Codes and Standards in Digital Industrial Radiology

by
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Status and new Situation

- 2005: Computed Radiology standards were completed and published in USA and Europe!
- The Digital Industrial Radiology (DIR) procedure is different from the film radiography procedure
- The optical impression of digital radiographic images is not different from film images in its structure (if not digitally processed, except brightness and contrast control)
- RT-trained personal can interpret digital images in analogy to film
- Digital images need a PC for presentation and may be altered by specialized image processing
- A basic training in image processing is essential to avoid miss interpretation
- Quantitative assessment of flaw sizes is improved by digital processing but the results may differ from those ones of film interpretation
- Electronic reference catalogues may support correct image assessment
# New Standards on Digital Industrial Radiology

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 13068</td>
<td>Radioscopy</td>
</tr>
<tr>
<td>EN 14096, ISO 14096</td>
<td>Film Digitisation</td>
</tr>
<tr>
<td>EN 14784 CR</td>
<td>Part 1: Classification of Systems, Part 2: General principles</td>
</tr>
<tr>
<td>ASTM CR</td>
<td>Classification (E 2446), Long term stability (E2445), Guide (E 2007), Practice (E 2033)</td>
</tr>
<tr>
<td>ASME CR Code Case 2476</td>
<td>Radiography (CR) with Phosphor Imaging Plates</td>
</tr>
<tr>
<td>ASTM E 07</td>
<td>DDA under development</td>
</tr>
<tr>
<td>ASTM E 2422</td>
<td>First digital catalogue, light alloy casting</td>
</tr>
</tbody>
</table>
All film based standards require:

- Minimum optical Density (e.g. > 2.0)
- Maximum film system class (e.g. ≤ ASTM T2)
- Maximum unsharpness (> 0.1 mm, FFD/FOD)

European CR Standards EN 14784 were developed to be comparable with Film Standards EN 444, EN 584-1, EN 462-5!
Signal/Noise Ratio as Equivalent to opt. Density

Definition of Signal/Noise Ratio and Contrast/Noise Ratio

\[ \text{SNR} = \frac{S}{S_{\text{RMS}}} \]

- Signal: \( S \)
- Noise: \( S_{\text{RMS}} \)
- Contrast: \( D - D_0 \)

2*Noise

Signal

Contrast
Effect of Granularity or Noise

\[ \sigma_D \]

Lost of information / perceptibility
Signal/Noise Ratio of CR Systems

- No principle increase of SNR with dose
- SNR Saturation

- Electronic noise
- Quantum Noise
- Structure noise

Square Root (Dose)

- 0,00
- 5,00
- 10,00
- 15,00

S/N
BAM 5 test weld, 8 mm Steel, 120 kV, different exposure time:

Exp. Time 1x

Exp. Time 4.3x

Exp. Time 43x

magnification

CR-System: FujiFilm DynamiX (XG 1)
Efficiency test “DDA Qualification Standard Proposal”, ASTM, USA

Direct converting detector of AJAT company, Finland

Limit of Film and CR Technology

\[ \text{SQRT(DOSE)} \]

\[ y(90\text{KV}, 30\text{AI}) = 646.92x + 40.82 \]

\[ y(90\text{KV}, 3\text{mm Cu}) = 597.56x + 31.843 \]

\[ y(120\text{KV}, 40\text{AI}) = 544.62x + 24.947 \]

\[ y(120\text{KV}, 5\text{mA no filter}) = 396.86x + 35.563 \]

\[ y(50\text{KV}) = 381.78x + 56.102 \]
K. Bavendiek et al.

Fuji IX25
$\text{SNR}_{\text{norm}} \approx 265$

PerkinElmer 1620
$\text{SNR}_{\text{norm}} \approx 1500$
Bad Pixels of DDAs

6.2.1 Dead Pixel — Pixels which are completely dead, no response at all.

6.2.2 Over responding pixel — Pixels whose gray values are greater than 1.3 times the gray value of an area of a minimum of 21*21 pixels. This test is done on offset corrected image.

6.2.3 Under responding pixel — Pixels whose gray values are less than 0.6 times the median gray value of an area of in a minimum of 21*21 pixels. This test is done on offset corrected image.

6.2.4 Noisy pixel — Pixels whose standard deviation in a sequence of 30 to 100 images without radiation is more than 6 times the median pixel standard deviation for the complete DDA. This test is done on dark images.

6.2.5 Non uniform pixel — Pixel whose value exceeds a deviation of more than +/-1% of the median value of its 9x9 neighbor pixel. The test should be performed with image Thus where the average gray value is at or above 75% of the DDAs linear range. This test is done on offset and gain corrected image.

6.2.6 Persistence / Lag pixel — Pixel whose value exceeds a deviation of more than +100% of the median value of its 9x9 neighbors and >1% absolute in the first image after X-ray shut down.

6.2.7 Bad neighborhood pixel — Pixels, where all 8 neighbor pixels are underperforming pixels, as defined immediately above, are also considered underperforming pixels.

Proposal on “DDA Qualification Standard” ASTM, E07, USA
Achievable Contrast Sensitivity and Exposure Time

- The contrast sensitivity improves with the increasing exposure time (becomes smaller!)

- The structural noise of the IPs limits the max. achievable SNR

- Step hole, plate hole and wire image quality indicators measure the increase of CNR and improvement of contrast sensitivity

- Unsharp digital detectors achieve a higher max. SNR and need less exposure time

- The normalized SNR$_N$ is independent on the unsharpness, but depends on the efficiency and plate homogeneity

- Unsharp detectors for radiography with higher energy (about $> 250$ keV) yield a considerable reduction of exposure time in comparison to film.
CR System Selection

European Standard

EN 14784-2
Table 4 — Required spatial system resolution in dependence on energy and wall thickness

<table>
<thead>
<tr>
<th>Radiation source</th>
<th>Wall thickness</th>
<th>Class IPA</th>
<th>Class IPB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max. pixel size (\mu m)</td>
<td>Double wire IQI number(^a)</td>
</tr>
<tr>
<td>X-ray</td>
<td>(w &lt; 4)</td>
<td>40</td>
<td>&gt; 13(^c)</td>
</tr>
<tr>
<td>(U_p \leq 50 \text{ kV})</td>
<td>4 (\leq w)</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(4 \leq w &lt; 12)</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(w \geq 12)</td>
<td>85</td>
<td>11</td>
</tr>
<tr>
<td>X-ray</td>
<td>(w &lt; 4)</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td>(50 \text{ kV} &lt; U_p \leq 150 \text{ kV})</td>
<td>4 (\leq w &lt; 12)</td>
<td>70</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>(w \geq 12)</td>
<td>85</td>
<td>11</td>
</tr>
<tr>
<td>X-ray</td>
<td>(12 \leq w &lt; 50)</td>
<td>110</td>
<td>10</td>
</tr>
<tr>
<td>(250 \text{ kV} &lt; U_p \leq 350 \text{ kV})</td>
<td>(w \geq 50)</td>
<td>125</td>
<td>9</td>
</tr>
<tr>
<td>X-ray</td>
<td>(w &lt; 50)</td>
<td>125</td>
<td>9</td>
</tr>
<tr>
<td>(350 \text{ kV} &lt; U_p \leq 450 \text{ kV})</td>
<td>(w \geq 50)</td>
<td>160</td>
<td>8</td>
</tr>
<tr>
<td>Yb 169, Tm 170</td>
<td></td>
<td>85</td>
<td>11</td>
</tr>
<tr>
<td>Se 75, Ir 192</td>
<td>(w &lt; 40)</td>
<td>160</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(w \geq 40)</td>
<td>200</td>
<td>7</td>
</tr>
<tr>
<td>Co 60</td>
<td></td>
<td>250</td>
<td>6</td>
</tr>
<tr>
<td>X-ray</td>
<td>(U_p &gt; 1 \text{ MeV})</td>
<td>250</td>
<td>6</td>
</tr>
</tbody>
</table>

\(^a\) If magnification technique is used, double wire IQI readout is required only.

\(^b\) The given IQI numbers indicate the readout value of the first unresolved wire pair corresponding to EN 454-5.

\(^c\) The symbol "> 13" requires the 13\(^{th}\) wire pair to be resolved with a dip separation larger than 20\% (see Figure 3 of EN 14784-1:2004).

\(^d\) The symbol ">> 13" requires the 13\(^{th}\) wire pair to be resolved with a dip separation larger than 50\%.

\(U_p = \text{tube voltage.}\)
TABLE 1  Element Number, Corresponding Unsharpness and Wire Diameter

<table>
<thead>
<tr>
<th>Element Number</th>
<th>Corresponding Unsharpness (mm)</th>
<th>Wire Diameter and Spacing, d (mm)</th>
<th>Tolerance of Wire Diameter and Wire Spacing (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt</td>
<td>0.10</td>
<td>0.05</td>
<td>±0.005</td>
</tr>
<tr>
<td>Pt</td>
<td>0.13</td>
<td>0.063</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>0.16</td>
<td>0.08</td>
<td>±0.005</td>
</tr>
<tr>
<td>Pt</td>
<td>0.20</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>0.26</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>0.32</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>0.40</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>0.50</td>
<td>0.25</td>
<td>±0.01</td>
</tr>
<tr>
<td>Pt</td>
<td>0.64</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>0.80</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>1.00</td>
<td>0.50</td>
<td>±0.02</td>
</tr>
<tr>
<td>W</td>
<td>1.26</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>1.60</td>
<td>0.80</td>
<td></td>
</tr>
</tbody>
</table>

A  This table is based on data provided in EN 462-5.

\( \gamma \)-radiography

New Discussion of European Project FilmFree for standard revision!

Contact shot with no geometric enlargement

Aerospace components

Nuclear weldments
Thin pipe welds: \( w > 4 \text{ mm} \)

Pipe weld medium & thick wall \( w > 12 \text{ mm} \)

Casting inspection
\( w > 50 \text{ mm}, \gamma \)-radiography
Required Image Quality Indicators

See also ASTM E747-97 → but different to EN 462

Description of Wire -IQI
For contrast only!

Wire IQI
EN 462-1

Step-Hole IQI
EN 462-2

Both IQI’s are required for CR!

For unsharpness only!

Duplex wire IQI / EN 462-5 / ASTM E 2002
Digital Radiology for Weld Inspection in Europe
Quality Levels for Welding are defined in:

EN ISO 5817 and EN ISO 10042

- Basis for Manufacturer and User Contracts

- Harmonized with European Pressurised Equipment Directive!
Quality Levels by EN ISO 5817

Title: “Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections”

- ISO 5817 was prepared by Technical Committee ISO/TC 44, Welding and allied processes, Subcommittee SC 10, Unification of requirements in the field of metal welding.
- The standard is considered as harmonized with the European Pressurized Equipment Directive (PED) and EN 13445

Quality Levels by EN ISO 10042

Title: “Welding — Arc-welded joints in aluminum and its alloys — Quality levels for imperfections”
### Table 1 — Limits for imperfections

<table>
<thead>
<tr>
<th>No.</th>
<th>ISO 6520-1 reference</th>
<th>Imperfection designation</th>
<th>Remarks</th>
<th>$t$ mm</th>
<th>Limits for imperfections for quality levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Surface imperfections</td>
<td></td>
<td></td>
<td>$\geq 0.5$</td>
</tr>
<tr>
<td>1.1</td>
<td>100</td>
<td>Crack</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>104</td>
<td>Crater crack</td>
<td>—</td>
<td></td>
<td>$\geq 0.5$</td>
</tr>
<tr>
<td>1.3</td>
<td>2017</td>
<td>Surface pore</td>
<td>Maximum dimension of a single pore for — butt welds — fillet welds</td>
<td>$0.5$ to $3$</td>
<td>$d \leq 0.3 \times s$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maximum dimension of a single pore for — butt welds — fillet welds</td>
<td>$&gt; 3$</td>
<td>$d \leq 0.3 \times s$, but max. $3 \text{ mm}$</td>
</tr>
<tr>
<td>1.4</td>
<td>2025</td>
<td>End crater pipe</td>
<td>$h$</td>
<td>$0.5$ to $3$</td>
<td>$h \leq 0.2 \times t$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$&gt; 3$</td>
<td>$h \leq 0.2 \times t$, but max. $2 \text{ mm}$</td>
</tr>
<tr>
<td>1.5</td>
<td>401</td>
<td>Lack of fusion (incomplete fusion)</td>
<td>—</td>
<td>$\geq 0.5$</td>
<td>Not permitted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micro lack of fusion</td>
<td>Only detectable by micro examination</td>
<td></td>
<td>Permitted</td>
</tr>
<tr>
<td>1.6</td>
<td>4021</td>
<td>Incomplete root penetration</td>
<td>Only for single side butt welds</td>
<td>$\geq 0.5$</td>
<td>Short imperfections: $h \leq 0.2 \times t$, but max. $2 \text{ mm}$</td>
</tr>
</tbody>
</table>

**What is EN ISO 5817?**

**Example page**
<table>
<thead>
<tr>
<th>Materials and type of joint</th>
<th>Thickness in mm 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EN 12062 Selection of Methods</strong></td>
<td>t ≤ 8</td>
</tr>
<tr>
<td>Ferritic butt-joints</td>
<td>RT or (UT)</td>
</tr>
<tr>
<td>Ferritic T-joints</td>
<td>(UT) or (RT)</td>
</tr>
<tr>
<td>Austenitic butt-joints</td>
<td>RT</td>
</tr>
<tr>
<td>Austenitic T-joints</td>
<td>(UT) or (RT)</td>
</tr>
<tr>
<td>Aluminium butt-joints</td>
<td>RT</td>
</tr>
<tr>
<td>Aluminium T-joints</td>
<td>(UT) or (RT)</td>
</tr>
<tr>
<td>Nickel-and copper-alloys butt joints</td>
<td>RT</td>
</tr>
<tr>
<td>Nickel-and copper-alloys T-joints</td>
<td>(UT) or (RT)</td>
</tr>
<tr>
<td>Titanium butt-joints</td>
<td>RT</td>
</tr>
<tr>
<td>Titanium T-joints</td>
<td>(UT) or (RT)</td>
</tr>
</tbody>
</table>

1) Thickness, \(t\), is the nominal thickness of the parent material to be welded.

() indicates that the method is applicable with limitations.
Welding Quality Standards

EN ISO 5817

EN ISO 10042

EN 12062

Method Transfer Function

Radiographic

Eddy Current

Magnetic Particle

Penetrant

Ultrasonic

Visual Examination

Quality levels based on real size of imperfections

Interface between quality levels and acceptance levels for indications

Steel: EN 1291

Steel: EN 1289

Steel: EN ISO 5817

Steel: EN ISO 10042

Characterisation Acceptance levels

Testing procedure

See extragraph

EN 1711

EN 1290

EN 571-1

See extragraph

EN 970

Result of TC121 SC 5 of March 2007

Progress of Digital Radiology
Ewert, April 2007
Quality levels based on real size of imperfections

Interface between quality levels and acceptance levels for indications

Method

Radiographic

Testing procedure

RT: Film Radiography EN 1435
RS: Radioscopy (digital) EN 13068-3
CR: Computed Radiography EN 14784-2

Characterisation Acceptance levels

Steel: EN 12517-1
Aluminium: EN 12517-2

Welding Quality Standards

EN ISO 5817
EN ISO 10042
EN 12062

EN 12517-1
Aluminium: EN 12517-2

Result of TC121 SC 5 of March 2007
Radiography Replacement by TOFD

CEN TC 121 WG 2: TOFD Acceptance Levels

• A new standard project under 5 month inquiry at CEN

• Making TOFD an acceptable NDT technique to test and evaluate welding quality in lieu to radiography

• With critical disagreements to ISO 5817

ToFD – Time of Flight Diffraction is a 2 probe Ultrasound Technique
Principle Set Up for ToFD

ASTM E 2373-04

TOFD Configuration and Signal origins

Lateral wave

Back-wall reflection

+ LW  + BW

Upper tip  Lower tip

Non-rectified A-scan presentation is needed to show the phase

FIG. 1
Automated UT and ToFD – Techniques versus Radiography - a contradictory discussion -

**ToFD:**
The ToFD problem in the surface-near regime was especially discussed, where the defect echo is hidden by the direct surface echo and where as pulse echo clearly can detect the defect. One reasonable approach can be the combination of pulse echo and ToFD or the combination of ToFD and other surface methods like PT/MT.

**Radiography:**
The classical radiography approach mainly is limited by the capabilities of the human beings as inspectors but also by the limited range of available incident angles to optimal crack detection in a standard radiographic procedure. Therefore, one needs approaches like Tomographic Methods in order to overcome these limits. These methods today are on the way to become available.
Ende
Film Replacement

the Procedure
Film System Classes are the Basis for all Classifications of Digital Detectors

Tab. 1: Overview about the film system classes in different standards and the corresponding SNR values and $G_2/\sigma_D$ values.

$$\text{SNR} = \log(e) \cdot \left(\frac{G_2}{\sigma_D}\right)$$

for linear detectors only

<table>
<thead>
<tr>
<th>System class</th>
<th>Minimum gradient-noise ratio at $D=2$ above $D_0$</th>
<th>Signal to Noise Ratio $D=2$ above $D_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>World ISO 11699-1</td>
<td>World Europe CEN 584-1</td>
<td>USA ASTM E1815-01</td>
</tr>
<tr>
<td>T1</td>
<td>C1 Special</td>
<td>T1</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>C3</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>C4</td>
<td>T2</td>
</tr>
<tr>
<td>T3</td>
<td>C5</td>
<td>II</td>
</tr>
<tr>
<td>T4</td>
<td>C6</td>
<td>III</td>
</tr>
<tr>
<td></td>
<td>W-A</td>
<td>W-A</td>
</tr>
<tr>
<td></td>
<td>W-B</td>
<td>W-B</td>
</tr>
<tr>
<td></td>
<td>W-C</td>
<td>W-C</td>
</tr>
</tbody>
</table>
What is Optical Density 2 at a Digital Detector?

This was our first question after getting a new system!

- Lets give an answer and develop a standard -

Do all values above 956 fulfill the standard requirement?
What is Optical Density 2 at a Digital Detector?

Characterization by (prEN 14784-1)
- SNR and Spatial resolution
e.g.: IP-3/200

<table>
<thead>
<tr>
<th>Grey value</th>
<th>Film system class</th>
</tr>
</thead>
<tbody>
<tr>
<td>956</td>
<td>Special</td>
</tr>
<tr>
<td>815</td>
<td>T1 (D4)</td>
</tr>
<tr>
<td>712</td>
<td>T2 (D7)</td>
</tr>
<tr>
<td>608</td>
<td>T3</td>
</tr>
</tbody>
</table>

Do all values above 956 fulfil the standard requirement?

Answer: Yes they do! More than this!
One CR system substitutes different film systems
New Development of Standard Conform Software for CR and Other Digital Technologies

Software IC: 
http://www.kb.bam.de/~alex/ic.htm

(I see)

Considers:
- Image processing
- Basic spatial resolution (EN 14784)
- Normalized SNR (EN 14784)
- Wall thickness measurement
- Synchronized image viewing of reference radiographs