Service life assessment and Condition Monitoring of critical components

- Technologies
- Concepts
- Examples

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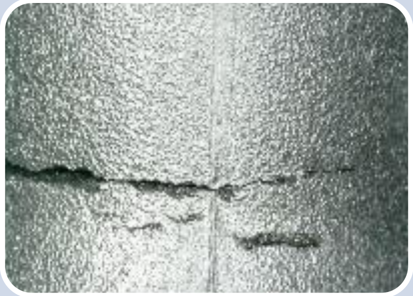
Condition monitoring

... a three-dimensional puzzle game

Damage mechanism



- Corrosion
- Plasticity
- Fatigue
- Current status
- Thermal shock
- ...
- Human

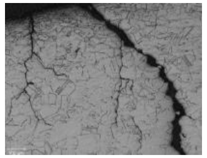
Object

- Pressure vessel
- Pipeline
- Boiler
- Storage vessels
- >Materials
- >Operating stress

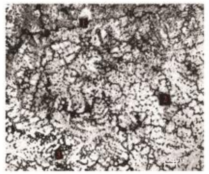
Method

- QA/QC incl.
- NDT+MT
- "Post Mortem" Lab
- Operator data
- Periodical tests
- FEM simulation
- "Real" CM

SCC

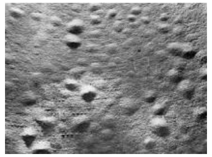


Corrosion

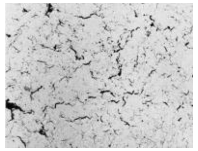


HIC

Blister



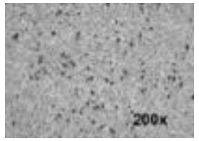
HTHA



Thermal shock

SOHIC

Creep



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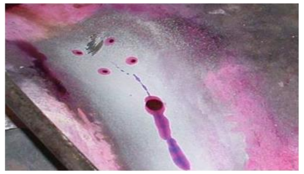
Method: Non-destructive testing (NDT)

„Backbone" of „known“ condition assessment

"Traditional" methods

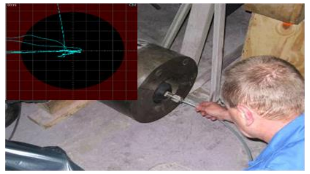
Visual testing (VT)

Dye Penetrant (PT)



Magnetic part. (MT)

Eddy Current (ET)



Surface (near to surface)

Volume

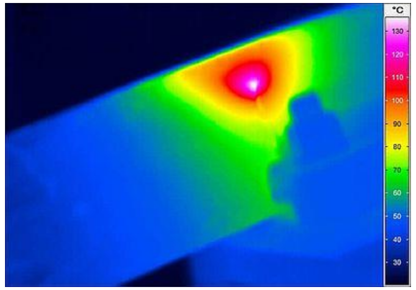
Acoustic Emiss. (AT)

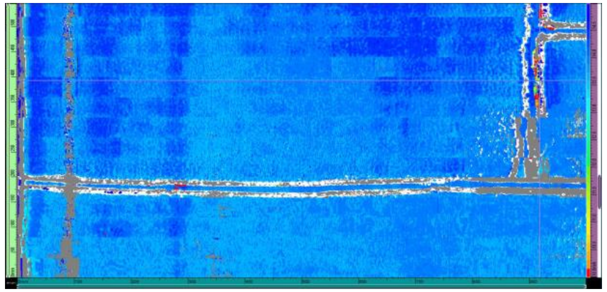
Ultrasonic (UT)

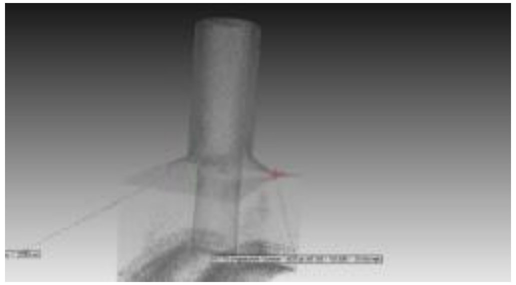
Radiographic (RT)

Leakage test. (LT)

"Novel" = PAUT, DR, CT, TT.
UT Camera







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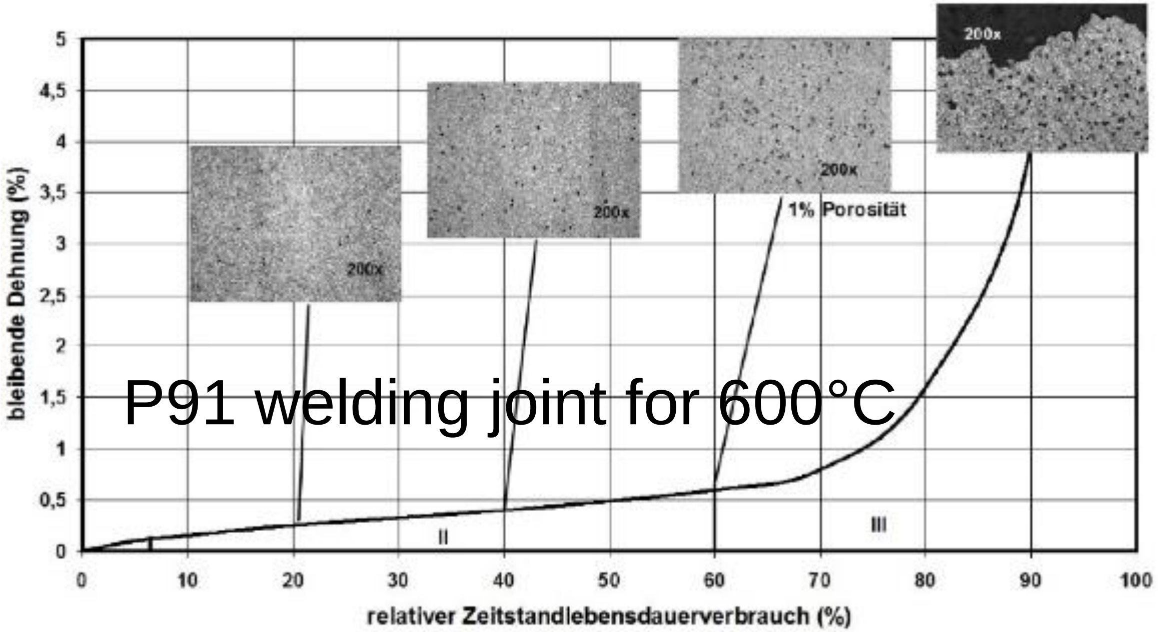
Method: Replica

„Backbone" of high-temperature component evaluation

- Components subject to creep rupture stress
- Zero recording! Control of the Heat treatment
- 1.evaluation mostly at t > 50%
- First of all, the most highly demanding components in terms of design
- Evaluation according to VGB-S-517 (Base, weld)



- ➢ Experience from the literature and from damage investigations
- ➢ Calculation results
- ➢ Differences between plant design and as-built
- ➢ Observations from previous operation of the plant (misalignment, hang-ups, water hammer, noise).
- ➢ Weld Connections to the replaced components (different age = different strength).

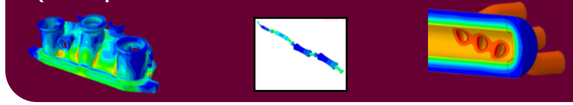
Method: Computational Engineering

FEA, Fracture mechanics, coupled methodes

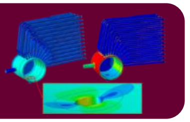
Services: 3D-Computation based Engineering services

Remaining Life Assessment
Of Power Plant Components

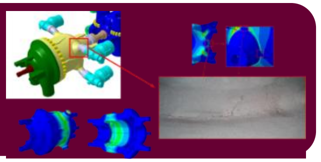
Condition Monitoring
(Temperatures, Strains, Vibrations)



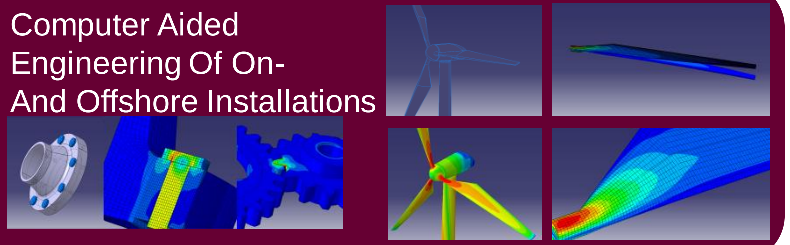
Root Cause Analysis,
Damage Assessment



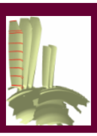
Integrity Assessm.
Of Damaged
Components



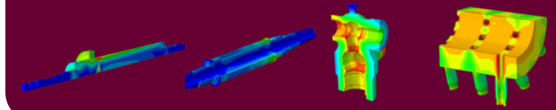
Computer Aided
Engineering Of On-
And Offshore Installations



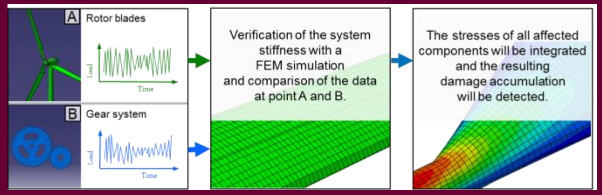
Reverse-Engineering Of
Damaged Components



Flexibilisation Of Operations



Condition Monitoring
(Structural Design And Vibrations)



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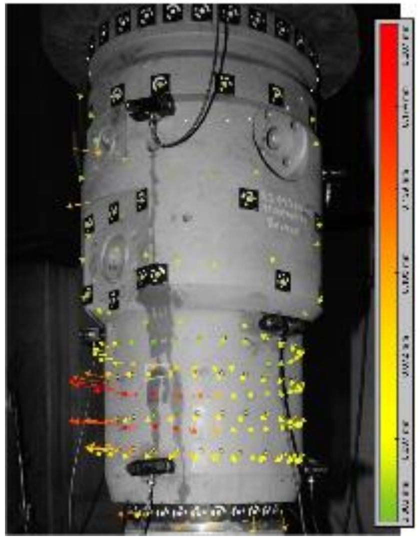
Method: Photogrammetry

Photogrammetry as recurring test method

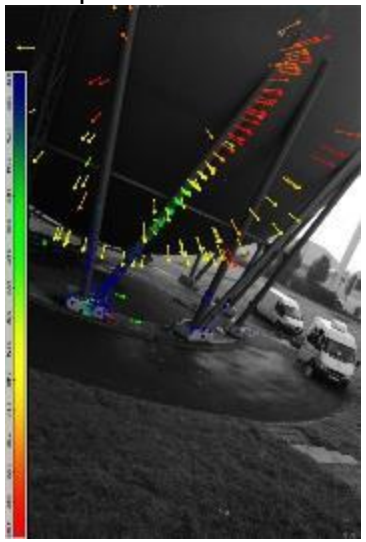
- Make deformations of even large objects visible
- Quantification as x,y,z vector
- Comparison with design (FEM)

- Effort
  - Attach measuring marks (adhesive/magnetic)
  - Zero shot + recurring photos of the object

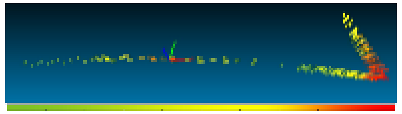
Pressure component
with local plastification

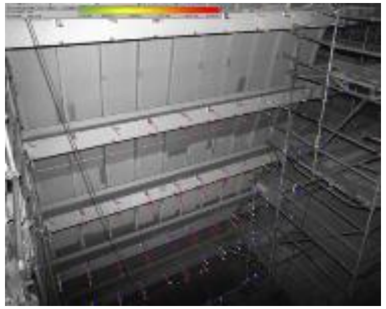


Natural gas sphere
For pressure test

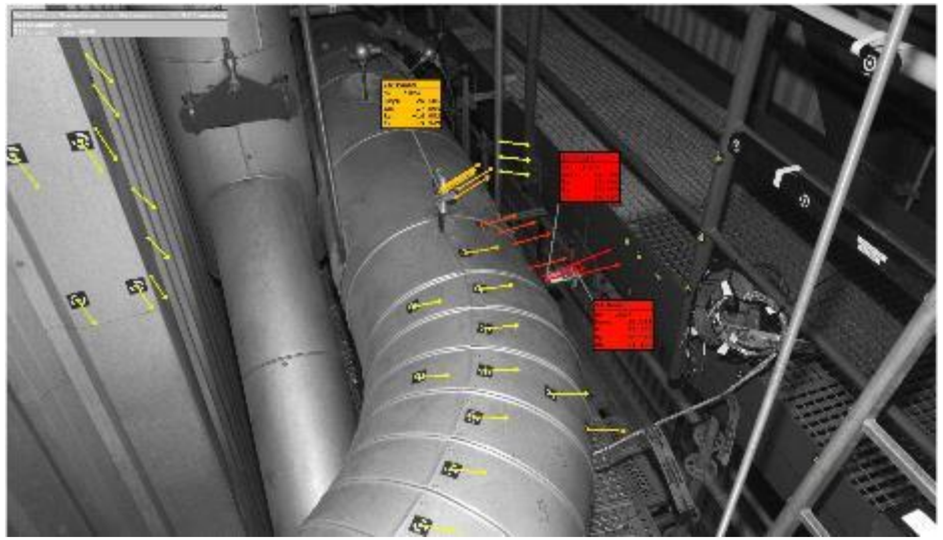


Coal bunker when filled





Pipe bend with large movement



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Method: Local temperature monitoring

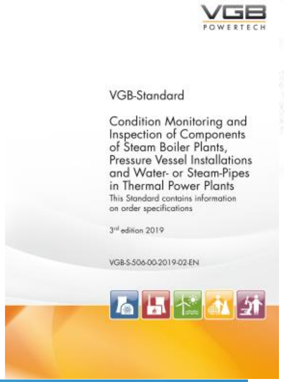
Global media temperature (operator data) vs. local thermal overload

- General thermal fatigue
- Thermal shock (inside)
- 2-phase flow
- Stratification
- H_2 accumulation
- Impeded thermal expansion

- Challenges
  - Retrofit in operation
  - Multichannel measurements
  - Long cable lengths
  - Measurement in the furnace
  - Measurement in the pressure chamber

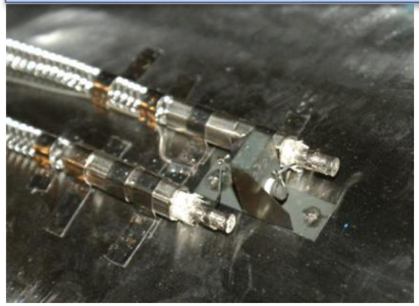
Method: HT strain measurements (VGB S-506)

Creep (up to 650 °C) and/or fatigue (up to 800 °C)



- Components
  - Headers and other thick-walled components
  - Pipe bends, boiler tubes
- Scenarios
  - Residual life rating >60% (>100%) TRD 508
  - Microstructure >3a (VGB-S-517) or other damage
  - Tertiary creep
  - Life time extension
  - Prolongation of internal inspections
  - Substituting conventional NDT methods

TÜV Rheinland capacitive sensor

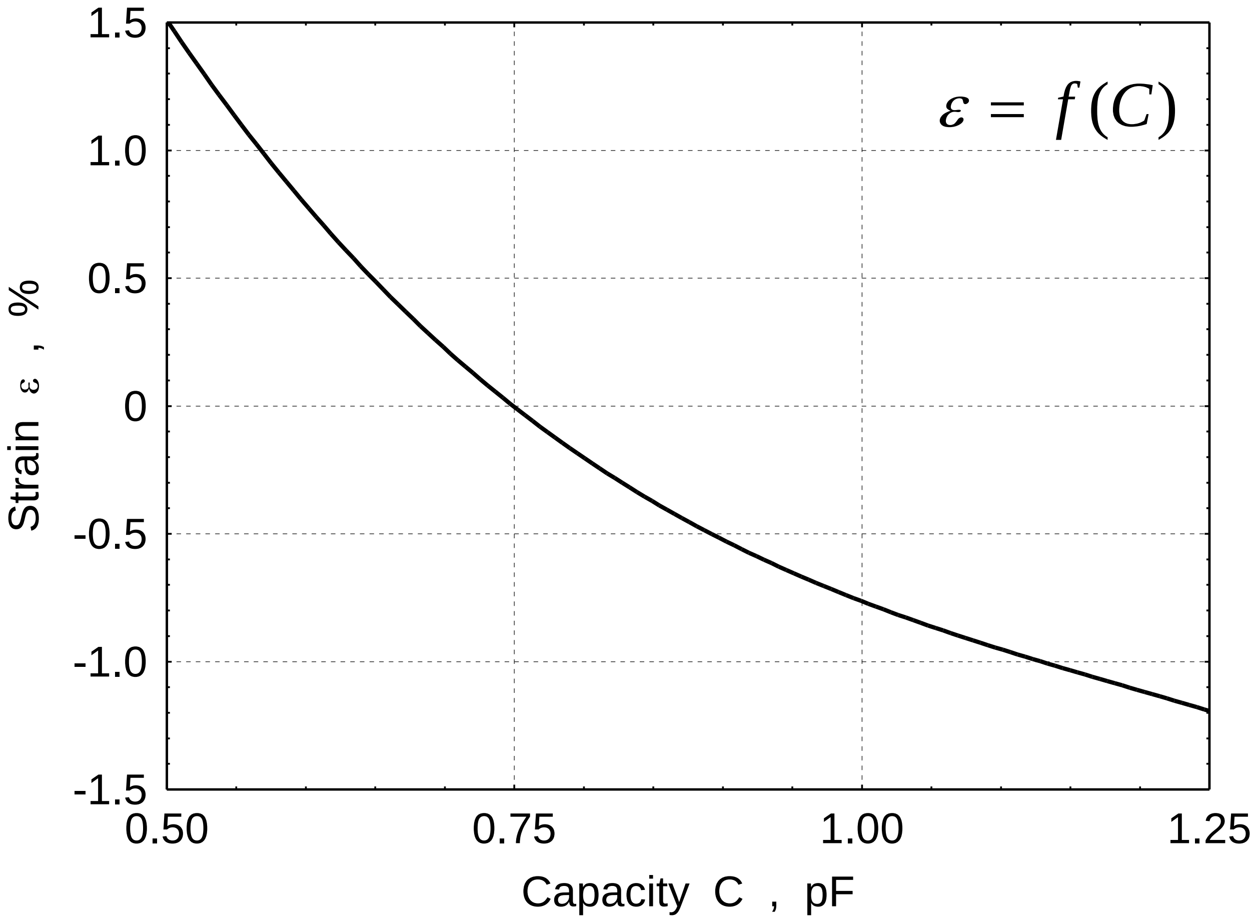


TÜV Rheinland sensor on headers

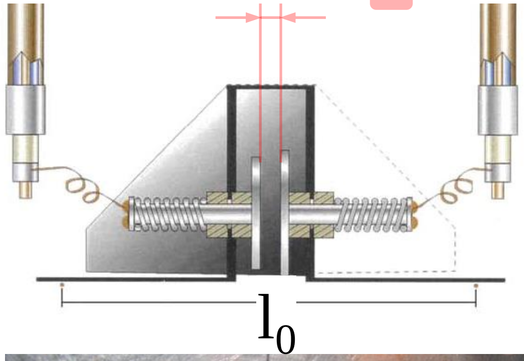
HT Strain gauge

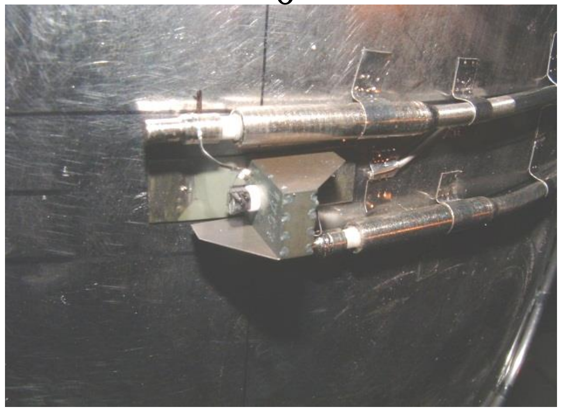
TÜV Rheinland capacitive sensor for creep and creep-fatigue

Theory



$$C = \varepsilon_0 \varepsilon_r \frac{A}{x}$$





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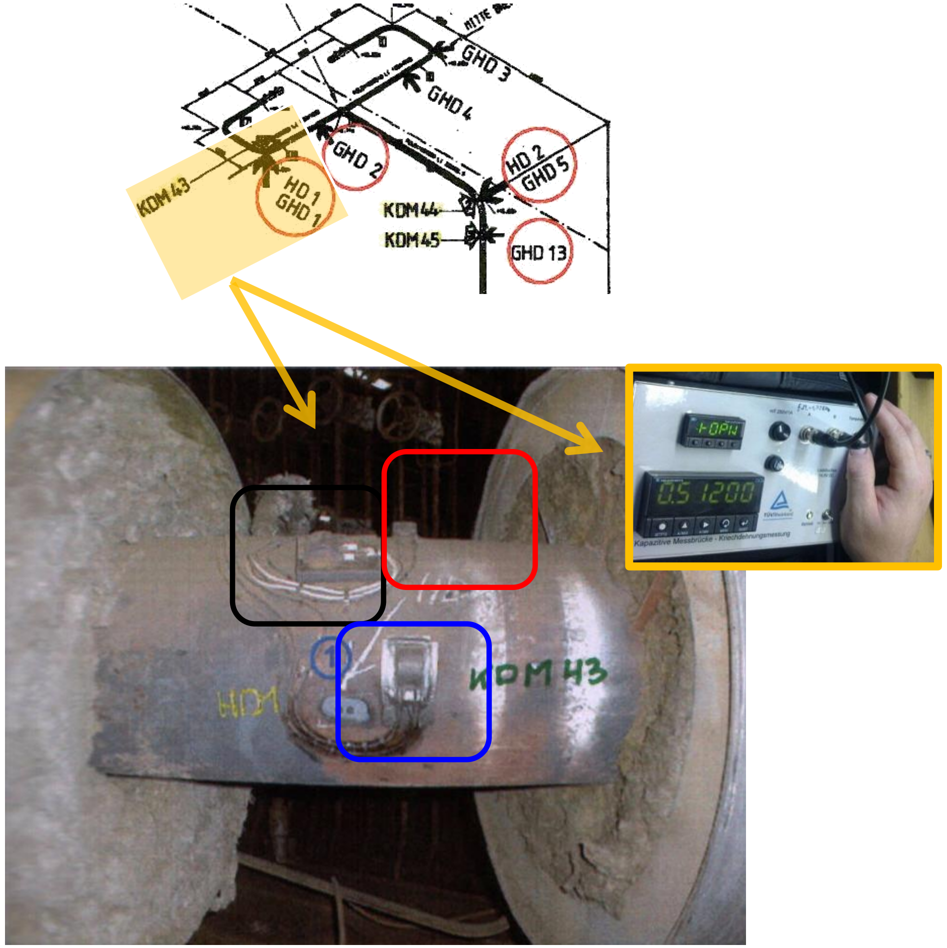
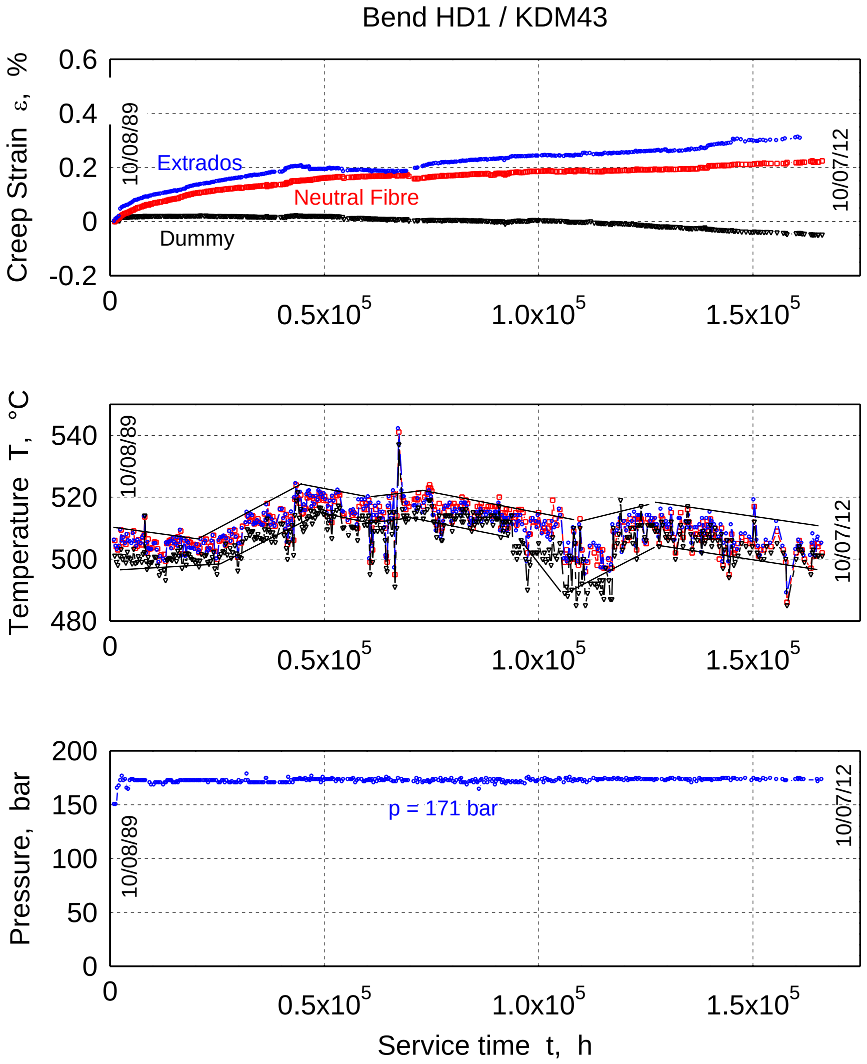
TÜV Rheinland capacitive sensor for creep and creep-fatigue

Typical remaining lifetime observation





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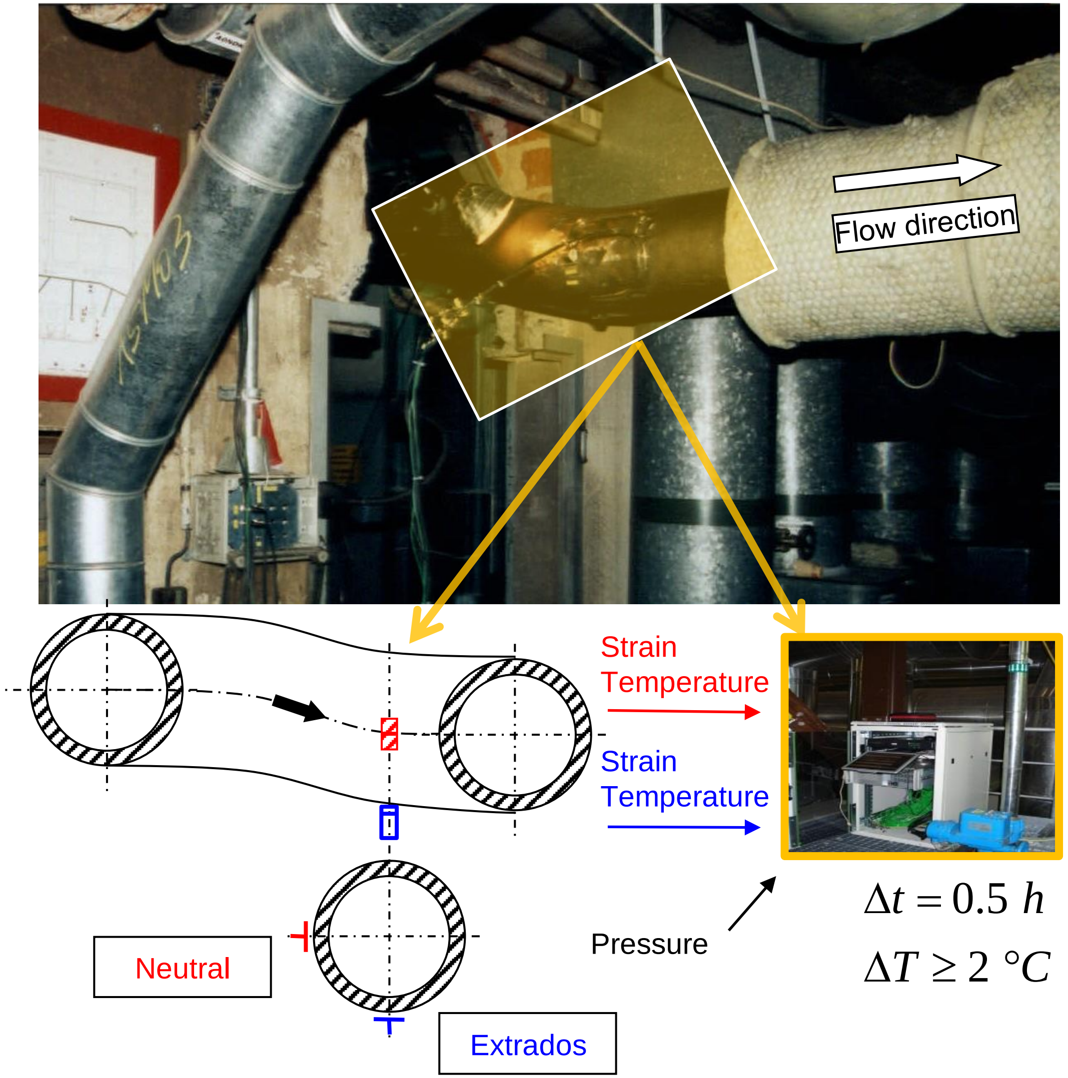
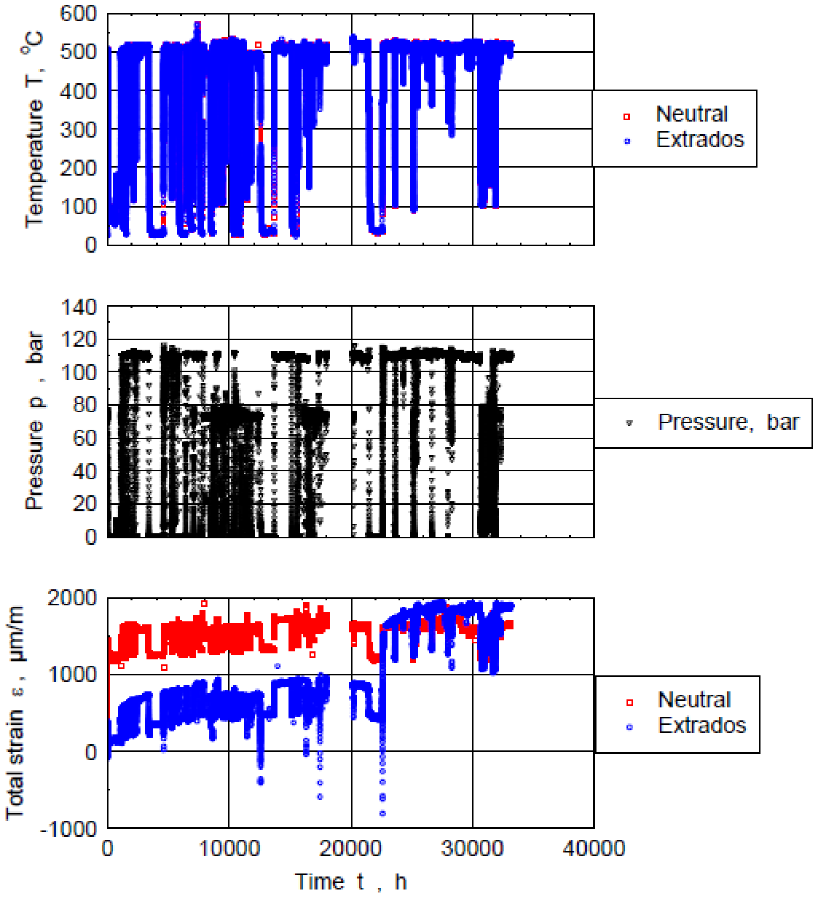
Creep-Fatigue (pre-damaged)



$$\Delta t = 0.5\ h$$

$$\Delta T \geq 2\ °C$$



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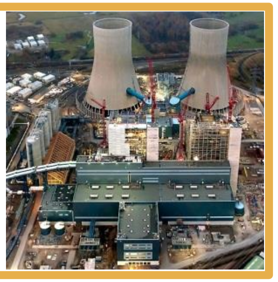
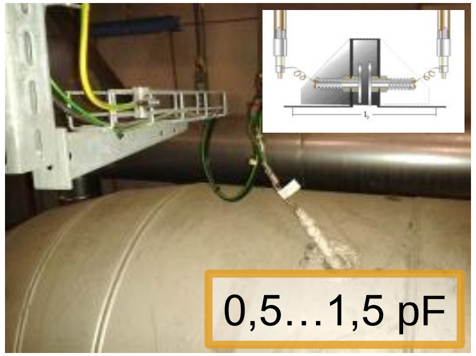
TÜV Rheinland capacitive sensor for creep and creep-fatigue

Basic design approval for prolongation of internal inspection (3 to 4 years!)

PP Westfalen D&E
RWE Power
Hard Coal 2x765 MWe
SH: 600°C/283 bar
RH: 610°C/60 bar



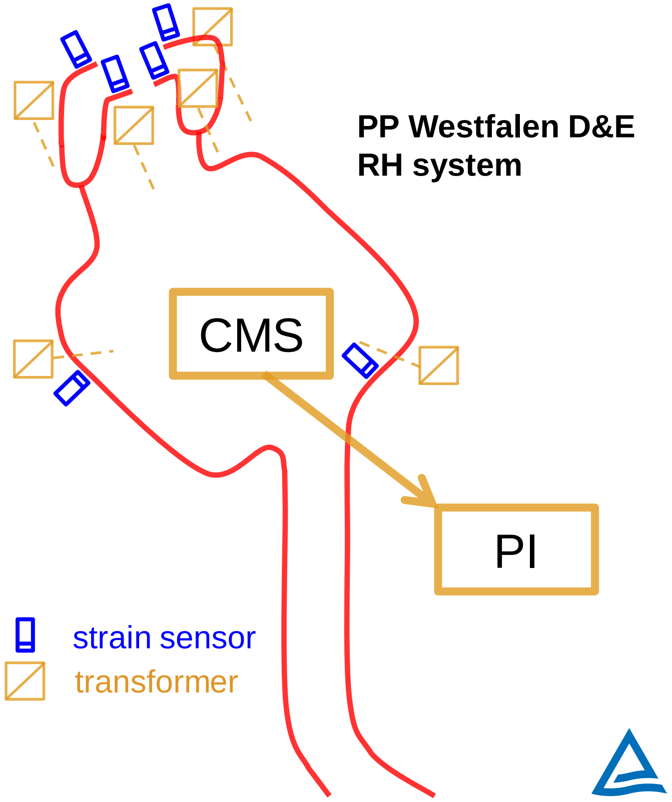
PP Eemshaven A&B
RWE Power
Hard Coal / Biomass 2x780 MWe
SH: 600°C/283 bar
RH: 610°C/60 bar



Each Component

Strains ε_i CMS

4…20 mA Process Interface (PI)



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TÜV Rheinland capacitive sensor for creep and creep-fatigue

Basic design approval for FEA Design by analyses

Newly erected power plants in Germany

- Dimensioning of wall thickness with FEM > “Design by analysis” (European PED)
- Outside the formula of EN 12952 code

PP Wilhemshaven
GDF Suez
Hard Coal 790 MWe
SH: 603°C/209 bar
RH: 621°C/75 bar

PP Neurath BoA 2&3
RWE Power
Lignite 2x1100 MWe
SH: 600°C/272 bar
RH: 605°C/55 bar

PP Walsum 10
Evonik
Hard Coal 790 MWe
SH: 603°C/290 bar
RH: 621°C/75 bar

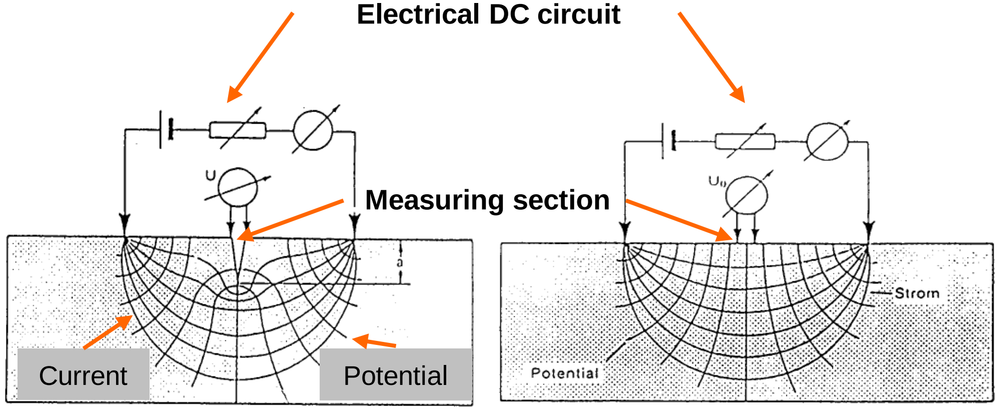
Validation of steam header FEM-Modell

- Local strain measurements of the wall area and between the tube rows are needed
- Comparison of FEM und measurements at 20,000 h (10%) and 60,000 h (30% lifetime)
- Strain limit **inside** 1.5% correlating with 0.17% **outside (!)**
- Requirement: Measurement resolution less than 1µm

Method: Potential Drop (DCPD)

Crack monitoring (up to 650 °C)

Principle of the "Direct Current Potential Drop" (DCPD) measurement technique



Crack

Reference

HP-valve with large crack in deposit weldments

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Method: Potential Drop (DCPD)

Crack monitoring (up to 650 °C)

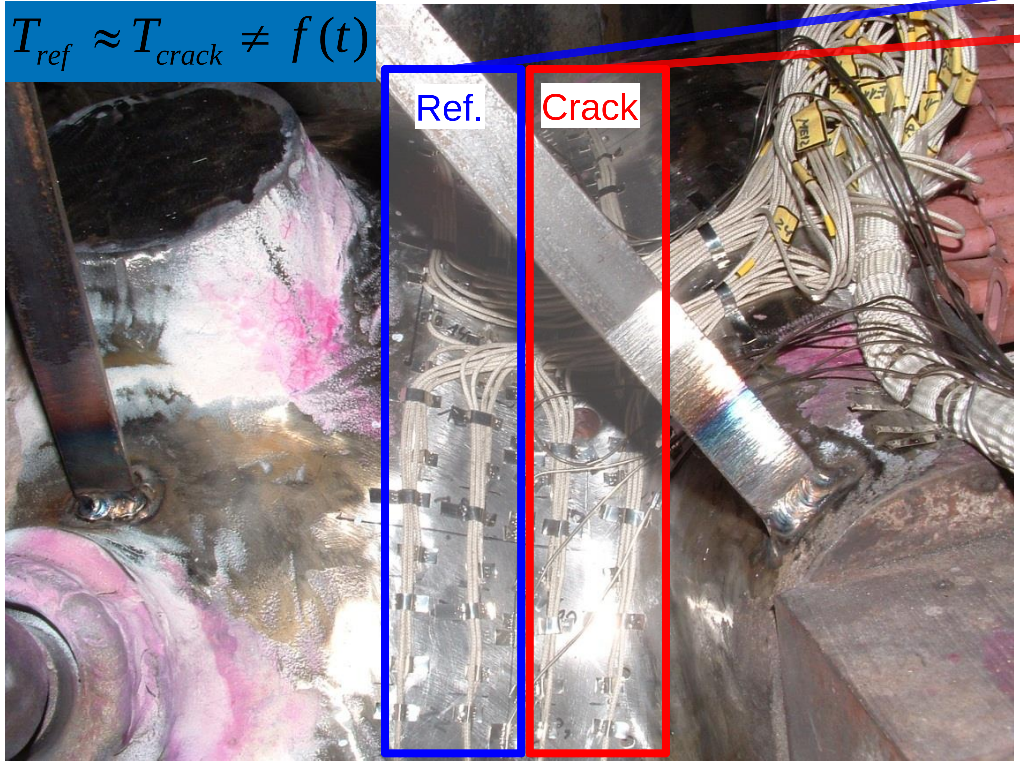
$$\Delta\bar{u}_{alarm} = \left(\frac{\Delta U_{i,t} / \Delta U_{ref,t}}{\Delta U_{i,0} / \Delta U_{ref,0}} \right) > 1.02$$

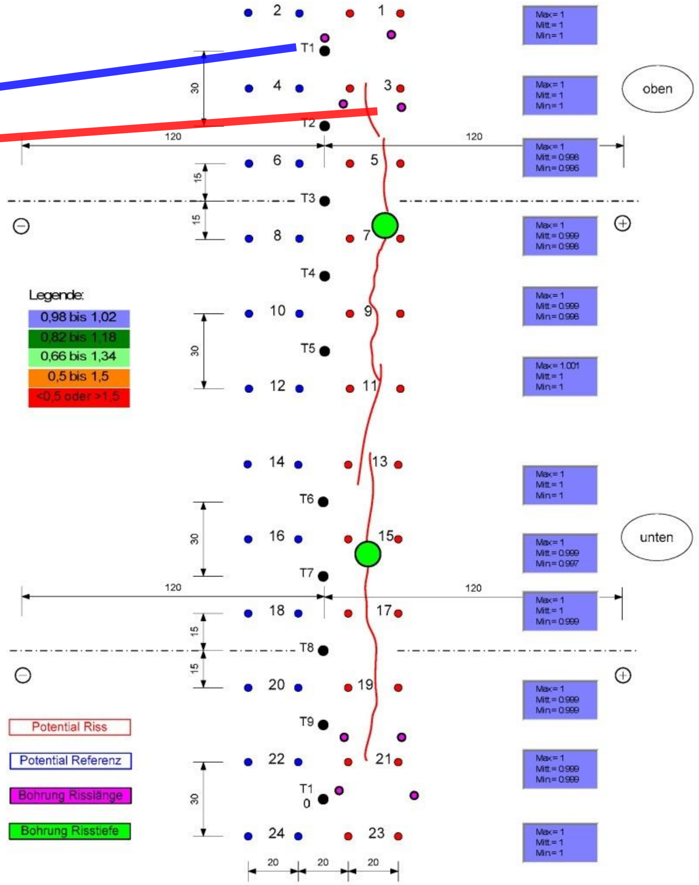
$$\Delta\bar{u}_{alarm} > 1.02\ (2\%\ scatter) \rightarrow \text{crack opening}$$

$$\Delta\bar{u}_{alarm} < 0.98\ (2\%\ scatter) \rightarrow \text{crack closing}$$

$$t = 0 \rightarrow \Delta\bar{u}_{alarm} = 1$$

$$T_{ref} \approx T_{crack} \neq f(t)$$





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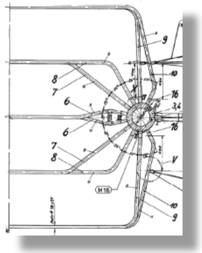
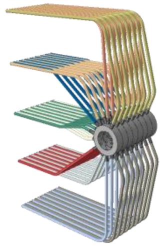
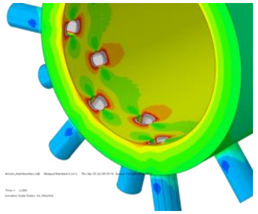
Method: Computational Engineering (FFS)

CAD modelling
- without crack
- with crack

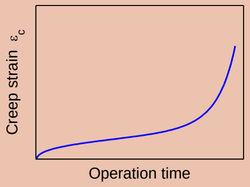


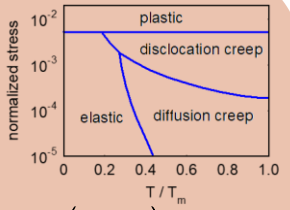


Thermo-mechanical FEM analysis
- transient
- steady state
- without crack
- with crack



Assumed material damage mechanisms
- TMF
- Creep
- Thermal shock steam condensation water evaporation
- Manufacturing defects





$$\left.\frac{da}{dN}\right|_{Fatigue-Creep\ cycle} = \frac{B(T_{cycle})}{1-D_t}\cdot(\Delta K_I)^n$$

$$\varepsilon_c = A_c\left[\frac{\sigma}{(1-\Omega_t(T,\sigma,t))^d}\right]^{n_c}\cdot t^{m_c}$$

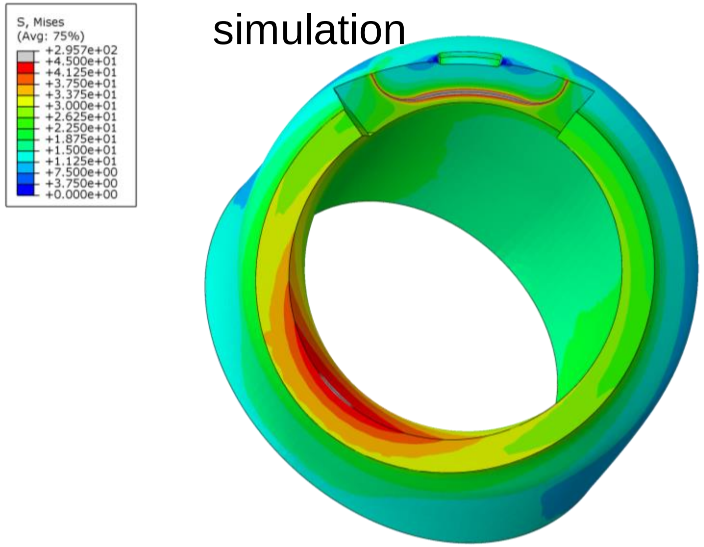
Recommendations

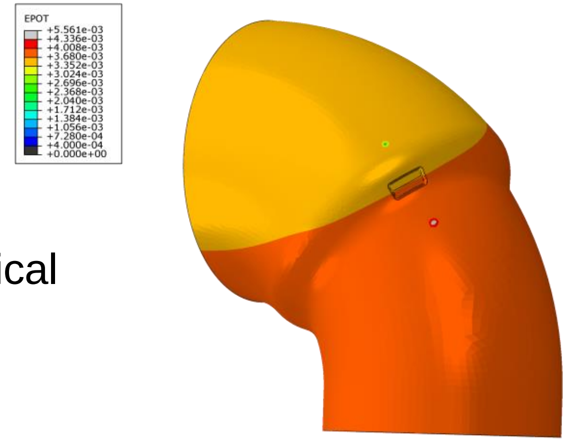
- ▶ **Carry out remote monitoring**
- ▶ **Adjust periodical inspections interval**
- ▶ **Increase NDE extent and methods**
- ▶ **Recommend overhaul, re-work**
- ▶ **Reduce loading parameters (T, p, ...)**

Coupled methods (valve body at 600 °C/250 bar)

Crack monitoring: FEM/fracture mechanics + potential probe + capacitive strain sensors

- Crack simulation





- Electrotechnical simulation

- Constantly "flood" component with DC current
- Measurement of the changing electrical voltage in the damaged area by means of "potential probes".
- Fracture mechanics concept needed
- Electrotechnical simulation
- Timing via strain sensors
- Alarm concept

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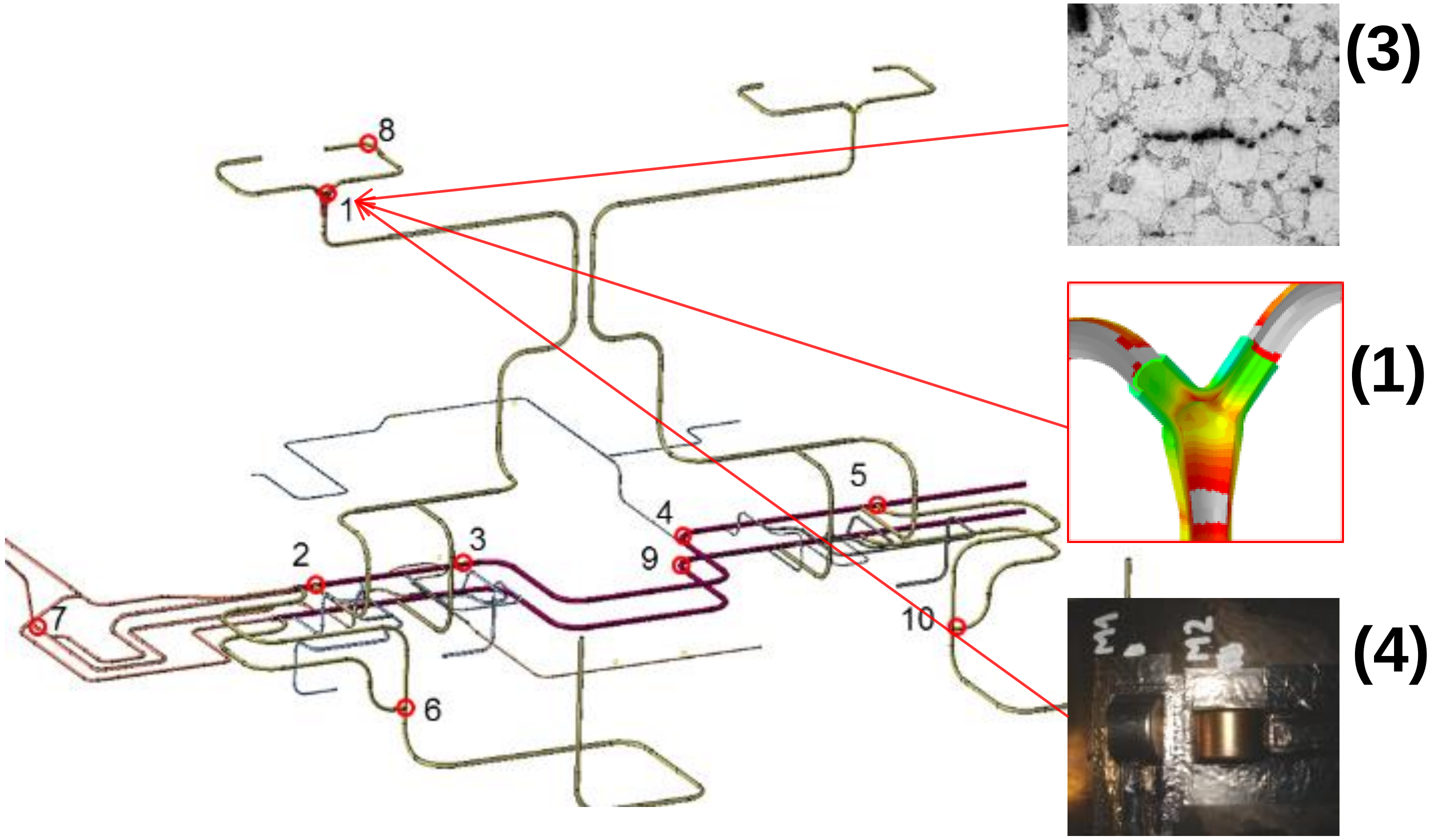
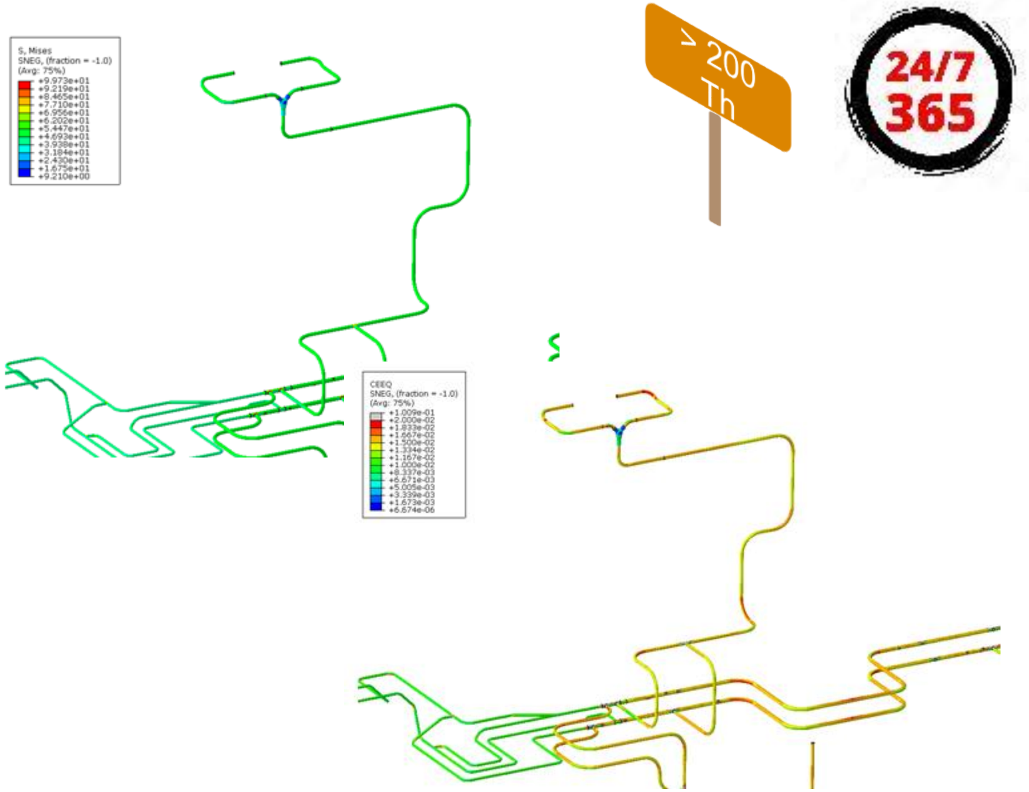
Coupled methods

Life time analyses of a piping system





About the procedure:

(1) Numerical determination of the creep strain distribution

(2) Determination of the most highly stressed positions (so-called hot spots)

(3) Recording of the ACTUAL condition by means of microstructure replica analysis

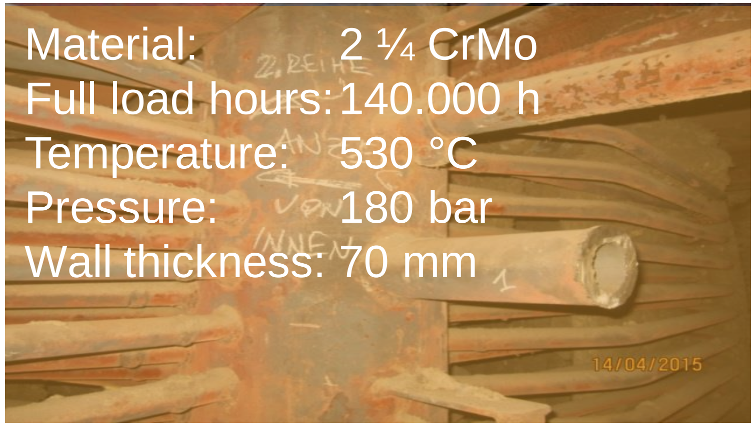
(4) Installation of high temperature creep strain measurements at the hot spots.

(5) Verification of the calculation model on the basis of the measured data

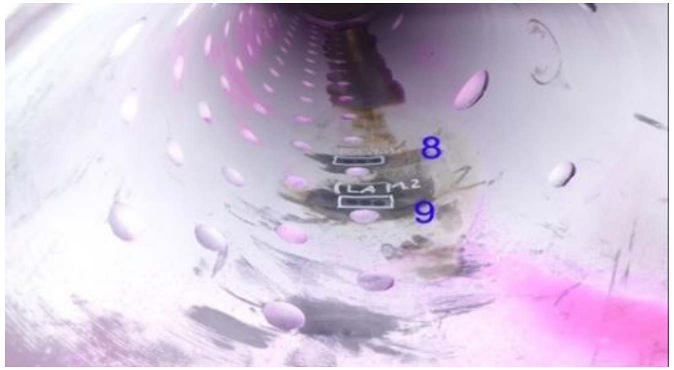
(6) Creep monitoring based on the combination of simulation and measurement data

Coupled methods

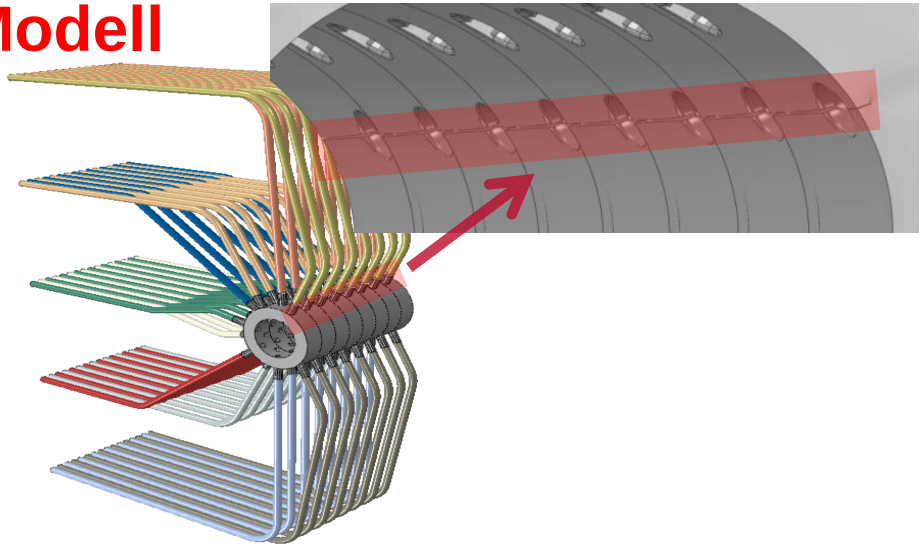
Header with internal crack



Material: 2 ¼ CrMo
Full load hours: 140.000 h
Temperature: 530 °C
Pressure: 180 bar
Wall thickness: 70 mm

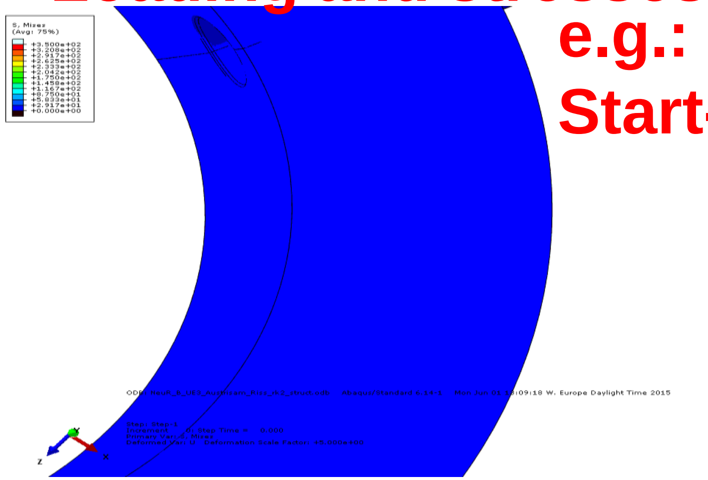


Modell



Loading and stresses

e.g.:
Start-up



Monitoring

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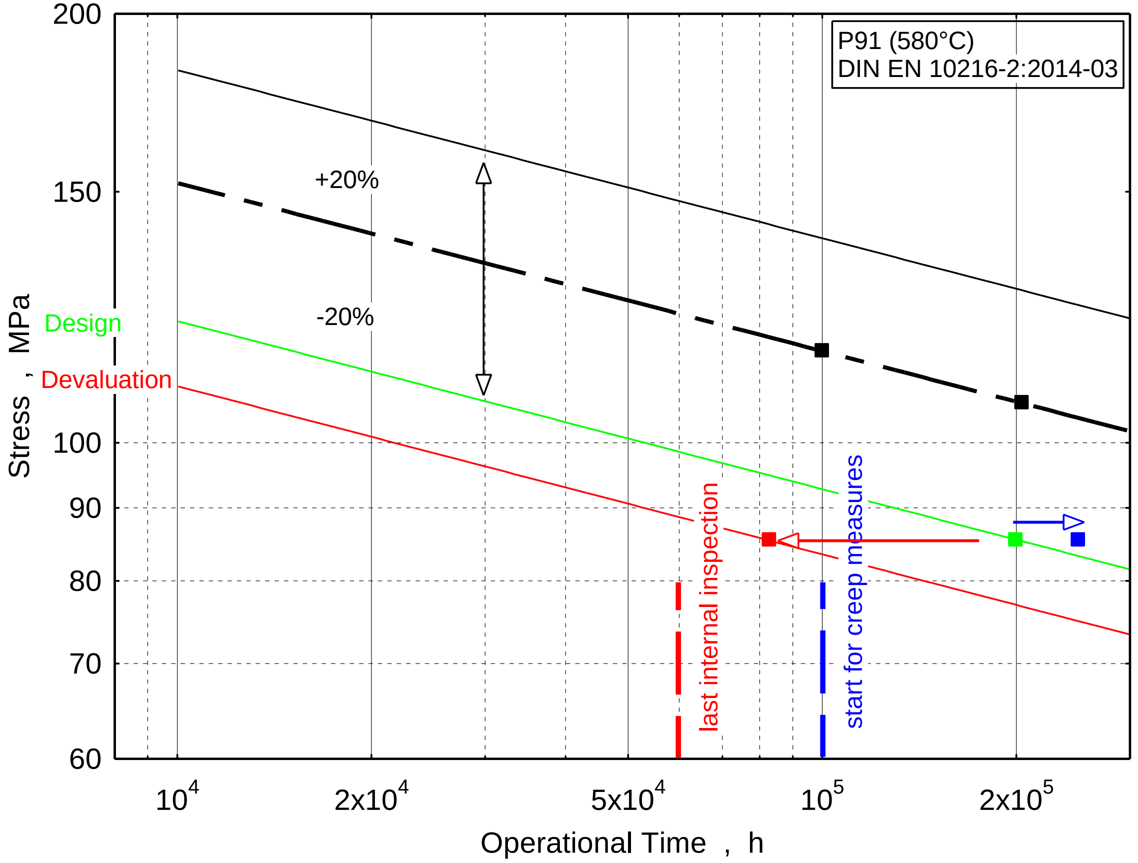
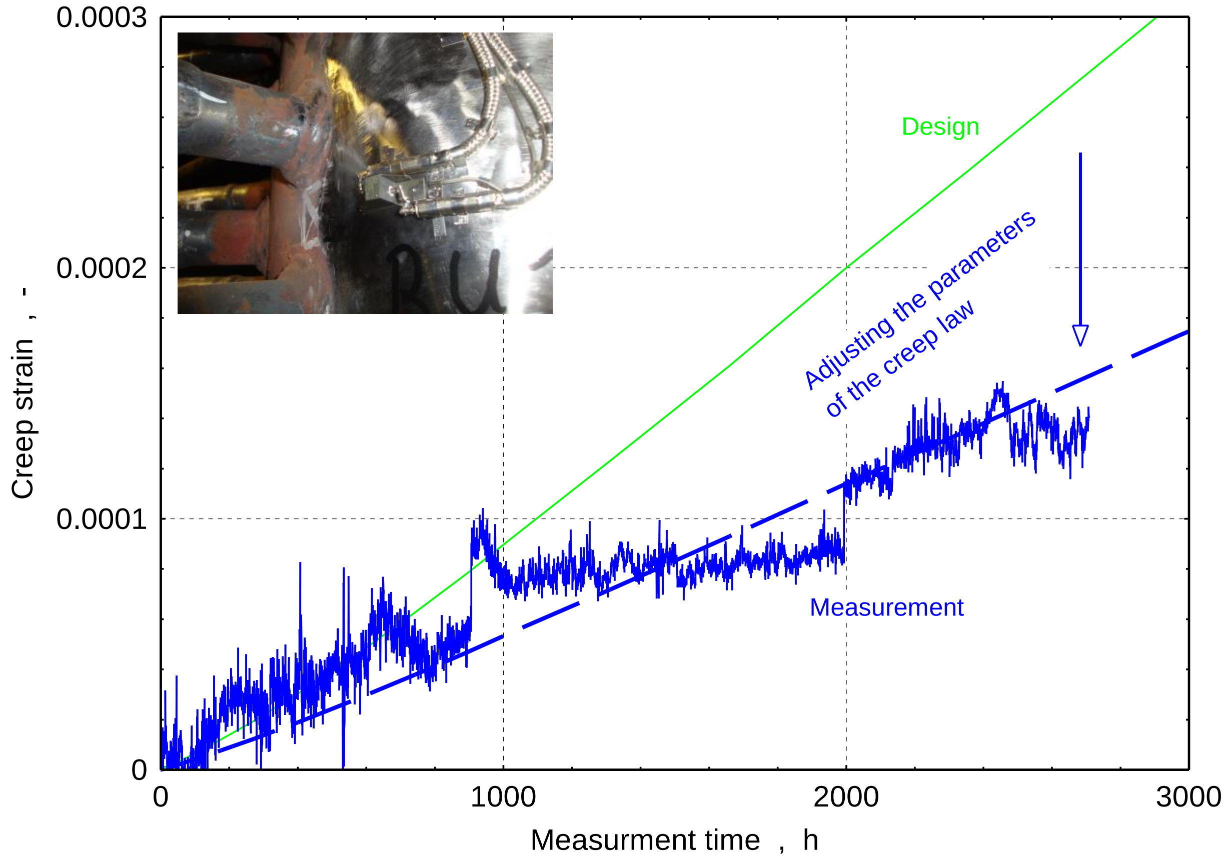
Coupled methods

Devaluation of P91

P91 (X10CrMoVNb9-1)	Devaluation of the creep strength parameter $R_{m\ 100.000}$ in [%] at temperatures of		
Evaluation acc.	550 °C	575 °C	600 °C
ASME Type I	-8%	-15%	-16%
ASME Type II	-5%	-12%	-11%
ECCC 2018_1	-8%	-8%	-6%
ECCC 2018_2	-12%	-12%	-11%





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