How to Make an Exposure Chart for Computed Radiography?

Uwe Ewert, Uwe Zscherpel, Mirko Jechow, Bernhard Redmer

uwe.ewert@bam.de
Outline

- Basics
  - Comparison of optical density and grey value in Computed Radiography
  - Determination of required minimum Grey Value $G_{V_{\text{min}}}$ for CR via Contrast Sensitivity ($\text{EPS}$)
  - Determination of required minimum Grey Value $G_{V_{\text{min}}}$ for CR via Signal-to-Noise Ratio ($\text{SNR}$)

- Measurement procedure for exposure diagram
  - Test exposures of IPs by new Draft of ASTM E 2033 and ISO/DIS 17636-2
  - EPS method
  - SNR method
  - Design of exposure diagram on basis of grey values

- Usage of exposure diagram

- Conclusions
9.3 Producing an exposure chart for X-rays

The step wedge
The production of an exposure chart calls for either a large step wedge or a series of plates of different thicknesses made from the same material to which the chart relates. The increase in thickness between each consecutive step is constant, but varies for different materials from 0.5mm to several millimetres.

Fig. 1-9. Step wedge
Exposure Chart for Films

The final graph shows the required mA▪minutes for exposure at a given tube kV under standard conditions for a given film system.

**Standard conditions are here:**

- Material: steel
- Film Focus Distance: 700 mm
- Optical density: 2.0
- Given film and exposure conditions

Radiographers are trained, how to calculate the exposure values under modified conditions.

GEIT-30158 (01/07) GE Inspection Technologies
Industrial Radiography Image forming techniques

**Fig. 7-9 Exposure chart for D7**
Material = steel; density = 2; ffd = 70 cm; screens = 0.02 mm lead;
Automatic processing, with developer G135 at 28°C, 8 min. cycle."
Operators want to define a minimum Grey Value as equivalent to the optical density in Film Radiography!

But, the optical density and grey values of digital images cannot be compared without relation to the image quality.

- The grey values depend on:
  - Bit depth
  - Scanner gain
  - Photo multiplier voltage
  - Imaging plate efficiency
  - Scanning LASER intensity
  - Exposure conditions (kV, mA•min, distance, shielding, filters).

The image quality can be measured by
- IQIs, as e.g. wires, step holes, plate holes or by
- Measurement of essential parameters as e.g. the normalized SNR.

The EPS and the normalized SNR can be converted to calibrated minimum grey values GV$_{\text{min}}$ which are required for CR exposure charts.
Determination of the minimum Grey Value $G_{V_{\text{min}}}$ by the EPS method

See ASTM E 2033 draft and the Draft on “Practice for the Use of … Computed Radiology for Aerospace Casting Inspections” (USA: MAI – group)

- A smooth ¾ inch (19 mm) steel plate with a set of plate holes is radiographed at 200 kV in $\geq 1$ m distance (ASTM E 746)

- Other IQIs are on the plate to increase the information on image response.
  - The exposure is performed with different mA•min settings
  - A graph is generated, see next pages

$\text{EPS} = \text{equivalent penetrrometer sensitivity}$ (see ASTM E 746, E 747, E 1025)
Example: EPS test with DÜRR HD CR scanner at 20 µm pixel size

Do you see the holes?

¾” (19 mm) steel plate, 200 kV

1 mm steel step for measurement of $\mu_{eff}$

April 2012, Ewert et al.

Exposure Chart for CR
Use EPS test plates (E 746) as follows:

- Expose the EPS plate set on ¾” (19 mm) of steel at conditions, as defined in ASTM E 746, about 12 times with doubling dose values (mA\textbullet\text{min})
- Measure for each exposure the GV and EPS value
- Plot a graph of EPS vs. Grey Value GV

Qualification procedure!

April 2012, Ewert et al.

Exposure Chart for CR
Determination of **Minimum Grey Value** $G_{V \text{min}}$:

**EPS test**

**EPS measurement conditions:**
see ASTM E 746

**EPS method for determination of performance levels**

- Plot a graph with measured EPS as function of grey value and
- determine from the graph the minimum required grey value $G_{V \text{min}}$ for the required EPS value of

<table>
<thead>
<tr>
<th>Table A.2</th>
<th>EPS X-ray</th>
<th>EPS Se 75</th>
<th>EPS IR 192</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP Level I</td>
<td>$\leq 1.41$</td>
<td>$\leq 1.57$</td>
<td>$\leq 1.71$</td>
</tr>
<tr>
<td>IP Level II</td>
<td>$\leq 1.71$</td>
<td>$\leq 1.82$</td>
<td>$\leq 1.92$</td>
</tr>
</tbody>
</table>

- Level I performance from PV 350 - 4095
- Level II performance from PV 140 – 4095

**EPS**= equivalent penetrameter sensitivity (see ASTM E 746, E 747, E 1025)
The required minimum ‘Grey Value’ $G_{V_{\text{min}}}$ can also be determined by SNR measurements with available software. This is based on the following equation:

\[ d_{\text{visible}} = PT \cdot \sqrt{\frac{SR_{\text{image}}}{\mu_{\text{eff}} \cdot \text{SNR}}} \]

New Formula

- **Material, keV, Source type**
  - Scattered radiation
  - Screens and filters

- **Exposure time**
  - Tube current, Activity
  - Detector efficiency
  - Source-to-Detector Distance

**Depends on Hardware:**
- Effective pixel size
- Magnification
- Focal spot size, source size

**SNR:** Signal to noise ratio

**$\mu_{\text{eff}}$:** Specific contrast, effective attenuation coefficient

**$SR_{b}$:** Effective pixel size in the image, basic spatial resolution of image
The determination of the basic spatial resolution for CR system qualification shall be performed under the following conditions additional to EN 14784-1:

1) Inspection of light alloys:
   - Tube voltage 90 kV,
   - prefILTER 1 mm Al.

2) Inspection of steel, copper ≤ 20 mm
   - Tube voltage 160 kV,
   - prefILTER 1 mm Cu.

3) Inspection of steel and copper alloys:
   - Tube voltage 220 kV,
   - prefILTER 2 mm Cu.

4) Gamma radiography
   - Use the gamma source as specified
   - prefILTER 2 mm Cu or 4 mm steel for Se-75, Ir-192, and 4 mm Cu or 8 mm steel for Co-60.
Step Wedge Method:

Linear and logarithmic step wedge
8 mm Cu filter
How to determine the minimum gray values $G_{V_{\text{min}}}$:

(E 2033, Annex 1)

Use step wedge method of ASTM E 2446 or ISO 16371-1 as follows:
- Expose the step wedge
- Measure in each step the gray value and SNR value
- Plot a graph and determine the minimum gray value for the required normalized SNR, corresponding to the required ISO testing class or ASTM level.

Calibration procedure!
Determination of **Minimum Grey Value** $G_{V\text{min}}$:

**SNR Method**

- The measurement is based on the fixed correlation of SNR and Grey Values of a CR system (IP and scanner) with fixed scanner settings.

ISO/DIS 17636-2 requires for Class A: $\text{SNR}_N \geq 70$ and for Class B: $\text{SNR}_N \geq 100$

ASTM E 2033 (Draft) requires for Level I: $\text{SNR} \geq 80$ (@$\text{SR}_b = 70$ µm) Level II: $\text{SNR} \geq 56$ (@$\text{SR}_b = 70$ µm)

Scanner parameters as gain, scan speed, laser intensity, scan pixel resolution and others shall not be modified for qualification and usage in the field.

Measure the SNR and mean grey value in all steps.

**SNR_{norm} = SNR \times 88.6\mu m/\text{SR}_b**
How to Plot an Exposure Graph on the basis of minimum gray values $GV_{\text{min}}$:

- Determine the minimum grey value $GV_{\text{min}}$ for the specific SR system and its parameter setting.
- Determine different $GV_{\text{min}}$ values for different IP types and scanner settings.
- Determine different $GV_{\text{min}}$ values for testing class A and testing class B of ISO/DIS 17636-2 or for ASTM E 2033 (Draft) level I and level II.
- Define a reference value $GV_{\text{reference}}$ for the exposure chart.
- Plot the required mA•minutes as function of the material thickness, which is required to achieve the $GV_{\text{reference}}$ under standard conditions.
- The operator may define the required $GV_{\text{min}}$ value depending on the testing requirements.
Exposure Chart for Computed-Radiography

- Material = Fe
- IP = ST VI
- DÜRR CR35 NDT
- BAM-certified scan-parameter
- No lead screens

Exposure chart, based on a qualified minimum grey value $GV_{\text{referenz}}$

- Measurement of the exposure value (mA min) for different tube voltages, which are required to obtain the qualified $GV_{\text{referenz}}$.
- Half logarithmic presentation with system parameters.

\[
B_w = \frac{B \cdot GV_{\text{min}} \cdot FDD^2}{GV_{\text{ref}} \cdot FDD_{\text{ref}}^2}
\]

- $GV_{\text{min}} = 26000$
- $GV_{\text{min}} = 10000$
Conclusions

- Exposure charts for CR can be designed in analogy to film radiography on the basis of grey values in the digital images.
- It is required to determine for each Imaging Plate type and scanner and its parameter setting a required minimum Grey Value $GV_{\text{min}}$.
- Two equivalent methods were developed:
  - The EPS method is based on the visual determination of EPS values under standardized conditions by visual evaluation of digital images and measured Grey Values.
  - The SNR method is based on measured normalized SNR values and measured Grey Values.
- Different $GV_{\text{min}}$ values apply for testing ISO class A and B or ASTM level I and II.
- The relative exposure times between CR and film radiography are different for class A and B or level I and II.
End

Correct exposure, but how? EPS? SNR?

uwe.ewert@bam.de