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- Comparison
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Basics of X-ray detectors

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<td>Direct detection</td>
<td>Basic XCounter &amp; AJAT technology</td>
<td>X-ray</td>
<td>CMOS circuit</td>
<td>Image</td>
</tr>
<tr>
<td>Scintillator (X-ray converted to light - Argus)</td>
<td></td>
<td></td>
<td>Integrating (Apil) or Photon counting (XCT)</td>
<td></td>
</tr>
</tbody>
</table>
**Functionality**

- **X-ray photon**
- **Continuous cathode**
- **CdTe 0.7 – 2 mm**
- **Pixel electrodes (100 µm)**
- **Charge sensitive amplifiers**
- **Comparators**
- **Counters (12 bit, up to 3 MHz)**

**Basics**

**Calibration**

**Comparison**

**Dual Energy**

**Conclusion**

**Characteristics**

- **No Offset**
  - (TH₁ – Suppression of noise)
- **Reducing amount of scattered radiation**
  - (TH₁ – higher contrast sensitivity)
- **Material discrimination**
  - (Dual Energy – TH₂)

**Basics**

**Calibration**

**Comparison**

**Dual Energy**

**Conclusion**
**Characteristics**  
No offset → no readout noise

Example:
high wall thickness and low photon energy (low tube voltage)

here:
- 70 mm steel  
- 270 kV (maximum 600 kV acc. ISO 17636-2)  
- 300 W (1.11 mA)
- 4800 single frames  
- 0.5 s per frame  
- max. grey values (photon counts): 10000  
- i.e. approx. 2 photon detections per pixel and frame

However:  
Testing class B (acc. ISO 17636-2) achieved!

<table>
<thead>
<tr>
<th>Image quality feature</th>
<th>Minimum requirement acc. to ISO 17636-2 (class B)</th>
<th>Direct converting Photon counting</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR in weld seam</td>
<td>70</td>
<td>105</td>
</tr>
<tr>
<td>Single wire (contrast sensitivity)</td>
<td>W10</td>
<td>W11</td>
</tr>
<tr>
<td>Duplex wire (spatial resolution)</td>
<td>D10 (0.2 mm)</td>
<td>D10 (0.2 mm)</td>
</tr>
</tbody>
</table>

**Characteristics**

direct conversion → sharper images, but more aliasing

**Basics**

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**Conclusion**

Calibration  
Comparison  
Dual Energy

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Characteristics

Thresholding → less scattered radiation → higher dynamic range

Anti-Coincidence
(“charge sharing correction”)

Problem:
Charge in the CdTe crystals (generated by 1 photon) can be distributed over several pixels

Solution:
Comparison with neighbor pixels → highest sum → Counter + 1
Anti-Coincidence
(„charge sharing correction“)

Result
Better resolution
(e specially under large angle of incidences)
\[ \rightarrow \text{laminography} \]

Expected vs. Measured basic spatial resolution $SR_b$ for 0.75 mm CdTe

Expected $SR_b$
Measured $SR_b$

Result
Better resolution
especially under large angle of incidences

Æ laminography

270kV; 1.11mA; $\alpha = 45°$

IQI
Pipe
Tube
Detector
$D = 350 \text{ mm}$
t = 35 mm

Anti-Coincidence
(„charge sharing correction“)

Basics
Calibration
Comparison
Conclusion

Calibration
(standard 2 point calibration)

Raw image
Offset image

White image
Offset image

• every pixel responds differently on similar intensity of radiation
• „Same grey values for same intensities“
Calibration

(1 point calibration for PCD)

- every pixel responds differently on similar intensity of radiation
- „Same grey values for same intensities”

High spectral sensitivity of calibration:

<table>
<thead>
<tr>
<th>Image spectrum calibrated with...</th>
<th>Total</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td><img src="image1" alt="Calibrated Image" /></td>
<td><img src="image2" alt="Total High" /></td>
<td><img src="image3" alt="Total Low" /></td>
</tr>
<tr>
<td>High</td>
<td><img src="image4" alt="High Spectrum" /></td>
<td><img src="image5" alt="High Spectrum" /></td>
<td><img src="image6" alt="High Spectrum" /></td>
</tr>
<tr>
<td>Low</td>
<td><img src="image7" alt="Low Spectrum" /></td>
<td><img src="image8" alt="Low Spectrum" /></td>
<td><img src="image9" alt="Low Spectrum" /></td>
</tr>
</tbody>
</table>

Consequence: $\text{spectrum}^{\text{meas}} \equiv \text{spectrum}^{\text{calib}}$

CFRP at 34 kV, 20mA
Polarization effects in mono-crystals → image interferences

- inhomogeneous field strength
- time dependent
- crystal defects become visible
- “Venes”

Solution
Reset high voltage after every frame

Comparison

<table>
<thead>
<tr>
<th></th>
<th>Indirect converting and integrating CMOS detector</th>
<th>Direct converting Photon counting</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM</td>
<td>Hamamatsu</td>
<td>Ajal/XCounter</td>
</tr>
<tr>
<td>Model</td>
<td>C7940DA-02, 2003</td>
<td>Fita 2X1, 2015</td>
</tr>
<tr>
<td>Pixels</td>
<td>2248 × 2368 (2x2 Pixel Binning: 1120 x 1184)</td>
<td>1024 × 512</td>
</tr>
<tr>
<td>Pixel size</td>
<td>50 µm (2x2 Pixel Binning: 100 µm)</td>
<td>100 µm</td>
</tr>
<tr>
<td>Active area</td>
<td>112 × 118 mm²</td>
<td>102 × 51 mm²</td>
</tr>
<tr>
<td>Active layer</td>
<td>CsI</td>
<td>CdTe</td>
</tr>
<tr>
<td>Layer thickness</td>
<td>300 – 400 µm</td>
<td>750 µm</td>
</tr>
</tbody>
</table>
**Radiographic inspection parameters**

<table>
<thead>
<tr>
<th>Filter</th>
<th>Indirect converting</th>
<th>Direct converting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
<td>2 mm Cu + 1.5 mm V2A</td>
<td>1.5 mm V2A</td>
</tr>
<tr>
<td>Detector</td>
<td>0.3 mm Cu + 1 mm Al</td>
<td>1 mm CFK</td>
</tr>
</tbody>
</table>

1. Fe-Plate; t = 40 mm
2. Fe-Pipe; D = 250 mm; t = 2 x 12 mm; water filled

**Comparison**

- **Basics**
- **Calibration**
- **Dual Energy**
- **Conclusion**
### Image quality feature

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<th>Minimum requirements acc. to ISO 17636-2 (class B)</th>
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<td>Duplex wire (spatial resolution)</td>
<td>D10 (0.20 mm)</td>
<td>D10 (0.20 mm)</td>
</tr>
<tr>
<td>Photon counting Detector:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNR similar</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>1 single wire more</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Better visibility of fine indications</td>
<td>++</td>
<td></td>
</tr>
</tbody>
</table>

#### 1. Fe-Plate; \( t = 40 \text{ mm} \)

- Water filled
- Photon counting Detector:
  - SNR similar
  - 1 single wire more
  - Better visibility of fine indications

#### 2. Fe-Pipe; \( D = 250 \text{ mm} ; \ t = 2 \times 12 \text{ mm} \); water filled

- Photon counting Detector:
  - Reduction of scattered radiation by thresholding
  - Higher contrast sensitivity
  - Higher basic spatial resolution
  - More indications visible

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<td>SNR in weld seam</td>
<td>W12</td>
<td>W14</td>
</tr>
<tr>
<td>Single wire (contrast sensitivity)</td>
<td>W12 (W13)</td>
<td>W14</td>
</tr>
<tr>
<td>Duplex wire (spatial resolution)</td>
<td>D9 (0.13 mm)</td>
<td>D10 (0.20 mm)</td>
</tr>
</tbody>
</table>

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Dual Energy

- 2 Energy thresholds → 2 images
- material discrimination
- attenuation coefficient $\mu$ dependent on
  - Energy $E$
  - density $\rho$
  - atomic number $Z$

Lambert-Beers law:

$$I = I_0 \cdot e^{-\mu d}$$

Total energy
High energy
Low energy

Basics
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Comparison
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Conclusion

Dual energy function:

$$F(Z) = \frac{\mu_{\text{low}}(Z)}{\mu_{\text{high}}(Z)} = \frac{\int_{E=0}^{E_{\text{max}}} W(E_1) \cdot \mu(E_1, Z) dE_1}{\int_{E=0}^{E_{\text{max}}} W(E_2) \cdot \mu(E_2, Z) dE_2}$$

Dual Energy Tresholding

Fe-Step wedge, 160 kV
LE image
HE image

LE profile
HE profile

Basics
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Conclusion
Photon counting Detectors based on CdTe feature
• low unsharpness
• no readout noise
• high contrast sensitivity
• high dynamics

➤ Ideal for high wall thicknesses and energies up to 300 keV
➤ Ideal for large changes in wall thickness

outperforms the image quality of conventional indirect converting CMOS detectors

Challanges:
• manufacturing of CdTe single crystals
• high price of CdTe single crystals (max. 12 x 25 mm²)
• spectral dependency of the calibration (especially in case of dual energy applications)
• high heat generation of ASICs → proper cooling and thermal stabilization!
For their engagement during the development, their valuable ideas, as well as their support, we say special thanks to:

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Thank you very much for your attention.

Questions?

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