Progress of Digital Industrial Radiology

by

Uwe Ewert

uwe.ewert@bam.de
http://www.bam.de
• Film replacement
  • Computed Radiography (CR) with phosphor imaging plates – High Definition Computed Radiography (HD CR)
  • Digital Detector Arrays (DDA)
    • High Contrast Sensitivity Radiography with DDAs
    • Automated Defect recognition
• Dual energy technique
• X-ray back scatter technique (BS RT)
• X-Ray Modeling and POD
• Portable Computed Tomography for
  • Nuclear power plants
  • Large flat components in Aircraft industry
• Small angle scatter CT and nano CT at Synchrotron
• Motion neutron - radiography
Film Replacement

Computed Radiography (CR) with phosphor imaging plates – high definition CR
Motivation for Film Replacement by Computed Radiography and DDA‘s:

- Shorter test and interpretation time
- New application areas by higher inspection quality and wall thickness range
- No chemicals and dangerous waste
- Less consumables
Filmless Radiography

Computed Radiography with Phosphor Imaging Plates
The Imaging Plate Cycle

Exposure of Imaging Plate

Exposure of Imaging Plate

Imaging Plate

Cassette

Lead filter

Exposure

Scanning the IP, Digitising and Erasing the residual Image

Processing Station

Data Output

He-Ne Laser

PMT

IP
## 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 digitized films from ASTM E 155 (BAM)</td>
</tr>
</tbody>
</table>
## System Selection

### 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</td>
<td>Double wire IQI number&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>X-ray</td>
<td>w &lt; 4</td>
<td>40</td>
<td>&gt; 13&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>4 ≤ w</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td>50 kV &lt; U&lt;sub&gt;p&lt;/sub&gt; ≤ 150 kV</td>
<td>w &lt; 4</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>4 ≤ w &lt; 12</td>
<td>70</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>w ≥ 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>150 kV &lt; U&lt;sub&gt;p&lt;/sub&gt; ≤ 250 kV</td>
<td>4 ≤ w &lt; 12</td>
<td>70</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>w ≥ 12</td>
<td>85</td>
<td>11</td>
</tr>
<tr>
<td>X-ray</td>
<td>12 ≤ w &lt; 50</td>
<td>110</td>
<td>10</td>
</tr>
<tr>
<td>250 kV &lt; U&lt;sub&gt;p&lt;/sub&gt; ≤ 350 kV</td>
<td>w ≥ 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 kV &lt; U&lt;sub&gt;p&lt;/sub&gt; &lt; 450 kV</td>
<td>w ≥ 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 ≥ 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></td>
<td>250</td>
<td>6</td>
</tr>
<tr>
<td>U&lt;sub&gt;p&lt;/sub&gt; &gt; 1 MeV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> If magnification technique is used, double wire IQI readout is required only.

<sup>b</sup> The given IQI numbers indicate the readout value of the first unresolved wire pair corresponding to EN 452-5.

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

<sup>d</sup> The symbol "＞＞ 13" requires the 13<sup>th</sup> wire pair to be resolved with a dip separation larger than 50 %.

U<sub>p</sub> = tube voltage.
Filmless Radiography

CR Applications
High Definition CR Systems for Welding

Systems available down to
- 12 µm pixel pitch and
- < 40 µm unsharpness
- "weld quality"

BAM 5: 8 mm steel

HD CR:
"VistaScan“, of Duerr, Germany
FUJI IP’s, light blue
Digital Radiography for Pipeline Testing

- 36 inch 12.7 mm Wall thickness Pipe Weld (SWSI-panoramic exposure)

FilmFree meeting
17.04.2007
Corrosion and Wall Thickness Measurement:

- $f =$ film focus distance
- $r =$ outer pipe radius
- $R =$ outer radius of insulation
- $w =$ projection of wall thickness $w$ on the detector plane

VEBA-OEL 2000
Wall Thickness Measurement

Tutorial at 24.04.2007
INDE2007, Chennai

Tangential Radiographic Technique (TRT)

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High Energy X-Ray Inspection in Lieu of Manual Maintenance Check of Large Components
Filmless Radiography

Flat Panel Detectors
and the new
High Contrast Sensitivity Technique
HCS-RT
New Flat-Panel Detector Technology

New Developments

Spahn 97
High Contrast Sensitivity Technique

Effect of Correct Calibration Procedures

SNR\text{norm} / Dose

DDAs exceed film quality!

SNR limit by materials structure

Current limit of film and CR technology
BAM 5 is a hand welded steel plate (St 35) 8 mm thick, the welding seam is max. 10 mm thick. It contains all types of welding flaws, especially nice cracks at the surface of the welding seam.
Fuji IX25
$\text{SNR}_{\text{norm}} \approx 265$

PerkinElmer 1620
$\text{SNR}_{\text{norm}} \approx 1500$

by K. Bavendiek et al.
Fast Test of Heat Exchangers with Tiled DDA
RT-testing of tube-to-tube-sheet joints
Gammat B3

Possible tube dimensions: 12*1.5 up to 76.1*4 (diameter*thickness)
Materials: carbon and stainless steel, Ni-alloys, Zr, (Ti, Ta)
Joint design shall be considered

Ir 192, Radiator: 1 x 0.5 mm²
Testing of Heat Exchanger Welds with a specialised Digital Detector Array Through the Detector

Practice test:

Alekseychuk, Zscherpel, Rost
D4 film with 130 kV:
1 min (1mm Sn filter)

X-Ray tube with DIC100TH detector
75 kV, 0.5 mA, 10s

Research-Project BASF/Ajat/BAM since 2006, first results on test weld
Imaging and Materials Characterisation with Dual Energy Technique
Explosive Detection by **Dual-Energy-Radiology**

Typical device for explosive detection of baggage and fin postal service

(Smiths Heimann)

- Fan beams at two different energies
- Baggage transport
- L-line detectors
- Smiths Heimann
Dual-Energy-Technique for Plastics and Composite Pipes

Inspection of a multi layer pipe, made from different plastics and with partial glass fibre reinforcement for chemical industry.
X-Ray Back Scatter Technique
for
Security and Aircraft Industry
X-ray Back Scatter Technique:

- Advantage is the single sided access
- Comscan – Technique was too slow and was applied only in very few areas
- New evaluation of back scatter technique due to the success in the security field
- New technologies are under development, e.g. in aircraft industry
X-Ray Back Scatter Technique with single sided access
X-Ray Back Scatter Technique with Single Sided Access

Organic materials are visible with high contrast
X-Ray Back Scatter Technique

BODYSEARCH™
The X-ray dose for BodySearch™ is much smaller than for medical diagnostics.

The air appears dark in the image because it does not scatter many X-rays.

Accepted e.g. in UK on voluntary basis

Source: http://www.as-e.com
X-Ray Back Scatter Technique

Backscatter image of a person

Source: http://www.as-e.com

Not accepted due to European Radiation Safety Regulations

Radiation protection permits: 1 mSv/year (100 mRem/year) for population but not without justification!

1 µRem = 0.01 µSv

Source: http://www.as-e.com
X-Ray Back Scatter – Flying Spot Technique

Letter bomb dummy

BAM-VIII.32, A.Lange

Compton Rückstreuung, 18 keV, Mo-k, Pinhole, Szint-Detektor, 0,25 mmm-Raster

Lange, Hentschel, BAM
Terahertz (THz): Letter Bomb Dummy

X-ray image

THz-Image

Kupsch, Lange, Beckmann, Hentschel
Back Scatter Technique with specialized Diaphragm

- X-ray tube
- Diaphragm
- Shielding box
- Imaging plate/Detector Array
- Camera

Osterloh
01/2007
Fast Back Scatter Technique with Specialized Diaphragm

Water in Honeycomb
Water in Honeycomb-Structures

Back scatter image

Radiograph

Planar-tomogram
New Equipment

Backscatter system of InnospeXion

Combination of

• High sensitive DDA and
• Specialised collimator
X-Ray Modeling for
- Film replacement
- Planning of testing
- POD
Modelling Tools

Surface presentation
- Interface to CAD and CT
- Separation of homogeneous regions
- Arrangement of different Polygons in the virtual scene

Processes:
- Absorption
- Compton-Scatter / Rayleigh-Scatter
- Interaction by Collision probability

\( (E_0, W_0) \)

\( m=0 \)
\( m>0 \)

Jaenisch, Bellon
Simulation-Example

- Complex Geometry: Cardan joint
Surface scan @ BAM VIII.1

- Strip projection

- ATOS 3D Digitizer (www.gom.com)
  - Flexible optical measurement device ATOS II
  - Is based on Triangulation
  - 3D-Coordinates are calculated
  - A Polygon net of the surface is generated (STL)
Modelling of a Scanned Weldment

- Result: 3D CAD Model of a weld
  - STL of “BAM 3”
Simulation of contrast function for copper welds of different thickness

Required for copper storage containers of the Swedish final repository of nuclear waste fuels

Measured with 9 MeV LINAC and BIR-line camera

Modelling Based POD

Pore Contrast Considering Measured Unsharpness and Noise for POD Calculation

Maximum pore contrast versus pore diameter from Simulation

- max pore contrast (no noise)
- above (noise level = 30)
- center (noise level = 60)
- below (noise level = 90)
- decision threshold (SNR = 2.7)
POD for Different Wall Thickness

Conservative POD Estimate from Simulation

SNR = 2.7

- POD (above)
- confidence bound
- POD (center)
- confidence bound
- POD (below)
- confidence bound

Modelling Based POD

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Mobile CT
in
Nuclear Power Plants and
in Aircraft Industry
Planar Tomography – Reconstruction of Cross sections

- Movement of X-ray tube parallel to pipe axis
- Acquisition of few hundred projections
- Reconstruction of cross sections

X-ray tube

Digital detector array
3D-Reconstruction of Weldments

Certification by European Network of Inspection and Qualification.

from outside to inside

Planar Tomography

Metallography

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Zerstörungsfreie Prüfung und Charakterisierung radiologischer Verfahren

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Zerstörungsfreie Prüfung und Charakterisierung radiologischer Verfahren
Mobile Tomosynthesis

CT of Large Components

Mobile Airplane Inspection by Digital Laminography

BAM, Lab. 6.21, Ewert
Planar Tomography

Stringer Component from Aircraft
Impact

Outside incorporated metal mesh

Central section in stringer

Inner surface with carbon fibre mesh
Nano CT
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Berlin Electron Storage SYnchrotron
BESSY

Double-Multilayer
Mono chromator, 5-70 keV

CCD-Camera

asymmetric
Si-Crystal,
Magnification 1: 50

rotating
Sample

7T WLS

Storage ring

3D-CT-single cut

3D-Scatter CT:
Ti/SiC-MMC, 39 keV,
light: crack contrast after fatigue

3D-Nano-CT:
Micro-driller, 19 keV,
Worm holes, white refraction contrast,
200 nm resolution

Gas turbine

Müller, Lange, Hentschel
Motion Neutron Radiography with Triggered Cycle
BMW-Engine of running production with external electric control at ILL in Grenoble

T. Bücherl, B. Schillinger
Oil cooling of pistons of running engine!

Valves (one after the other)

Oil at piston bottom

Oil ray is injected from downside to the piston

T. Bücherl, B. Schillinger
Summary:

- **Computed Radiography** with **Phosphor Imaging Plates** is gaining more and more importance for mobile inspection and **Film Replacement**.

- New **High Definition CR (HD CR)** systems allow the CR application for Weld and Casting inspection with low energy X-rays.

- New calibration methods enable the **High Contrast Sensitivity Technology (HCS RT)** for radiographic inspection. The contrast sensitivity can be enhanced by a factor of 10 in comparison to film.

- New **Digital Detector Arrays (DDA)** are now available for stationary and mobile testing. They are also applied for automated defect recognition (ADR), CT, Back Scatter and Dual Energy Applications.

- **Back Scatter Techniques** are increasingly applied for Security and NDT.

- **Numeric Radiographic Modelling** is applied for Experiment Planning, Film replacement, POD-calculations and training.

- **Mobile and portable CT devices** are suitable for non destructive cross sectioning in nuclear power industry and aircraft applications.

- **Neutron radiography** at research reactors was enhanced for visualisation of motions.
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