EN 16407 Parts 1 and 2: Newly published European standards for the in-service digital and film radiography of pipes

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Dr Stephen F Burch, ESR Technology Ltd, Oxfordshire, UK
steve.burch@esrtechnology.com
In-service inspection of pipes

- Flaws of interest generally corrosion & erosion
- Can be internal or external
- Corrosion product often present for external flaws
- External insulation often present

Most widespread application is combination of tangential & double wall double image (DWDI)

- Typically for 3“ (75mm OD) pipes and smaller
- Measure through-wall extent of corrosion

Also double-wall single image radiography for larger pipe diameters

- Flaw detection
- Qualitative estimates of through-wall size
Main radiation sources:

- Usually Iridium 192
- Selenium 75 less frequently
- Very rarely portable X-ray sources

Main types of detectors:

- Conventional radiographic film still used quite widely
- Computed Radiography (CR) based on re-usable imaging plates and laser scanners well established
- Digital Detector Arrays (flat panels): some applications
European standards

EN ISO 17636-1 & -2 cover radiography of new welds

No standards for in-service radiography

- Wide variations in practices adopted by different organisations
- No IQI values specified for in-service inspection
- Variable exposures, source positioning, source selection
- Subjective assessment of image quality

Sensitivity and quality of resulting radiographs and digital images very variable

Quality can be less than for weld radiography, but control/standardisation still important
Introduction to HOIS Joint Industry Project (JIP)

HOIS is a major well established JIP on good practice for NDT/NDE in the oil & gas industry

• 30+ years

Current membership 44

Members comprise:

• Oil and Gas producers - operators
• NDT service companies
• NDT equipment vendors
• Testing & Inspection Companies
• A regulatory authority (UK HSE)

Managed by ESR Technology

Global representation: Americas, UK, Europe, Middle East, Australasia
Early HOIS sponsored blind trial of CR for ISI gave unexpectedly poor results (2003)

Follow-up showed this to be due to limitations in procedures used, not the inherent capabilities of the equipment.

Productive collaboration with CR experts at BAM, Berlin.
  • Professor Uwe Ewert & Dr Uwe Zscherpel

Several practical CR trials to develop and validate the recommended practice

HOIS Recommended Practice
  • Published in January 2010 – available for download from www.hoispublications.com

Now progressed to form basis of new EN standards
New EN standards, published January 2014

Two part standard, covering film and digital radiography (CR/DDA)

- EN 16407-1, Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays — Part 1: Tangential radiographic inspection

- EN 16407-2, Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays — Part 2: Double Wall radiographic inspection

Developed by CEN/TC 138/WG 1

- HOIS RP used as input
BSI Standards Publication

Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays
Part 1: Tangential radiographic inspection

BSI Standards Publication

Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays
Part 2: Double wall radiographic inspection

"making excellence a habit"
For wall loss in-service inspection of pipes only

- Corrosion/erosion flaws
- NOT cracks

Techniques covered:

- Tangential radiography (EN 16407-1)
- Double wall techniques (EN 16407-2)

Two quality classes

- Standard TA, DWA (tangential, double wall)
- Improved TB, DWB

Detectors

- Radiographic film
- Computed radiography (imaging plates, laser scanning)
- Digital detector arrays (DDA)
Tangential techniques

Beam axis through pipe centre line

- Often combined with double wall double image

Beam axis offset
Double wall techniques

Double wall double image (DWDI)
- Often combined with tangential

Double wall single image (DWSI)
Radiation Sources

• Types of source
• Source selection
• Size and strength of sources

Recommended Source to Detector Distances

• DWSI
• DWDI
• Tangential Inspection

Sensitivity/quality measures:

• Single wire IQI values based on experimental measurements (double wall techniques)
• Density of film
• Digital Image quality criteria
  • Basic spatial resolution of detector system (SRb)
  • Normalised Signal-to-noise ratio (SNR_N)
Maximum penetrated thickness $w_{\text{max}}$ occurs at tangent position with pipe internal diameter

$W_{\text{max}} \gg$ twice wall thickness

<table>
<thead>
<tr>
<th>Radiation source</th>
<th>Limits on maximum penetrated thickness, $w_{\text{max}}$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic (for generalised wall loss)</td>
</tr>
<tr>
<td></td>
<td>Improved (for pitting flaws)</td>
</tr>
<tr>
<td>X-ray (100 kV)</td>
<td>$\leq 10$</td>
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<tr>
<td></td>
<td>$\leq 7$</td>
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<tr>
<td>X-ray (200 kV)</td>
<td>$\leq 30$</td>
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<tr>
<td></td>
<td>$\leq 20$</td>
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<tr>
<td>X-ray (300 kV)</td>
<td>$\leq 40$</td>
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<tr>
<td></td>
<td>$\leq 30$</td>
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<tr>
<td>X-ray (400 kV)</td>
<td>$\leq 50$</td>
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<tr>
<td></td>
<td>$\leq 35$</td>
</tr>
<tr>
<td>Se 75</td>
<td>$\leq 55$</td>
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<tr>
<td></td>
<td>$\leq 40$</td>
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<tr>
<td>Ir 192</td>
<td>$\leq 80$</td>
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<tr>
<td></td>
<td>$\leq 60$</td>
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<tr>
<td>Co 60</td>
<td>$\leq 120$</td>
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<tr>
<td></td>
<td>$\leq 85$</td>
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</tbody>
</table>
Key parameter is penetrated thickness of pipe (twice the wall thickness)

Also include any liquid product inside pipe and external insulation

<table>
<thead>
<tr>
<th>Radiation source</th>
<th>Penetrated thickness, $w$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>basic technique DWA</td>
</tr>
<tr>
<td>Yb 169</td>
<td>$1 \leq w \leq 15$</td>
</tr>
<tr>
<td>Se 75</td>
<td>$5 \leq w \leq 55$</td>
</tr>
<tr>
<td>Ir 192</td>
<td>$7 \leq w \leq 85$</td>
</tr>
<tr>
<td>Co 60</td>
<td></td>
</tr>
<tr>
<td>X-ray equipment with energy from 1 MeV to 4 MeV</td>
<td>$30 \leq w \leq 200$</td>
</tr>
<tr>
<td>X-ray equipment with energy from 4 MeV to 12 MeV</td>
<td>$w \geq 50$</td>
</tr>
<tr>
<td>X-ray equipment with energy above 12 MeV</td>
<td>$w \geq 80$</td>
</tr>
</tbody>
</table>
Setting the SDD involves a trade-off between image sharpness and exposure time.

For wall-loss applications, image unsharpness can be larger than for weld radiography.

Distances based on geometric unsharpness, $U_g$, *projected onto the plane of interest*

- Basic technique: $U_g = 0.6 \text{ mm}$
- Improved technique: $U_g = 0.3 \text{ mm}$

For tangential technique, also require

$$SDD \geq PDD + 3,5 \cdot D_e$$

Where PDD is pipe centre to detector distance.
SDD formulae (where practical)

Tangential basic TA

\[ SDD \geq \frac{d \cdot PDD}{0.6} \]

Tangential improved TB

\[ SDD \geq \frac{d \cdot PDD}{0.3} \]

Double wall basic DWA

\[ SDD \geq \frac{d \cdot b}{0.6} \]

Double wall improved DWB

\[ SDD \geq \frac{d \cdot b}{0.3} \]
Wire IQIs not appropriate

For film, set limits on optical densities:

- Optical density on the pipe centre line ≥ 1,5.
- Optical density in the un-impeded beam (outside the pipe): 3,5 – 4 (max).
- Optical density in a tangent position of the inner pipe wall ≥ 0,5.

For digital images, use normalised signal to noise ratio $\text{SNR}_N$

- In free beam: $\text{SNR}_N > 70$ (TA), $\text{SNR}_N > 100$ (TB)
Double wall radiography – image quality

Single wire IQI values measured experimentally for limited penetrated thickness ranges

For digital images, use normalised signal to noise ratio $SNR_N$

- On pipe centre line: $SNR_N > 50$ (TA), $SNR_N > 80$ (TB)

Film density:

- Minimum optical density of 2 (1.5 by agreement between contracting parties)
Techniques for calibration of distances:

- Pipe OD
- External comparators

Techniques for measurement of remaining wall thickness:

- Interactive on-screen (cursor) methods
- Grey level profile methods
  - Interactive
  - Automated
Double wall Radiography EN 16407-2 – Estimation of differences in penetrated thickness

Based on:  \[ I(w) = I(0) \exp(-\mu w) \]

where

- \( I \) is radiation intensity,
- \( \mu \) is attenuation coefficient,
- \( w \) is penetrated thickness

At best, can only give the difference in penetrated thickness between two measurement positions

Unless care taken, many factors can reduce accuracy of derived values

- Recent blind trial showed no correlation between actual and measured differences in wall thickness
Estimation of differences in penetrated thickness (cont)

Important to:

• Derive attenuation coefficient $\mu$ using a step wedge calibration object on each image being analysed
• Measurement and reference areas need to be close together in image
• The underlying image grey level profile between the two measurement positions needs to be assessed and any variations taken into account

Example showing non linear grey level profile: two point measurement method cannot give accurate results
For wall loss flaws, sensitivity is a function of several variables including:

- Flaw depth
- Flaw diameter
- Penetrated thickness
- Radiation source used

CR images of 2mm diameter holes with Ir 192 for penetrated thickness $15 < w < 25$mm showed:

- Small decrease in sensitivity with reduced $w$
- Standard quality % sensitivity ~ 4% (of total pen. thickness)
- Higher quality % sensitivity ~ 2.5 - 3% (of total pen. thickness)

Sensitivity with Se 75 about 1% better
Validation – repeat blind POD trial

Original CR POD trial in 2003 gave comparatively poor performance

- POD ~ 60%
- Procedure used was not fully developed for the DWDI application

Repeat CR trial on same specimens in 2007 in accordance with HOIS CR recommended practice

- Used DWSI to detect flaws (quicker than DWDI)
- POD ~ 98%

Clear improvement
External corrosion usually covered by scabs formed from corrosion product (rust)

- Prevents direct measurement of wall loss
- Can be dangerous to remove the scab – may cause leaks

Tangential radiography often used on small bore pipework to determine remaining wall thickness

Recent HOIS trials have shown significant under-sizing can occur for some corrosion morphologies. OK on others

Significant safety issue as tangential radiography often used for fitness for service assessment and/or justification for removal of corrosion product

In-service examples of under-sizing reported, including one in which through-wall degradation was not found
There was a notable absence of agreed international standards for in-service radiography (film & CR).

Two part standard EN16407 developed to fill this gap

- Based on extensive experimental trials

EN16407 published in January 2014

Process initiated to submit them by the fast track procedure to ISO.

Consider revisions to include issue with under-sizing of some forms of external corrosion
Acknowledgements

EN16407 developed by CEN/TC 138/WG 1

- Thanks to national experts on this committee
- Committee Chairman and Secretary

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