MAKOMON
Monitoring of the structural integrity of materials and components in reactor circuit

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MAKOMON 2011-2014
Nondestructive testing/evaluation NDT/NDE of NPP primary circuit

- NDE applications for detecting cracks in primary circuit components
  - Ultrasonic applications
  - Radiography
  - Eddy Current
- New ultrasonic methods,
  - Laser ultrasound
  - Nonlinear ultrasonics
- Ultrasonic simulation and POD
- Eddy current inspection techniques for primary circuits
  - Magnetite in Steam Generators
  - Eddy current simulation
- Digital Radiography
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Nondestructive testing/evaluation NDT/NDE of NPP primary circuit

- NDE applications for detecting cracks in primary circuit components
  - Comparison of artificial flaws in austenitic steel welds with
  - NDE results compared to real measurements / DE

- Simulation and POD
  - Ultrasonic simulation of the defects in primary circuit components and POD
  - Model assisted POD calculations for fatigue flaws

- Eddy current inspection techniques for primary circuits
  - Magnetite in Steam Generators
  - Measurements of Magnetite Piles on Steam Generator Tubing with Eddy Current Techniques
Comparison of artificial flaws in austenitic steel welds with NDE methods
Background

- Reliable evaluation of the performance of in-service inspection procedures, equipment and personnel requires representative artificial defects.
- Ultrasonic indications are dependent on defect characteristics like roughness, crack opening, tilt, skew and branching.
- It is crucial for the reliability to know how well artificial defects like thermal fatigue or mechanical fatigue cracks correspond to service-induced cracks.

a) EDM-notch
b) Welded crack simulation
c) Grown crack
d) Service-induced crack
Test blocks

- Welded AISI 316L test plates:
  1. Thermal fatigue crack and EDM notch
  2. Two mechanical fatigue cracks
Methods

- NDT
  - Phased Array ultrasonic
  - Conventional ultrasonic
  - Computed tomography
  - Eddy Current
- DT
  - Scanning Electron Microscope
    - Surface and fracture surface
  - Stereo microscope
  - 3D profilometry
  - Cross-section investigation
    - Optical Microscope
Ultrasonic Inspections

- Conventional ultrasound
- Phased array ultrasonic methods
  - influence of different reflector properties on indications.
Mechanical fatigue crack

Photography

Profilometry

3D-Profilometry

Crack: MFA
$R_q = 326.67 \, \mu m$
$R_a = 287.06 \, \mu m$
Thermal fatigue crack

Photography

Profilometry

3D-Profilometry

Line profiles

Crack: TF

$R_q = 485.30 \, \mu m$

$R_a = 390.99 \, \mu m$
Tomographic x-ray imaging
UT vs. DT measured height

Conventional UT  Phased Array UT

Conventional UT  Phased Array UT

Conventional UT  Phased Array UT

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UT vs. DT measured length

Conventional UT | Phased Array UT

Conventional UT | Phased Array UT

Conventional UT | Phased Array UT
Notes from the results

- Crack tips were observed in mechanical fatigue cracks but not in thermal fatigue crack

- Higher frequency in ultrasonic testing can give more information of crack morphology and can also enable accurate height sizing of shallow cracks

- Phased array UT seems to give more accurate results in height sizing and conventional UT in length sizing
Ultrasonic simulation and POD
Probability of detection (POD)

- POD -curve tells the probability for flaw of certain size to be found.
  - What is the largest flaw that a NDT-method can miss?
- At least 40 measurements is required to obtain POD-curve with reasonable confidence
  - New measurement = money and time
- Computer simulations to create new measurement points to POD -curve → model assisted POD
Model assisted POD calculations for fatigue flaws

- One popular way to measure the reliability of NDE are probability of detection (POD) curves
  - Generating POD requires a large amount of measurements with artificial defects → expensive
- CIVA simulation program has been used to model fatigue cracks
  - Development of modelling tools allows fast and cheap way to generate measurements
- The model and measurements have been then combined to create data points for POD curve calculations
- Meta-modelling has been implemented to accelerate the modelling efforts
POD for MF flaw

- Skew = (0±5)°, tilt = (90±5)°
- Three different focal laws
- The $a_{90}$ defect height is 2.74 - 9.40 mm
  - The wide range is due to difference in measured SNR values
  - If constant 17.3 dB SNR value (SW45°) is used, the $a_{90}$ values are
    2.74 mm (SW 45°)
    2.90 mm (SW 55°)
    3.04 mm (SW 70°)
Eddy Current Measurements

1 - signal from magnetite
2 - signal from TSP

10 kHz
Measurements of Magnetite Piles on SG Tubing with Eddy Current Techniques

- The goal was to further develop and test a technique capable to size the magnetite piles within the SG tubing.
- Absolute technique
- Frequencies, between 10 and 200 kHz
Eddy Current Measurements with Single Probe

Amplitude [Vpp] vs. The distance between the top of the magnetite pile and the lower surface of the tubes [mm] at different frequencies:
- 12.5 kHz
- 25 kHz
- 50 kHz
The best sensitivity was achieved, when the eddy current frequency was low 12.5kHz, 25kHz or 50 kHz.

Extension of the magnetite pile can be mapped.

Single probe technique is found more reliable.
Conclusion

- Artificial cracks from different manufactures in austenitic stainless steel test blocks were sized with different ultrasonic techniques, x-ray tomography and digital radiography
  - Results were compared to the true state defect dimensions as determined by destructive analysis
- The modelling and measurements was combined to create POD curves for fatigue cracks
  - Many different POD curves were calculated using CIVA simulations and meta-modelling. The results show the advantage of using meta-modelling to decrease the calculation times
- Tests to map the magnetite existence in the steam generator tubing mock-up with eddy current technique have shown a single probe technique more reliable
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