Digital Radiology for Corrosion Inspection and Wall Thickness Measurement of Insulated Pipes

Content:
- basic principles of TRT
- software for evaluation and documentation
- corrosion depth evaluation
- validation of methods
- development of standards

AGFA, GE S&IT, HOIS, IAEA

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May 2011, Bodo, Norway

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Projection Radiography

Examples on Corrosion and Erosion

Corrosion and Seads
Corrosion
Erosion

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History: radiographic wall thickness evaluation

- applied since ca. 1950
- nearly no literature until 1980
- growing importance in chemical industry caused by on-stream application
- since 1996 projects BASF und BAM for physical studies
- Never standardized (first CEN draft 2010 by S. Burch, HOIS)

classical tangential set-up of TRT:
- pipe line
- radiation source, Ir 192
- insulation
- profile line
- film, imaging plate, or flat panel
**Projection Radiography**

**Example: distribution station**

*on-site exposure, Ir 192*  
*film*  
*source*

*radiograph*

**Error sources:**
- wrong density range
- inaccurate edge detection (unsharpness)
- wrong magnification factor
**Principle of projection radiography (TRT)**

- **tangential penetration of pipe wall**
- \( w' \) measured on film
- \( f \) - film focus distance
- \( r \) - outer pipe radius
- \( R \) - outer radius of insulation
- \( w' \) - wall thickness projection on detector plane

Digitized film

- Imaging plate
- **AGFA BAM project in 1995 ff** (Peter Willems)
- Special NDT IP reader prototype (28 \( \mu \)m pixel)

- D7 + Pb, 50 \( \mu \)m pixel size
- 25 % exposure time, 145 \( \mu \)m pixel size
Projection Radiography

**film digitization (FD)**

**imaging plate (CR)**

**flat panel (DDA)**

- single program for evaluation of all digital images, no size limitation
- support for all detectors by external 16 bit LUT tables for linearisation (gray value proportional to radiation intensity)
- easy documentation by protocol generation in PDF format

16 bit software platform

**image processing know-how on Windows PC:**
(since 2006 ISee!, see [http://www.kb.bam.de/ic.html](http://www.kb.bam.de/ic.html))

- fully 16 bit data depth for evaluation and display
- unlimited image sizes, limited only by main memory (>1 GByte)
- all detectors (digitized film, imaging plates, flat panel detectors) via external 16 bit Lookup Tables (LUT) linearizable, ASCII text
- fast rekursive moving average filtering for arbitrary sizes of high and low pass filters, convolution with variable kernels, FFT-Filters
- sub-sampling for image display with true averaging
- error estimation for measured values and geometric correction
- quick documentation of measurements by protocol generation and transfer to Word (wtScope for BASF, wtModule in Rhythm, GE S&IT)
- protection of application by individual encrypted license keys
**Projection Radiography**

- input exposure parameters
- wall thickness result
- table with measurement regions
- tangential wall thickness algorithm
- wall thickness deviation in measurement region

**PC based wall thickness measurement**

- synchronous display of positions in profile and image!
- position correction by hand, if algorithm fails!

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**Projection Radiography**

**PC generated measurement protocol**

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**Projection Radiography**

**PC based wall thickness measurement**

**Algorithms:** problem: correct detection of wall positions

characteristic points, curve fitting, CT reconstruction

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**BASF**

Digital Radiology for Corrosion Inspection

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Limits of Tangential Radiography (TRT):

\[ L_{\text{max}} = 2W \sqrt{D_a/W - 1} \]

**Energy:**
- 100 kV : 10 mm
- 200 kV : 30 mm
- 300 kV : 40 mm
- 400 kV : 50 mm
- Se-75  : 60 mm
- Ir-192 : 75 mm
- Co-60 : 120 mm

Steel pipes up to 20” with NDT film and X-ray, Ir-192, Co-60

Algeria Hungary Romania Iran Pakistan Germany Uruguay Syria India Turkey Malaysia Canada
Fabricated Reference Blocks with Steps and Holes:

Idea: explore inspection methods with known wall thicknesses
algorithm detects edges, visual not seeable in image:

extension of application range in comparison to visual evaluation

Ir 192, DN200:
6 → 11 mm

Co 60, DN300:
14 → 24 mm

2006: Validation of wtScope, CR-Tower and Ir-192

Not accessible with Ir-192

Uncertainty 0.2 mm

0.5 mm

BAM
BASF
GE S&IT
Validation as measurement method according to ISO 17025:

2.9 Validation results for stepped pipes DN 100 filled with H₂O

Steel pipes 50 – 300 mm dia, empty, water filled, w/o insulation

Second inspection technique possible:

2. Corrosion assessment from local film density changes (Double Wall Technique, DWT)
Local corrosion: wall thickness differences in penetration direction (DWT)

Source → Pipe → Erosion $w - \Delta w$ → Intensity change, $\Delta I$ → Detector

**Attenuation law:**

$$I_w = I_0 e^{-\mu_{eff} w}$$

$\mu_{eff}$ - effective attenuation coefficient

**Relative measurement:**

2 step algorithm

1. Calibration:

$$\mu_{eff} = \frac{\ln(D_{REF} / D_{IQI})}{\Delta w_{IQI}}$$

2. Measurement:

$$\Delta w = \ln(D_{REF} / D_{MEAS}) / \mu_{eff}$$

**DWT for local corrosion**

1. Calculation of effective attenuation coefficient $\mu_{eff}$

- Known hole depth
- Known pipe wall thickness $w$ at reference point

**Result:**

$$\mu_{eff} = f(w)$$

Dep. on radiation energy and wall thickness differences
Double wall technique 6" and 8" (100 kV), with and without insulation

\[ y = 0.6689x - 0.3385 \quad R^2 = 0.7316 \]
\[ y = 0.5039x - 0.3927 \quad R^2 = 0.3817 \]

- Iran, Uruguay
- decreasing \( \mu_{\text{eff}} \) with penetrated wall and insulation

80 % of all measurements: \( \mu_{\text{eff}} = 0.046 +/- 0.005 \text{ mm}^{-1} \)
Computer based evaluation with wtScope/iSee! software: accuracy 10% wt, $\mu_{eff}=0.028/mm$.

Practical application: profile plot in wall thickness loss.
real pipe, inner corrosion, insulated

corrosion mapping after median high pass (gray value prop. penetrated wall thickness, 1x300 points):

corroded pipe with weld

corrosion mapping after median high pass (gray value prop. to penetrated wall thickness 1x200 points):
Comparison Film / CR

DWT with Ir-192:

Result of wtScope validation for CR Tower by BAM / BASF / GE S&IT

reason: scatter sensitivity!

Parameter | Ir-192 | Co-60  
--- | --- | ---  
DWT: $\mu_{\text{eff}}$ | 0.046 +/- 0.005 mm$^{-1}$ | 0.028 +/- 0.004 mm$^{-1}$  
TRT: $L_{\text{max}}$ for $D_{\text{center}} = 2$ and $D_{\text{max}} = 4$ | 80 mm | 130 mm  
TRT: $L_{\text{max}}$ for $D_{\text{max}} = 8$ | 95 mm | 155 mm

agreed results of IAEA CRP: Limits of film application!

Accuracy for TRT wall measurement: < 0.3 mm

Accuracy for DWT depth measurement: 0.5 mm or 10%wt
**Summary**

- Program for PC based routine measurements on images from all radiographic detectors, tangential wall thickness measurement and local corrosion, simple documentation
- Wall thickness range enlarged compared with visual evaluation in projection radiography
- Measurement of corrosion depth (in centre of pipe)
- Validation as measurement methods acc. to ISO 17025
- Programs transferred to GE S&IT for worldwide marketing (Rhythm Version 3 all methods implemented)
- Differences in sensitivity to scattered radiation between film and imaging plates

Inspection technique not yet standardised, written practice necessary!

*Standard development at CEN started in 2010*
Digital Radiology for Corrosion Inspection

BASF

Proposed Draft standards:
Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays
— Tangential radiographic inspection
— Double wall radiographic inspection

Dr Steve F Burch, ESR Technology

HOIS

See NDT informasjon fra Norsk Forening for Ikke-devstruktiv Proving, April 2011

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The End