FOERSTER

Magnetische
Pruefanlagen GmbH

JOHNSON MATTHEY

HYDROGEN & SYN GAS TECHNICAL TRAINING SEMNAR

FAILURE MECHANISMS & INSPECTION TECHNIQUES IN STEAM METHANE REFORMERS

NOVEMBER 5TH - 7TH, 2023

TEMPE, ARIZONA, UNITED STATES

FOERSTER - MAKING QUALITY VISIBLE

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

Employees

600 Worldwide

Export

80 %

Annual Revenue

> 100 Mio. EUR

FIVE SPECIALIZED BUSINESS UNITS

TS
Test Systems

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

CT
Component Testing

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

MT
Mobile Testing

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

DS
Detection & Security

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

IN
Inspection

- Non-destructive testing of reformer tubes in chemical plants

FOERSTER - INDUSTRY EXPERTISE

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

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TOPICS TO BE DISCUSSED

Magnetische Pruefanlagen GmbH

- 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 Assessement
- Summary

FOERSTER GROUP

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)

FRIEDRICH FOERSTER

1948

Head Office,
in Reutlingen, Germany

2024

NDT SERVICES FOR STEAM METHANE REFORMERS

Magnetische Pruefanlagen GmbH

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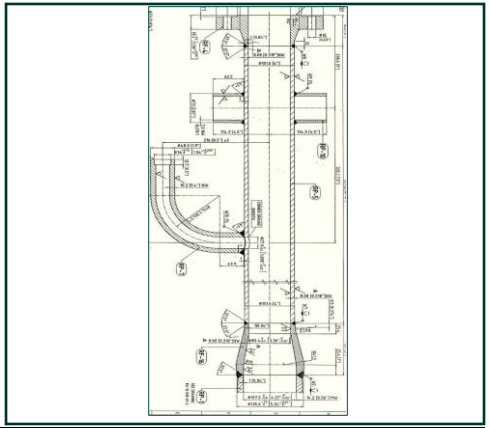
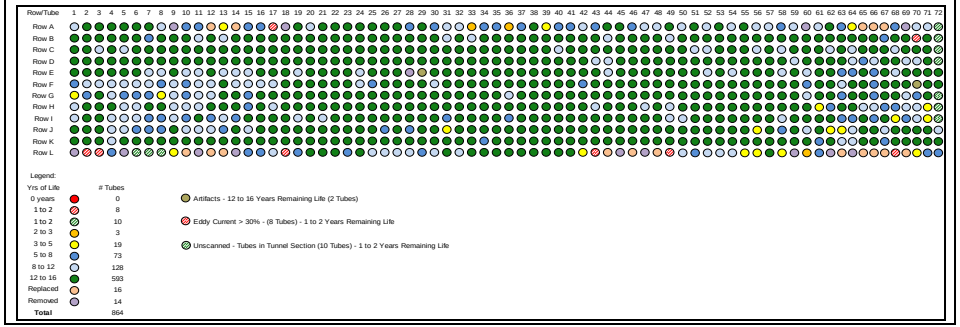
Reformer Tubes (NH_3/CH_3OH/H_2)
Midrex Tubes (DRI Steel Plants)
GTL Inspection

- Internal Laser (LEO-iScan)
  ID Eddy Current (EC)
- External Eddy Current Inspection
  Including OD Laser
  (LEO-SCAN)
- Inspection of the Top Ends
- Remaining Life Assessment with
  TubeLife Software

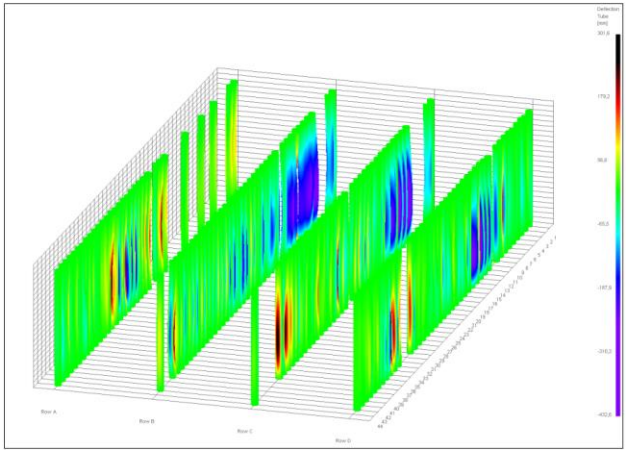
Pigtails

- Computer Linked
  OD
  Inspection
- Permeability





LATEST DVELOPMENTS FOR REFORMER TUBE TESTING



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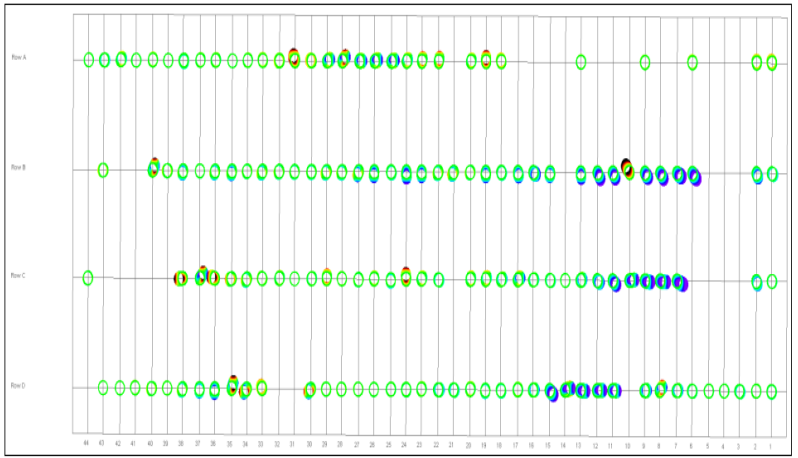

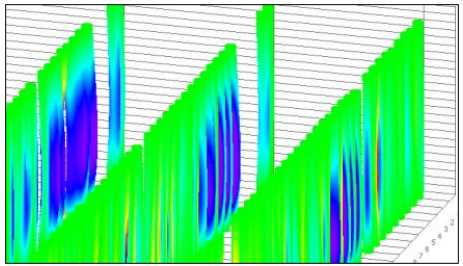

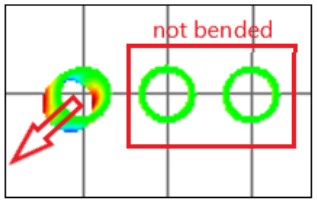

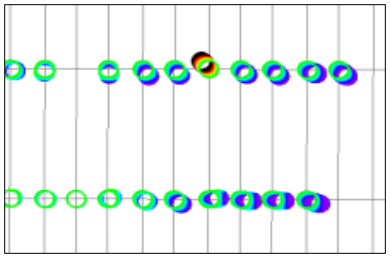

NDT SERVICE FOR STEAM METHANE REFORMERS REFORMERS

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..

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NDT SERVICE FOR STEAM METHANE REFORMERS

Magnetische Pruefanlagen GmbH

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

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LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

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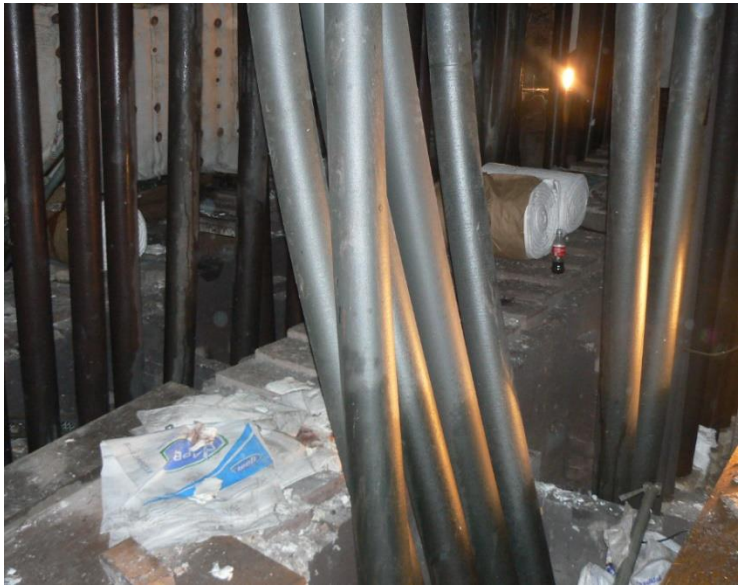
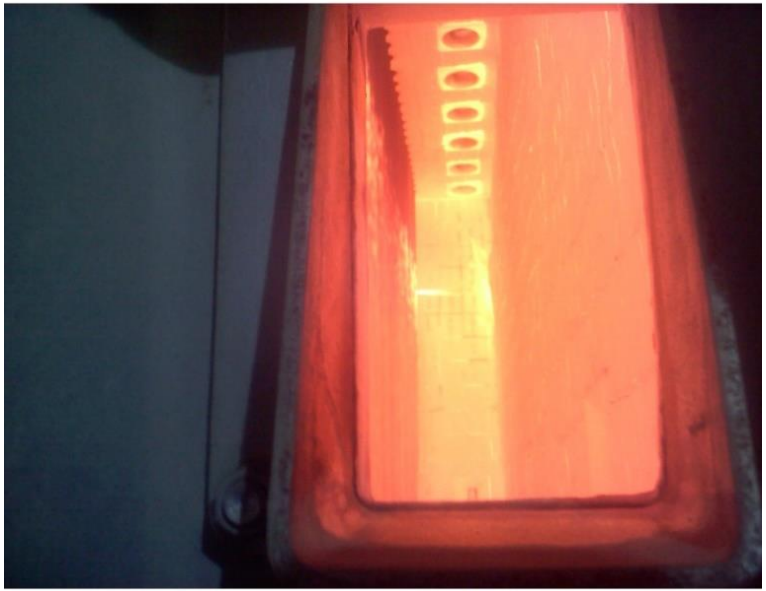
Pruefanlagen GmbH

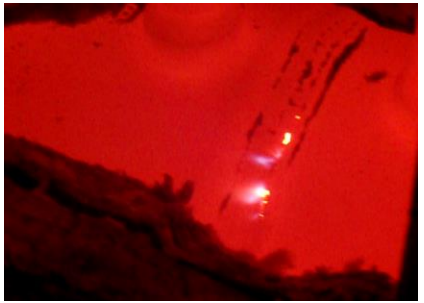




FAILURES - CAUSE AND EFFECT RELATIONS

MP Successful External Eddy Current Technique







In Service Tube and Header Failures

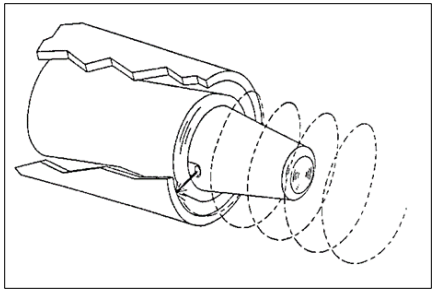
LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

REFORMER INTERNAL TUBE INSPECTION (LOTIS)

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.

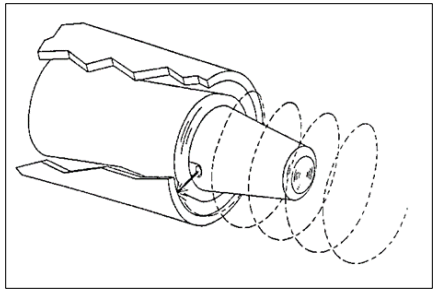


REFORMER INTERNAL TUBE INSPECTION (LOTIS)

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.



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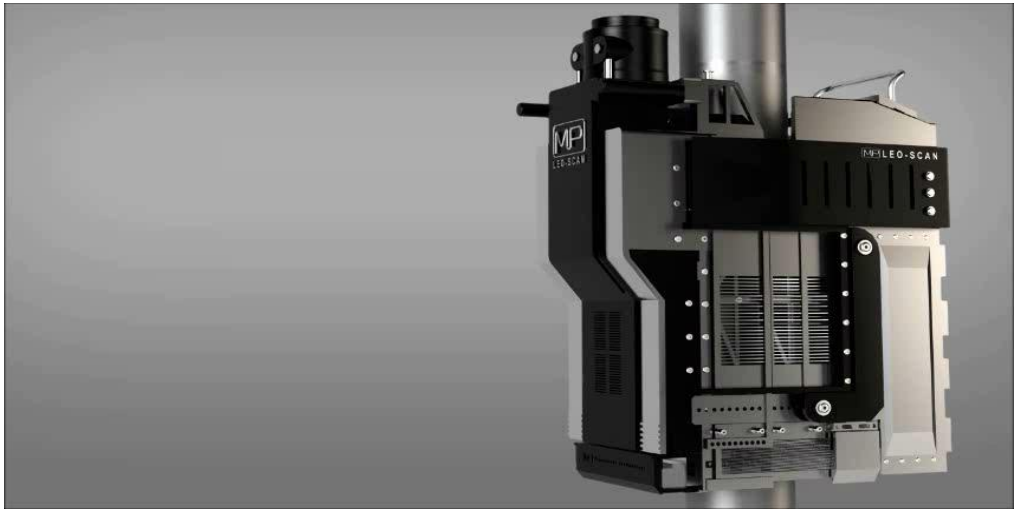
LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Magnetische Pruefanlagen GmbH

LEO - SCAN (**L**aser **E**ddy Current **O**utside 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

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LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

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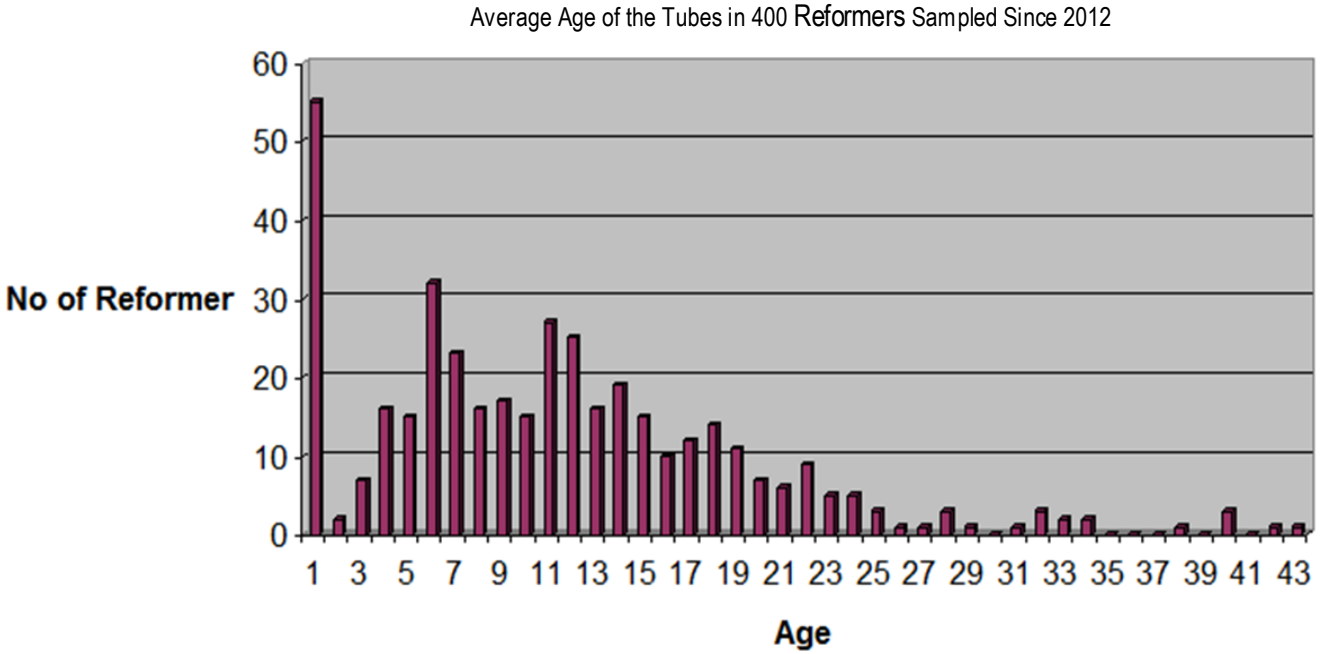
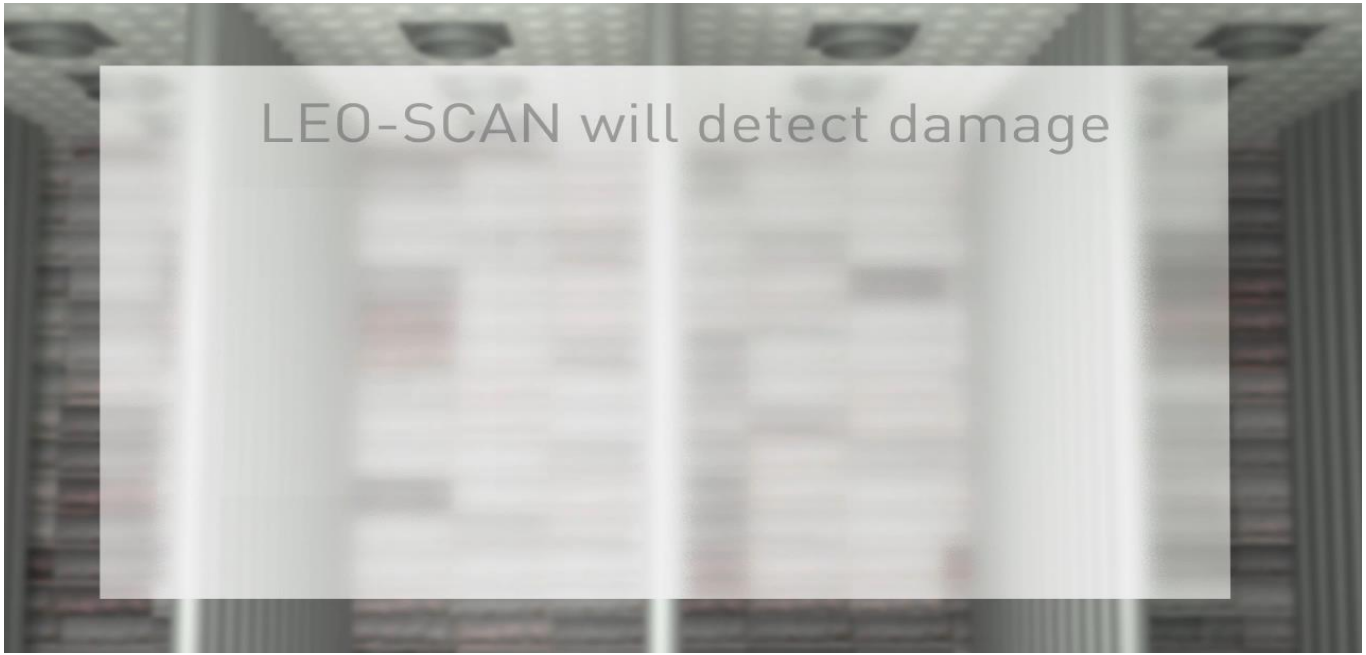


FAILURES - CAUSE AND EFFECT RELATIONS

Creep Damage



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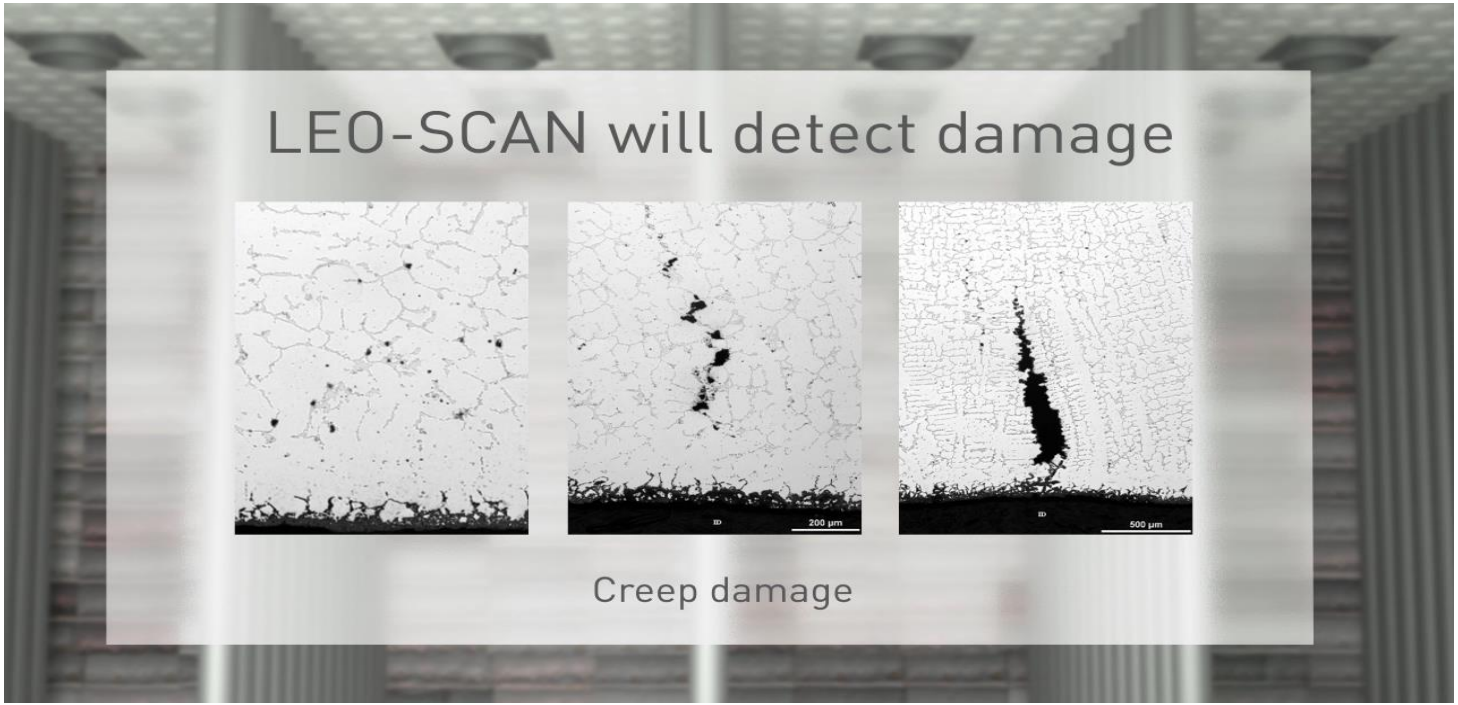
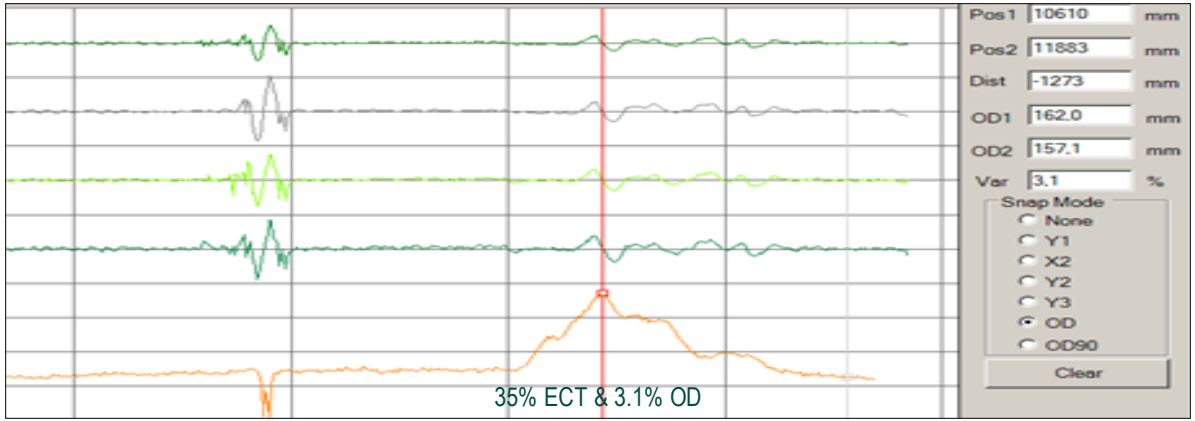
FAILURES - CAUSE AND EFFECT RELATIONS

Magnetische Pruefanlagen GmbH



FAILURES - CAUSE AND EFFECT RELATIONS

CRACKING AND EXPANSION CORRELATED AT NORMAL CREEPING



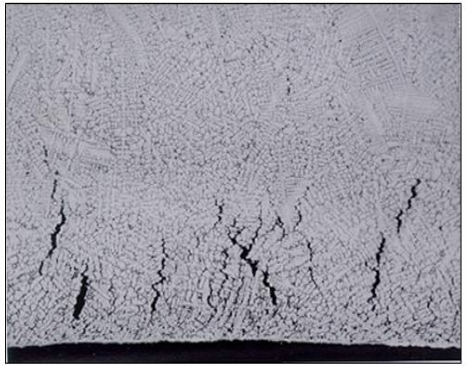


Figure 1. Photomicrograph of creep damage near the ID of Terra tube A-3
Magnification 25 X Etchant: Oxalic Acid

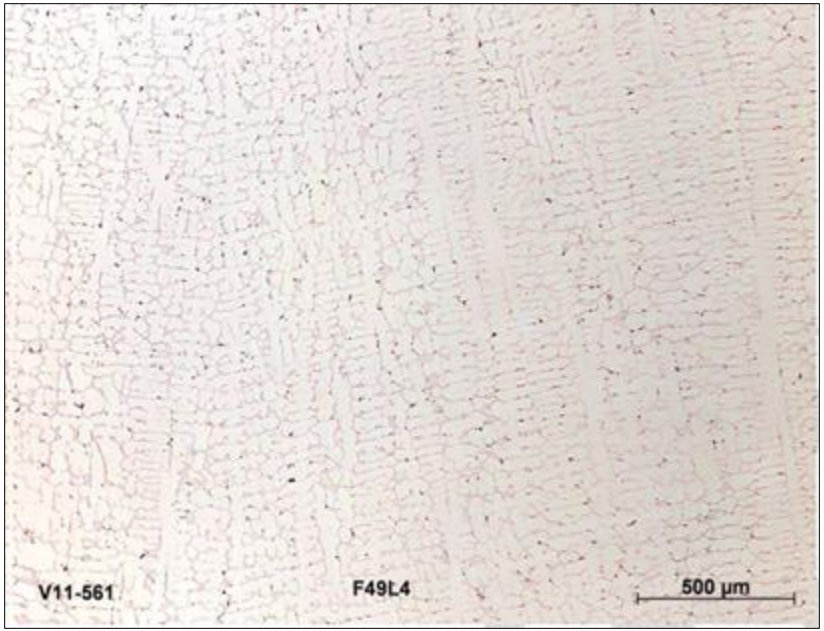
CREEP DAMAGE OCCURS OVER DESIGN LIFE TIMESCALES!

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

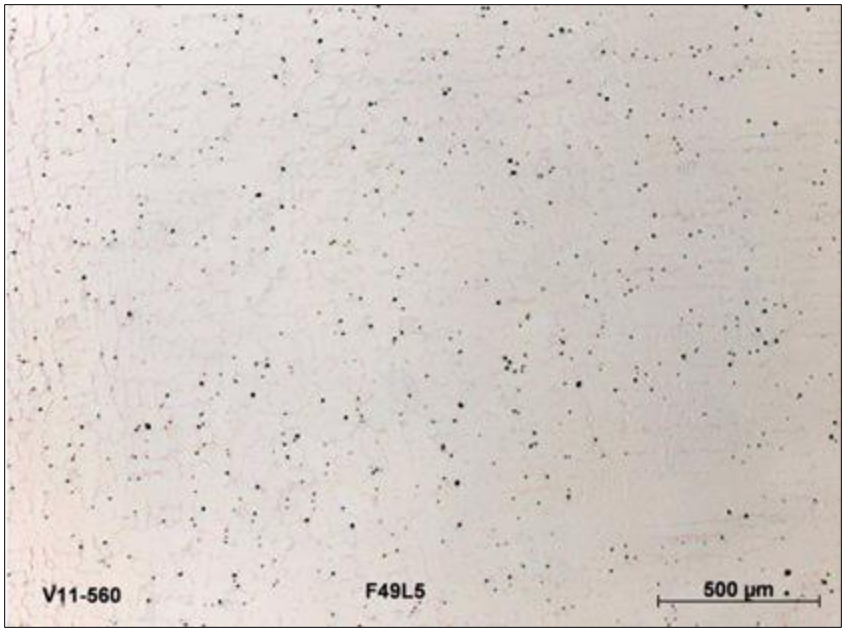
Class 0	*: As received, without thermal service load;*
Class 1	*: Creep exposed, without cavities;*
Class 2A	*: Isolated cavities;*
Class 2B	*: Numerous cavities without preferred orientation;*
Class 3A	*: Numerous oriented cavities;*
Class 3B	*: Chains of cavities and/or grain boundary separations;*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

PROGRESSION OF CREEP DAMAGE IN CATALYST TUBE MICROSTRUCTURES

CREEP DAMAGE CLASSIFICATION



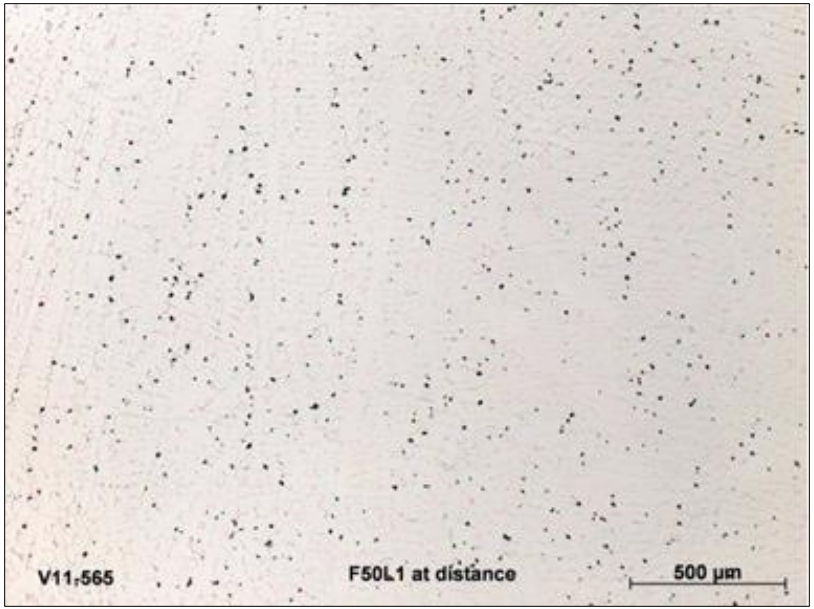
CREEP CLASSIFICATION - NO CREEP DAMAGE - CLASS 1



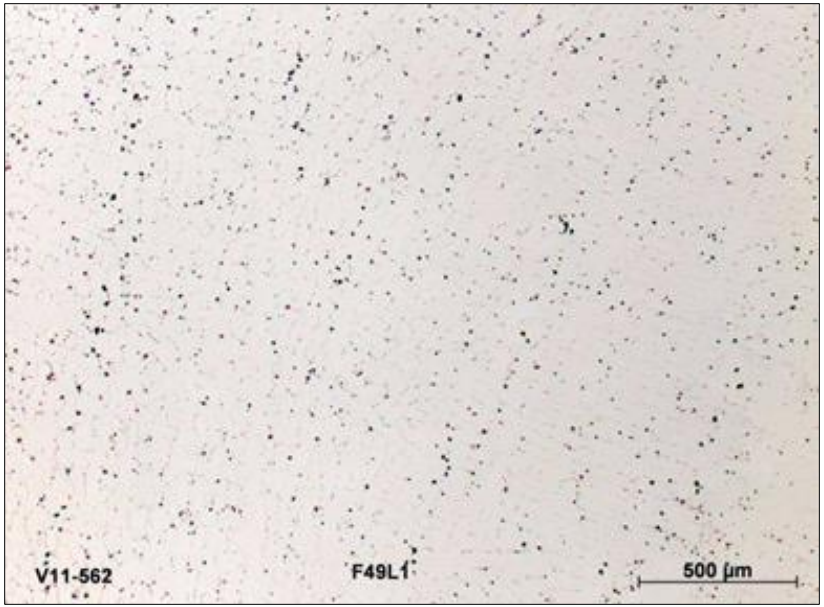
CREEP CLASSIFICATION – CREEP DAMAGE (BLACK SPOTS) - CLASS 2A

PROGRESSION OF CREEP DAMAGE IN CATALYST TUBE MICROSTRUCTURES

CREEP DAMAGE CLASSIFICATION



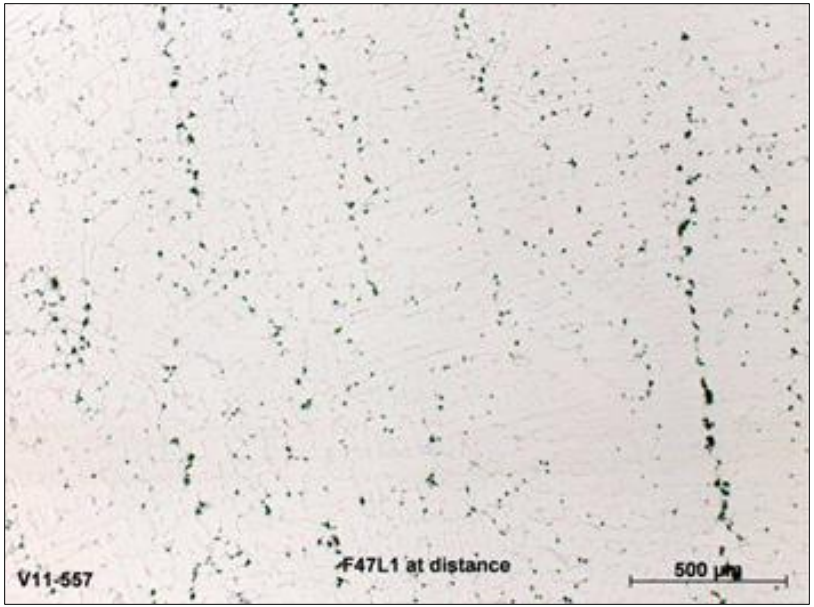
CREEP CLASSIFICATION - CREEP DAMAGE (BLACK SPOTS) - CLASS 2B



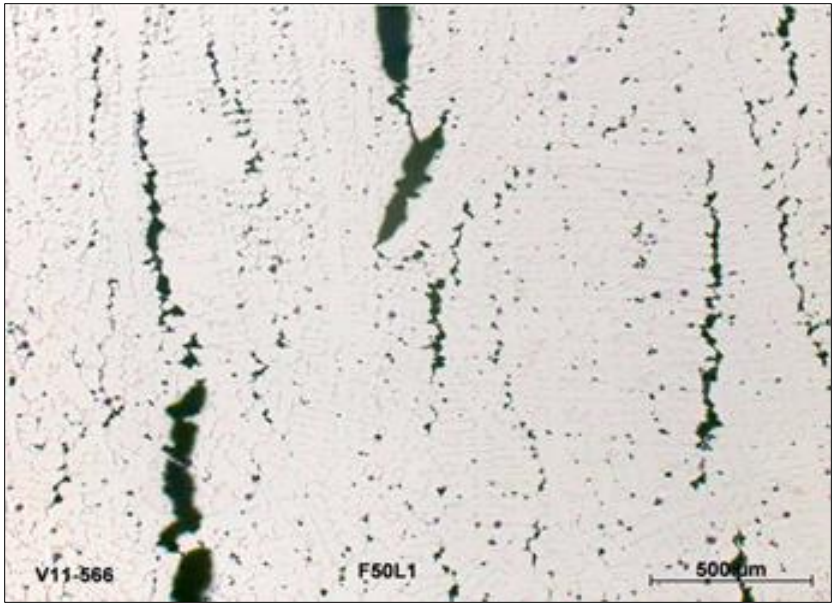
CREEP CLASSIFICATION - CREEP DAMAGE (BLACK SPOTS) - CLASS 3A

PROGRESSION OF CREEP DAMAGE IN CATALYST TUBE MICROSTRUCTURES

CREEP DAMAGE CLASSIFICATION



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

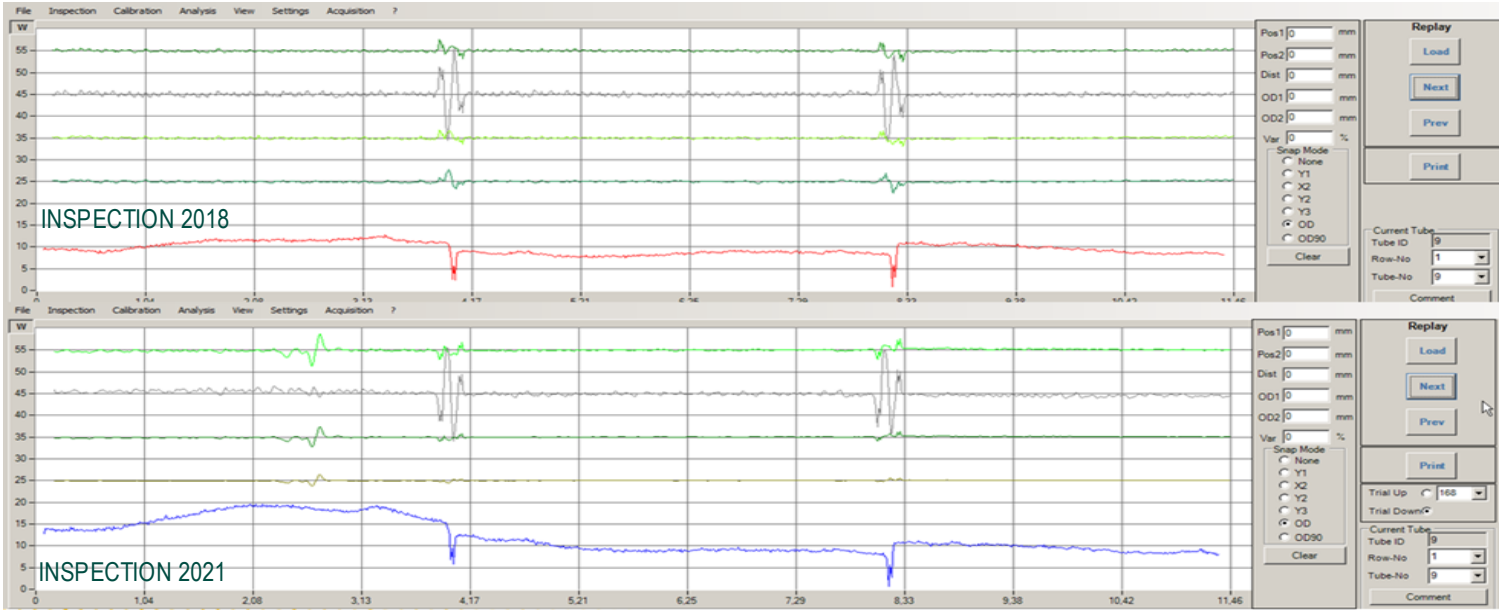


CREEP CLASSIFICATION - MACRO (OPEN) CRACKS - CLASS 5

FAILURES - CAUSE AND EFFECT RELATIONS

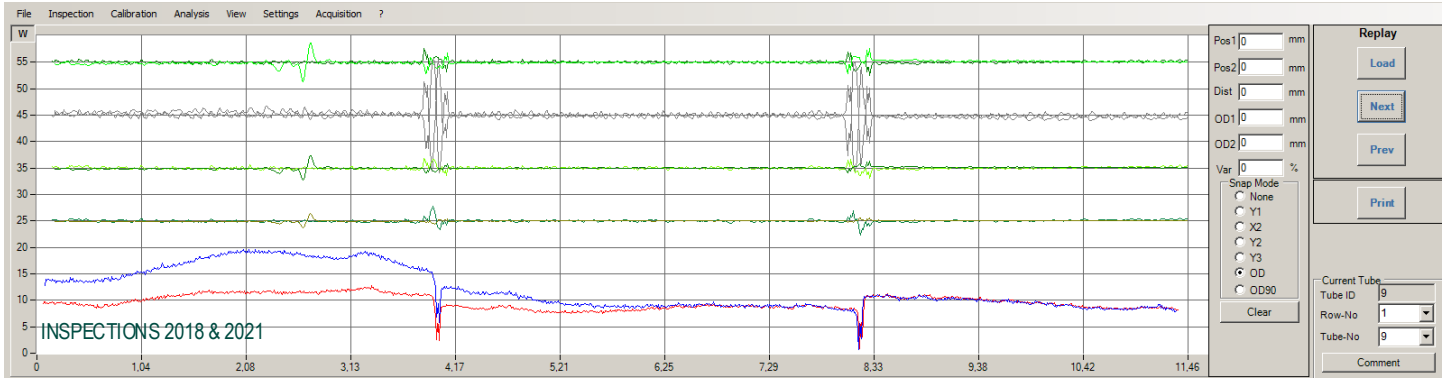
Foerster Successful External Eddy Current Technique

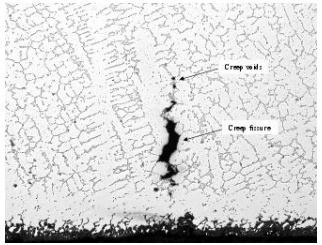
CRACKING & EXPANSION CORRELATED AT NORMAL CREEPING



FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique



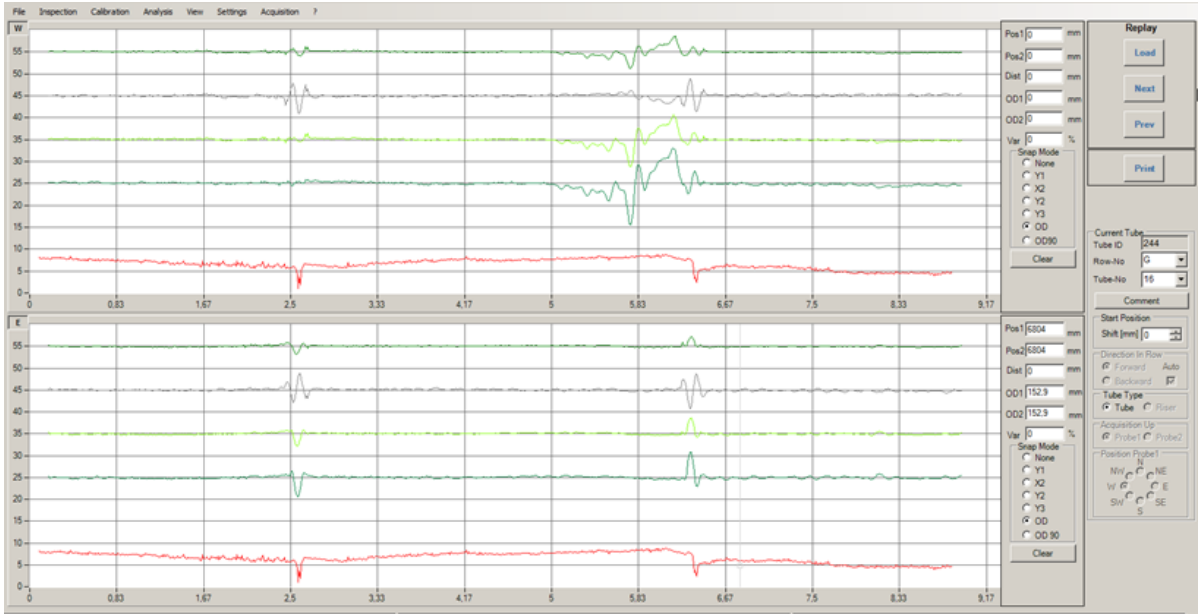


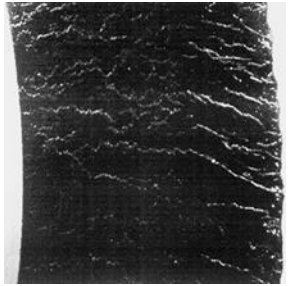
Cracking and Expansion Correlated at Normal Creeping

FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique

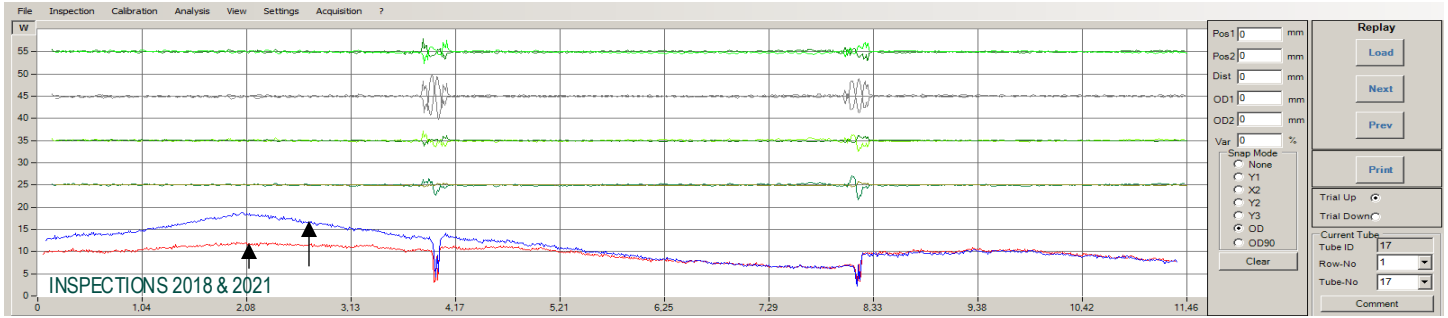
CRACKING WITH LITTLE OR NO EXPANSION (EXAMPLE: THERMAL SHOCK)

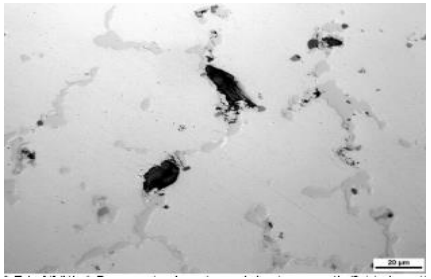




FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique

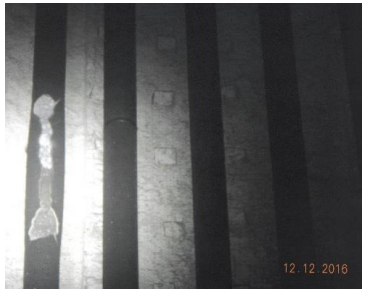


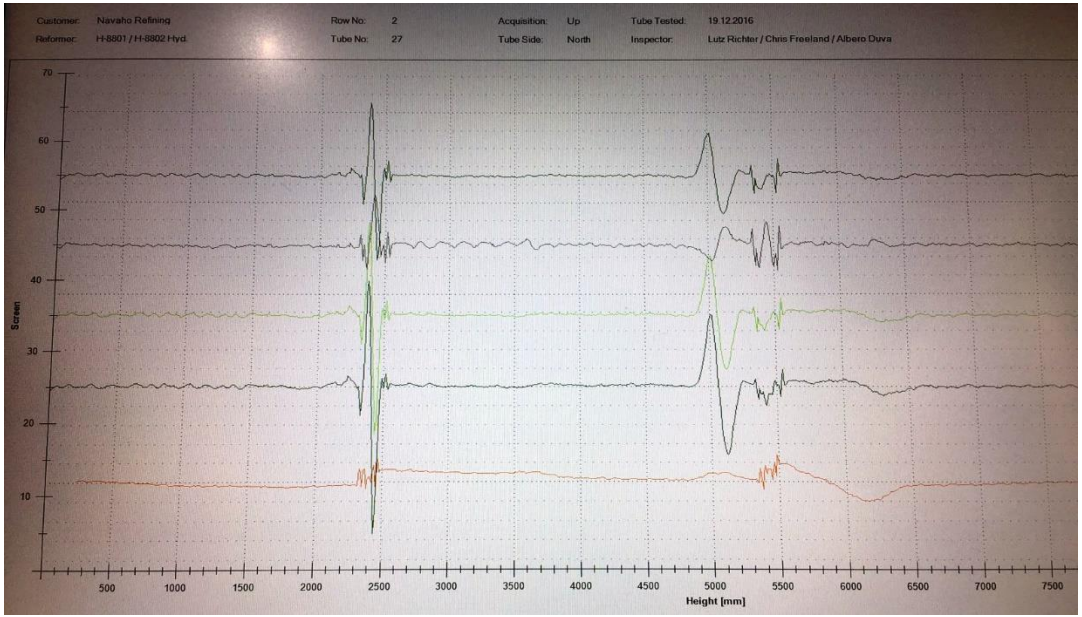


Expansion with Little or No Cracking

FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique

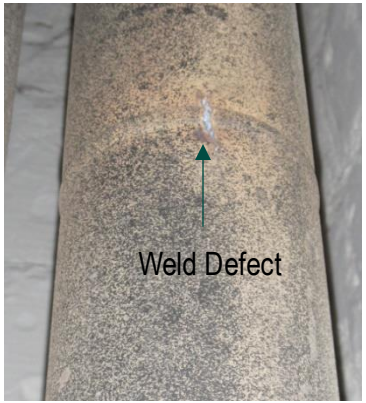


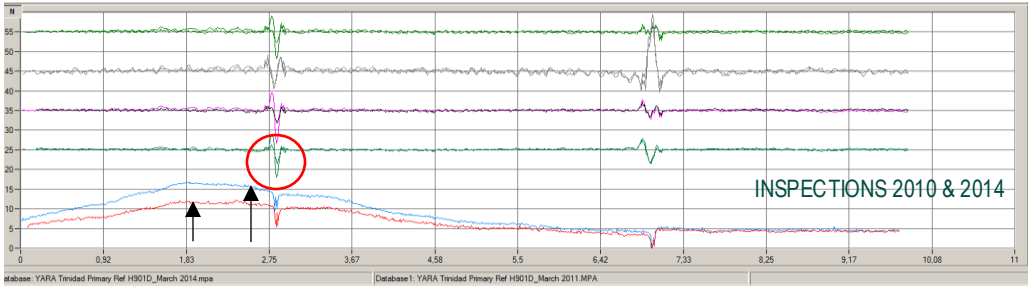


Little or No Expansion with Significant Cracking

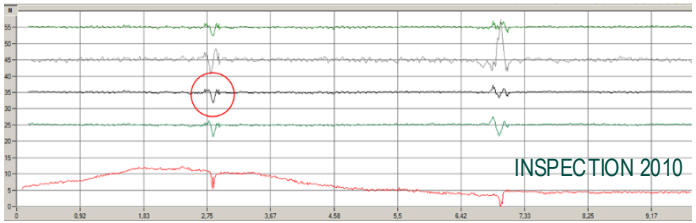
FAILURES - CAUSE AND EFFECT RELATIONS

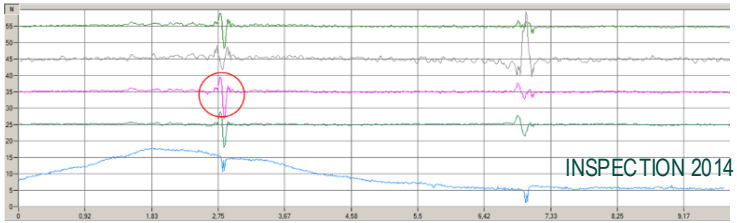
Foerster Successful External Eddy Current Technique





LONGITUDINAL WELD DEFECTS

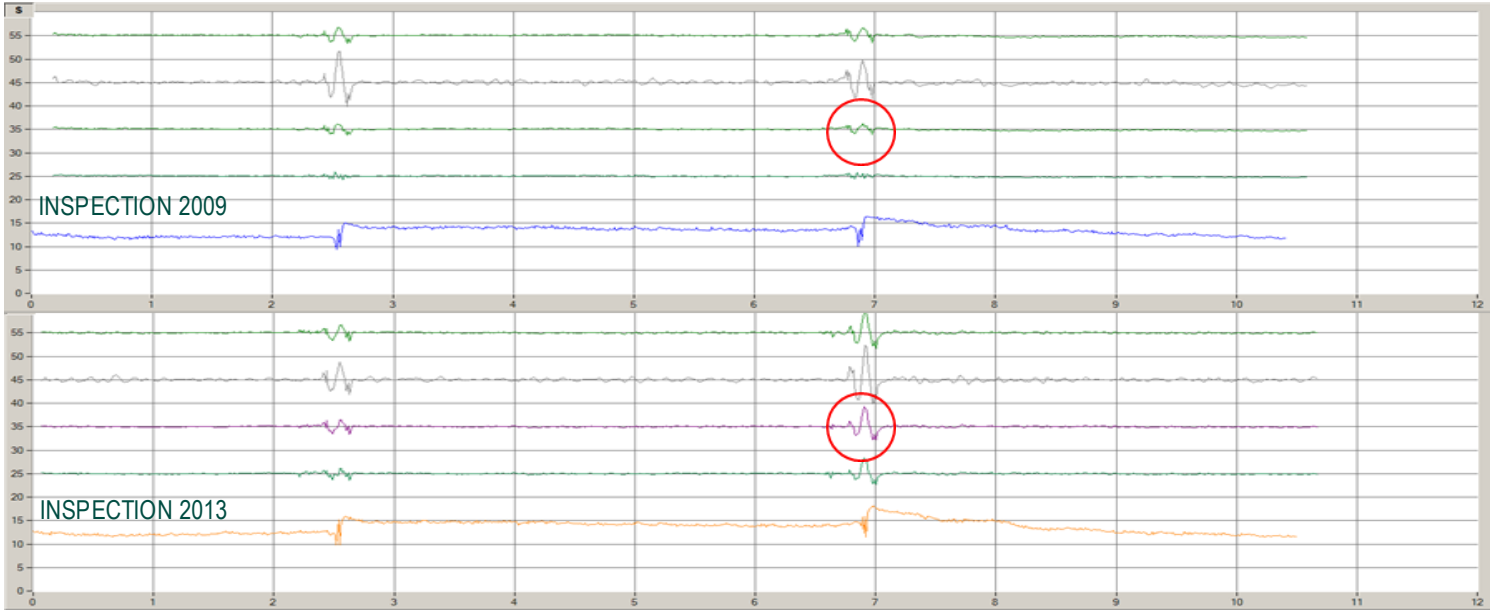




FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique

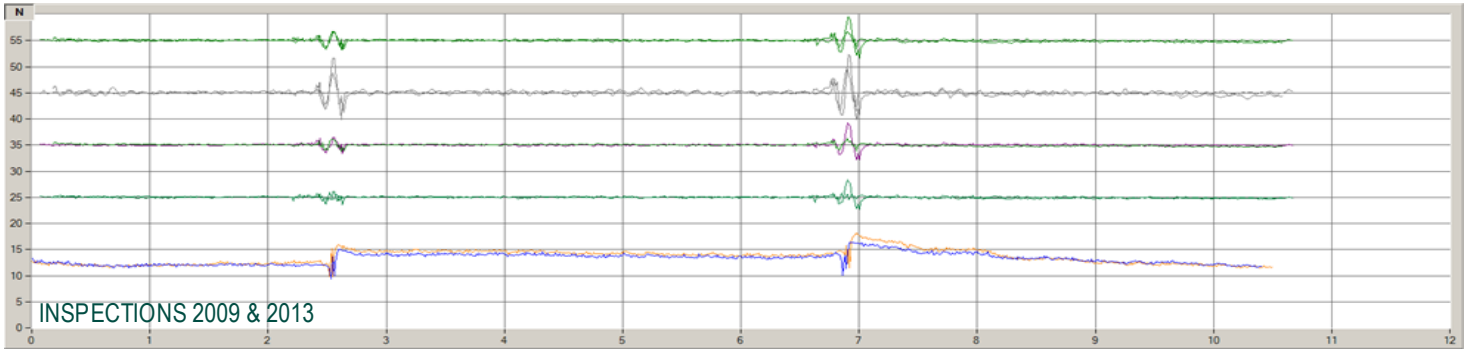
CIRCUMFERENTIAL WELD DEFECTS

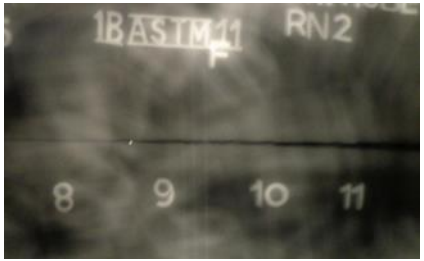


FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique

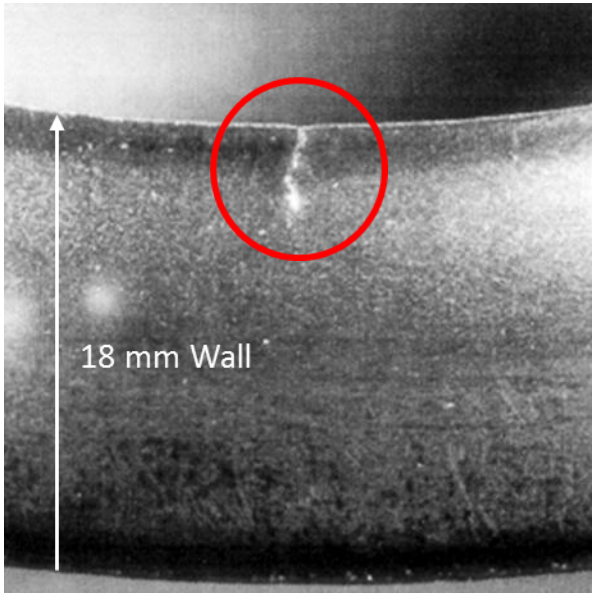
CIRCUMFERENTIAL WELD DEFECTS



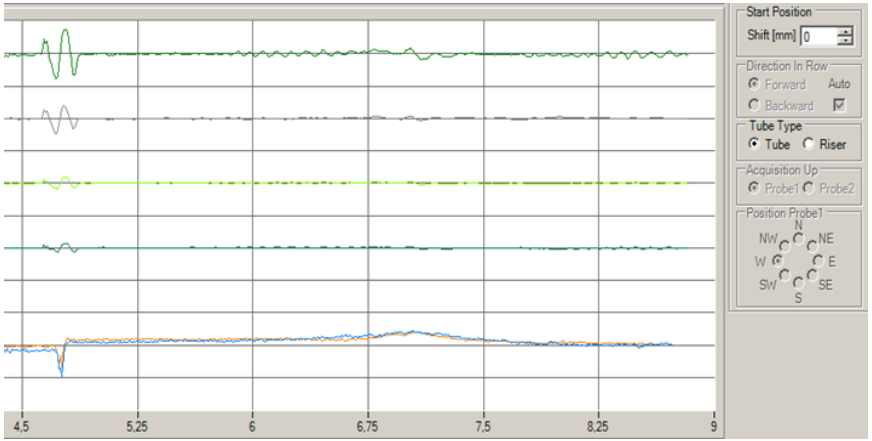


FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique



DEFECTS CLOSE TO THE INSIDE DIAMETER (ID)



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LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Magnetische
Pruefanlagen GmbH

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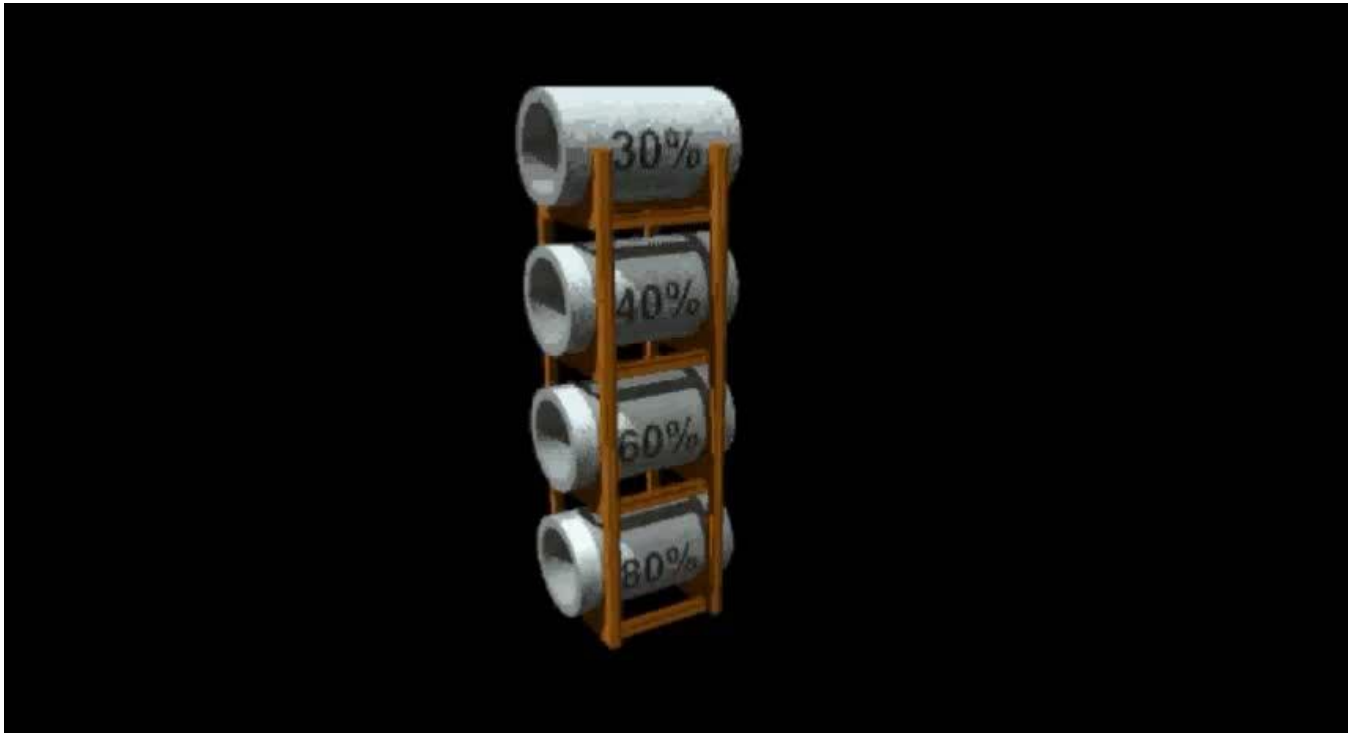
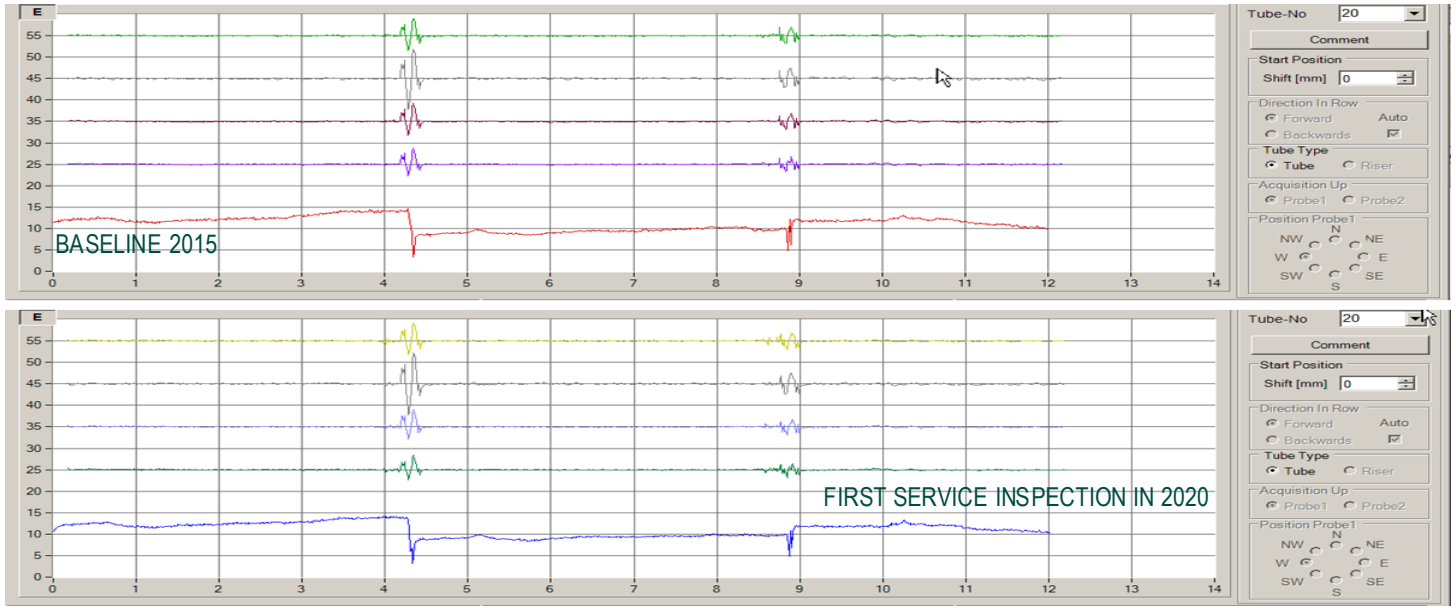
Pruefanlagen GmbH



BASELINE INSPECTION

BASE LINE INSPECTION

Foerster Successful External Eddy Current Technique



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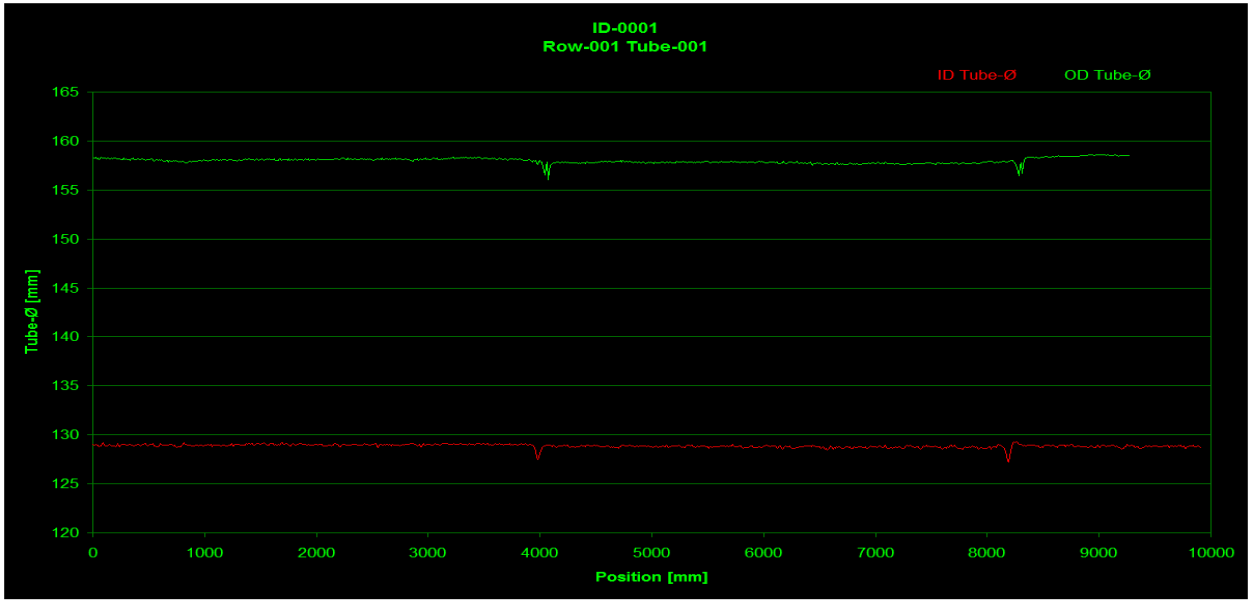
BASE LINE INSPECTION

Magnetische Pruefanlagen GmbH

INSIDE DIAMETER / OUTSIDE DIAMETER DATA



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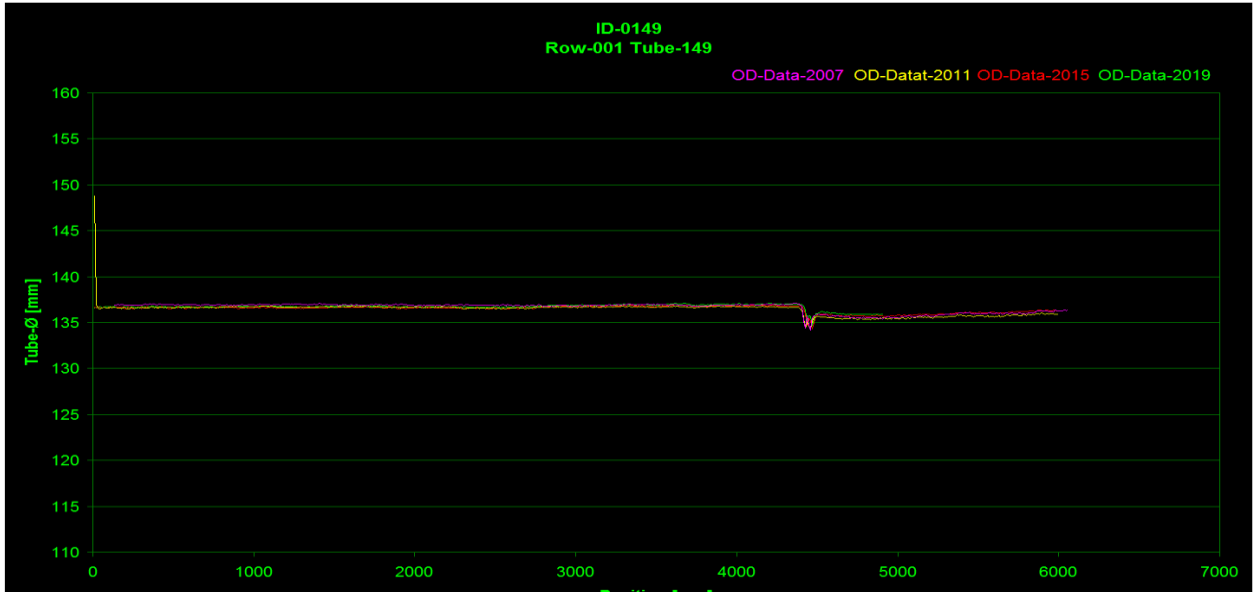
BASE LINE INSPECTION

Magnetische Pruefanlagen GmbH

SEVERAL INSPECTIONS OVERLAYED - NO DAMAGE



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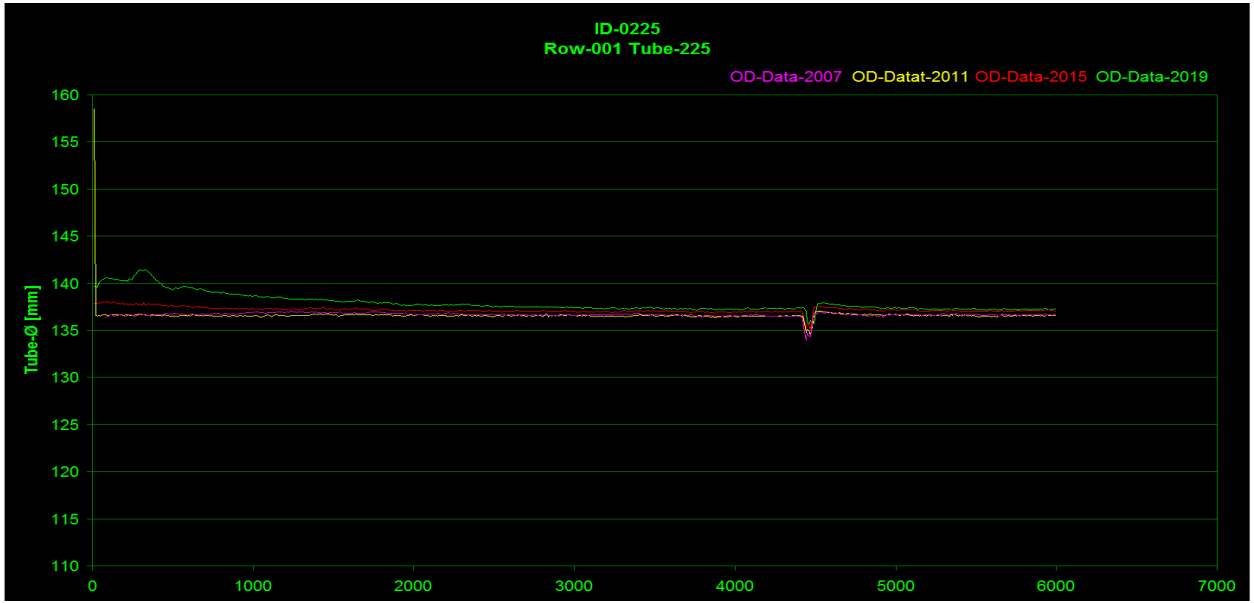
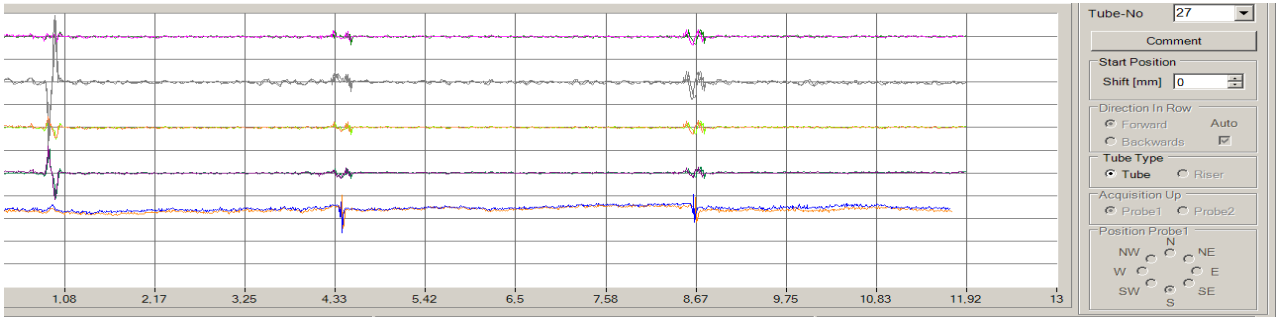
BASE LINE INSPECTION

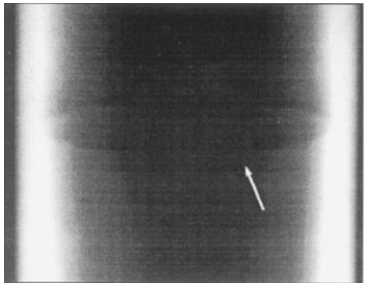
Magnetische Pruefanlagen GmbH

SEVERAL INSPECTIONS OVERLAYED - DAMAGE OBSERVED



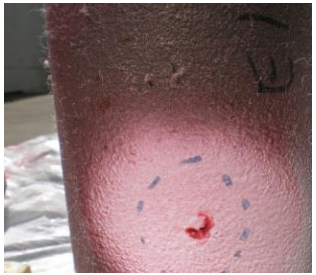
Foerster Successful External Eddy Current Technique





Foerster Successful External Eddy Current Technique

Manufacturing Artifacts



Manufacturing Artifacts

FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique

Manufacturing Anomalies

Manufacturing Anomalies

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FAILURES - CAUSE AND EFFECT RELATIONS

Magnetische Pruefanlagen GmbH

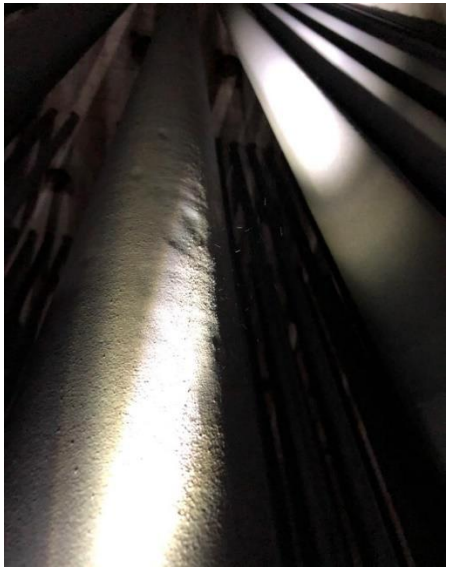
Foerster Successful External Eddy Current Technique

Manufacturing Anomalies

Manufacturing Anomalies

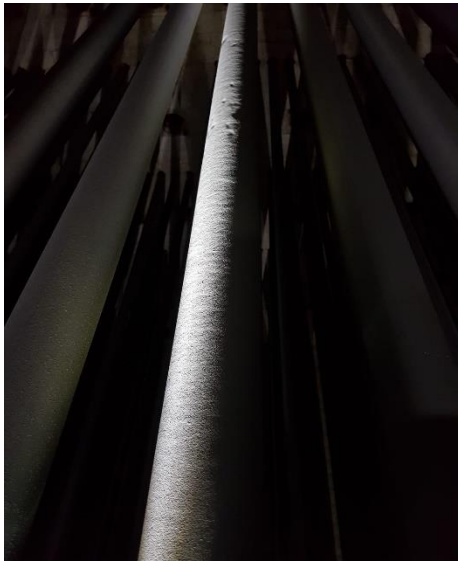
FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique



FAILURES - CAUSE AND EFFECT RELATIONS

Foerster Successful External Eddy Current Technique



Manufacturing Anomalies

Manufacturing Anomalies

FAILURES - CAUSE AND EFFECT RELATIONS

Outlet Pigtail Damage

In Service Damage

FAILURES - CAUSE AND EFFECT RELATIONS

Outlet Pigtail Damage

In Service Damage

FAILURES - CAUSE AND EFFECT RELATIONS

Outlet Pigtail Damage

In Service Damage

FAILURES - CAUSE AND EFFECT RELATIONS

Outlet Pigtail Damage

In Service Damage

FAILURES - CAUSE AND EFFECT RELATIONS

Outlet Pigtail Damage

In Service Damage

FAILURES - CAUSE AND EFFECT RELATIONS

Outlet Pigtail Damage

In Service Damage

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LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Magnetische Pruefanlagen GmbH

Documentation

Data-Sheet

Customer : MMMMM

Unit : Reformer F-101

Date : 08.09.2014

Inspector : MMMMM

Magnetische Prüfanlagen GmbH

TUBE-POSITION		DEFECT POSITION in CENTIMETER				CRACK(S) in % of the wallthickness									TUBE OUTER DIAMETER creep related OD variability min to max in [%]									INCREASE compared to last inspection	
ROW	TUBE	SIDE W	SIDE E	SECTION	DISTANCE	small indication	30%	35%	40%	45%	50%	> 50%	Artefact	crack visible	0.5 - 0.9%	1.0 - 1.4%	1.5 - 1.9%	2.0 - 2.4%	2.5 - 2.9%	3.0 - 3.5%	> 3.5%			CRACK	EXPANSION
A	12			1											x										
A	13			1											x										
A	37			1											x										0,3%
A	38	x	x	1	-375			x							x									new	
A	41	x	x	1	-250		x																	>5%	
A	42		x	2	28	x																			
B	9	x	x	2	64,0								x												
B	9		x	2	129,4								x												
B	12			1											x										0,6%
B	19	x	x	1	-366	x									x									new	0,2%
B	24		x	1	-347	x																		new	
B	31		x	1	-370	x									x									new	0,5%
B	32	x	x	1	-369	x																		new	
B	34	x	x	1	-368	x									x									new	0,3%
B	35	x	x	1	-371	x									x									new	0,6%
B	37			1											x										
C	2	x	x	1	-371	x																		new	
C	4	x	x	1	-372	x																		new	
C	9		x	2	160,4	x																			
C	12	x	x	1	-368	x									x									new	0,4%
C	13	x	x	1	-362			x																new	0,6%
C	16	x	x	1	-368	x									x									new	0,4%
C	32			1											x										
C	34		x	1	-364		x								x									new	0,5%
C	37			1	-368	x									x										0,6%

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LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

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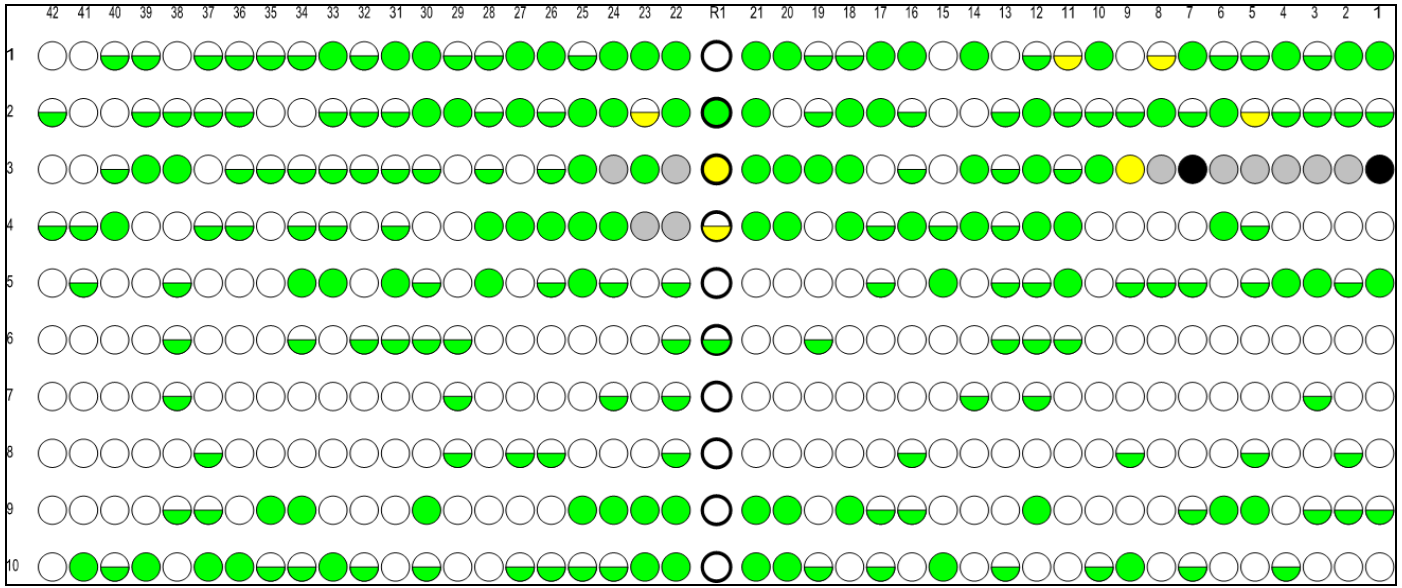
Documentation

Eddy Current Indications



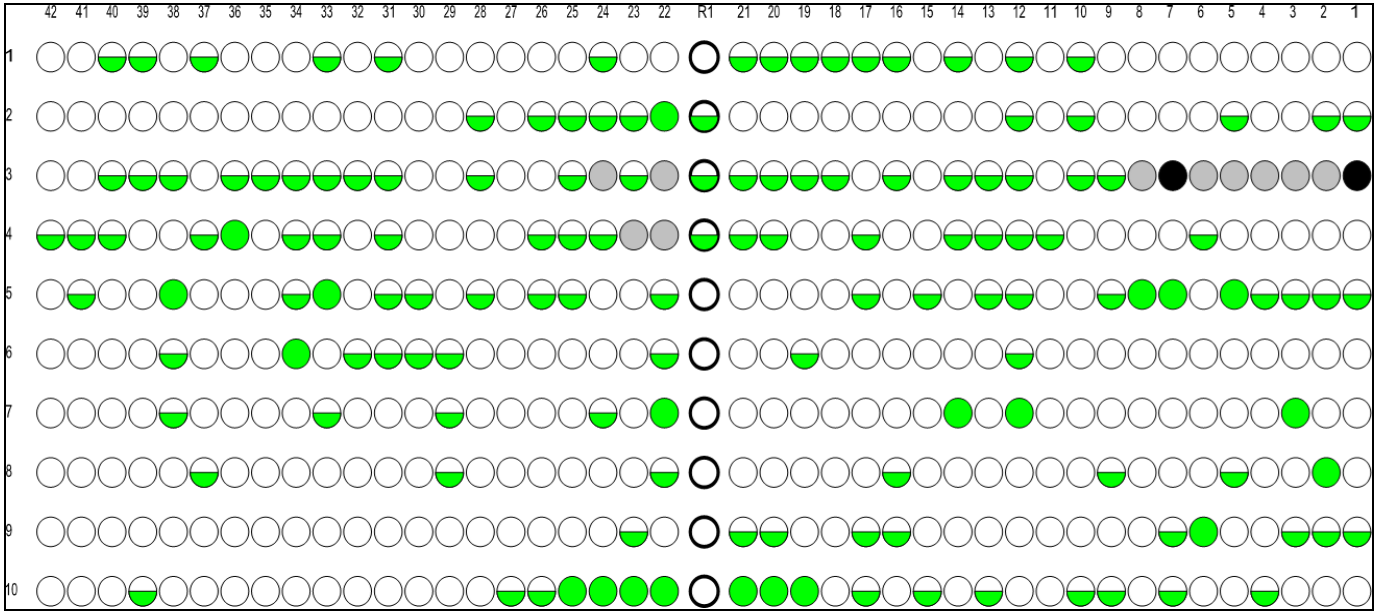
Color Definition

#	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

LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Documentation

Expansion Measurement



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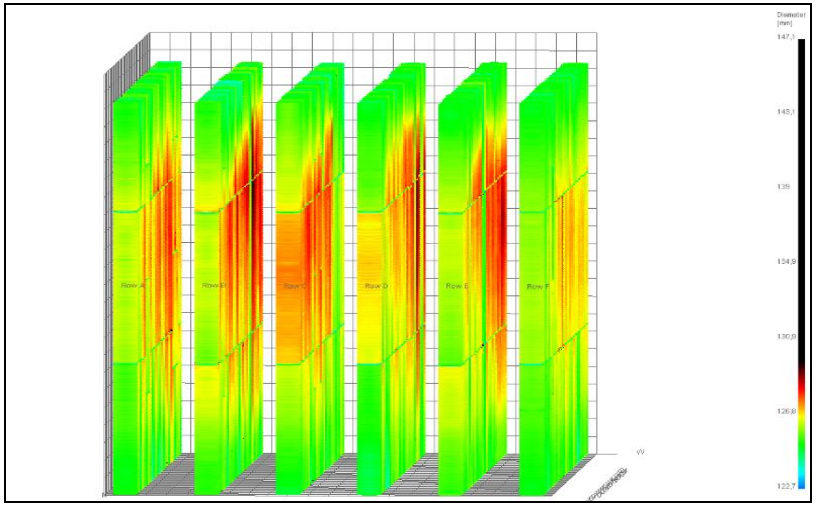
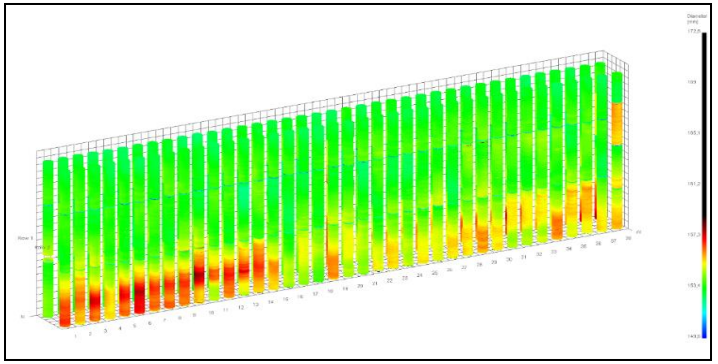
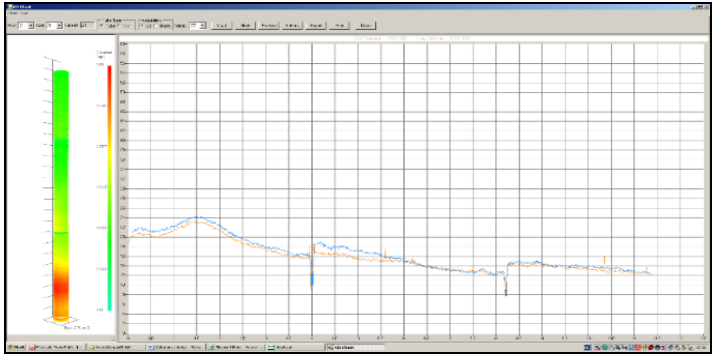
LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Documentation







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LEO-SCAN EXTERNAL INSPECTION OF REFORMER TUBES

Magnetische Pruefanlagen GmbH

Documentation

REFORMER TUBE FITNESS FOR SERVICE

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
+49 7121 140-528
+49 171 7677934

DS:
Mr. Kolja Kramny
Kolja.Kramny@foerstergroup.com
+49 7121 140-397
+49 160 2564245

IN:
Ms. Kara Ellis (Chicago, Illinois)
Kara.Ellis@foerstergroup.com
+1 815-979-3238

CT
Mr. Michael Pfaller
Michael.Pfaller@foerstergroup.com
+49 7121 140-65
+49 151 68412296

IN:
Mr. Edgar Remedios (Houston, Texas)
Edgar.Remedios@foerstergroup.com
+1 281-705-6243

MT
Mr. Volker Hiller
Volker.Hiller@foerstergroup.com
+49 7121 140-657
+491702914098

IN:
Mr. Christopher Baczek
christopher.baczek@foerstergroup.com
+48 606 802 028

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Thanks for your Attention!