Digital Radiography in Aerospace

Underlying principles and migration from film technology
The big challenge?
Different applications

- Disbonds
- Cracks
- Delaminations

- Cracks
- Pores
- Inclusions

- Porosities
- Inclusions
- Geometry

- Delaminations
- Pores
- Inclusions
# X-ray tube types

<table>
<thead>
<tr>
<th></th>
<th>Nanofocus–Tube</th>
<th>Microfocus–Tube</th>
<th>Minifocus–Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal spot size $d$</td>
<td>150 nm</td>
<td>2 $\mu$m – 300 $\mu$m</td>
<td>0,3 – 1 mm</td>
</tr>
<tr>
<td>Voltage $U$</td>
<td>Up to 190 kV</td>
<td>Up to 450 kV</td>
<td>Up to 600 kV</td>
</tr>
</tbody>
</table>
Focal spots

- Close to the flatpanel
  - Big focal spot
  - less magnification
  - less unsharpness

- In the middle
  - Big focal spot
  - In the middle
  - Magnification = 2

- Close to the tube
  - Big focal spot
  - high magnification
  - high unsharpness

- Close to the tube
  - small focal spot
  - High magnification
  - less unsharpness

NDT in Canada 2018 | June 19–21 | Halifax, NS
Basics of X-ray inspection

FLAT PANEL

Photodiodes (flatpanel pixel)
Standards and qualification

- **Customer requirements**
  - Boeing (BSS 7044), Airbus (AITM), etc.

- **Industry requirements**
  - NADCAP, ISO 9100 etc.

- **Method standards**
  - ISO, ASTM, etc.
System Performance Checks

- ASTMD 2737
- MTR
- SNR
- Image Lag
- Burn In
- SL/OL
- CS/CNR
- SR
- BP - Classification

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Long-term eval. – ASTM2737

- DR phantom for detector evaluation
- Containing: Step wedge, two hole penetrometers, 2 Duplex IOI’s
- Standardized performance evaluation
- Report generation according to ASTM
- Other company specific phantoms available as well
Spatial Resolution (SRb)

**IMAGE QUALITY – RESOLUTION**

http://physwiki.apps01.yorku.ca/images/thumb/3/3e/Fig15_airy.png/400px-Fig15_airy.png

Duplex Image quality indicator (IQI)

Spatial Resolution (SRb)

The dip (2) must be a minimum of 20% of the maximum (1). This calculation has to be done by software and not by human eyes.
Spatial Resolution (SRb)
Contrast Sensitivity (CS)
Contrast Sensitivity (CS)

\[
\text{CNR} = \frac{G_{\text{median}} \text{[hole]} - G_{\text{mean}} \text{[beside squares]}}{\text{Sigma}[\text{beside squares}]}
\]

\[
\text{CS [%]} = \frac{\text{GBV}}{\text{CNR}} \times \frac{\text{MT}_{\text{IQI}}}{\text{MT}_{\text{total}}} \times 100
\]

**Known Parameter:**

- \( \text{MT}_{\text{step}} = 50\text{mm} \)
- \( \text{MT}_{\text{IQI}} = 0.5\text{mm} \)
- \( \text{GBV} = 2.5 \)

**Measured Parameter:**

- \( G_{\text{median}} \text{[hole]} = 4800 \)
- \( G_{\text{mean}} \text{[beside squares]} = 4600 \)
- \( \text{Sigma}[\text{beside squares}] = 50 \)

**Calculation:**

- \( \text{MT}_{\text{total}} = 50.5\text{mm} \)
- \( \text{CNR} = \frac{4800 - 4600}{50} = 4 \)
- \( \text{CS [%]} = \frac{2.5}{4} \times \frac{0.5\text{mm}}{50.5\text{mm}} \times 100 \)
- \( \text{CS [%]} = 0.6188\% \)
Signal to Noise (SNR)

\[ \text{SNR}_N = \frac{\text{SNR}_{\text{measured}}}{\frac{88.6 \mu m}{SR_b}} \]

From the image

<table>
<thead>
<tr>
<th>System-Parameter</th>
<th>Hochauflösendes System</th>
<th>Standardsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppeldraht-BPK-Qualifizierung</td>
<td>13+ 13 12 11 10 9 8 7 6</td>
<td></td>
</tr>
<tr>
<td>Basis-Ortsauflösung $SR_b$</td>
<td>40 µm 50 µm 63 µm 80 µm 100 µm 130 µm 160 µm 200 µm 250 µm</td>
<td></td>
</tr>
</tbody>
</table>

From the image

\[ \text{SNR}_{\text{measured}} = \text{Meanvalue} \frac{\text{Standard deviation}}{\text{Standard deviation}} \]
Report generation

<table>
<thead>
<tr>
<th>Test</th>
<th>Acceptance Test</th>
<th>5-Groove-Wedge</th>
<th>Material of the used IGls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aluminum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Titanium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CRES</td>
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</table>

<table>
<thead>
<tr>
<th>Tests</th>
<th>Unit</th>
<th>Result (new)</th>
<th>Limit</th>
<th>Result</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution</td>
<td>SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contrast Sensitivity</td>
<td>CS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Thickness</td>
<td>MTR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal-to-Noise Ratio</td>
<td>SNR</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Signal Level</td>
<td>SL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Image Lag</td>
<td>Lag</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burn In</td>
<td>BI</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Offset Level</td>
<td>OL</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bad Pixel Distribution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Date of Tests       |       |              |       |        |        |
| Conclusion          |       |              |       |        |        |
| Operator            |       |              |       |        |        |
### Bad pixel report – ASTM 2597

<table>
<thead>
<tr>
<th>single bad pixel</th>
<th>2x2 cluster2</th>
<th>2x3 cluster4</th>
<th>rel3x4 cluster7-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>C C C C</td>
<td>C C C C</td>
<td>C C C C C</td>
<td>C C C C C C C C C C</td>
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<tr>
<td>C D C C</td>
<td>C D C C C</td>
<td>C D D C C</td>
<td>C D C C D C C C C C</td>
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<tr>
<td>C C C C</td>
<td>C C D C C</td>
<td>C C D D C C</td>
<td>C D K K C C C C C C</td>
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<tr>
<td>C C C C</td>
<td>C C C C C</td>
<td>C C C C C</td>
<td>C C C D D C C C C C</td>
</tr>
</tbody>
</table>

#### 2x24 Line26

| C C C C         | C C C C     | C C C C     | C C C C C C C C C C|
| C C C C         | C C D C C C C C       | C C C C C C D C C|
Bad pixel report – ASTM 2597

Bad Pixel Identification according to ASTM 2597
This tool will identify bad pixel automatically by acquiring analyzing image series.
Please make sure that there is nothing between tube and detector.
Do this analysis with 0.5mm copper filtering.
First usage (for every mode):
- Set kV10, kV50 and kV80 to 100
- Select mA10, mA50 and mA80 as that the the detector saturation is 10%, 50% and 86%
- Press “Store Default” to save default values for this detector mode
Creation of bad pixel map:
- Click “Detect Bad Pixel”
- Wait until acquisition and analysis has finished.
- Check result
- Press “Save Bad Pixel/Map”
Alternative: TAM Phantom
Digital filters

Conventional Image  LIVE Filters
Measurement
Digital references images
Digital reference images
Digital overlays
Computed Tomography

- QUICKScan
- Reconstruction and analysis
- Statistics and decisions

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Compute Tomography
Commercial justification

- Costs through productivity losses
- Costs through capital investments

Costs vs. Degree of Automation
Commercial justification
Thanks for your attention

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