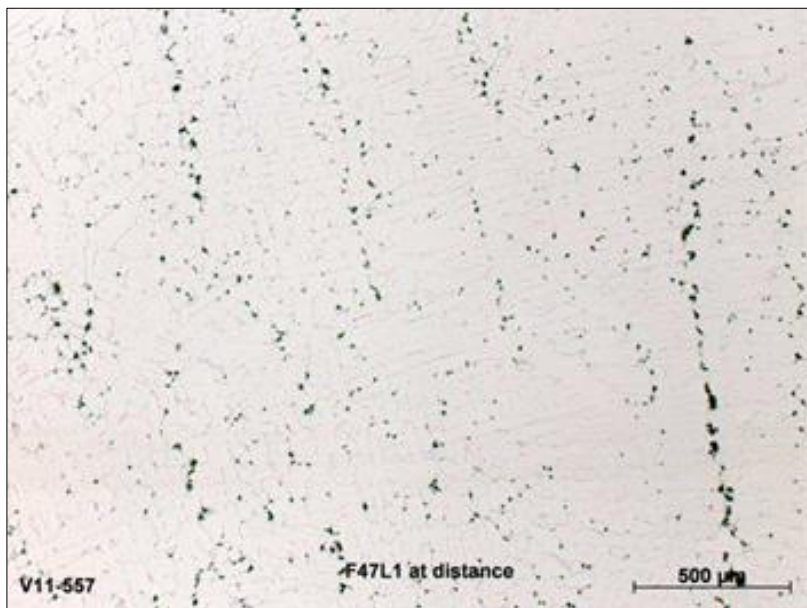


CREEP CLASSIFICATION - CREEP DAMAGE (BLACK SPOTS) - CLASS 2B

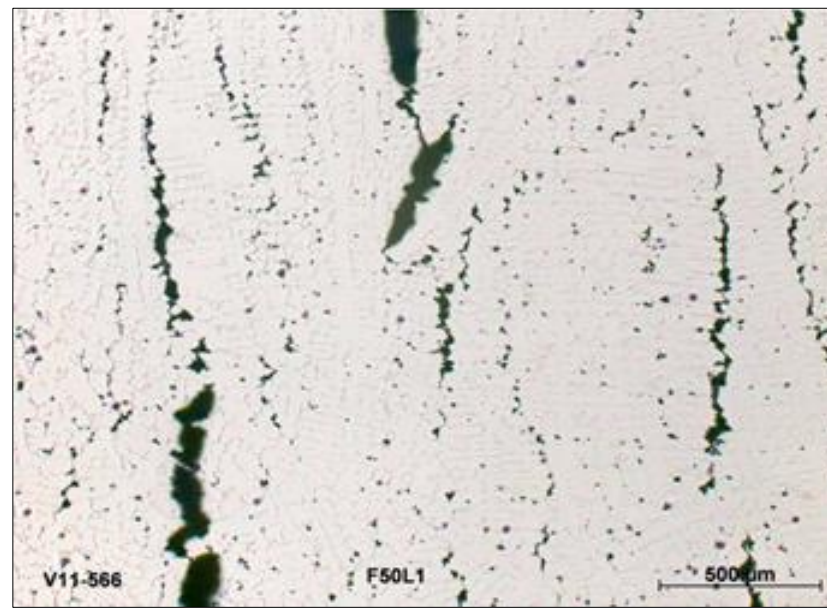


CREEP CLASSIFICATION - CREEP DAMAGE (BLACK SPOTS) - CLASS 3A

## CREEP DAMAGE CLASSIFICATION



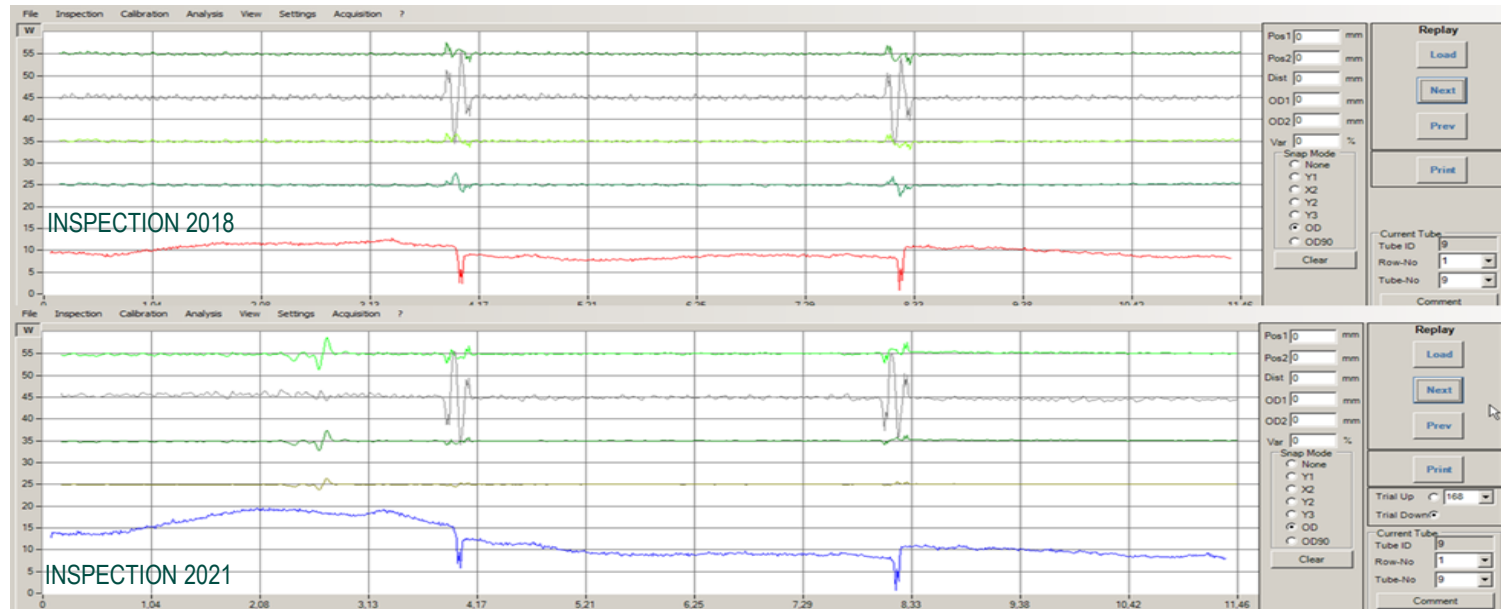
CREEP CLASSIFICATION - ALIGNED CAVITIES, MICRO CRACKS - CLASS 3B - 4



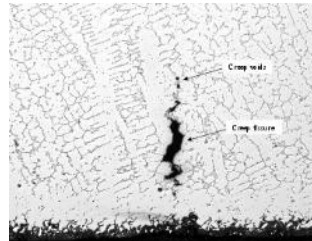
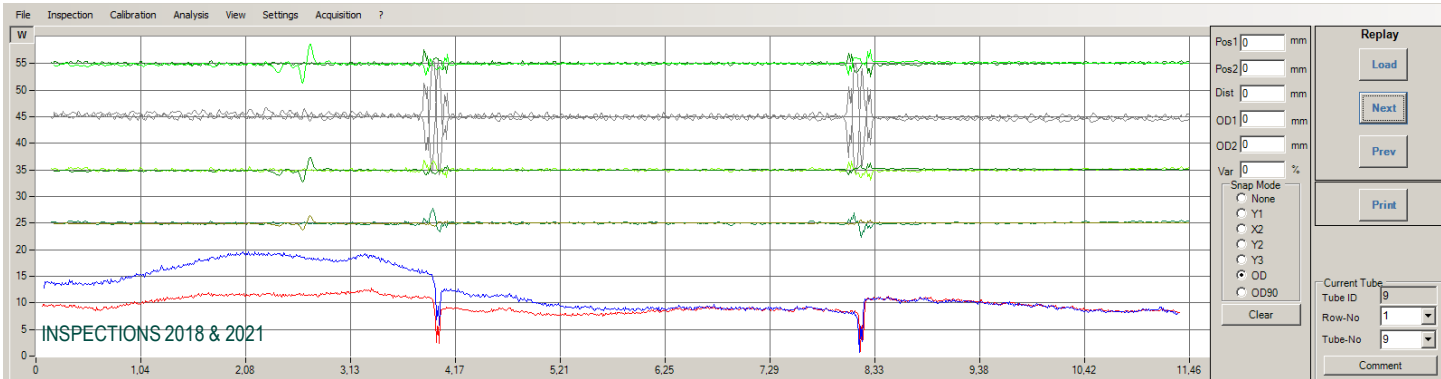
CREEP CLASSIFICATION - MACRO (OPEN) CRACKS - CLASS 5

## Foerster Successful External Eddy Current Technique

### CRACKING & EXPANSION CORRELATED AT NORMAL CREEPING



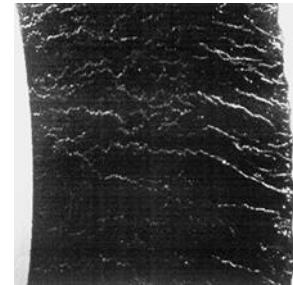
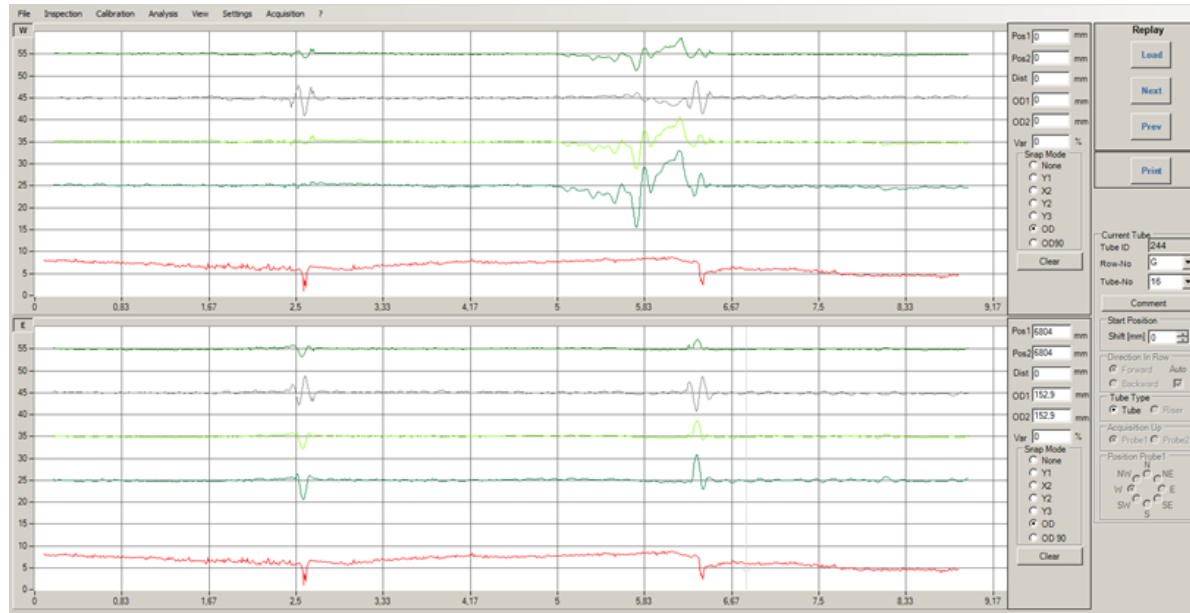
## Foerster Successful External Eddy Current Technique



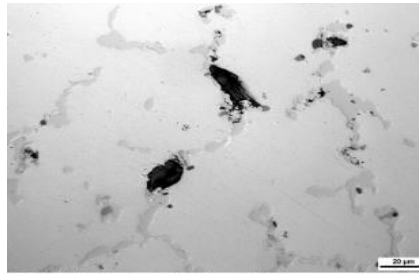
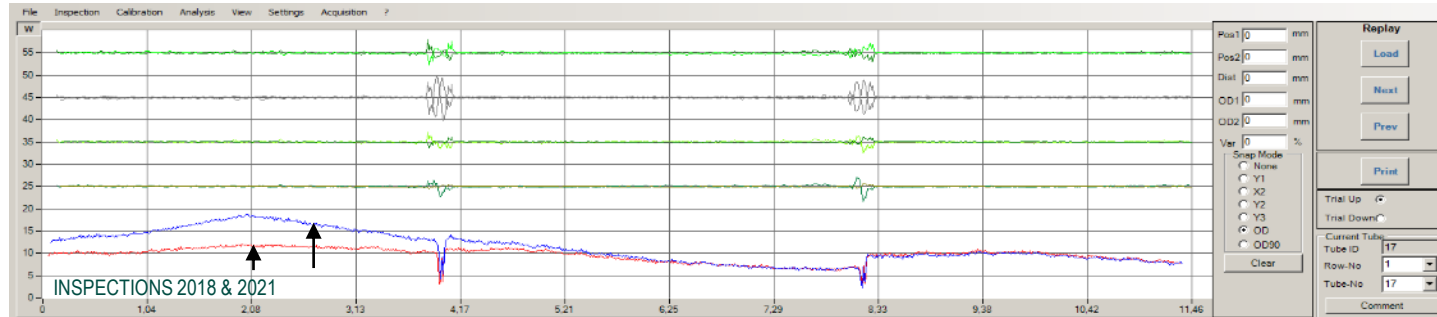
Cracking and Expansion Correlated at Normal Creeping

## Foerster Successful External Eddy Current Technique

CRACKING WITH LITTLE OR NO EXPANSION (EXAMPLE: THERMAL SHOCK)

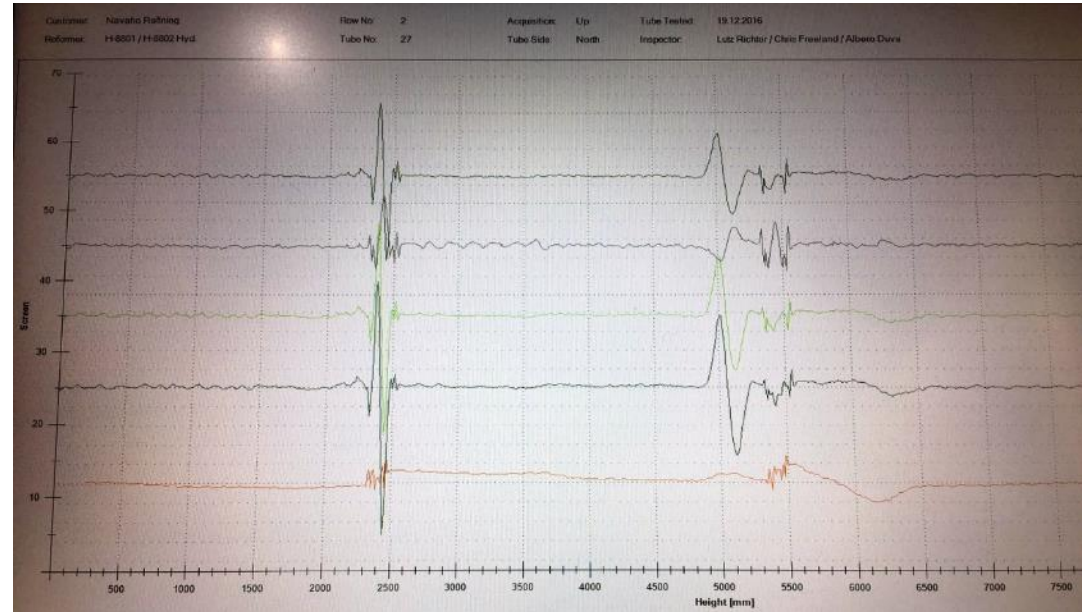
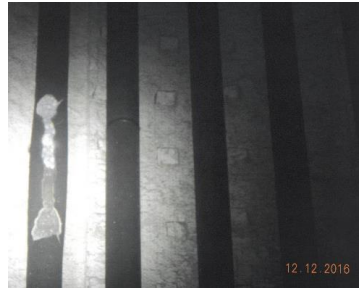


## Foerster Successful External Eddy Current Technique



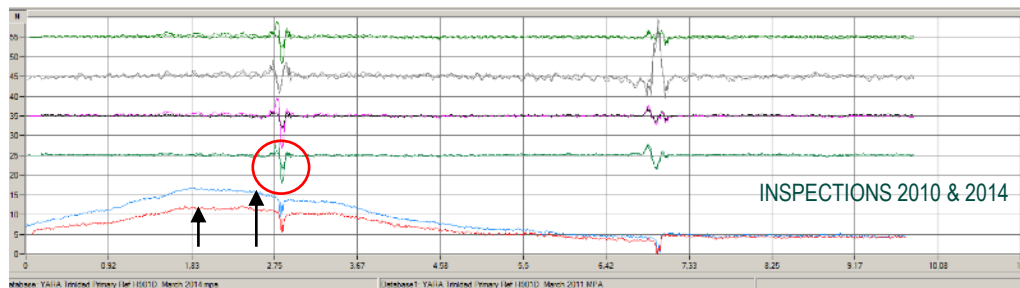
Expansion with Little or No Cracking

## Foerster Successful External Eddy Current Technique

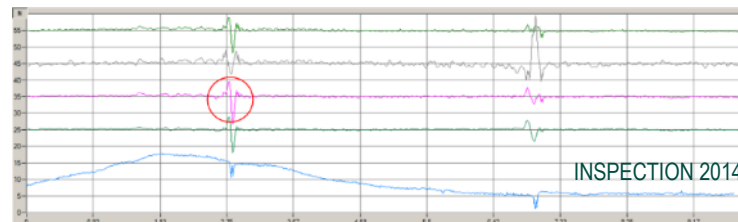
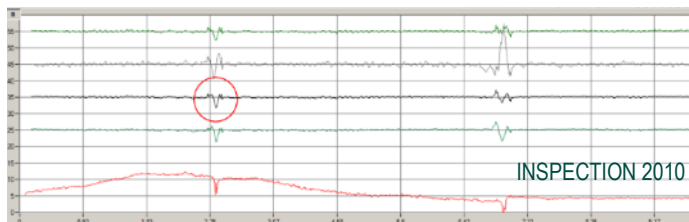


Little or No Expansion with Significant Cracking

## Foerster Successful External Eddy Current Technique

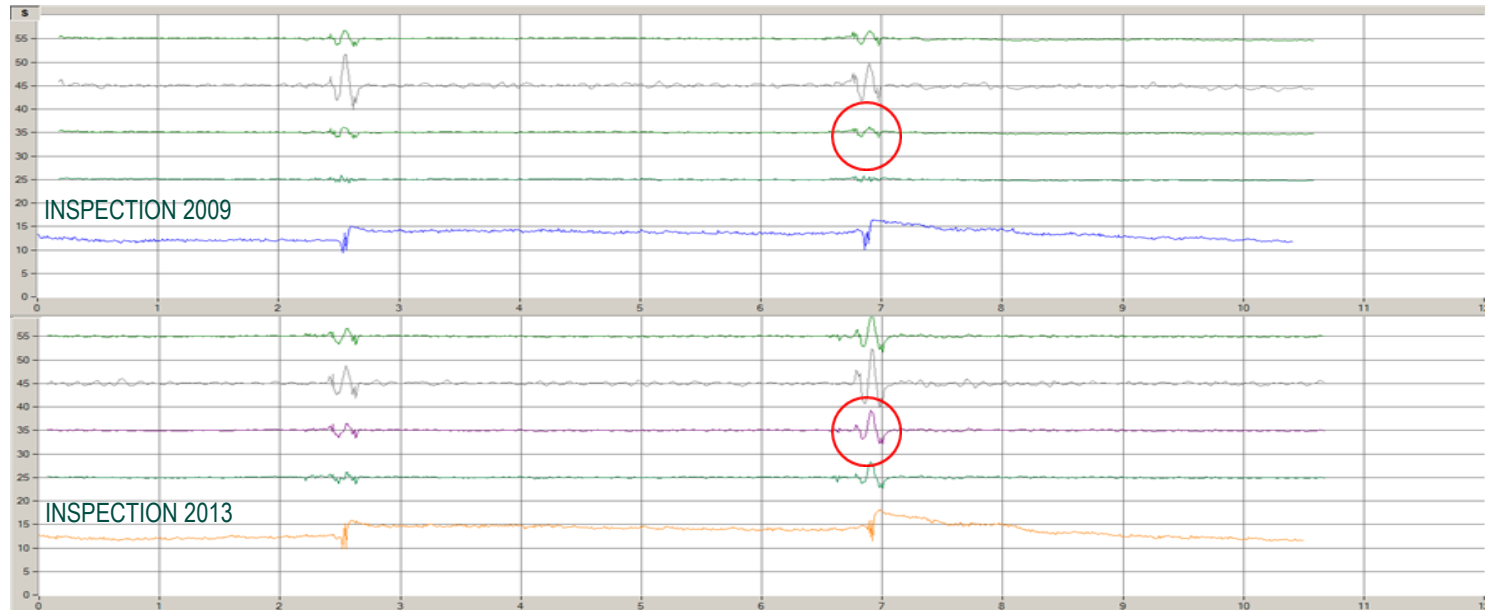


### LONGITUDINAL WELD DEFECTS



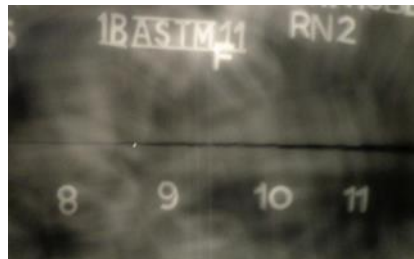
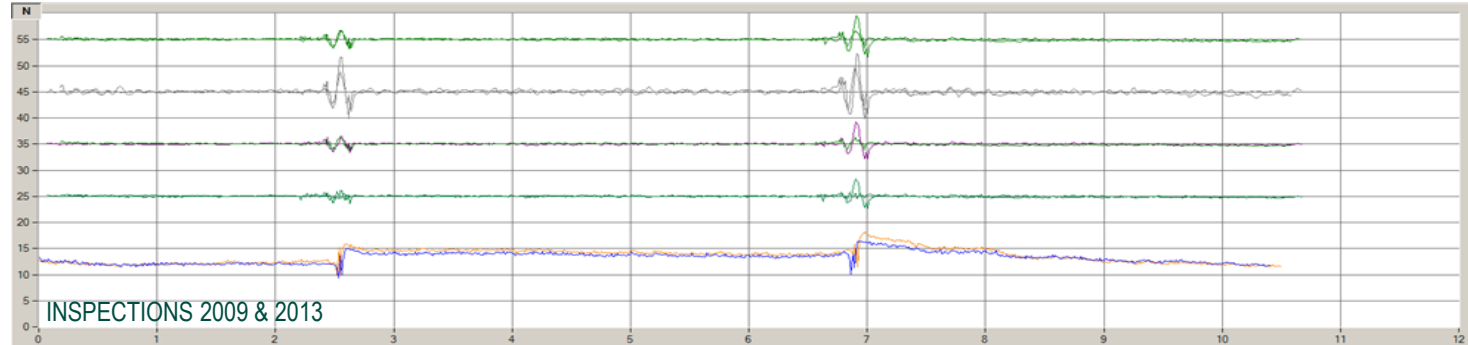
## Foerster Successful External Eddy Current Technique

### CIRCUMFERENTIAL WELD DEFECTS

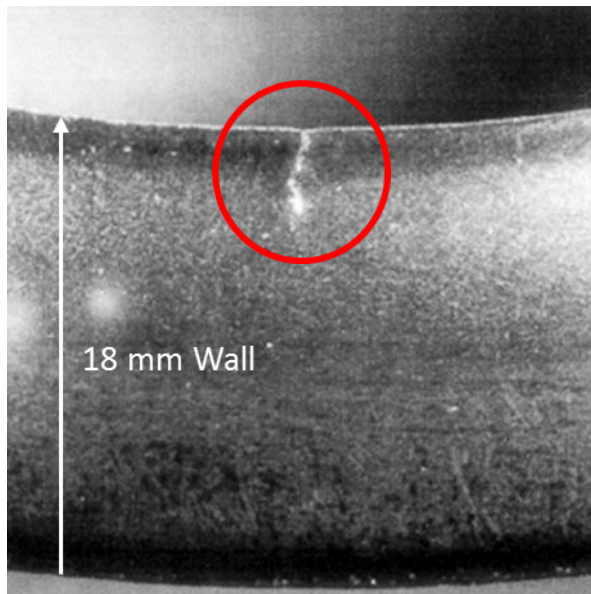


## Foerster Successful External Eddy Current Technique

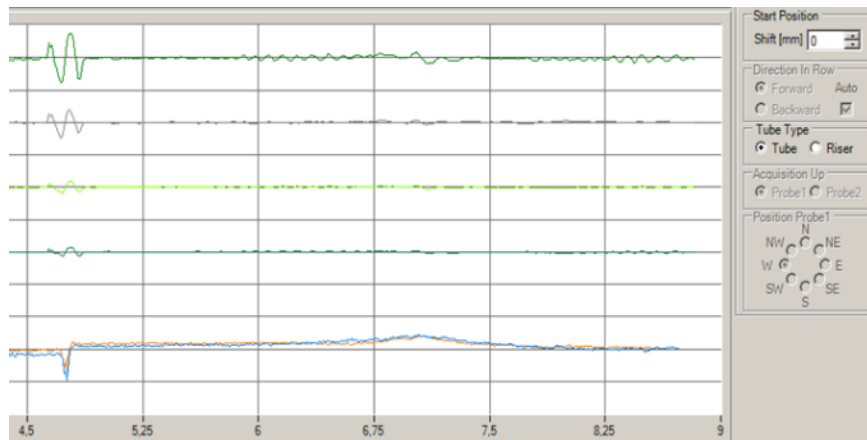
### CIRCUMFERENTIAL WELD DEFECTS



## Foerster Successful External Eddy Current Technique



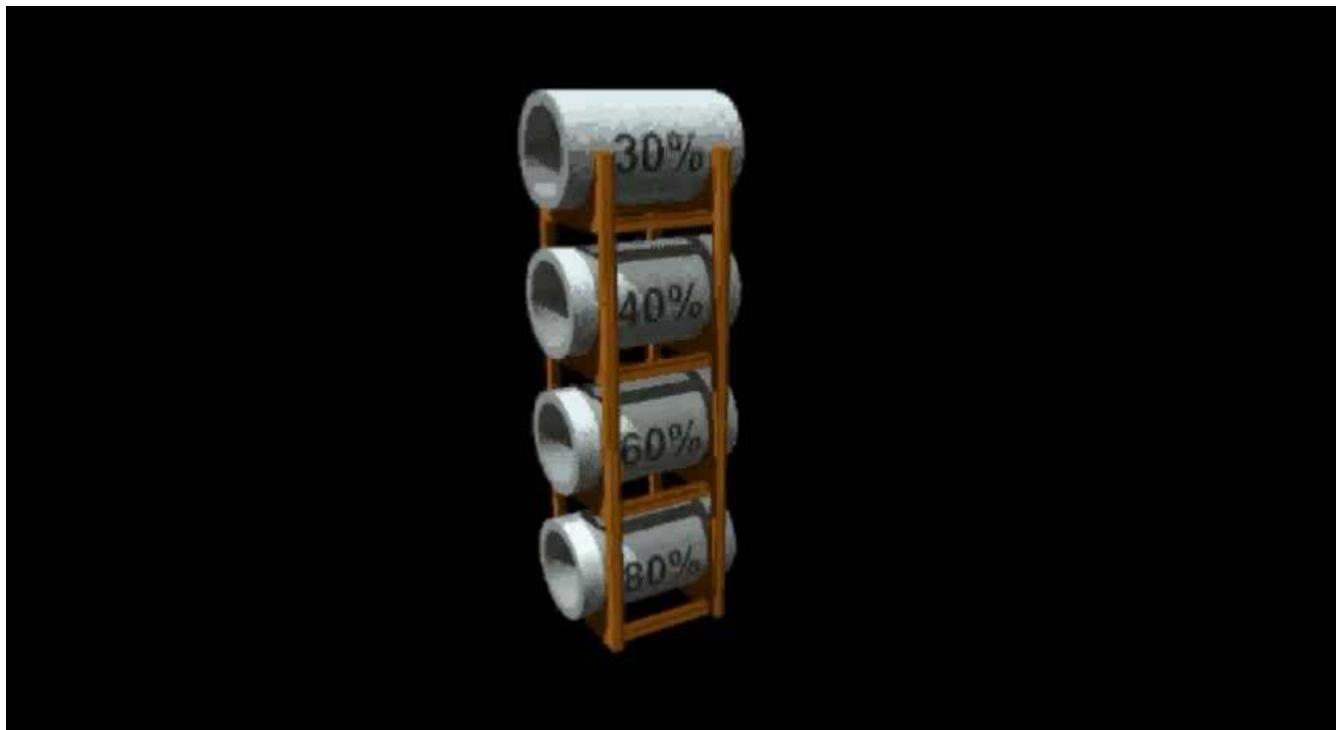
DEFECTS CLOSE TO THE INSIDE DIAMETER (ID)



## LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES



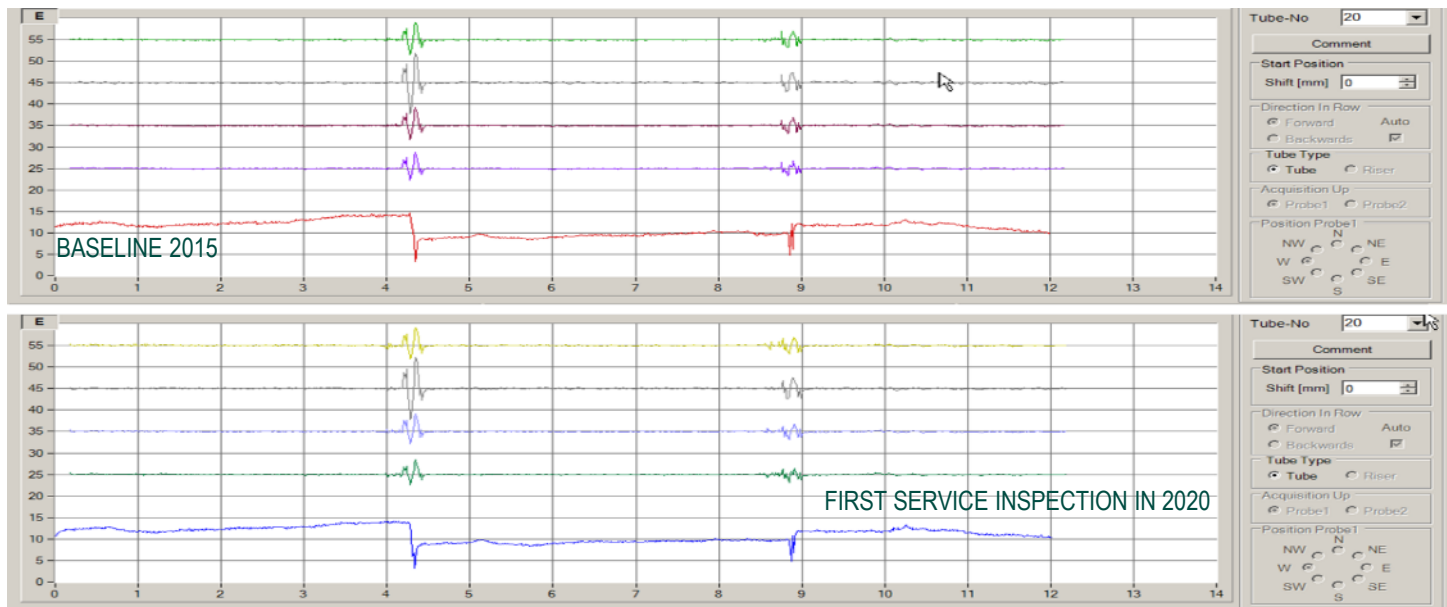
## LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES



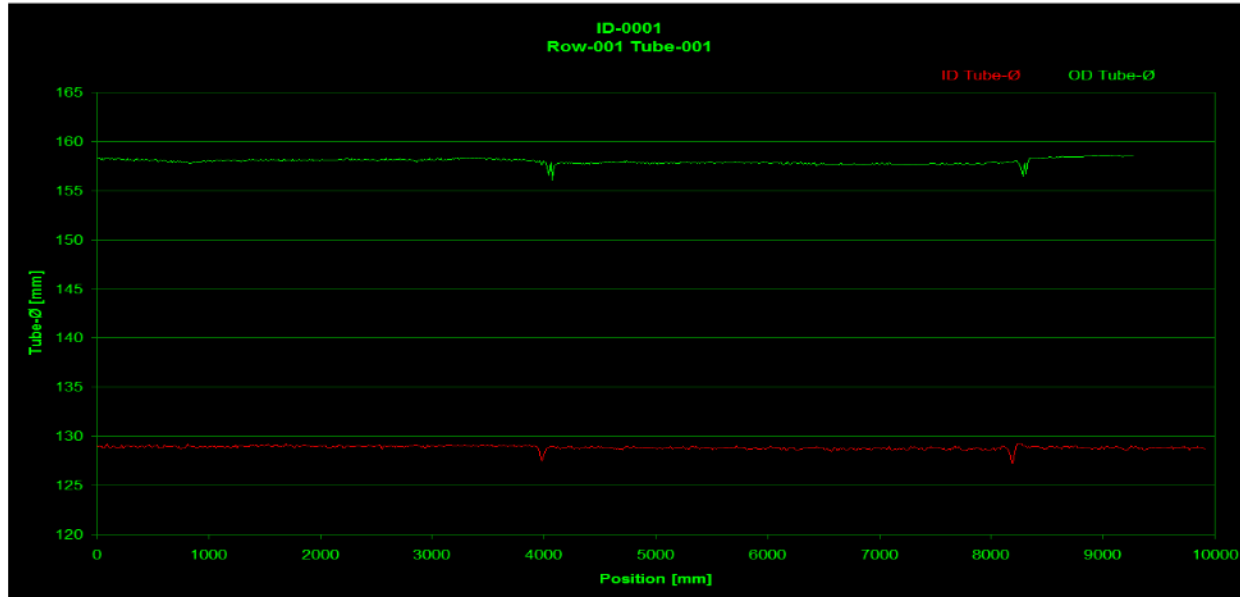


# BASE LINE INSPECTION

## Foerster Successful External Eddy Current Technique



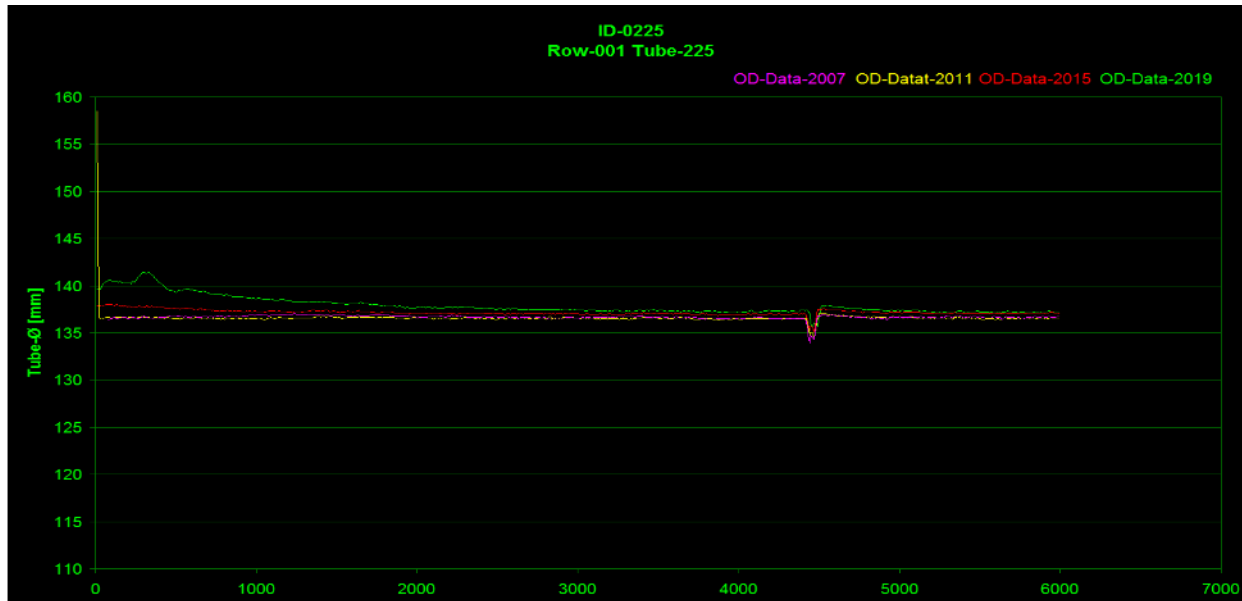
## INSIDE DIAMETER / OUTSIDE DIAMETER DATA



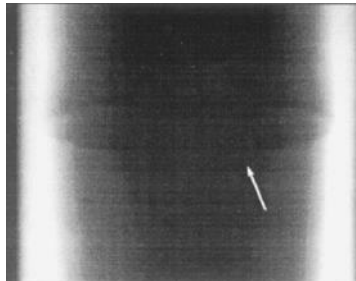
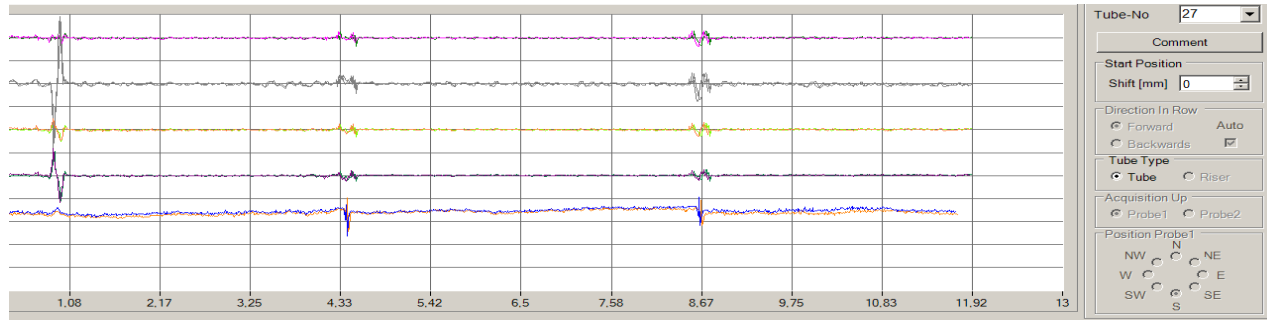
## SEVERAL INSPECTIONS OVERLAYED - NO DAMAGE



## SEVERAL INSPECTIONS OVERLAYED - DAMAGE OBSERVED



## Foerster Successful External Eddy Current Technique



### Foerster Successful External Eddy Current Technique



Manufacturing Artifacts



Manufacturing Artifacts

### Foerster Successful External Eddy Current Technique



Manufacturing Anomalies

Manufacturing Anomalies

### Foerster Successful External Eddy Current Technique

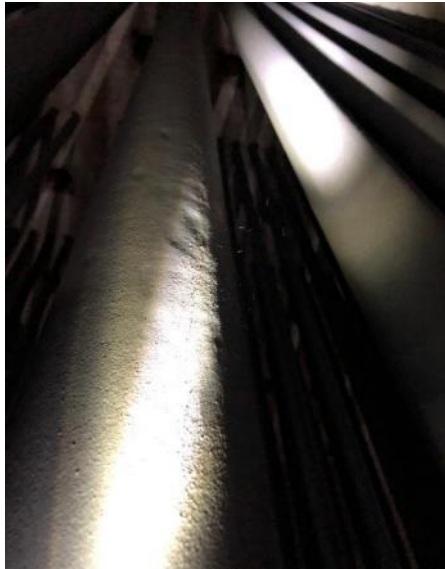


Manufacturing Anomalies



Manufacturing Anomalies

## Foerster Successful External Eddy Current Technique



### Foerster Successful External Eddy Current Technique



Manufacturing Anomalies

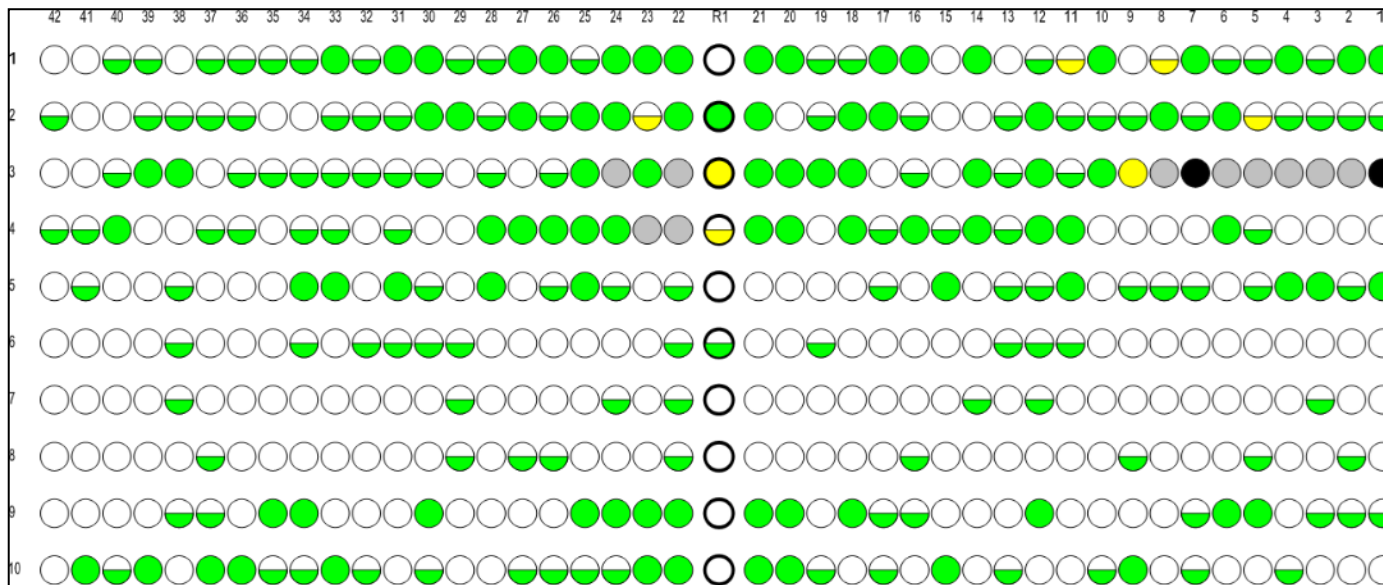


Manufacturing Anomalies

[illegible]

## Documentation

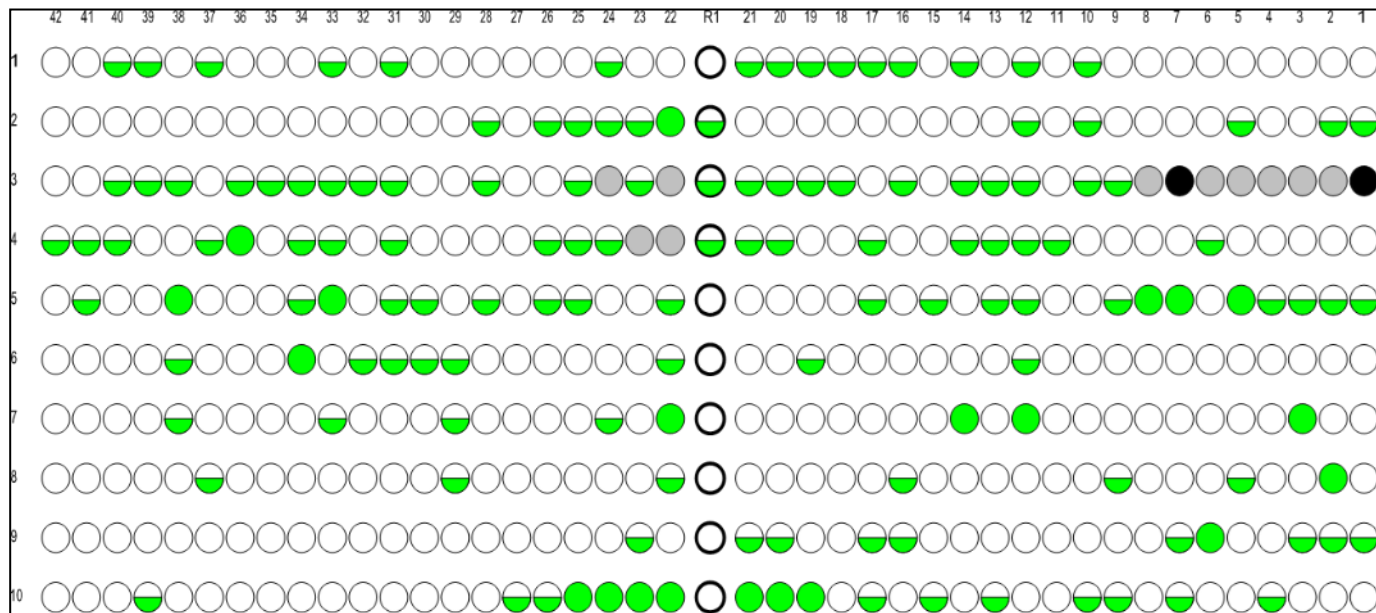
### Eddy Current Indications



Color Definition		
#	Colors	Cracks Expansions
1	no indication	0 - 0.4%
2	small indication	0.5 - 0.9%
3	30%	1.0 - 1.4%
4	35%	1.5 - 1.9%
5	40%	2.0 - 2.4%
6	45%	2.5 - 3.0%
7	50%	3.0 - 3.5%
8	> 50%	> 3.5%
9	open crack	open crack
10	not inspected	not inspected

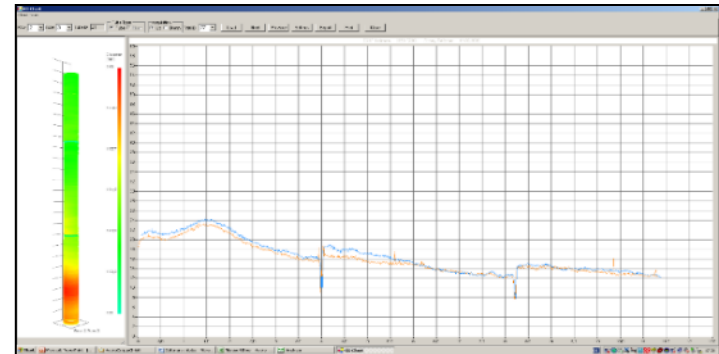
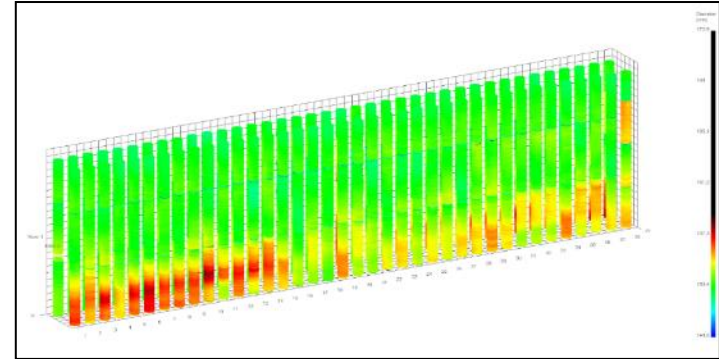
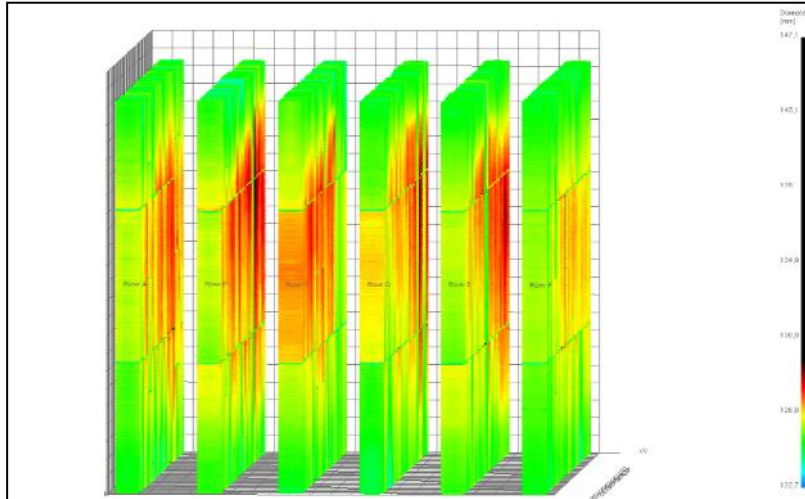
## Documentation

### Expansion Measurement



Color Definition		
#	Colors	Cracks Expansions
1	no indication	0 - 0.4%
2	small indication	0.5 - 0.9%
3	30%	1.0 - 1.4%
4	35%	1.5 - 1.9%
5	40%	2.0 - 2.4%
6	45%	2.5 - 3.0%
7	50%	3.0 - 3.5%
8	> 50%	> 3.5%
9	open crack	open crack
10	not inspected	not inspected

## Documentation



## Documentation



## FITNESS FOR SERVICE (FFS) - API579

What is a Fitness For Service Assessment?

A quantitative engineering evaluation that is performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage.

There are three levels of assessment techniques and acceptance criteria:

- Level 1: Is intended to provide conservative screening criteria that can be used with a minimum amount of inspection or component information.
- Level 2: Inspection information similar to that required for a Level 1 assessment are needed, however, more detailed calculations are used in this evaluation.
- Level 3: The most detailed inspection and component information is typically required, and the recommended analysis is based on experimental techniques.

### CONTACT DETAILS

TS:

Mr. Thomas Hahn

[Thomas.Hahn@foerstergroup.com](mailto:Thomas.Hahn@foerstergroup.com)

+49 7121 140-528

+49 171 7677934

CT

Mr. Michael Pfaller

[Michael.Pfaller@foerstergroup.com](mailto:Michael.Pfaller@foerstergroup.com)

+49 7121 140-655

+49 151 68412296

MT

Mr. Volker Hiller

[Volker.Hiller@foerstergroup.com](mailto:Volker.Hiller@foerstergroup.com)

+49 7121 140-657

+491702914098

DS:

Mr. Kolja Kramny

[Kolja.Kramny@foerstergroup.com](mailto:Kolja.Kramny@foerstergroup.com)

+49 7121 140-397

+49 160 2564245

IN:

Mr. Peter Sachs

[Peter.Sachs@foerstergroup.com](mailto:Peter.Sachs@foerstergroup.com)

+49 7121 140-612

+49 160 94617857

IN:

Mr. Edgar Remedios

[Edgar.Remedios@foerstergroup.com](mailto:Edgar.Remedios@foerstergroup.com)

+1 281 705 6243

Thanks for your Attention!